Occupational exposure to vibration from hand-held tools

A teaching guide on health effects, risk assessment and prevention
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Occupational exposure to vibration from hand-held tools: a teaching guide on health effects, risk assessment and prevention

Lage Burström
Greg Neely
Ronnie Lundström
Tohr Nilsson

World Health Organization

Protection of the Human Environment
Occupational and Environmental Health Series
Geneva
AFFILIATIONS AND ACKNOWLEDGEMENTS

The World Health Organization is actively engaged in protecting workers from health hazards of occupational exposure to vibration from hand-held tools. For supporting protection and promotion of workers' health a teaching guide on health effects, risk assessment and prevention have been developed.

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PREFACE

Many countries, particularly those with emerging economies, have seen rapid industrial growth which is often accompanied by increased activities in the construction sector and its related economic activities. However, current knowledge about risks to the health and safety of workers and their prevention is not being applied sufficiently.

This guide was developed to address this gap and to support the prevention of risks to health and safety from occupational exposure to vibration from hand-held tools, typically from the use of hand-held power tools. The exposure can have serious short- and long-term health and behavioural consequences for the worker. Research and practice have shown that most of these problems can effectively be prevented by applying simple techniques and protective measures at the workplace.

These measures can be taught during a 1 to 3-day course covering the basics, about hand-arm vibration exposure presented in this teaching guide. Trainers will appreciate that the teaching guide was developed to allow maximal flexibility in course content, as each chapter can be used separately and the course can easily be tailored to adjust to different audiences or limited time schedules. The teaching activities can be conducted with limited access to equipment or supplies. Additionally, each chapter contains detailed lecture notes, relevant references from the literature, text and graphic material appropriate for use as overhead transparencies or slides. The material was primarily prepared to assist trainers in developing countries, however, much of the material is equally relevant and easily adaptable to many audiences in industrialized countries.

The WHO Global Plan of Action on Workers' Health (2008-2017), which was endorsed by the World Health Assembly in 2007, calls for building capacities for primary prevention of occupational hazards, diseases and injuries, including strengthening of human, methodological and technological resources and the training of workers and employers. The Global Plan stipulates the introduction of healthy work practices and work organization, stimulating a health promoting culture at the workplace. We hope this training guide will contribute to this goal by effectively assisting occupational
health and safety professionals in the preparation and delivery of training to prevent adverse consequences for workers' health from hand-transmitted vibration.

We would appreciate your feedback, particularly regarding the teaching materials, their user-friendliness, as well as results from evaluations (ochmail@who.int).

This teaching guide on exposure to hand-transmitted vibration is the tenth publication in the Protecting Workers' Health series, and the second teaching guide within the series. The Occupational Health Programme would like to thank their collaborators at the Umeå University in Sweden for authoring this publication.

Dr Carlos Dora  
Coordinator

Interventions for Healthy Environments  
Department of Public Health and Environment
Introduction
1.1. Purpose of the Teacher’s Guide

The Teacher’s Guide can be used to assist in the preparation and delivery of a 2-day course, adapted to provide a one-day introductory course, or expanded to 3 days that also include technical visits. The Guide contains sufficient resource material to initiate, organize, deliver, and evaluate courses of different lengths. The course material includes overhead transparencies and handouts necessary for lectures and workshops.

The Teacher’s Guide stands on its own: it does not require further background information with respect to occupational hand-arm vibration, management principles, training, etc. To increase the benefit for the course participants, a course coordinator should include local issues that address concerns such as legal frameworks, general practices, etc. The course coordinator may also want to invite guests or course participants to prepare specific local topics. For example, national authorities could present current legal frameworks or current policies, and occupational health managers could present their general practices. In this case, invited presenters should be contacted well in advance and agree to the presentation.

1.2. How to use the Teacher’s Guide

The Guide helps a tutor organise and develop lectures on Occupational Hand-Arm Vibration. The material can also be used to assist in organizing workshops.

Well before the beginning of the course, the tutor should read the Guide. To illustrate points discussed in the guide, the tutor should prepare local examples, preparation that also requires careful planning and plenty of time.

This guide uses overhead transparencies as the principal visual aid; however, if an overhead project is not available, the content of the slides can be copied onto flipcharts or blackboards.
1.3. Target groups for the course on occupational hand-arm vibration

The Teacher’s Guide is targeted at people involved in the education of individuals who are either exposed to occupational hand-arm vibration, need to manage environments where workers come into contact with vibration, or need to deal with various health effects of vibration:

Officials from national or regional authorities involved with developing policies in vibration management;

- Environmental or health and safety regulators;
- Occupational health professionals;
- Other health professionals;
- Employers;
- Occupational health service.

1.4. The objectives of the course on hand-arm vibration

The course tutor should state the learning objective in the opening lecture of the course. It is likely that the backgrounds, functions, and level of knowledge of the participants will vary. The course should address the following objectives:

- To raise awareness of health risks associated with occupational exposure to hand-arm vibration;
- To provide fundamental information on hazards and management practices for health and risk assessment;
- To provide a foundation for the formulation of policies, the development or improvement of legislation, and production of technical and medical guidelines;
- To promote the application of health and risk factor surveillance;
- To encourage the development of good working environments, management practices, and technologies;
- To enable participants to develop their own vibration management plans and training programs.
At the end of the course, the participants should be able to demonstrate that they have the knowledge to obtain these objectives.
Practical aspects of teaching the course
2.1. The rationale behind teaching a hand-arm vibration course

Negative effects from hand-arm vibration affect the well-being and the productivity of millions of workers around the world. This is particularly tragic given that much is known about how these effects can be minimised (often at relatively low costs). Gathering fundamental knowledge about the sources of vibration, the physical characteristics of vibration, and the potential effects of vibration can be considered the first step in building an effective prevention program. The course outlined in this manual was developed to help spread this type of information.

2.2. Planning the hand-arm vibration course

Planning and preparation are the keys to good teaching results. Much like the tip of an iceberg, the time spent lecturing in a course is only a small percentage of the total time and effort that should go into the course. This guide is meant to help reduce this time and effort by providing a course co-ordinator or lecturer with some of the basic material necessary for running the course. However, this manual cannot replace planning and preparation. The lecture information and structure provided by this manual should be adapted for the specific audience and goal of each specific course. In particular, the course will need to be adjusted to address issues that may be specific to a certain region or type of work.

The course co-ordinator is responsible for all practical aspects of running the course. These duties include contacting and engaging the teachers, securing the teaching facilities and equipment to be used, and providing students with information about the course.

One of the course co-ordinator’s most important tasks is to make a schedule for the course. The schedule is the backbone of the course – the one document that everybody can refer to for information about the course. In particular, a well-written schedule should be able to serve as historical documentation of the course, allowing those that did not take the course to understand what was taught, when it was taught, and who taught it. The course schedule should contain information about where and when the course is to take place,
what topics will be covered, who will be teaching the course, and what kind of examination will be given. Always have the name and contact information for the course co-ordinator listed on the schedule in case there are any questions. An example of a course schedule is presented at the end of this chapter.

Unless otherwise agreed upon, the course coordinator is responsible for making sure everything runs smoothly during the actual running of the course. It would be unfortunate if 10 minutes of an hour lecture were lost because a lecturer has difficulties finding the room or time was spent trying to find chalk for the chalkboard.

Another important job for the course coordinator is conducting evaluations. The two types of evaluations that need to be conducted, student progress and the course evaluation from the student perspective, are described in a later section of this chapter. Another type of evaluation the coordinator should conduct is the course evaluation from the teacher’s perspective. Generally, it is sufficient for the coordinator to speak with teachers after their respective lecture in order to find out what the teacher thought about the course. However, if there are many teachers involved or if the coordinator is not present for the lecture, it may be useful to develop a questionnaire to send out to all the teachers. Whether collected orally or through a questionnaire, the coordinator should summarise the results and share the insights from the evaluation with all the teachers. The summary will also be valuable to whoever organizes the course in the future.

2.3. The problem solving approach to learning

A good way to reinforce important parts of the lecture material is to give the students an opportunity to solve problems. By allowing the students to directly apply the material they have learned or to work out an answer to a problem before receiving a lecture, it is possible to activate and engage them in a way that provides them with deeper insights into the material and enhance their retention of the material. In addition, this strategy allows the lecturer to incorporate material of local or industry specific interest into the course. The problem solving approach to learning usually involves introducing different
scenarios to the class and asking them either individually or in groups to work out a solution for the scenario. Throughout this manual, suggestions for such scenarios have been made that can be used or modified by the lecturer.

In a related fashion, at the end of the course students could be given the opportunity to reflect about how the things they have learned could be implemented in their workplace – an action planning session. Time permitting, students could write a plan of action and then present their plans to each other. However, if time is short, it would still be valuable to give students a few minutes to write down their thoughts about how the course materials could be applied in their particular situation.

2.4. Formal presentation

There is no one best way to give a lecture. Before a lecturer can decide on the appropriate way to present material for any particular audience, he or she needs to answer several questions.

Who is in the audience and what do they need to know?

The motivation and background of the audience will play an important role in how the lecturer sets up the presentation. Motivated listeners should be able to follow a 45-minute lecture without too many problems. Unfortunately, listeners aren’t always motivated. Some people attending the lecture may be there because their employer requires them to, or they are only interested in a very small portion of the whole lecture. Before preparing the lecture, try to anticipate the level of motivation of the audience. If it is likely that many will have low motivation, consider introducing interactive aspects into the lecture, such as demonstrations, that help to capture the audience’s attention. Similarly, the type of material to be presented will vary depending on the background of the audience. On the one hand, workers may already understand a great deal about the physical characteristics of vibration since they work daily with vibrating machinery, but they may lack some of the proper or scientific names for the phenomena they have experienced. On the other hand, members of management may already have the vocabulary, but they may lack a practical understanding of the physical characteristics. The
lecturer should always decide on what the main message is that the audience should walk away with. Every part of the lecture should then try to support that theme. There is always a temptation to try to deliver many messages, but the reality is that the audience can only absorb a certain amount of information and the lecturer will only have a limited time to present the evidence necessary to understand the messages.

What resources are at my disposal?

Will there be an overhead projector available? Is it a large lecture hall where the audience is far away or a regular classroom that is more intimate? Finding out as much information about the resources available before preparing a lecture can save time and effort. For example, some demonstrations may not be appropriate in a large lecture hall where students sitting in the back of the room may have difficulty seeing what is happening. Furthermore, always consider the possibility that equipment may fail or other unforeseen incidents may occur and be prepared to give the lecture without the use of aides.

How much time do I have?

The depth and form of the lecture will depend on the amount of time available. If only a short amount of time is available, the lecture will need to be direct and to the point. If there is plenty of time, then using a problem solving approach as described above might be appropriate. Whether there is a lot or little time available, it is important to keep track of how much time is left during the lecture. Pace the lecture accordingly and eliminate material if time is running short. A common tendency when time is running short is to start speaking faster in order to cover all the intended material. In general, this is not a good approach. Both lecturer and audience become stressed and much material is either totally missed or misunderstood. While preparing the lecture, think about which parts could be eliminated if necessary and consider putting the most important material early in the lecture.

The best way to ensure a good presentation is to practice. Asking colleagues and friends to listen to the presentation and provide feedback is an excellent way to get an idea of how long the lecture will take and where there might be room to improve the presentation.
2.5. Audio-visual teaching aids and other resources

Audio-visual teaching aids can greatly enhance the learning experience for the students. Improperly used, however, they may have just the opposite effect.

The most basic type of audio-visual aid is using a chalkboard or whiteboard to write text or draw simple diagrams to support your lecture material. As with all other types of aide, it is important to find the right amount information to present. In general, you will want to keep what you write brief, supporting your oral presentation by writing down key words and phrases. It is also often helpful to write any names, dates, or numbers that you present. Keep in mind, however, that it can be tricky to maintain good contact with your audience while writing on a board since you usually will have to turn your back toward the students frequently. Also keep in mind the size of the text you are writing – even the person in the back of the classroom should be able to read what is written!

Slides and overheads are common teaching aides, but both require special equipment to present them that may not always be available. Slides and overheads are particularly useful when presenting pictures or tables and diagrams that would be either difficult or time consuming to draw on a board. Slides and overheads with text should be used to supply support and structure to what the speaker is saying and thus should generally consist of short phrases and keywords. Be careful to not place too much text on a slide or overhead; the audience should be primarily attending to the speaker and not reading text. Accompanying the lecture material presented in this guide are perforated pages to be used for overheads. In some cases, you may be able to use these pages as is; in other cases, you may need to make adjustments that are appropriate for the specific course you are conducting.

Another useful classroom aide is demonstrations. The course described in this manual could particularly benefit from classroom demonstrations. For example, many people have difficulties understanding the difference between frequency and intensity when describing the physical characteristics of vibration. However, by allowing students to try hand held tools that generate
vibration of varying frequency and intensity, students can experience the difference between these two characteristics.

2.6. Evaluation

Evaluations are a necessary part of any good course. There are two types of evaluations. If the course is a formal part of an education or is a requirement by an employer, it may be necessary to certify that the students have achieved an acceptable level of competency. There are several methods for doing this including a wide variety of written and oral examinations. The best type of evaluation to conduct will depend on several factors such as how much time is available, what resources are available, and, perhaps most importantly, what the goal of the course was. For example, if the course was designed to educate key persons in an organization to identify symptoms for potential hand-arm vibration injuries, then a written exam with multiple choice questions focusing on physiological and neurological aspects of hand-arm vibration may be appropriate. However, a course designed for safety engineers might want to adopt a testing strategy involving letting the students evaluate different scenarios. Regardless of the form, it is important to remember that a good exam takes time to prepare. Always inform the students at the beginning of the course if an exam will be held, letting them know both when the exam will take place and what form it will be in. Just as preparing a multiple-choice exam is different from preparing an oral exam, studying for a multiple-choice exam is different than studying for an oral exam!

The other type of evaluation that should be conducted is an appraisal of how well the course fulfilled its goals. Everyone who participated in the course, lecturers and students, should be given the opportunity to evaluate the course. This type of feedback is valuable for developing future courses and can provide individual speakers with insightful comments that may help them when preparing future lectures. Accordingly, it is necessary that the course evaluation provide the respondent with an appropriate means to express their opinion. Questions should clearly distinguish the material presented and the person who presented it. A lecturer cannot improve their presentation if they do not know if a poor evaluation was given because the material was inappropriate or if the way it was presented was inappropriate.
Bibliography


16. American Conference of Governmental Industrial Hygienists (ACGIH), Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices. ACGIH: Cincinnati, 2005.

Example of a Course Schedule

Hand-arm Vibration in the Work Place: Managing the Problem  
April 7th, 2007, 9:00 am – 4:00 pm  
Lecture Room B, Department of Occupational Medicine, Umeå University

The goal of this course is to provide management and worker’s representatives an overview of how to manage problems associated with hand-arm vibration once it has been established that there is a risk. The focus of this course will be on solutions to minimise or eliminate exposure as well as how to treat hand-arm related injuries. Legal aspects will also be discussed.

Course Organizer: Greg Neely

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<thead>
<tr>
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<th>Speaker</th>
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<td>Introduction</td>
<td>Greg Neely</td>
</tr>
<tr>
<td>10:00</td>
<td>Health and risk factor surveillance</td>
<td>Ronnie Lundström</td>
</tr>
<tr>
<td>10:50</td>
<td>Coffee break</td>
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<tr>
<td>11:00</td>
<td>Exposure limitations</td>
<td>Lage Burström</td>
</tr>
<tr>
<td>12:00</td>
<td>Lunch break</td>
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</tr>
<tr>
<td>13:00</td>
<td>Treatments and management</td>
<td>Tohr Nilsson</td>
</tr>
<tr>
<td>14:00</td>
<td>Legal and compensation aspects</td>
<td>Lage Burström</td>
</tr>
<tr>
<td>14:50</td>
<td>Coffee break</td>
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<tr>
<td>15:00</td>
<td>Open discussion and action planning session</td>
<td>Lead by Greg Neely, all speakers present.</td>
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The Speakers:

Lage Burström, PhD, Umeå University  
Greg Neely, PhD, Umeå University  
Ronnie Lundström, PhD, Umeå University  
Tohr Nilsson, PhD, Umeå University
Before attending, the course participants should obtain and read their respective company’s policies regarding work related injuries and work safety. Additional reading materials will be made available during the lectures.
Course Resources
LECTURE 1: OVERVIEW AND OBJECTIVES

Teacher’s notes

Overhead 1.1. Basic concept of vibration
Overhead 1.2. Occupational exposure to vibration
Overhead 1.3. Example of a HAV exposure (1)
Overhead 1.4. Example of a HAV exposure (2)
Overhead 1.5. Example of a HAV exposure (3)
Overhead 1.6. Example of a HAV exposure (4)
Overhead 1.7. Example of a HAV exposure (5)
Overhead 1.8. Effect categories of exposure to HAV
Overhead 1.9. Effects of exposure to HAV (symptom summary)
Overhead 1.10. Objectives of the course

Suggested study activities

List and discuss possible sources of HAV at your own workplace.
3.1.1. Teacher’s notes

Overhead 1.1. Basic concept of vibration

Vibration describes the movement of an object that swings around a rest position (point of equilibrium) such as a clock pendulum. The rest position is at “A” and the end points are at “B” and “C”. There are some physical measurements needed to describe this motion:

- The size of the oscillation (level, amplitude);
- The number of oscillations per second (frequency);
- The type of oscillation;
- Time during which the oscillation occurs.

Overhead 1.2. Occupational exposure to vibration

Many workers experience work-related vibration. For example, workers in mechanical workshops use hand tools that create vibration and forest workers drive all-terrain vehicles that create vibration. An operator of hand tools experience vibration in their hands and arms and all terrain vehicle operators experience vibration in their whole body. Therefore, occupational exposure to vibration is subdivided into two main categories: hand-arm vibration (HAV) and whole-body vibration (WBV). Sometimes the term hand-transmitted vibration (HTV) is used instead of HAV. This course focuses only on HAV.

Overhead 1.3. Example of HAV exposure (1)

Construction workers often use a ballast stop machine to compact and crush stones on a railway track. The machine is heavy (about 30-50 kg) and produces compacting impacts with a frequency of about 40 impacts per second. The amplitude of the vibration is quite large and almost visual. The vibration is transmitted to the operator’s hands, arms, shoulders, head, and most of the upper body.
Overhead 1.4. Example of HAV exposure (2)

Forestry workers often use of petrol driven chain saws to cut branches after the tree has been felled. Construction workers often use electrically driven chain saws. Modern saws are relatively light (only about 5 kg) and produce dominant vibration around 100 oscillations per second, largely depending on changes in the engine’s rotational speed due to varying load on the cutting chain. The vibration is transmitted to the operator’s hands, upper limbs, and sometimes the shoulders.

Overhead 1.5. Example of HAV exposure (3)

In many types of work straight and angle grinders are used. For example, grinders of various design and size are used in mechanical workshops, car repair workshops, and in the production industry. Most grinders are powered by electricity or compressed air.

The grinder is relatively light-weighted (only a few kg) and produces dominant vibration in the range of about 100-150 oscillations per second, largely depending on changes of the engine’s rotational speed due to varying load on the grinding wheel. The vibration is predominantly transmitted to the operator’s hands and forearms.

Overhead 1.6. Example of HAV exposure (4)

Modern dental high-speed drills used by dentists’ in normal practice are transmitting vibration with very high frequencies to their hand. The drills are of low weight, only a few hectograms. Typically, the dominant vibration frequencies are around 1 kHz. The vibration is predominantly transmitted to the fingers of the operating hand in direct contact with the tool.
Overhead 1.7. Example of HAV exposure (5)

Physiotherapist, which use ultrasonic therapy devices has been shown be exposed to very high frequency vibration, i.e. more than 10 000 Hz. The devices are of very low weight, only a few hectograms. The vibration is only transmitted to superficial tissue layers of the operating hand in direct contact with the tool.

Overhead 1.8. Effect categories of exposure to HAV

The HAV effect categories can be summaries as:

Vascular disturbances
  - Vibration White Fingers (VWF)

Neurological disturbances
  - Numbness
  - Reduced tactile and thermal sensitivity
  - Reduced manual dexterity

Effect on the locomotor system
  - Muscles
  - Bones
  - Joints
  - Tendons

Comfort and performance

Overhead 1.9. Effects of exposure to HAV (symptom summary)

Exposure to HAV may thus result in various adverse effects on the hands and fingers. These adverse effects may lead to hands that are clumsy, “dead”, stiff, white, “blind”, and more.
Overhead 1.10. Objectives of the course

The objectives of the course on vibration are as follows:

- To raise awareness of health risks associated with occupational exposure to vibration;
- To provide fundamental information on hazards and management practices for health and risk assessment;
- To provide a foundation for the formulation of policies, the development or improvement of legislation, and production of technical and medical guidelines;
- To promote the application of health and risk factor surveillance;
- To encourage the development of good working environments, management practices, and technologies;
- To enable participants to develop their own vibration management plans and training programs.
LECTURE 2: PHYSICAL CHARACTERISTICS

Teacher’s notes

Overhead 2.1. Basic concepts and definitions
Overhead 2.2. Vibration motion
Overhead 2.3. Vibration level
Overhead 2.4. Vibration type
Overhead 2.5. Vibration frequency and analysis
Overhead 2.6. Summation and weighting
Overhead 2.7. Vibration directions
Overhead 2.8. Duration (exposure time)

Suggested study activities

Try to calculate the 8-hour equivalent acceleration if we have a tool acceleration of 10 m/s² and the exposure time is 2 hours.

This could be calculated by using formula 2.6:

\[
a_{eq(8)} = \sqrt{\frac{T}{8}} \cdot a_T = \sqrt{\frac{2}{8}} \cdot 10
\]

The 8-hour equivalent acceleration is 5 m/s².
3.2.2. Teacher’s notes

Overhead 2.1. Basic concepts and definitions

A vibration is defined as an object that moves around a rest position (point of equilibrium), such as a clock pendulum. The rest position is at “A” and the end points are at “B” and “C”. The following measurements describe this motion:

- The size of the oscillation (level, amplitude);
- The number of oscillations per second (frequency);
- The type of oscillation;
- Time during which the oscillation occurs.

Overhead 2.2. Vibration motion

The dimensions and level of a vibration can be described in terms of acceleration. The acceleration (a) describes how the speed of an object changes over time. The unit of acceleration is m/s². Acceleration is the magnitude usually used to describe the effects of vibration on humans.

The changes of the vibration can also be described over time. A vibrating object first moves over a distance, stops at the end position (B), and then moves in the opposite direction past the rest position (A). The movement then continues to the second end position (C), stops, and moves in the opposite direction back to the rest position (A) or beyond.

Overhead 2.3. Vibration level

The period (T) describes the time taken for a vibration to carry out this entire movement back to the original position (OH 2.3). The movement occurs during a continual change of position during a single oscillation. Therefore, it is important to describe the oscillation in a simple manner.
One method is to mark the value constantly being recorded – the instantaneous value. The highest instantaneous value during a period is called the peak value ($a_{\text{peak}}$). As a rule, it does not matter whether the instantaneous value is positive or negative; only the maximum value is given.

However, it is preferable to indicate some kind of mean value for the period under consideration. There are several ways of doing this, but the most common way is to give the vibration’s effective mean value – the RMS value (root mean square). The effective mean value or RMS value refers to the vibration’s energy content per second.

The effective value (RMS value) for acceleration is defined as

$$a_{\text{RMS}} = \sqrt{\frac{1}{T} \int_{0}^{T} (a(t))^2 \, dt}$$

*Formula 2.1.*

where $a(t)$ is the acceleration’s instantaneous value at time $t$, and $T$ indicates the total time for which the acceleration’s effective value ($a_{\text{RMS}}$) should be calculated.

**Overhead 2.4. Vibration type**

Vibration can be divided into the following categories:

- **Harmonic and Periodic Vibration:**
  A vibration that is made up of one or several sinusoidal components is called harmonic or periodic, a vibration that repeats itself. The most common form of periodic signal is sine vibration.

- **Random Vibration:**
  Vibration that does not repeat itself continuously, meaning that future behaviour cannot be predicted, is called random.
Transient Vibration:
Vibration that is of short duration and caused by mechanical shock is called transient.

Most vibration that occurs in a work context is a combination of harmonic, random, and transient vibration.

Overhead 2.5. Vibration frequency and analysis

The frequency of a vibration describes how often oscillations occur during a specific period and is measured in number of oscillations per second. This unit is called a Hertz (Hz). Frequency is defined as

\[ f = \frac{1}{T} \]

Formula 2.2.

where \( f \) is the frequency and \( T \) the period for the vibration. For instance, if \( T=0.2 \) second, then \( f=1/0.2=5 \) (Hz).

Dividing vibration into different frequencies is called frequency analysis. Normally, it is not possible to calculate the frequency of noise vibration according to the formula 2.2. Instead more sophisticated mathematical methods must be used such as Fourier analysis. Analysing the frequency of a vibration means obtaining its frequency spectrum. OH 2.5 shows the relationship between the oscillating process of vibration over time and the corresponding frequency spectrum.

Frequency analysis can be performed in various ways such as by dividing vibration into different bands in which each band covers (about 10 Hz around the centre frequency). However, the usual method is to use a constant relative bandwidth for analysis. This means that the analysis is performed using a bandwidth of 10% of the centre frequency. This kind of frequency recording means that analysis on a logarithmic frequency scale has the same resolution over the entire frequency range. At a constant relative bandwidth the analysis is carried out through octave bands or parts thereof. The
appearance of the octave bands used and their centre frequencies have been standardised. When using test readings to assess risk the injury of vibration, the 1/3 octave band is the one used.

**Overhead 2.6. Frequency summation and weighting**

Instead of a frequency spectrum, totalled acceleration can be calculated within a specific frequency range. This is done by totalling the acceleration for the respective bands as follows:

\[
a = \sqrt{\sum_{n=1}^{i} a_i^2}
\]

*Formula 2.3.*

where \(a\) is the sum of the acceleration and \(a_i\) the acceleration for the \(i\) frequency band.

This produces a single numerical value for the frequency section. Sometimes different frequencies are allotted different significance according to their effect on the user. This means that the values for different frequency bands are weighted very differently when totalling – the frequency weighting. The formula used in this case is as follows:

\[
a = \sqrt{\sum_{n=1}^{i} (K_i \cdot a_i)^2}
\]

*Formula 2.4.*

where \(a\) is the sum of the acceleration, \(a_i\) the acceleration for the \(i\) frequency band, and \(K_i\) the weighting for the \(i\) frequency band.
Overhead 2.7. Vibration direction

Often a vibration consists of simultaneous movement in more than one direction. That is, a fixed level of vibration is in a fixed direction – the vibration describes a vector in space. These vectors are labelled x, y, and z. These three directions are also orthogonal and perpendicular to one another.

If the acceleration in the different directions is known, the vibration’s summation vector (a) can be calculated using this formula:

\[ a_v = \sqrt{a_x^2 + a_y^2 + a_z^2} \]

*Formula 2.5.*

where \( a_x \), \( a_y \), and \( a_z \) are the acceleration in the x-, y-, and z- directions.

Overhead 2.8. Duration (exposure time)

Duration or exposure time, the total time during which oscillations occur, is highly significant when assessing effects on humans. Usually daily exposure to vibration is expressed by means of the vibration level and daily exposure time. The mathematical correlation used (formula 2.6) enables comparison of exposure, which occurs over varying lengths of time. To calculate an equivalent 8-hour value the following formula is used:

\[ a_{eq(8)} = \sqrt{\frac{T}{8}} \cdot a_T \]

*Formula 2.6.*

where \( a_{eq(8)} \) is the 8-hour equivalent acceleration, \( T \) is the actual exposure time in hours, and \( a_T \) is the acceleration during the period T hours.
If exposure to vibration comprises several different time intervals, the daily vibration exposure is calculated as follows:

\[ a_T = \sqrt{\frac{1}{T} \cdot \sum_{i=1}^{n} a_i^2 \cdot t_i} \]

*Formula 2.7.*

where \( a_T \) is acceleration during the period, \( T \) is the hours, \( a_i \) is the acceleration during the \( i \) period, \( t_i \) is the period’s extent, and \( T \) is the total exposure time in hours.
LECTURE 3: THE EFFECTS ON HUMAN PERFORMANCE

Teacher’s notes

Overhead 3.1.  Effects on human performance
Overhead 3.2.  The motor control problem (1)
Overhead 3.3.  The motor control problem (2)
Overhead 3.4.  Combating the motor control problem (1)
Overhead 3.5.  Combating the motor control problem (2)
Overhead 3.6.  The tactile problem (1)
Overhead 3.7.  The tactile problem (2)
Overhead 3.8.  Combating the tactile problem

Suggested study activities

Two point threshold demonstration

Both motor and tactile effects on performance can be demonstrated by allowing the students to operate a hand held tool for a while and then having them perform tasks that require precision or good finger sensitivity. For example, before using a power tool ask students to check their two-point threshold. A two-point threshold is the distance that is needed in order for the perceiver to feel that there are two distinct objects touching the skin surface. During a medical exam, thin, round plastic strands with dull ends are often used for such threshold determinations, but any similar type of items may be used in this demonstration. For example, you could use pen or pencil tips or the ends of wooden matches.

Start by placing the two objects very close (almost touching each other) on the surface of one finger. Both objects should touch the finger surface at the same time. When asked, the students will probably respond that they felt only one point of contact. Begin moving the objects slightly apart each time until the student can feel two distinct objects. Measure the distance between the two objects; this is the two-point threshold for this person. Now let the students work with a power tool for approximately 5 minutes. Afterwards, measure the two-point threshold again. Has it changed? What happens if you measure the two-point threshold several minutes after stopping work with a power tool? If you increase the work time to 10 minutes, what happens to the threshold?
3.3.1. Teacher’s notes

Overhead 3.1. Effects on human performance

In many jobs, workers perform skilled hand movements. For example, an operator of a grinder must use precise hand movements to properly manipulate the shape and texture of a metal object. Even in jobs where skilled movements are not critical, there are many workers who are required to perform tasks involving prolonged or repetitive motions of the hands and arms.

There are two primary ways in which hand-arm vibration can interfere in these tasks. First, the actual vibration may make it difficult to maintain control over the instrument or tool being used. This is called the motor control problem. Second, both short and long term exposure to hand-arm vibration may cause a loss of sensitivity that can impair performance. This is called the tactile problem. While these two problems are not totally unrelated, for our present purposes it might be beneficial to treat them separately.

Overhead 3.2. The motor control problem (1)

Generally, motor skills are easy to take for granted. Riding a bicycle on a familiar road and on a pleasant day requires so little effort that we can usually focus our attention on any number of other activities at the same time. We can talk to person on the bicycle next to us or think about what we are going to eat for dinner. And yet, riding a bicycle is a rather complex task. You have to balance your body on a thin metal frame with two wheels that make contact with the ground at only two places. Not only do you have to do this while the metal frame with wheels is moving, you need to both supply the energy for the movement and control the direction of the movement. Navigating the bicycle requires split second timing between hand movements, speed adjustments, and weight shifting to maintain balance based on continuous monitoring of distances, speed, and the road conditions. This complexity, sometimes painfully, is obvious when we first learn how to ride a bicycle. However, with practice the complexity fades away. The complexity
can resurface when we ride our bicycle on a wet or icy surface or when we need to carry something large and bulky with us on the bicycle.

Although not all motor tasks may be as complex and dynamic as riding a bicycle, the fact remains that performing even the most simple task requires more effort and coordination than we are usually aware of. Tasks performed with the hand are no different. They require a complex coordination between the joints in the fingers, wrists, elbows, and shoulders. The hand is required to exert just the right force at just the right time. Sometimes it needs to grasp something hard enough to get a hold of it and yet soft enough that the object doesn’t break. Throughout the task, information needs to be sent to the brain about the location of the different parts of the hand and arm so that the brain can coordinate these movements with other parts of the body.

Control over the actions of our hands and arms are primarily governed by two systems in the human body, systems that together provide us with complex feedback that is necessary to perform the motor activity.

The proprioceptive system is a collection of receptors located in the joints of the body that convey to the brain a precise representation of the joint angles. Using this information, the brain can calculate the position of the hand or arm in space. For the completion of tasks to be conducted by the hands, the joints in the fingers, wrists, elbows, and shoulders are of primary importance in terms of proprioception.

The kinaesthetic system conveys a sense of motion of the limbs to the brain through information on how the muscles of the body are expanding and contracting. This information is necessary for the brain to coordinate motion and to determine the force by which objects will be grasped or transported.

Overhead 3.3. The motor control problem (2)

Hand-arm vibration degrades the signals from the receptors to the brain making exact knowledge of the position of the hands and arms difficult to calculate. This phenomenon is relatively easy to demonstrate. Take a power drill and, with the power not on, try to touch the tip of the drill on a spot
marked on a piece of wood. You may find the first attempt a bit clumsy, but you learn pretty quickly to compensate for the weight of the machine and the effects of gravity. By the second or third attempt, you should be able to set the tip of the drill down on the spot quickly and reliably. Now turn the machine on and attempt to do the same task. The task is now much more difficult and, depending on the intensity of the power of the machine, you might not be able to ever reliably set the tip of the drill on the spot.

Thus hand-arm vibration makes most tasks more difficult to complete. This means that workers have to devote more mental effort to the task at hand, leaving them with less time to attend to other things and people in the environment. This in turn increases the likelihood of accidents and injuries in the workplace. Furthermore, it increases the discomfort level workers experience. The mental fatigue and physical fatigue associated with hand-arm vibration decreases the time workers can perform tasks.

Overhead 3.4. Combating the motor control problem (1)

As with most environmental hazards, the most effective way to guard against loss in performance due to hand-arm vibration is to avoid or minimise exposure. In most instances, however, it is unlikely that it will be possible to eliminate all exposure. Most tools or instruments that cause hand-arm vibration are used because the task at hand requires more force than a human can generate. Additionally, many of these tasks require skilled movements that may be difficult or impossible to automate. Thus most solutions for hand-arm vibration exposure will involve some method or device for isolating or dampening the vibration.

Machine side – Changes can be made to the tool or instrument. These changes can be anything from actually exchanging high vibrating tools for low vibrating tools to modifying an existing tool by adding a better grip.

User side – These interventions can include providing vibration-dampening gloves to teaching workers better grips and working positions. Visual contact with the hand and tool reduces motor control problems associated with hand arm vibration.
Overhead 3.5. Combating the motor control problem (2)

Training can improve most motor skills. However, it should be noted that performance on any task would always be determined in part by the quality of the information and feedback available to the operator. Thus the introduction of hand-arm vibration to a task will almost always result in poorer performance. Generally, accuracy in a skilled motor task is improved by increasing the amount time available to complete the task. In situations where hand-arm vibration may interfere with the accuracy in which a task needs to be completed, a worker may need more time to complete the task.

Overhead 3.6. The tactile problem (1)

While motor control problems are concerned with acute effects that may impair general motor performance, tactile problems are generally the result of prolonged exposure and are most problematic in fine motor activity. Typically, tactile problems are most obvious directly after exposure. For example, after using a power tool, a worker may experience difficulties picking up and manipulating small pieces of hardware such as screws and nuts. Without exposure, the worker may have no problem distinguishing the size of screws in their pocket just by touching them; however, the simple task may be nearly impossible after working with a power tool for several minutes.

Receptors lying just under the skin respond to pressure on the skin and relay subtle changes in force applied to the hands and fingers to the brain. With this information, the brain can identify textures, adjust finger pressure to properly handle objects, and make judgements about the size, weight, and form of objects.

Overhead 3.7. The tactile problem (2)

Exposure to hand-arm vibration, even for short periods of time, can damage or impair the receptors, making fine motor activity more difficult. The loss of sensitivity in the fingers makes it more difficult to make judgements of texture, weight, and form of the objects being handled. The longer the exposure, the
more severe the loss in sensitivity will become and the longer it will take for the fingers to regain their normal sensitivity. In extreme cases, permanent damage may occur and sensitivity will never return.

**Overhead 3.8. Combating the tactile problem**

As pointed out earlier, the most effective way of combating such problems is by eliminating human exposure to vibration. When this isn’t possible, minimising the exposure as much as possible is necessary. These techniques were discussed above. Of particular importance for the tactile problem is ensuring proper recovery times. Loss of sensitivity in the fingers is one of the first signs that serious and permanent damage may be occurring and allowing proper recovery times is an important precaution.

Completing as many fine motor movements as possible before using power tools can minimise the effects on performance. For example, all the small pieces of hardware could be laid out in advance so that they can be easily identified and picked up. Another way to compensate for decreased tactile sensitivity in some situations is to increase the visual information. By looking directly at the hands while performing a task, much of the information that was lost to the tactile system can be regained through the visual system.
LECTURE 4: EFFECTS ON HUMAN BODY - VASCULAR SYSTEM

Teacher’s notes

Overhead 4.1. Work with vibrating machines
Overhead 4.2. Hand-arm vibration syndrome (HAVS)
Overhead 4.3. Vibration and the upper extremity
Overhead 4.4. Temporary vascular effects
Overhead 4.5. Permanent effects: Vibration white fingers
Overhead 4.6. What goes wrong?
Overhead 4.7. Regulation of the peripheral vascular system
Overhead 4.8. Vascular system of the upper extremity
Overhead 4.9. Who is at risk for VWF?
Overhead 4.10. What could elicit the vascular symptoms?
Overhead 4.11. What modifies the vascular symptoms?
Overhead 4.12. Possible disability and handicap
Overhead 4.13. What will the physician do?
Overhead 4.15. Assessment of the medical history
Overhead 4.16. Staging of the vascular symptoms (1)
Overhead 4.17. Staging of the vascular symptoms (2)
Overhead 4.18. Assessment of physical status
Overhead 4.19. Assessment with laboratory tests
Overhead 4.20. Other causes of “white fingers”
Overhead 4.21. Clinical evaluation of vascular symptoms
Overhead 4.22. Management and treatment of vascular effects
Overhead 4.23. Prognosis for vascular symptoms

Suggested study activities

Assess finger temperature before and after exposure to vibrating tools and before and after tobacco use and in combination.
3.4.1. Teacher’s notes

Overhead 4.1. Work with vibrating machines

Work with vibrating machines includes exposure to a manifold of possible health hazards among which vibration is only one. Such tasks may introduce the worker to the risk of a variety of disorders in addition to the risk of contracting hand-arm vibration syndrome. Work-related neuro-musculoskeletal disorders are the most common health hazard connected to hand-intensive manual work. There is an established association between the ergonomic load of the work and the contraction of disorders in the upper extremity such as shoulder and hand-wrist tendonitis, epicondylitis, thoracic outlet syndrome, and carpal tunnel syndrome. Several specific ergonomic exposure parameters have been identified as distinctive risk factors: load sustained over time (force, repetitiveness, posture), undue “fit, reach, and see”, task-invariability, cold, vibration, and local mechanical stresses. Under unfavourable conditions, interaction between work, work demands, support, organisation, and the worker may result in sustained stress and eventually in stress-related disorders. High-energy expenditure from power tools relates to noise and dust exposure. The noise may cause noise-induced hearing loss. The content of the dust or the coating of the particles may be hazardous to the lung function. Lubrication from the machines and vapours emitting from cooling liquids may irritate the mucous membranes in the eyes, nose, throat, and lungs, as well as the skin, an exposure that often causes allergic reactions.

Overhead 4.2. Hand-arm vibration syndrome (HAVS)

Extensive and long-lasting exposure to manual work involving the use of vibrating power tools has been associated with persistent health disorders. The major health hazards reported include the following: a disorder of the peripheral micro-circulation, cold-induced Raynaud's phenomenon or "vibration white fingers" (VWF), and neurological disorders in the peripheral nervous system, either in the form of nerve entrapment at various locations or as a peripheral nerve effect in the form of diffusely distributed neuropathy. The manifestation of the neuropathy can reduce perception (numbness, impaired
ability to experience touch, or temperature) or result in increased pain or sensations of “needles and pins”. The musculoskeletal system may also be influenced by vibration, resulting in impaired sensory-motor function or by adverse effects on joints or bones. These health effects are collectively summarised as the hand-arm-vibration syndrome (HAVS). Until 1986, HAVS was classified by one single scale, irrespective of the fact that the neurological and vascular components may develop either concordantly or independently. Today, the components are recognized as separate entities and assessed separately.

**Overhead 4.3. Vibration and the upper extremity**

Physical vibration-exposure characteristics such as frequency and intensity relates to which body-part and how detrimental the effects will be on the worker. The possible hazardous effects from vibration could be mediated by simple mechanical impact or by general physiological responses. High-frequency vibration exposure mechanically influences the body parts close to the contact area. Low frequency vibration-exposure may exert mechanical influence further away from the contact area, negatively influencing other parts of the body. In slide 4.3, red-colour indicates areas under mechanical impact from vibration in relation to 1000 Hz 100 Hz and 10 Hz vibration frequency. Effects from general physiological responses could influence both close and distant body parts. The influence of local impact compared to centrally mediated physiological mechanism is not known. In addition to the physical characteristics of vibration, organisational aspects such as continuous or intermittent work and the opportunity to take rest-periods determine the influence of vibration. Individual characteristics in work technique, tool handling, body constitution, posture, skill, and the use of protective equipment also control the influence of vibration on the worker.

**Overhead 4.4. Temporary vascular effects**

Exposure to vibrating machinery introduces disturbances in sensibility, motor control, and blood circulation. The body responds actively to the exposure, and the detrimental effects entail interaction between worker attributes, work,
and vibration. Some of the effects are temporary changes, from which recovery is generally rapid, while others are assumed to be permanent.

The acute responses include the following: temporary threshold shift for vibrotactile, thermal perception, and two-point discrimination, vascular tone change, nerve conduction impairment, increased axon excitability experienced as post-exposure paresthesia, altered sensorimotor reflexes such as the tonic vibration reflex and g-loop interference indicated by disillusion of limb position with unstable performance.

Vibration significantly reduces finger blood flow and increases vascular resistance when compared with pre-exposure and non-vibrated finger values. Temporary vasodilatation occurs in vibrated fingers immediately after vibration exposure, whereas a progressive finger blood flow reduction occurs in both vibrated and non-vibrated fingers after 15 – 30 minutes of exposure. The extent of the digital circulatory response depends on the magnitude and frequency of the vibration exposure. The vibration exposure at 125 Hz has the greatest impact. Acute vascular vasoconstriction has also been demonstrated remotely in the lower extremities during exposure to one single finger.

Overhead 4.5. Permanent effects: Vibration white fingers “VWF”

The principal vascular disorder associated with exposure to hand-arm vibration is traditionally called vibration-induced “white fingers”. That is, workers using hand-held vibrating machines may experience episodic attacks of clearly demarked finger blanching in response to exposure to body cooling due to cold, cooling conditions such as windy, damp conditions, and vibration exposure or emotional stress. Significant and well-demarked pallor of the affected digits, associated with concomitant numbness, characterizes a “white-finger” episode. In addition, this reduction in peripheral blood-flow inhibits bleeding if cut. A “white-finger” episode often begins with blanching in the distal phalanges and may extend proximally to additional phalanges. Spotted patches of blanching may also occur. There may be a sequence of colour changes in which blanching is followed by redness. Blanching is accompanied with reduced sensibility and redness may be followed by a
sensation of pain. People who have contracted an altered vascular function may experience a sensation of increased sensitivity to cold even without noticing “white fingers”. This “cold-intolerance” may stem from either neurosensory or vascular dysfunction. The increased sensitivity of the peripheral vascular system resulting in vasospasm is variously called vibration induced white fingers (VWF) or “secondary” Raynaud’s phenomenon (in contrast to “primary” Raynaud’s phenomenon where the aetiology is unknown).

Overhead 4.6. What goes wrong?

Vibration-induced white finger is a disorder characterised by complete closure of digital blood vessels. The characteristic vascular “unnormality” is an enhanced vasospastic (contraction of the muscles in the vessels) reaction to cold. The reason for this reaction is not fully understood.

A strong vasoconstriction response obstructs the blood flow. If this constriction is restrained to the arterioles, the blood is trapped in the capillaries and the blood will lose its oxygen and become dark, resulting in a bluish skin colour. If the venous capillaries are also constricted the skin will not get any blood and the skin will turn white in colour. Skin colour reveals whether the vessels are patent. Vasospasm normally affects peripheral arteries and spare the deep branches.

Overhead 4.7. Regulation of the peripheral vascular system

At least two reasons have been identified that may explain why vibration exposure causes permanent vascular damage: disturbance on local and central vasoregulatory control through neural and endocrine (sympathetic and parasympathetic unbalance) systems and shear stress factors. The disorder is characterised by a relative increased sympathetic drive in relation to the parasympathetic system. This results in a local imbalance between dilating factors and constricting factors, conditions that are possibly related to endothelial disorder and to increased contractility in the vessel due to hypertrophic muscular contractors in the vessel. Cold temperature introduces a
strong sympathetic drive contracting the vessels. Increased physiological stress
response, noise, and emotion may also influence the autonomic system. This
complex causal relation is in line with the multifactorial aetiology of Raynaud’s
phenomenon.

**Overhead 4.8. Vascular system of the upper extremity**

All tissues in the body require adequate blood flow. Thermoregulatory needs
are the main determinants of finger blood flow. The vasculature of the upper
extremity comprises a common brachial artery that divides into radial and
ulnar artery, the deep palmar arch arteriovenous anastomoses and the
ascending veins.

**Overhead 4.9. Who is at risk for VWF?**

Adverse health effects of hand-arm vibration exposure may be suspected
among all workers presenting symptoms of vascular, neurosensory, or
musculoskeletal damage.

The latency time from start of exposure to contraction of symptoms varies with
exposure characteristics, the subject’s susceptibility, and the type of
manifestation. The latency time can be short or counted in years or decades.

- Presently, there is no information on specific parameters of
  susceptibility except other disorders influencing the vascular,
  neurological, or musculoskeletal systems.
- For vascular manifestations, older age seems to be associated with
  increased risk of disease.
- Tobacco use influences the presentation of symptoms of white fingers.
  Tobacco use accompanies prevalent attacks of white finger symptoms
  and is associated with a bad prognosis.
- Living in a warm climate reduces the presentation of symptoms of
  white fingers.
Overhead 4.10. What could elicit the vascular symptoms?

Episodes of white finger are usually precipitated by exposure to cold. The cooling effect is increased in situations when people handle cold objects or are exposed to high humidity, water, and melting snow or ice. Stressful situations or concomitant exposure to nicotine increases the risk of an attack. Exposure to vibration is also known to elicit symptoms. Sometimes the exposure from as little as an electric toothbrush or an electric shaver is enough to trigger vasospasm. Concomitant vibration and pressure on the vessels in the hand increases the risk for vasospasm.

Overhead 4.11. What modifies the vascular symptoms?

The circadian rhythm (reduced endocrine activity in the evening and late at night and increased activity early in the morning till midday) is correlated to when white finger attacks are most easily triggered. Attacks often come in the morning when the endocrine activity increases and the metabolism is low, and attacks are less prevalent in the afternoon. Attacks are also easier to elicit when the stress-system is enhanced. The experience of strain or emotional stress interacts synergistically with the endocrine system and increases the probability of the occurrence of white finger attacks.

Metabolic activity related to nutrition can also interact with the triggering of vasospasm. Low metabolic activity and a reduced food intake favour the occurrence of attacks.

Nicotine or other vaso-contractive agents promote the occurrence of white finger episodes. Alcohol, however, may inhibit the occurrence of white finger.

A low systemic blood pressure or low local blood pressure due to compression to the vessels increases the risk of white fingers. Medication (depending on its active components) could reduce or enhance the risk of vasospasm.
Overhead 4.12. Possible disability and handicap

Adverse health effects from vibration (HAVS) may decrease manual dexterity and make performing manual tasks difficult. These effects cause the worker to lose the ability to withstand cold and damp environments, withstand stress or exposure to vibration, and lead to restrictions in daily life due to pain. This handicap could result in a disability, reduction in quality of life, and possible loss of work. Recently, studies have noted that even minor vibration can negatively influence a worker’s vascular and neurological functions, conditions that can negatively influence a person’s quality of life. Recent studies suggest that vibration induced white fingers negatively influences worker’s lives more and in more ways than previously understood.

Overhead 4.13. What will the physician do?

The purpose of the consultation may focus on symptom-evaluation: evaluation of the possible relation between work and disease, investigation of work-compensation, or evaluation of the contribution of confounding factors.

Assessment of occupational and medical history

The work up of a person presenting with problems related to work with vibrating machinery implies the gathering of information on the medical history with information on type, onset, and duration of symptoms. The history will specifically inquire on the last episodes of white finger symptoms. During the clinical evaluation, personal history and occupational history is also collected.

Assessment of physical status

The assessment should include a complete physical examination. Both upper and lower extremities should be examined. In successive steps, the examination should try to rule out inadequate findings and rule in possible vibration-related diagnosis.
Assessment of possible specific test

Laboratory tests and specific investigations might be proposed after collecting the medical history and completing the physical examination.

Possible treatment and management

The level of diagnostic ambition is connected to the repertoire of treatment and management. There is no specific medication that can cure HAVS vascular component. Reduction of exposure is the most important “treatment”.

Possible specific information

One of the most important functions of the consultation is to give information on prognosis, contributory factors, factors affecting improvement of symptoms, prevention, and worker’s compensation.


The diagnosis of Raynaud’s phenomenon, “white fingers”, must recognise that causes other than vibration may contribute to these symptoms and signs. Diagnosis of “vibration-induced white fingers” requires establishing that there has been significant exposure to hand-transmitted vibration. Important aspects of vibration exposure include mean frequency, intensity level, times, and durations. The amount of vibration transmitted to the hand is modified by ergonomic factors such as grip and push forces, and work organisation and work technique influences the amount of exposure. In addition to vibration, there are other occupational exposures that might influence the occurrence of “white fingers” such as exposure to lead, vinyl chloride, and arsenic.

Overhead 4.15. Assessment of the medical history

The medical interview is widely accepted as the “best” available method of diagnosing “white fingers” (Raynaud’s phenomenon). The criteria for the diagnosis of vibration-induced white fingers include the following: cold related
episodes of well-demarked finger blanching, current activity if such episodes have been noticed during the last two years (if exposed to cold), exposure to hand transmitted vibration before the appearance of vasospastic episodes, and no other probable cause of Raynaud’s phenomenon. The medical interview should include information on symptom descriptions, distribution of blanching, time, and duration for occurrence of episodes of white fingers, and information on other possible diseases (autoimmune diseases such as Rheumatoid arthritis, CREST-syndrome, SLE, MCTD, Sjögrens syndrome, thyreoiditis, primary billary cirrhoses, and blood and vessel abnormalities such as obstructions). Identification of “white fingers” on a standardised colour chart increases the specificity of the diagnostic process.

Several drugs used to treat hypertension, asthma, and cancer are also vasoactive. Such medications include beta-blockers, ergotamine, klonidin, metysergid, bleomycin, vinblastin, lithium, and methyl amphetamine. Information on tobacco use reveals the major vasoactive exposure among the majority of people.

**Overhead 4.16. Staging of the vascular symptoms (1)**

Symptoms of white fingers have been classified according to several classification systems. The early staging according to the Taylor-Pelmear Scale was based on information concerning white finger symptoms, information about the occurrence of the symptoms in summer and winter, and ensuing social and work impairment. Staging according to the subsequent Stockholm Workshop Scale was based on information concerning symptoms and the distribution of white fingers on the hand. Grading the stage of the condition is made separately for each hand. In the evaluation of the subject, the grade of the disorder is indicated by the stages and the number of affected fingers on each hand.
<table>
<thead>
<tr>
<th>Stage</th>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>No attacks</td>
</tr>
<tr>
<td>1</td>
<td>Mild</td>
<td>Occasional attacks affecting only the tip of one or more fingers</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>Occasional attacks affecting distal and medial (rarely also proximal) phalanges of one or more fingers</td>
</tr>
<tr>
<td>3</td>
<td>Severe</td>
<td>Frequent attacks affecting all phalanges of most fingers</td>
</tr>
<tr>
<td>4</td>
<td>Very severe</td>
<td>Symptoms identified in stage 3 and addition trophic skin changes in the fingertips</td>
</tr>
</tbody>
</table>

**Overhead 4.17. Staging of the vascular symptoms (2)**

These pictures illustrate the various stages according to the Stockholm Workshop scale for the classification of cold-induced Raynaud’s phenomenon in the hand-arm vibration syndrome. Note that the staying relates to number of phalanges not number of fingers:

*Picture 1: Stage 1*  
*Picture 2: Stage 2*  
*Picture 3: Stage 3*  
*Picture 4: Stage 4*

**Overhead 4.18. Assessment of physical status**

In addition to the general examination, the examiner focused specifically on the peripheral vascular system and the cardiovascular system.

The examiner inspects the appearance of the distal parts of the hands and fingers including locking for possible scarring, trophies, or nail-aberrations.

The examination should include provocation tests of vascular patency and the screening for signs of other diseases associated to Raynaud’s phenomenon.
Overhead 4.19. Assessment with laboratory tests

Cold provocation tests

Often, Raynaud’s phenomenon can be diagnosed on the bases of a medical interview, a questionnaire, or by identification of white fingers on a colour chart. When medico-legal or clinical uncertainty demands objective support, the increased sensitivity of the peripheral vascular system as presented by episodes of white fingers can be assessed using standardised cooling and measurement of re-warming or by comparing distal blood pressure before and after cooling. A negative result from a cold provocation test, however, cannot safely rule out a VWF-disorder.

Chemical screening

Because rheumatologic diseases are related to an increased risk of Raynaud’s syndrome, a minor chemical laboratory screening (sedimentation rate, ANA, ANF) could be justified.

Overhead 4.20. Other causes of “white fingers”

Although primary Raynaud’s phenomenon is the most common cause of white fingers, its aetiology is unknown. In a normal population in “temperate” European countries a prevalence of about 5% for men and 30% for women could be expected. Other aetiologies for Raynaud’s phenomenon (secondary) are various diseases, such as connective tissue diseases, vascular diseases, including vascular compression or trauma, medication, and occupational exposures.

Overhead 4.21. Clinical evaluation of vascular symptoms

The diagnostic process addresses the consistency of the vascular symptoms with secondary Raynaud’s phenomenon and whether the characteristics of the vibration exposure are consistent with the hand-arm vibration syndrome. The diagnosis is performed in relation to possible treatment and management,
including the decision of future employment. To rule out other possible causes, other exposures must be considered.

The severity of the disorder is classified according to symptom stage scale. In some countries the doctors are required to perform extensive investigations if compensation from workers compensation fund is expected. The diagnostic precision depends on the aim of the investigation.

**Overhead 4.22. Management and treatment**

The major treatment for vibration white fingers is primary prevention by exposure reduction. This treatment should be supplemented with information on personal prevention actions that could modify symptoms – tobacco use, stress, heating, nutrition, noise, and work technique.

Only in severe cases should medical treatment be considered and in such cases only in combination with exposure reduction.

Adequate management includes documentation for possible referral to workers’ compensation or litigation.

**Overhead 4.23. Prognosis for vascular symptoms**

Clinical and epidemiological studies indicate that white finger symptoms can be reversed. After discontinued exposure to vibration, almost every other subject could be improved. The chance for improvement is higher for subjects classified as mild cases, few exposure years, and young. Continued tobacco use results in an unfavourable prognosis.
LECTURE 5: EFFECTS ON HUMAN BODY - NEUROSENSORY SYSTEM

Teacher’s notes

Overhead 5.1. Work, vibration & the neurosensory system
Overhead 5.2. Temporary neurosensory effects
Overhead 5.3. Permanent effects: neurosensory shift
Overhead 5.4. Neurosensory system
Overhead 5.5. Motor system
Overhead 5.6. What goes wrong (1)?
Overhead 5.7. What goes wrong (2)?
Overhead 5.8. Who is at risk for neurological effects?
Overhead 5.9. What elicits the neurosensory symptoms?
Overhead 5.10. What modifies the neurosensory symptoms?
Overhead 5.11. Possible disability and handicap
Overhead 5.12. What will the physician do?
Overhead 5.13. Assessment of the occupational history
Overhead 5.14. Assessment of the medical history
Overhead 5.15. Staging of neurosensory symptoms
Overhead 5.16. Assessment of physical status
Overhead 5.17. Assessment with laboratory tests
Overhead 5.18. Other causes of “neuropathy”
Overhead 5.19. Clinical evaluation of neurosensory effects
Overhead 5.20. Management & treatment of nerve effects
Overhead 5.21. Prognosis of neurosensory effects

Suggested study activities

With open eyes, try to put your second fingertip on three predefined spots.
With your eyes blindfolded and with simultaneous exposure to vibration, try to point to these spots. Do you notice any differences?
3.5.1. Teacher’s notes

Overhead 5.1. Work, vibration, & the neurosensory system

Extensive and long-lasting exposure to manual work involving the use of vibrating power tools has been associated with persistent health disorders. These health hazards include neurological disorders in the peripheral nervous system, either in the form of nerve entrapment at various locations or as a peripheral nerve affection regarded as a diffusely distributed neuropathy. There seems to be a wide variety of neurological effects especially involving the sensory system. The detrimental effect might be in close contact with the exposure, but may also be remote due to the physiologic flow in the nerve. Posture may introduce additional stress or pressure on the nerves resulting in entrapment syndromes (e.g., between muscles and bones in the thoracic outlet).

Overhead 5.2. Temporary neurosensory effects

The acute responses revealed in experiments with vibration exposure include the following: temporary threshold shift (TTS) for vibrotactile, thermal perception, and two-point discrimination, vascular tone change, nerve conduction impairment, increased axon excitability experienced as post-exposure paresthesia, altered sensorimotor reflexes such as the tonic vibration reflex and g-loop interference indicated by disillusion of limb position with deranged performance.

A temporary threshold shift for vibration perception thresholds increases (that is, reduced sensibility) with increased acceleration and is maximal at 125 Hz. The magnitude of the TTS change is also influenced by the initial vibration perception threshold (VPT) value.

A temporary threshold shift for thermal perception has attracted little attention. Researchers have showed the frequency dependency (maximal effect at 125 Hz) to be similar to that for vibrotactile perception. They found a marked effect on warmth perception but less effect on cold perception. Any
interpretation of the results must take into account the finger temperature change accompanying the temporary reduction in peripheral vascular flow manifested as reduced finger temperature.

High intensity vibration exposure produces long-lasting hypesthesia. Accompanying paresthesia may be attributed to disturbances in peripheral afferent fibres.

Researchers have demonstrated that vibration increases the EMG activity in the muscles of the hand–arm system. Vibratory exposure reduces the endurance time of muscles. The tonic-vibration reflex as revealed by EMG on motor unit synchronisation is strongest below 150Hz.

The acute disturbances are temporary and affect most exposed workers. In none of these studies did any major effects remain after more than one hour. Many of these acute effects are not consciously perceived and so far have been underrated as potential risk factors in accidents involving a fall, dropping objects, improper use of controls, and traumatic injuries.

**Overhead 5.3.  Permanent effects: neurosensory shift**

Disturbances in hand function (commonly reported as numbness, paresthesia, and difficulty in performing manipulative tasks) have been witnessed by workers handling vibrating power-machines and among ordinary manual workers. The association between reported symptoms and vibrotactile acuity is not straightforward. One study noted that these symptoms were predicted by questions relating to hand function, a finding that is compatible with basic somatosensory concepts of negative (loss of function) and positive phenomena (additional symptoms). Negative symptoms dominate and refer to numbness and other loss or absence of feeling, reduced proprioception, and difficulty with motor skills. The positive symptoms include dysaesthesia and tingling. Previously, symptoms were categorised as present or absent, and later stages were based on the Stockholm Workshop scale. The various descriptions include “numbing of the hands was particularly common at night” or “they were forced to rub and shake their hands”. Recently, researchers noticed the occurrence of cold intolerance expressed as pain and discomfort when cold
and without blanching due to exposure to a cool environment. Such symptoms are a major problem following injury to digital nerves. Hypoesthesia (a negative manifestation) reflects failure at any level along the sensory channels from the sensory end organs to cortex. The person may or may not be aware of the deficit. Negative sensory symptoms are often late indicators of afferent dysfunction. Positive manifestations also reflect dysfunction and are expressed mostly as symptoms (such as tingling, buzzing, and pricking) without signs. Positive phenomena are largely due to abnormal generation of impulses in sensory channels. Microelectrode recordings from the median nerve on human subjects exposed to vibration and to electric pulse trains indicate that paresthesia could be attributed to disturbances in afferent sensory fibres. A significant category of positive sensory phenomena involves inadequate subjective response to natural stimulation of receptors (e.g., abnormal intolerance of cold in a case series of vibration-exposed patients). The discrepancy between symptoms and signs may entail sensory impairment without subjective recognition or symptoms. Experience suggests that neurological symptoms can exist without detectable signs and there might be signs that avoid detection.

The sensory units (nerve fibres with their endings, cell bodies, and central processes) are characterised by their type of nerve fibre, type of end organ, and their adequate stimuli. The cardinal signs of altered sensory unit function are elevated threshold as a loss of function and lowered threshold as a sign of increased sensitivity at quantitative sensory testing (QST). Symptoms of numbness have been noticed without sensory loss at QST. This may be due to positive phenomena or to sensory dysfunction confined to supra threshold stimulus. Disorders affecting primarily small neurons give rise to painful dysaesthesia, burning, searing pains, and sensory loss. Injury can result in both hyper- and hypoesthetia.

Overhead 5.4. Neurosensory system

When understood as a sense organ the hand entails peripheral sensory end-organs in the skin and nerves that carry the stimuli to nerve impulses and to the cortex. Disturbances of the sensory system can be located anywhere from the peripheral nerves and sensory end-organs to the central cortex.
Overhead 5.5. Motor system

The motor system is controlled by afferent somatosensory endings that transmit information concerning the status of the muscles. The efferent information controls the muscular activity. The interplay between ingoing information and outgoing control makes up the prerequisite for the delicate neurosensory function.

In addition to the sensory end organs, the large sensory and motor nerves the autonomic nerves regulate the activity in vessels and sudomotor activity.

Overhead 5.6. What goes wrong (1)?

Researchers have reported histologic al changes such as thickening of muscular layers, fibrosis in the peripheral arteries, demyelinating neuropathy, and loss of nerve fibres in the peripheral nerves of workers who used vibrating tools.

Excessive vibration exposure of rat-tail resulted in ultra structural changes such as detachment of the myelin sheath – constriction of the axon and deranged paranodal regions accompanied by reduced nerve conduction. These results agree with earlier findings.

Finger biopsies from patients with vibration white fingers have a characteristic perineurial fibrosis, thickened perineurium, reduced number of nerve fibres, and reduction in the size of myelinated fibres. The structural nerve injuries associated with vibration are dominated by myelin breakdown and interstitial perineurial fibrosis associated with incomplete regeneration or with organisation of oedema. Experimental evidence of disturbed microcirculation in relation to vibration exposure is revealed by the associated formation of intraneural oedema. The thin (unmyelinated) sympathetic nerve fibres seem to be particularly sensitive to the detrimental effect of vibrating machines. These symptoms are collectively named “diffuse neuropathy”.

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Overhead 5.7. What goes wrong (2)?
Throughout the body, peripheral nerves leave the spine and pass through small holes, long tunnels, and narrow spaces to reach their endpoints. The possible compression of these nerves can result in entrapments such as carpal tunnel syndrome, thoracic outlet syndrome, or other compression syndromes. Vibration exposure increases the risk of entrapment.

Overhead 5.8. Who is at risk for neurological effects?
Reviews of epidemiological studies on upper extremity disorders have reported several work related ergonomic risk factors – load sustained over time (force, repetitiveness, posture), undue “fit, reach and see”, task invariability, unfavourable psychosocial work variables, cold, vibration and local mechanical stresses. An association between specific occupational risk factors and repetitive motion disorders, including nerve compression at the carpal tunnel, is gaining increasing scientific support. The separate neurological effects from vibration are often unclear because this effect may be more easily identified as being caused by the work rather than by hand-transmitted vibration per se.

Neurological disorders may arise in short exposure times. In the worst case, very severe impact might cause nerve injury resulting in persistent symptoms.

Generally, the symptoms may develop over several years, but in some cases neuropathy related to work with vibrating machines develops quickly and may disable even young workers. The variability may be related to personal susceptibility, others diseases of the nerves, abuse of alcohol, exposure to other neurotoxin agents (e.g. lead, mercury, arsenic), work technique, or unfavourable work patterns. The nerves free mobility may vary between people with various body constitutions and postures.

Overhead 5.9. What elicits the neurosensory symptoms?
Neurological disorders may exist without eliciting sensations perceived by the worker as a symptom. In cases where precision demands high manipulative
dexterity, a deterioration in finger tactile perception may be noticed. The sensation of numbness may be increased when the finger temperature is reduced. A significant category of positive sensory phenomena involves inadequate subjective response to natural stimulation of receptors. The occurrence of cold intolerance expressed as pain and distressing coldness (without blanching as a result of exposure to a cool environment) is one such finding.

**Overhead 5.10. What modifies the neurosensory symptoms?**

The symptoms may be increased when decreasing the ambient temperature. The major synergistic effect comes from other disorders such as cervical neck pain or diseases that might cause polyneuropathy. The redistribution of body fluids during the night may increase the risk of nocturnal symptoms.

**Overhead 5.11. Possible disability and handicap**

The human hand is a large sense organ in which the sensory functions allow sensory motor control as well as sensory discrimination. Disturbance in this system results in serious handicap or difficulty in performing manual tasks. Workers exposed to harmful vibration may present with considerable impairment of hand function. They may also complain of numbness, a sensation of needles and pins, pain, sensory impairment, and weakness. The cold intolerance often results in difficulty coping with coldness and dampness due to pain or loss of function.

**Overhead 5.12. What will the physician do?**

A consultation may focus on evaluating symptoms, the possible relation between work and disease, work-compensation, treatment and management, or the contribution of confounding factors. For the neurological component the diagnostic process is equivalent to that for vascular symptoms (4.13).
**Assessment of occupational and medical history**

A worker presenting with problems related to work with vibrating machinery requires collecting a medical history with information on type, onset, and duration of symptoms. During the clinical evaluation, a personal history and occupational history are collected.

**Assessment of physical status**

Depending on the purpose of the assessment, an adequate and physical examination is performed. Both upper and lower extremities should be examined.

**Assessment of possible specific test**

Laboratory tests and specific investigations might be proposed after finishing the history and examination.

**Possible treatment and management**

The level of diagnostic ambition is connected to the repertoire of treatment and management. There is no specific medication that can cure HAVS neurological components except decompression of entrapments, which in some cases may relieve the symptoms. Reduction of exposure is the most important treatment.

One of the most important functions of the consultation is to provide information on prognosis, contributory factors, factors affecting improvement of symptoms, prevention, and workers’ compensation.

**Overhead 5.13. Assessment of the occupational history**

The diagnosis of neurosensory disorders in relation to work with vibrating machines must recognise that causes other than vibration can produce these symptoms and signs. Diagnosing “HAV-blind fingers” (fingers “blind” as to sensation of touch and temperature) requires knowing that a patient has been
significantly exposed to hand-transmitted vibration. Important aspects on the vibration exposure include mean frequency, intensity level, times, and durations. The amount of vibration transmitted to the hand is modified by ergonomic factors such as grip and push forces. Low temperature may influence the outcome. Work organisation and work technique influence the amount of exposure. In addition to vibration, there are other occupational exposures – such as a few specific organic solvents and heavy metals – that might influence the occurrence of neuropathy.

**Overhead 5.14. Assessment of the medical history**

The basis for a tentative, hypotheses-driven diagnostic procedure requires several steps: thorough history with symptom description (positive, negative, and provokable symptom manifestations); information on qualitative quantitative (hypo- and hyperesthesia); and temporal sensory abnormalities – course, pattern, and symptom distribution specified on a pictorial symptom manikin. Many professionals believe a medical history is the most important source of information. Several studies conclude that a medical history leads to the final diagnosis in three of four cases, whereas physical examinations and laboratory tests independently lead to the final diagnosis in about 10% of the time. History and pain drawings have repeatedly proved important in diagnoses of neuropathy. When researchers categorised hand diagrams as classical, probable, possible, and unlikely carpal tunnel syndrome, they found the hand drawing to be individually the best predictor with a positive predictive value of 0.6. The medical history also entails assessment of other diseases or medication that might be related to neuropathy.

**Overhead 5.15. Staging of neurosensory symptoms**

The neurological component of the hand-arm vibration syndrome is currently staged according to the Stockholm workshop scale. Grading the stage of the neurosensory conditions is made separately for each hand.
<table>
<thead>
<tr>
<th>Stage</th>
<th>Symptoms and signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0SN</td>
<td>Exposed to vibration but no symptoms</td>
</tr>
<tr>
<td>1SN</td>
<td>Intermittent numbness with or without tingling</td>
</tr>
<tr>
<td>2SN</td>
<td>Intermittent or persistent numbness, reduced sensory perception</td>
</tr>
<tr>
<td>3SN</td>
<td>Intermittent or persistent numbness, reduced tactile discrimination and/or manipulative dexterity</td>
</tr>
</tbody>
</table>

**Overhead 5.16. Assessment of physical status**

Guided by hypotheses developed from the history, a careful bedside examination is performed including the test of somatosensory, motor function, tendon reflexes, and provocation manoeuvres. Such an examination is a prerequisite for an adequate interpretation of electrophysiological tests and QST. Interpretation of pain and sensory abnormalities calls for the examination of pain in the musculoskeletal system.

Two injuries are easily confused: one at a receptor level in the fingertips and one in the carpal tunnel. Cervical spine disorders affecting the nerves may also mimic a vibration neuropathy as could poly neuropathy. Careful clinical assessment, neurophysiologic testing, and quantitative sensory testing are therefore recommended in the diagnosis of subjects with hand-intensive work and exposure to vibration. The discrepancy between symptoms and signs may include sensory impairment without subjective recognition or symptoms. This applies to thermal and tactile sensibility.

The bedside examination outlines the modality profile of the sensory dysfunction and the relative contribution of negative and positive irritative symptoms. It is usually easy to document and to interpret the mechanism of threshold or supra threshold findings of hypo- or hyperesthesia when the character of the evoked perception remains normal. The cardinal signs of altered quantitative sensory abnormality are an elevated sensitivity threshold as a measure of loss of function and a lowered threshold as a sign of increased sensitivity. It becomes significantly more difficult to decipher the pathophysiology when the sensation evoked is qualitatively abnormal. This is
especially the case with lesions producing positive, irritative symptoms such as paresthesia, dysaesthesia, allodynia, and pain. An array of qualitative, spatial, and temporal aberrations may occur in one or more modalities.

The cardinal signs of altered sensory unit function are an elevated threshold as a loss of function and a lowered threshold as a sign of increased sensitivity at quantitative sensory testing (QST). Numbness has been noticed without sensory loss. This may be due to positive phenomena or to sensory dysfunction confined to supra threshold stimulus.

A significant category of positive sensory phenomena involves inadequate subjective response to natural stimulation of receptors. Studies have demonstrated abnormal intolerance of cold in a case series of vibration-exposed patients. Altered sensory perception to vibration is also demonstrated in a study that found increased sensitivity to vibration among carpal tunnel syndrome patients.

**Overhead 5.17. Assessment with laboratory tests**

Quantitative sensory testing (QST) of the perception thresholds for vibration, cold, warmth and pain reveals the basic sensory function, and is a prerequisite for diagnosing the neurosensory vibration disorder component. Pain from the musculoskeletal system has to be encountered when interpreting the QST-results. In the diagnostic hypotheses testing process, electrodiagnostics are used in cases where there is clinical uncertainty about whether weakness is neurogen or myogen, whether the neuropathy is axonal or demyelinating, and when the clinical localisation of nerve lesion is difficult, on how to obtain and to determine the distribution and extent of the neuropathogenic process. In the past few decades, advances in the techniques of neurophysiologic evaluation have revolutionised the detection and characterisation of neuropathies. Chemical laboratory screening refers to other courses of neuropathy.
Overhead 5.18. Other causes of “neuropathy”

Once neuropathy is confirmed, more than 100 possible associations (e.g., focal neuropathies from compression and entrapment, ischemia, drugs, endocrine-, metabolic-disorders, infections, immune states, toxins, genetically determined disorders, and pharmaceutical agents) can be ruled out.

Overhead 5.19. Clinical evaluation of neurosensory effects

The diagnostic process answers the question of how consistent the neurosensory symptoms are with hand-arm vibration syndrome and if the vibration exposure characteristics are consistent with the outcome. The diagnosis is performed in relation to possible treatment and management, including the decision of future employment. To rule out other possible causes, other exposures must be considered.

The severity of the disorder is classified according to symptom stage scale. In some countries, the doctors are required to perform extensive investigations if compensation from the workers’ compensation fund is expected. The diagnostic precision depends on the aim of the investigation.

Overhead 5.20. Management & treatment of nerve effects

The major treatment for vibration-induced neurosensory disorders is primary prevention by exposure reduction. This treatment should be supplemented with information on personal prevention actions – e.g., tobacco use, stress, heating, nutrition, noise, and work technique – that could modify symptoms. Providing a clear and comprehensive understanding of the disease is the best way to reduce total risk.

Only in severe cases should medical treatment, often as surgical treatment or pain relief medication, be considered. In such cases, medical treatment should be combined with reduction of vibration exposure.
Adequate management includes documentation for possible referral to workers’ compensation or litigation.

**Overhead 5.21. Prognosis of neurosensory effects**

After discontinued exposure to vibration:

- In mild cases positive manifestations such as tingling and pain could be reduced.
- The chance for improvement is inconsiderable in severe cases where structural changes have appeared.
- Continued work results in an unfavourable prognosis.
LECTURE 6: EFFECTS ON HUMAN BODY - MUSCULOSKELETAL SYSTEM

Teacher’s notes

Overhead 6.1. Work, vibration, and the musculoskeletal system
Overhead 6.2. Temporary musculoskeletal effects
Overhead 6.3. Permanent musculoskeletal shift
Overhead 6.4. Musculoskeletal system
Overhead 6.5. Manifestations of musculoskeletal shift
Overhead 6.6. What goes wrong?
Overhead 6.7. Who is at risk for musculoskeletal effects?
Overhead 6.8. What elicits musculoskeletal symptoms?
Overhead 6.9. What modifies musculoskeletal symptoms?
Overhead 6.10. Possible disability and handicap
Overhead 6.11. What will the physician do?
Overhead 6.12. Assessment of the occupational history
Overhead 6.13. Assessment of the medical history
Overhead 6.15. Assessment of physical status
Overhead 6.16. Assessment with laboratory tests
Overhead 6.17. Other causes of “musculoskeletal” disorders
Overhead 6.18. Clinical evaluation of musculoskeletal effects
Overhead 6.19. Management & treatment of musculoskeletal effects
Overhead 6.20. Prognosis of musculoskeletal effects
Overhead 6.1. Work, vibration, and the musculoskeletal system

In manual work, muscular force is transformed into motion. Physical work is characterised by biomechanical and ergonomic workload parameters. The muscular effort expended can be reduced by using powered machines. At any given muscular load, a power machine can exert an increased energy. The impact of vibration per se depends on exposure characteristics such as frequency and intensity. The harmful effects from work with vibrating tools may be the conjoint effect from vibration, repetitive movements, grip forces, push forces, non-neutral posture, and local stress.

Overhead 6.2. Temporary musculoskeletal effects

Vibration temporally increases the EMG activity in the muscles of the hand–arm system. Vibratory exposure reduces the endurance of muscles. The temporary vibration effect on tonic-vibration reflex as revealed by EMG on motor unit synchronisation is strongest below 150Hz.

The interplay between the acute perturbations and the coupling between the hand-arm system and the machinery determines the actual vibration dose transmitted. The acute disturbances are temporary and affect most exposed workers. Major effects seldom remain more than one hour after interrupted exposure.

Overhead 6.3. Permanent musculoskeletal shift

Vibration-exposed workers have an excessive risk of musculoskeletal disorders compared to non-vibration exposed controls. The disorders include muscle-limb pain, muscle-tendon syndromes, and reduced muscular capacity. Osteoarthritis and stiffness are also reported. The combined effect of neurosensory and muscular impairment may also be experienced as reduced manual dexterity due to loss of neuro-muscular control. The effects have been
patoanatomic localised to muscle, bone, and joints close to the vibration source. The musculoskeletal disorders require high intensity exposure and significant impact vibration sustained over long time in order to develop.

**Overhead 6.4. Musculoskeletal system**

The effects on the various parts of the upper extremity – muscle, tendons, joints, and bone – are associated with the specific vibrating tool and vibration characteristics.

**Overhead 6.5. Manifestations of musculoskeletal shift**

The major symptoms and signs associated to musculoskeletal disorders are listed below:

- reduced force and muscular function
- reduced manual dexterity
- possible muscular pain or tendonitis
- symptoms of arthritis and joint or tendon degeneration, dupuytrans contracture

Additional support for osteoarthritis comes from x-ray investigation.

**Overhead 6.6. What goes wrong?**

Muscular work under the influence of hand-transmitted vibration may initially result in increased grip strength; however, after sustained exposure, this may result in reduced force. Until recently, remaining reduced muscular strength has been regarded as a distortion in the neuro-muscular interplay; however, recent experimental studies on animals have demonstrated a change in muscle morphology related to vibration exposure. Such findings have also been confirmed in human subjects. Tendons inserted to muscles are expected to be at risk for tendonitis when the muscle strain is sustained, static, or the load high. Tendonitis as the result of the extra load from vibration is thus a
plausible outcome, but this correlation has not been clearly established. The association to vibration per se is still lacking, and there is a relation to work with vibrating tools. The same fact counts for injury to the joints. Work with vibrating machines places workers at risk for joint pathology (mainly hand, elbow, and wrist osteoarthritis). The evidence for an exclusive vibration effect on the joints is weak. Studies have noted an association between working with vibrating tools and osteoporosis and cysts in the bones of the hand.

**Overhead 6.7.** Who is at risk for musculoskeletal effects?

Long sustained work entailing heavy vibration exposure is an underlying premise for contracting musculoskeletal disorders. The relative importance of hand-transmitted vibration compared to other ergonomic risk factors is often unclear. Ergonomic and vibration exposure must both be considered when evaluating the risk. The incidence of contracting musculoskeletal problems when working with vibrating machines has not been established.

In the case where vibration is believed to be a major cause of osteoarthritis, a heavy exposure of high magnitude of low frequency or of percussive character for a long time period is presumed.

**Overhead 6.8.** What elicits musculoskeletal symptoms?

Reduced function in the muscles is a sustained phenomenon that may be noticed as a symptom only when demands on high manual dexterity and force are introduced.

Joint disorders follow the symptomaticity of osteoarthritis with circadian variation in symptoms with morning stiffness, pain at increased load, and possible local pain due to damaged structures.

Although an x-ray image may indicate bone cysts and vacuoles, patients rarely notice them and report them as symptoms.
Overhead 6.9. What modifies musculoskeletal symptoms?

The major modifiers of musculoskeletal symptoms are sustained load and pain and stiffness related to load, immobilisation, and body fluid redistribution while sleeping in recumbent position. The background excitability of the somato-sensory pain system influences the magnitude of the musculoskeletal symptoms.

Overhead 6.10. Possible disability and handicap

The impairment resulting from work with vibrating machines may be experienced as muscle weakness, loss of hand co-ordination, impaired dexterity, clumsiness, hand cramps and focal pain and dysfunction in joints. The disability is manifested as difficulty in performing manual tasks, and exerting force and restricts activity due to pain, or loss of function.

Overhead 6.11. What will the physician do?

The clinical diagnosis includes the assessment of occupational and medical history, a physical examination, laboratory tests, and possible treatment and management. An important aspect of the management is to provide information on possible prognosis about what aggravates the symptoms and about what lessens the symptoms.

The preventive measures have to comprise the total ergonomic setting in order to cover the ergonomic load factors and vibration exposure.

Overhead 6.12. Assessment of the occupational history

The occupational history is assessed with reference to equal detail for both vibration and ergonomic load factors.
Overhead 6.13. Assessment of the medical history

A worker presenting with musculoskeletal problems related to work with vibrating machinery requires collecting a medical history with information that includes a detailed symptom description, information on qualitative and quantitative aspects of the symptoms, localisation, onset, progress, aggravating and relieving actions, temporal course, and duration of symptoms. The symptoms and their distribution may be specified on a pictorial symptom manikin.


Information from medical history, physical examination, and occupational history forms the basis for a diagnosis. To date, the resulting diagnosis has no staging related to the musculoskeletal component of the hand-arm vibration syndrome.

Overhead 6.15. Assessment of physical status

In addition to general screening, the physical examination related to musculoskeletal problems specifically focuses on the following: the neuromuscular system including the peripheral sensory system and the motor system and appearance of muscles, tendons, bone, and joints. Muscle provocation tests identify sore muscles and tendons where pain may indicate underlying inflammatory processes. Strength test for various specific muscles should be included.

Overhead 6.16. Assessment with laboratory tests

The basic laboratory assessment includes tests that could indicate the presence of other diseases related to the symptoms reported. Blood tests such as sedimentation rate and rheumatoid factors could be used to rule out possible inflammatory diseases.
The laboratory assessment may include radiographic or magnetic resonance imaging for bone and joint involvement. Muscular dysfunction may be explored further using electro-diagnostic (nerve conduction tests and electromyography) testing.

**Overhead 6.17. Other causes of “musculoskeletal” disorders**

Ergonomic factors interfere with the incidence of musculoskeletal disorders. The contribution from vibration and ergonomic load factors are usually non-separable. Pain sustained over a long time may transform to non-protective chronic pain separated from the original nociceptive muscle or joint disorder. Osteoarthritis may relate to hereditary susceptibility. Inflammatory episodes and immune dysfunction are associated with increased prevalence of musculoskeletal problems.

**Overhead 6.18. Clinical evaluation of musculoskeletal effects**

The major evaluation addresses symptoms consistent with arthritis, tendonitis, or primary muscle dysfunction related to vibration or confounding factors. The musculoskeletal disorders require high intensity exposure and significant impact vibration sustained over long time in order to develop. Confounding exposures except from ergonomic load are infections or other conditions triggering the immune system.

Pain from the musculoskeletal system has to be encountered when interpreting QST-results.

**Overhead 6.19. Management and treatment**

Primary prevention includes a total ergonomic evaluation with reduction of exposure load.

Information on personal prevention actions that could modify symptoms (e.g., local stress and ergonomic work technique)
In advanced cases of osteoarthritis, surgical intervention or medical treatment follows the evidence-based management.

Possible documentation for workers’ compensation or litigation

**Overhead 6.20. Prognosis of musculoskeletal effects**

Evidence stating the prognosis for muscular disorders is scarce. The chance for improvement is inconsiderable in severe cases where structural changes have appeared. Morphologic changes demonstrated in muscle fibres support the view that the disorder is permanent. The same holds for osteoarthritis where pantoanatomic changes accompany advanced cases. After a long time, osteoarthritis with severe pain may be reduced while impaired function remains.
LECTURE 7: MEASUREMENT AND RISK ASSESSMENTS

Teacher’s notes

Overhead 7.1. Measurement and risk assessments
Overhead 7.2. Measurement and evaluation strategy
Overhead 7.3. Identifying the operations
Overhead 7.4. Daily exposure time
Overhead 7.5. Duration of vibration measurements
Overhead 7.6. Choice of accelerometer
Overhead 7.7. Accelerometer mounting and position
Overhead 7.8. Measurement directions
Overhead 7.9. Frequency range and weighting
Overhead 7.10. Measurement equipment
Overhead 7.11. Eliminating sources of uncertainty
Overhead 7.12. Calculating the 8-hour energy-equivalent vibration
Overhead 7.13. Risk assessments
3.7.1. Teacher’s notes

**Overhead 7.1. Measurement and risk assessments**


The evaluation of vibration exposure from handheld machinery is based on the measurement of vibration magnitude and exposure times. Additional factors – such as grip forces, feed forces applied by the operator, the posture of the hand and arm, the direction of the vibration and the environmental conditions – are not taken into consideration.

**Overhead 7.2. Measurement and evaluation strategy**

To perform reliable measurements and to develop a strategy for the evaluation of hand-transmitted vibration at the workplace the assessment of vibration exposure can be broken up into a number of stages:

- Identifying the operations, which make up the operator’s normal working pattern
- Evaluation of the typical daily exposure time for each operation identified
- Selection of operations to be measured
- Measuring and establish the frequency weighted acceleration value for each selected operation
- Calculating the 8-hour energy-equivalent vibration total value (daily vibration exposure).
Overhead 7.3. Identifying the operations

It is important to take measurements on all handheld machines or hand-supported components are part of daily exposure. For this reason, one must identify the sources of the vibration that are likely to contribute significantly to the overall vibration exposure. Moreover, it is important to recognise the different ways the machine is used and the characteristics of the base or object being processed. The vibration exposure may vary greatly from one operation to another either due to the use of different power tools or machines or different modes of operation. It is also very important to ascertain which tools are attached to the machine – e.g., types of grinding discs, drills, saw chains, chisels, saw blades, etc. In addition, it can be helpful to obtain usable information from the operators about the types of work situation that produce most vibration. There will also be information about manufacturers, importers, etc.

Overhead 7.4. Daily exposure time

Daily exposure time should be determined for each vibration source using stopwatches, video recordings, and time studies. In some work, the daily exposure time can be based on measurement of the actual exposure time during a period of normal use (e.g., as evaluated over a complete work cycle or during a typical 30 minute period) and information on work rate (e.g., the number of work cycles per shift or the shift length). Information about daily exposure time is often an overestimate since work breaks are also included.

Fundamental for the evaluation of daily vibration exposure is based on only one working day, and it cannot be indiscriminately extrapolated to allow the averaging of exposures over longer periods. However, in some situations it may be desirable to obtain an evaluation of exposure based on exposure information obtained over longer periods such as when the amount of time using handheld machines changes significantly from one day to the next.
Overhead 7.5. Duration of vibration measurements

Vibration exposures are often for short periods that are repeated many times during a working day. The measurements should reflect a mean value over a period representative of a typical application of a handheld machine. The measurements should start from when the operator first takes hold of the machine until he lets go. If possible several measurements should be taken at different times of day to take into account the variations of vibration load. The smallest acceptable measurement period should not be less than 1 minute, and for each work element a minimum of three measurements should be taken. Exposure to vibration of very short duration (less than 8 seconds) increases uncertainty in the measurements, so considerably more than three measurements should be carried out to ensure a total sample time greater than 1 minute.

Sometimes it is either impossible or extremely difficult to take measurements under realistic working conditions. Simulated work processes can then be performed in order to measure the vibration. This may apply when exposure is for a very short time or when the machine is picked up or put down in a rough manner.

Overhead 7.6. Choice of accelerometer

To determine acceleration on a vibrating surface, an accelerometer is normally used. The most common form of measuring transducer is a piezoelectric accelerometer containing a mass pre loaded with a spring resting on a piezoelectric crystal. When the accelerometer is exposed to movement, the mass acts on the crystal with a force corresponding to the acceleration. Then the piezoelectric crystal gives off a charge corresponding to the acceleration.

The choice of accelerometer depends on anticipated vibration levels, the frequency range desired, and the appearance or characteristics of the vibrating surface. As a rule, the accelerometer chosen should be as small as possible in order to reduce its effect on the vibrating surface. The mass of the accelerometer should not exceed 5% of the mass of that part of the structure.
on which the accelerometer is mounted. This means that the total weight of the machine will not govern the choice of transmitter weight.

**Overhead 7.7. Accelerometer mounting and position**

The accelerometer should be positioned in the middle of the area gripped by the operator. Normally, however, this is not possible since it will have a prejudicial effect on the machine’s handling. The accelerometer should be placed as near as possible to the surface with which the operator’s hand is in contact.

The accelerometer should be mounted on the vibrating structure in a stable manner; this is best done with screws or glue. On cylindrical handgrips, a hose clamp can be used to attach the accelerometer. This is particular useful when the tool handle has a soft outer coating. Since this coating can affect the vibration transmission, it is important that the transducer is fixed with a force that fully compresses the resilient material. In some situations, however, neither of these methods is possible. If this is the case, special hand adapters can be used. Measurements using hand adapters should be made with care since the results can be affected by the grip strength and feed force applied by the operator.

**Overhead 7.8. Measurement directions**

Measurements should be done in the three orthogonal directions: x, y, and z. The orientation of the co-ordinate system should be defined according to the vibrating machine, work piece, or handle.

Some typical measurement locations and axes for the most common hand-held power tools have been defined in the figure.

Simultaneous measurement in three main directions is preferable to separate measurements for each direction. However, some instruments only allow measurements along each of the three axes. This is acceptable if the operating conditions are similar for all three measurements.
If the vector sum cannot be determined by direct measuring, the values measured in the direction with the highest acceleration (the dominant axis) could be multiplied using a suitable factor between 1 and 1.7 (typically between 1.2 and 1.5). Determining this factor, however, requires information about the acceleration in the other directions. If, for example, acceleration in the non-dominant levels is 30% of the dominant one, the following equation could be used:

\[ a_v = \sqrt{\left( a_{h,w,\text{dominant}}^2 \right) + \left( 0.3 \cdot a_{h,w,\text{dominant}} \right)^2 + \left( 0.3 \cdot a_{h,w,\text{dominant}} \right)^2} \approx 1.1 \]

*Formula 7.1.*

where \( a_v \) is the acceleration’s summation vector and the frequency weighted acceleration for the dominant direction.

**Overhead 7.9. Frequency range and weighting**

When measuring vibration from handheld machinery, two magnitudes should be determined: the daily period of exposure and the total frequency weighted acceleration level in m/s² expressed as effective values for each of the three directions of vibration. The measurements of acceleration should be done for frequencies between 5 Hz and 1500 Hz.

Measured acceleration should be frequency weighted either by means of a special weighting filter or by weighting the acceleration levels given in octave or 1/3-octave bands. Within the frequency range 6 Hz to 16 Hz there is no weighting of measured acceleration, but at higher frequencies the acceleration signals should be weighted using a factor that increases by 6 dB per octave.

**Overhead 7.10. Measurement equipment**

Measuring vibration may be done using a simple direct reading instrument with a built in weighting filter, mean value formation, and presentation. These
instruments generally meet the requirements of current standards. Their disadvantage is that it is difficult to establish measuring errors. More advanced instrument arrangements are often based on some type of frequency analysis, such as recorders for storing measurements and computer or other special analysing instruments. These more costly and complex systems, however, will give more information about the frequency distribution of vibration and provide information on any dominant frequencies, information that may help identify effective vibration control measures.

Overhead 7.11. Eliminating sources of uncertainty

Because uncertainty in the results should be minimised, equipment should be calibrated both before and after measuring using a calibrator that generates a sine vibration of known frequency and acceleration.

The most common sources of uncertainty in vibration measurement are cable connector problems, triboelectric effect, and DC-shift.

Cable connector problems are the most common problem with the measurement of hand-transmitted vibration. This often occurs at the connection to the accelerometer where damage is most likely.

Electromagnetic interference could affect the vibration measurement. To avoid these problems, one could screen the cables or use twisted cables. Another solution could be to avoid signal cables running parallel to power cables or by grounding the signal cable’s screening. In addition, electrical insulation between the accelerometer and the vibrating surface could help.

Triboelectric effect occurs when the instrument cables are exposed to high vibration amplitudes. This could result in electrical signals being produced as a result of deformation. For this reason, signal cables should be secured (using adhesive tape) to the vibrating surface near the accelerometer.

The DC-shift occurs when piezoelectric transducers are subjected to very high accelerations at high frequencies, accelerations that are produced by percussive tools. The vibration signal can be distorted such that a false
additional low-frequency component appears in the vibration signal. To measure vibration of percussive tools, use a mechanical filter between the vibrating structure and the transducer. A mechanical filter will provide vibration insulation in the work itself and prevent unwanted or unhelpful signals reaching the transmitter. High frequency vibration will be removed.

**Overhead 7.12. Calculating the 8-hour energy-equivalent vibration**

The injury potential of hand-transmitted vibration is estimated from the vibration total value formed from the three frequency-weighted accelerations in each vibration directions.

Together with the exposure time, the 8-hour energy-equivalent frequency weighted acceleration, \( a_{eq(8)} \) is calculated. The following formula is used:

\[
a_{eq(8)} = \sqrt[8]{T} \cdot a_T
\]

*Formula 7.2.*

where \( a_{eq(8)} \) is the 8-hour equivalent acceleration, \( T \) is the actual exposure time in hours, and \( a_T \) is the acceleration during the period \( T \) hours.

If exposure to vibration comprises several different time intervals, the daily vibration exposure is calculated as follows:

\[
a_T = \sqrt{\frac{1}{T} \cdot \sum_{i=1}^{n} a_i^2 \cdot t_i}
\]

*Formula 7.3.*

where \( a_T \) is acceleration during the period \( T \) hours, \( a_i \) is the acceleration during the \( i \) time period, \( t_i \) is the period’s extent, and \( T \) is the total exposure time in hours.
The 8-hour energy-equivalent frequency weighted acceleration, $a_{eq(8)}$, is used for assessment of the prevalence’s of finger blanching (vibration-induced white finger) in a group of operators.

The following formula gives an estimate of the relationship between the measured daily vibration exposure and number of years before the exposure produces finger blanching for 10% of the exposed operators.

$$D_y = 31.8 \cdot (a_{eq(8)})^{-1.06}$$

Formula 7.4.

where $D_y$ is the group mean exposure duration (years) and $a_{eq(8)}$ is the 8-hour energy-equivalent daily vibration exposure (m/s²).

The same relationship is also shown in the figure.

The relationship should only be used on groups of workers and not on any particular individual within the group. The probability of individual symptoms depends on such factors as susceptibility, pre-existing diseases and conditions, the work environment, and personal characteristics.

Studies suggest that symptoms of the hand-arm vibration syndrome are rare in people exposed to an 8-hour energy-equivalent vibration total value $a_{eq(8)}$ of less than 2 m/s² and unreported for $a_{eq(8)}$ values of less than 1 m/s².
LECTURE 8: HEALTH AND RISK FACTOR SURVEILLANCE

Teacher’s notes

Overhead 8.1. Health and risk factor surveillance (HRFS)
Overhead 8.2. Definition of surveillance
Overhead 8.3. Purpose of surveillance
Overhead 8.4. Nine goals with surveillance
Overhead 8.5. Benefits with surveillance
Overhead 8.6. Data collection instruments
Overhead 8.7. Health surveillance
Overhead 8.8. Risk factor surveillance
Overhead 8.9.1. HAV HFRS: Flow chart for step 1
Overhead 8.9.2. HAV HFRS: Flow chart for step 2
Overhead 8.9.3. HAV HFRS: Flow chart for step 3
Overhead 8.10. Surveillance case definitions
Overhead 8.11. Ethical and legal aspects on HRFS
Overhead 8.12. Reporting

Suggested study activities

Identify and discuss possible methods for risk factor data collection in your country and at your workplace.
How can HRFS be implemented at your workplace?
3.8.1. Teacher’s notes

Overhead 8.1. Health and risk factor surveillance (HRFS)

Health and risk factor surveillance (HRFS) aims to detect early signs and symptoms of an incipient work-related disorder due to hand-arm vibration exposure. In addition, other contributing factors should be considered such as a possible increased susceptibility due to other vascular, neurological, and/or musculoskeletal disorders.

A surveillance system can be part of a health and safety program or a stand-alone activity. HRFS is an important tool that preserves or improves health and productivity in the working life.

Overhead 8.2. Definition of surveillance

Surveillance is defined as “the ongoing systematic collection, analysis, and interpretation of health and exposure data in the process of describing and monitoring a health event. Surveillance data is used to determine the need for occupational safety and health action and to plan, implement, and evaluate ergonomic interventions and programs”.

Overhead 8.3. Purpose of surveillance

Surveillance is usually used to evaluate and to improve workers’ health and safety. Another objective is to initiate and evaluate change with the goal to increase productivity and quality.

Overhead 8.4. Nine goals with surveillance

The nine goals listed below are linked to surveillance data used to design prevention activities:

OCCUPATIONAL EXPOSURE TO HAND-TRANSMITTED VIBRATION

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- Identify new or previously unrecognised problem;
- Determine the magnitude of the work-related disorder;
- Identify occupational groups, departments, and work sites to target control measures;
- Track trends over time;
- Describe health and risk factors for management and work sites to initiate preventative changes;
- Identify potential control measures by observing low risk groups;
- Basis for prioritising preventative actions;
- Evaluate the progress of preventative actions; and
- Generate hypotheses for research.

**Overhead 8.5. Benefits with surveillance**

HRFS has the potential to be a good tool for improving workers’ health and well being since it can detect individuals or groups of individuals at risk and therefore initiate changes at an early stage. HRFS provides the possibility to monitor the incidence of sick leave due to hand-arm vibration disorders. An increased incidence or sick leave may prompt the employer or company to undertake preventative actions to improve workers’ health and to reduce the risk factor. There are also examples where HRFS has revealed improper workers’ health and where actions have revealed major earnings for a company.

Work sites with health problems are often work sites with production problems. Preventative actions can increase workers’ health and increase production and quality.

**Overheads 8.6. Data collection instruments**

There are two methods for collecting surveillance data, “passive” and “active”. Passive health surveillance uses existing data such as company casebooks, insurance records, workers’ compensations records, absentee records, and grievances. Passive risk factor surveillance uses retrospective data collected at the work site or reported data from other, but comparable
work sites (e.g. literature, data bases on internet). This method is predominantly used to survey health outcomes. Application of an active HRFS method implies seeking information more “actively” by using checklists, interviews, questionnaires, physical exams, job analysis, and vibration measurements. Analysis and interpretation of surveillance data requires tools and methods good enough to lead to appropriate action as well as follow-up. Individuals responsible for accomplishing a HRFS program also require training to ensure a proper administration.

**Overhead 8.7. Health surveillance**

A pre-employment medical examination may be offered to a worker who will enter a job involving the handling of vibrating tools. The main objectives are to obtain baseline health data for the individual for comparison at subsequent periodical examinations and to verify the presence of symptoms that can be regarded as possible medical contra-indications for hand-arm vibration exposure. In addition, a worker should be made aware of the risk for developing a hand-arm vibration disorder (HAVD). The pre-employment medical examination must be conducted in accordance to the principles and practice of occupational medicine and should include a case history (family, social, work, and personal health history), a complete physical examination, and if necessary screening tests and special diagnostic investigations. Periodic health factor surveillance assessments should be conducted regularly.

**Overhead 8.8. Risk factor surveillance**

When a worker begins a job, he or she should be offered a risk factor evaluation, at the least a rough estimation of expected vibration magnitude and duration of exposure. Passive risk factor surveillance methods can be used for this purpose, such as checklists, results from previous measurements on the company’s vibrating tools, national or international vibration databases, or measurements from other institutions (e.g., declared values by the European Council). Workplace measurements may be necessary if no records exist on vibration levels for tools. This is a more active risk factor surveillance method that can be used in HFRS. If the estimated or measured
risk factor is above an unacceptable level, then a workplace or job intervention is required. Periodic risk factor surveillance assessments should be conducted with a regular interval.

**Overheads 8.9.1-3.** Hand-arm vibration health and risk factor surveillance (HAV HFRS): Flow charts.

Overheads 8.9.1, 8.9.2, and 8.9.3 show a schematic model of a periodic HAV HFRS program. The program can be broken down in to three steps. The first step (Overhead 8.9.1) uses “passive” methods for collecting surveillance data. In the second step (Overhead 8.9.2), surveillance data is collected using “active” methods. The third step (Overhead 8.9.3) represents a stage where the presence of health or risk factors requires different forms of medical or technical intervention. The model suggests that HFRS should be performed every two years or if changes in the workplace occur. It has been suggested that re-assessment should be made at shorter intervals, maybe every six months, after a worker begins a job in order to detect those individuals especially sensitive to vibration. A re-evaluation should also be offered if an increase in exposure occurs or if a person reports symptoms that may be related to exposure.

**Overhead 8.10.** Surveillance case definitions

To be able to apply the HFRS model shown in previous flow charts it is clear that surveillance case definitions are needed for exposure (+/- RF) as well as symptoms (+/- HAVD). At present, no consensus on these case definitions exists. In the mean time the following case definition is suggested.

**Exposure:** A surveillance case for exposure (i.e. +RF) is defined as an 8-hour equivalent acceleration level above 1 m/s² based on measurement and assessments conducted in accordance with ISO 5349.

**Symptoms:** A surveillance case for symptoms (i.e. +HAVD) is defined as SN1 for neurological symptoms and Stage 1 for vascular symptoms in accordance with the Stockholm workshop scales.
For musculoskeletal symptoms no scale or staging is available at present so the decision must be based on the doctor’s own evaluation of symptoms and signs.

**Overhead 8.11. Ethical and legal aspects on HRFS**

The employers should provide a HFRS program for their employees who are exposed to vibrating hand-held tools. They should also provide necessary facilities for running the program. The management of the HFRS program should be under the supervision of people with certified training in at least occupational health and risk factor evaluation.

The “International Code of Ethics for Occupational Health Professionals”, published by the International Commission on Occupational Health (2002), provides some guidance for ethical and legal aspects on HRFS. In “Duties and obligations of occupational health professionals” the text states the following:

"The occupational health professionals must advise the management and the workers on factors at work which may affect workers’ health. The risk assessment of occupational hazards must lead to the establishment of an occupational safety and health policy and of a programme of prevention adapted to the needs of undertakings and workplaces. The occupational health professionals must propose such a policy and programme on the basis of scientific and technical knowledge currently available as well as of their knowledge of the work organisation and environment. Occupational health professionals must ensure that they possess the required skill or secure the necessary expertise in order to provide advice on programmes of prevention, which should include, as appropriate, measures for monitoring and management of occupational safety and health hazards and, in case of failure, for minimising consequences. (Paragraph 3)”. This means that active health surveillance of work-related hand-arm vibration disorders is important.

Paragraph 8, which is a special paragraph on health surveillance, states that "The occupational health objectives, methods and procedures of health surveillance must be clearly defined with priority given to adaptation of workplaces to workers who must receive information in this respect. The relevance and validity of these methods and procedures must be assessed. The surveillance must be carried out with the informed consent of the workers."
The potentially positive and negative consequences of participation in screening and health surveillance programmes should be discussed as part of the consent process. The health surveillance must be performed by an occupational health professional approved by the competent authority.

The Code of Ethics also deals with providing workers with surveillance information. Paragraph 9 states, "The results of examinations, carried out within the framework of health surveillance, must be explained to the worker concerned".

**Overhead 8.12. Reporting**

Reporting surveillance results is very important. This can, however, be done in many different ways, from a simple oral report to the employer to an extensive written report and/or detailed discussions with employer and employees in order to initiate and promote preventative measures.
LECTURE 9: PREVENTATIVE MEASURES

Teacher’s notes

Overhead 9.1. Preventative measures
Overhead 9.2. Alternative production techniques
Overhead 9.3. Design and layout of workplaces and workstations
Overhead 9.4. Reduce exposure times to minimise prolonged exposure
Overhead 9.5. Choose the right handheld tool
Overhead 9.6. Choose the right accessories
Overhead 9.7. Reducing vibration on existing machines
Overhead 9.8. Replacing and/or buying a new machine
Overhead 9.9. Service and maintenance
Overhead 9.10. Training and work techniques
Overhead 9.11. Personal safety equipment

Suggested study activities

List and discuss possible preventative measures at your own workplace.
3.9.1. Teacher’s notes

Overhead 9.1. Preventative measures

It is important for all users of vibrating handheld machinery to avoid or reduce exposure wherever possible. This could be done in the following ways:

- Alternative production techniques;
- Designing and layout of workplaces and work stations;
- Avoiding prolonged exposure;
- Choosing the right handheld tool;
- Choosing the right accessories;
- Reducing vibration on existing machines;
- Replacing and/or buying a new machine;
- Training and work techniques;
- Service and maintenance; and
- Personal safety equipment.

Overhead 9.2. Alternative production techniques

Check whether it is necessary to use vibrating hand-held tools to perform the actual work task. Sometimes good opportunities are available involving alternative production techniques that reduce the need for vibrating machinery or operations. For instance, instead of riveting, welding or gluing could be used. Other options are various forms of automation industrial robots or remote control.

Check whether a task may be achieved a different way. Often a change in construction can reduce the need to use vibrating machinery. Types of welding and the positioning of a joint can be very significant for the amount of grinding required and consequent exposure to hazardous vibration.
Overhead 9.3. Design and layout of workplaces and workstations

Good ergonomic design and layout of workplace and workstations can reduce the vibration load. Vertically adjustable tables or work platforms can mean that machine operators no longer need to adopt unsuitable working positions or work with their wrists bent. In some regions of the world, it is important to protect exposed workers from cold and damp. When tools are not being used, you should store them so the handles are not cold when the next operator needs the tools.

Another possibility is to hang up the machine in a balancing block. The weight of the machine is borne by the block, which reduces the load on the operator, making things tidier and also making the machine more easily accessible.

Overhead 9.4. Avoiding prolonged exposure

More comprehensive measures include planning work so that consecutive long periods of exposure are avoided. Vibration free periods give the body the opportunity to recover. Instead of concentrating the exposure to one period of the working day, it is better to spread out the vibration exposure over the whole working day. In addition, introducing work breaks and/or alternating jobs (job rotation) that do not expose a worker to vibration can significantly reduce vibration.

Overhead 9.5. Choose the right handheld tool

Make sure it is necessary to use a tool that produces vibration. Perhaps the work does not require such a tool. The selection of a machine should be based on its intended purpose. One should choose one that is both efficient and generates low levels of vibration. Another important issue is whether the machine provides good ergonomic posture or if it will require the wrists to bend. Manipulating a pistol grip tool above one’s head could result in un-ergonomic wrist positions. Instead, a tool with a straight grip should be used.
When manipulating a tool below the knees, a pistol grip provides the most ergonomic manipulation.

**Overhead 9.6. Choose the right accessories**

It is very important that accessories should be suitable for the machine and its task, and tools such as drills, saw chains, and chisels should be sharp. Tools that do not have sharp edges will lead to higher vibration levels. Vibration from handheld grinding machinery is often caused by unbalanced grinding discs, which result from variations in roundness and thickness, material wear and tear, and the way it is mounted on the grinding machine. Lower tolerances of roundness and thickness variations plus the size of the central hole can produce significant advantages. For example, when working with grinding machines, the quality of the grinding discs and the way they are mounted can affect vibration exposure by 3 times.

**Overhead 9.7. Reducing vibration on existing machines**

Improving a machine’s vibration characteristics retrospectively is often both difficult and expensive. However, some solutions are available:

- Balance unit for grinding machines;
- Anti-vibration support handles; and
- Insulating the machine.

The balance unit for a grinding machine contains a number of ball bearings, which can move freely in a groove. Any imbalance in the grinding disc will make the ball bearings move in the direction away from the imbalance and thus counteract it. This movement takes only a fraction of a second. If the imbalance alters during grinding, the ball bearings will quickly change position to compensate for the new imbalance.

Anti-vibration handles reduce the intensity of vibration transmitted to the operator. The handles have a spring positioned between the machine housing
and the handle. However, these handles should be chosen carefully since there effects are highly frequency-dependent.

One solution could be to cover the machine with some kind of insulating material or to fit a handle to dampen the vibration. However, judging the success of these measures is difficult since the effectiveness of the insulation depends on several factors, among them the frequency content and level of the vibration, grip strength, feed force, and ergonomic design.

Overhead 9.8. Replacing and/or buying a new machine

When buying a new machine, it is important to also require information about the tool vibration. Often the acceleration values can be obtained from manufacturers and suppliers. Naturally, one should look for the lowest value possible. It is also important that selection of a machine should be based on its intended purpose. One should choose a tool that is both efficient and generates low levels of vibration. A machine that vibrates less will be of no assistance if the operator is forced to work longer. In addition, it is important that the machine is really suitable for the operation in question.

A good ergonomic machine design can very likely reduce the risk of future health problems from working with vibrating machinery. The design of the handle has a direct effect on the operator's ability to use a suitable amount of hand power with a natural grip. This enables him to adopt a natural working position. Moreover, a handle of a suitable material can also provide insulation against heat and cold. The diameter and length of the handle should be adjustable for the size of the operator’s hand. This is especially important for sites with workers of both sexes. Other important factors are the weight of the machine as well as the starter design and the force required to start the machine, the amount of resistance required.

Overhead 9.9. Service and maintenance

Ageing and/or poorly maintained equipment could lead to unnecessarily high vibration levels. It is important that regular service and maintenance of
machinery should function well and routines for periodic inspection be instituted. Even a relatively small imbalance produced by bent machine axes can be sufficient to produce a high vibration loading. In addition to straightforward service and maintenance, a simplified kind of vibration measurement can also be used as part of the inspection routine.

**Overhead 9.10. Training and work techniques**

Operators using vibrating handheld machines should be trained to use them correctly and safely, letting the machine do the work rather than the operator. In this way, grip and feed force can be reduced, which will also reduce the amount of vibration transmitted to the hand. For example, operators can be taught to let the amount of feed force required decide where to position the hand on the machine’s handle. For a machine with a pistol grip, this means that for a high amount of feed force the hand will be high up on the handle, whereas for low amounts it may be better to hold it lower down. It is also important for the operator to be aware of the reason why one should not guide a chisel with the hand, and to know how to select machinery and accessories such as grinding discs, chisels, and power saw chains. Factors such as these can affect vibration loading considerably.

**Overhead 9.11. Personal safety equipment**

The use of personal safety equipment should be used in addition to other measures or as a last resort when these have not produced satisfactory results. In addition to reducing vibration loading, protective equipment should be comfortable to use and not have an adverse effect on the machine’s ease of handling. Gloves, which are designed to reduce the transmission of vibration, are an obvious way to lessen the risk of injury. Gloves have been developed for this purpose.

Heated handles, warm and weatherproof clothing, and heating pads can also help lessen the effects of vibration.
LECTURE 10: LEGAL AND COMPENSATION ASPECTS

Teacher’s notes

Overhead 10.1. Vibration as risk factor
Overhead 10.2. Standards
Overhead 10.3. Standards for vibration
Overhead 10.4. Occupational Exposure Limits (OELs)
Overhead 10.5. Threshold Limit Values (TLVs)
Overhead 10.6. European vibration directive
Overhead 10.7. Compensation aspects 1
Overhead 10.8. Compensation aspects 2

Suggested study activities

Try to find out if there is any occupational exposure limits to vibration in your country and the possibilities for compensation for an occupational disease related to the exposure of hand-transmitted vibration.
3.10.1. Teacher’s notes

**Overhead 10.1. Vibration as risk factor**

WHO has classified complain of exposure to mechanical vibration as an occupational disease. This classification is intended to improve labour safety and health surveillance as well as compensation. Mechanical vibration may induce vascular and neurological diseases of the hand and wrist and diseases related to the carpal region.

In 1977 the International Labour Office (ILO) listed vibration as an occupational hazard and recommended that measures have to be taken to protect employees from vibration and that the responsible authorities have to establish criteria to determine the danger. Moreover the ILO has stated that exposure limits must be defined when necessary. Supervision of employees exposed to vibration must also include a medical examination before the beginning of a particular job as well as regular check-ups later on.

**Overhead 10.2. Standards**

A standard is a recommendation with respect to the design of a product, for example, or to application of a testing method in a particular way. Standards are of several different types. A global standard is drawn up at worldwide, international level, by the ISO (International Organization for Standardisation) for example.

Standardisation involves finding mutually applicable solutions for recurrent problems. The work is performed in collaboration with representatives of manufacturers, users, business, consumers and other public interests. Technical, social and financial factors are all taken into consideration. An attempt is made to reach agreement whenever possible and to achieve consensus. Standardisation work is undertaken by technical committees, working parties or as projects. The committees include experts in appropriate fields from business, organizations and other bodies with an interest in a particular standardisation project.
Overhead 10.3. Standards for vibration

The International Standardisation Organization (ISO) has published many standards to provide guidelines relating to vibration from handheld machinery. The most known and used standard for measurement and assessment of vibration transmitted to the hand is ISO 5349-1. The appendix of the standard presents a relationship between the daily vibration exposure and number of years before the exposure produces finger blanching for a group of exposed operators.

Many countries have their own vibration exposure standards. However, they are usually identical to the international standards. Sometimes differences in wording arise when consensus has been reached for more far reaching standardisation. The contents of the standards are only recommendations and have no legal implications.

Overhead 10.4. Occupational Exposure Limits (OELs)

The Japan Society for Occupational Health (JSOH) recommends the Occupational Exposure Limits (OELs) as reference values for preventing adverse health effects on workers caused by occupational exposure to hand-arm vibration. JSOH point out that these exposure limits do not represent a definitive borderline between safe and hazardous conditions and it is not correct to conclude that working environments above OEL are the direct and sole cause of health impairment in workers, or vice versa. JSOH also states that due to the variance in individual susceptibilities, discomfort, deterioration of pre-existing ill health or occupational disease may be induced at levels of exposure below the OELs, even though the chances of this should be remote.

In the recommendation two different exposure limits are given, one daily and one short-term. The limit values are the frequency weighted acceleration vector sum in accordance with ISO 5349. The daily exposure is recommended not to exceed 2.8 m/s² as an 8-hour equivalent value. The short-term exposure is set to 25 m/s² for time periods shorter then den 6 minutes per day.
**Overhead 10.5. Threshold Limit Values (TLVs)**

American Conference of Governmental Industrial Hygienists (ACGIH) has developed Threshold Limit Values (TLVs) as recommendations or guidelines for exposure of hand-arm vibration. These guidelines are intended for use in the practice to contribute to the overall improvement in worker protection, and the values are not developed for use as legal standards.

The table below shows the recommended hand-arm vibration daily exposure times for different frequency weighted acceleration of the hand-held tools in the dominant vibration direction.

<table>
<thead>
<tr>
<th>Total daily exposure duration</th>
<th>Frequency weighted acceleration in the dominant vibration direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 hours and less than 8 hours</td>
<td>4 m/s²</td>
</tr>
<tr>
<td>2 hours and less than 4 hours</td>
<td>6 m/s²</td>
</tr>
<tr>
<td>1 hour and less than 2 hours</td>
<td>8 m/s²</td>
</tr>
<tr>
<td>Less than 1 hour</td>
<td>12 m/s²</td>
</tr>
</tbody>
</table>

Table 1. Threshold limit values according to ACGIH.

For a work task where the used hand-held tool produces a frequency weighted acceleration (in the dominant direction) of more than 4 m/s² the daily exposure time should not exceeds 4 hours per day. This is whether or not the exposure time is continuously or intermittently.

ACGIH states that these values are not fine lines between safe and dangerous exposures. Because of wide variations in individual susceptibility, exposure of an individual at, or even below, the threshold limit values may result in annoyance, aggravation of a pre-existing condition, or occasionally even physiological damage. Moreover, it is recommended that workers be given 10 minutes of vibration free periods for every hour of exposure.
Overhead 10.6. European vibration directive

The European Union has approved a directive that covers minimum health and safety requirements regarding the exposure of workers to the risks rising from vibration. The employers shall, as an obligation, assess and, if necessary, measure the levels of mechanical vibration to which the workers are exposed.

In the directive, two exposure values are stated. The values given are the frequency weighted vector sum in accordance with ISO 5349. The first limit is when acceleration exceeds 2.5 m/s$^2$ as an 8-hour equivalent value. This limit is called the "action value". The second is when the daily 8-hour equivalent value exceeds 5 m/s$^2$ and is called the “daily exposure limit value”. If the action value is exceeded, the employer should establish and implement a programme of technical and/or organisational measures intended to reduce to a minimum exposure to vibration and the attendant risks. Moreover, workers exposed to vibration in excess of the action value shall be entitled to appropriate health surveillance. In any event, workers shall not be exposed above the exposure limit value. If the exposure limit value is exceeded, the employer should take immediate action to reduce exposure below this value.

Overhead 10.7. Compensation aspects 1

An employer should make the utmost effort to prevent workers from being injured, diseased, or killed as a result of their activities during work with hand-held vibration tools. However, if the worker unfortunately receive an industrial accident, and suffers an injury or illness related to work some compensation aspects will arise. This compensation to the worker is related for his/her salary for the period during which he/she cannot work, physical suffering, disability benefits and for the expenses necessary for medical care, rehabilitation etc.
Among the countries around the world there is a large divergence concerning compensation for an occupational disease related to the exposure of hand-transmitted vibration. Moreover, the workers compensation legislation is often complex. In some countries the workers' compensation program forms part of the general social insurance system. In other countries there will be a separate workers' compensation system based on compulsory or voluntary insurance. In the rest of the world there exists no regulated system for compensation. Although it exist a compensation system, vibration work-related disorders might in some countries not be included in the definition of an occupational disease. Furthermore, there is considerable diversity in the level of compensation of workers for medical costs, rehabilitation, loss of salary etc.

In many countries the employees also have the right to sue the employer under the Civil Law. Civil law process could be used for compensation aspects of the damage received through another's action or inaction. The employee will argue that the employer failed in his or her duty of care to safeguard the worker's health. Court awards could be from very small to very large depending on the different countries law system.

Today, the most outstanding industrial compensation deal ever made was conducted in the United Kingdom. In January 1999 the High Court approved a scheme of compensation for all ex-miners at British Coal, the state-owned enterprise, to recover compensation if suffering from vibration white finger. The forecast of compensation from the government is £500 million.
Full Overheads (Separate Volume)
Evaluation Sheet: Occupational Exposure to Vibration from Hand-held Tools - Teaching Guide

Thank you for using the Occupational Exposure to Vibration from Hand-held Tools - Teaching Guide. In order to improve this teaching guide for future additions we would appreciate it if you could take a few minutes to complete the following questions. This questionnaire should be filled in by the person responsible for organizing the course in which the guide was used.

Information about how the guide was used

Country the guide was used in: .................................................................

Language the course was taught in: .........................................................

How many students participated and what was their background? .............

How often did the course meet? ................................................................

Which chapters in the teaching guide were used?

| Lecture 1: Overview and objectives | Lecture 6: Effects on human body – musculoskeletal system |
| Lecture 2: Physical characteristics | Lecture 7: Measurement and risk assessments |
| Lecture 3: Effects on human performance | Lecture 8: Health and risk factor surveillance |
| Lecture 4: Effects on human body – vascular system | Lecture 9: Preventative measures |
| Lecture 5: Effects on human body – neurosensory system | Lecture 10: Legal and compensation aspects |
Describe briefly who the instructor/instructors were and a little bit about their background:

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The guide book

In general, what did you think about the guide in terms of its

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<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Good</th>
<th>Excellent</th>
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<tr>
<td>Organization?</td>
<td>□</td>
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<tr>
<td>Readability?</td>
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<td>Usefulness?</td>
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Comments (provide specific examples if possible):

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Were the suggested overheads from the guide used (check all that apply)?

- □ No, not at all
- □ Not directly, but the content did serve as inspiration for the creation of new overheads or other teaching materials
- □ Yes, overheads were used but the content had to be translated/modified
- □ Overheads content were used as is
- □ Used as overheads
- □ Used as paper handouts
- □ Used electronically (e.g. part of a PowerPoint presentation or electronic document for downloading)
Comments (provide specific examples if possible):

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Were any of the suggested activities from the guide used (check all that apply)?

☐ No, not at all
☐ Not directly, but the content did serve as inspiration for the creation other activities or teaching materials
☐ Yes, but the content had to be modified
☐ Yes, used as is

Comments (provide specific examples if possible):

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Will you use the guide again? .................................................................
Would you recommend the guide to others? ...............................................

Please use the following area to provide specific feedback about any aspect of the guide. All suggests and comments for improving the material is welcomed.

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Fax: +41.22.7911383, E-mail: ochmail@who.int
Practical approaches for environmental or health and safety regulators; occupational health professionals and trainers; occupational health services; and employers and worker representatives

This Teacher's Guide can be used to assist in the preparation and delivery of a 2-day course, adapted to provide a one-day introductory course, or expanded to 3 days that also include technical visits. The guide contains sufficient resource material to initiate, organize, deliver, and evaluate courses of different lengths. The course material includes overhead transparencies and handouts necessary for lectures and workshops.

Most importantly the present guide stands on its own: it does not require further background information with respect to occupational vibration from hand-held tools, management principles, training, etc. To increase the benefit for the course participants, a course coordinator should include local issues that address concerns such as legal frameworks, general practices, etc. The course coordinator may also want to invite guests or course participants to prepare specific local topics. For example, national authorities could present current legal frameworks or current policies, and occupational health managers could present their general practices. In this case, invited presenters should be contacted well in advance and agree to the presentation.