IMPLEMENTATION AND EFFECTIVENESS OF THE EUROPEAN DIRECTIVE RELATING TO VIBRATION IN THE WORKPLACE

September 2012

To the extent this document includes views or recommendations of other parties, they do not neccessarily reflect the views of Safe Work Australia.

safe work australia

IMPLEMENTATION AND EFFECTIVENESS OF THE EUROPEAN DIRECTIVE RELATING TO VIBRATION IN THE WORKPLACE

Parts 1 and 2

for
SAFE WORK AUSTRALIA
Commonwealth of Australia

by

Marion Burgess   BSc (Hons) MSc (Acoust), FAAS
Acoustics & Vibration Unit, School of Engineering and Information Technology
UNSW at ADFA, Canberra

and Gary Foster   BSc MSc, FAIOH, COH
Foster OHS Pty Ltd

September 2012

978-0-642-78573-2 [PDF]
978-0-642-78574-9 [RTF]

Table of Contents

Executive Summary

This study was undertaken in direct response to one of the recommendations from the Safe Work Australia study on “National Hazard Exposure Worker Surveillance (NHEWS) – Exposure to vibration and the provision of vibration control measures in Australian workplaces” [Safe Work Australia, 2010] for an investigation of:

“*...whether or not it would be beneficial for Australia to adopt the minimum health and safety requirements of the EU Directive on vibration in regulations or codes of practice*”.

This report comprises the findings from Parts 1 and 2 of the investigation relating to the European Union Directive. Part 3 will be a separate report focused on a cost effective strategy for a research plan and methodology for a vibration workplace exposure measurement research study in Australia.

The main findings from this study are that the implementation of both the EU Machinery Directive (2006/42/EC) and the EU Directive on Vibration (2002/44/EC) has led to increased availability of plant and equipment that produces a lower vibration exposure for the user. The mandatory requirements for provision of emissions data by manufacturers and the employer assessment of vibration exposure has led to a greater awareness by employers of the prevalence of excessive vibration in the workplace and the means for reducing such exposure. There is general agreement that the mandatory workplace action and exposure limits for Hand-Arm Vibration (HAV) in the EU Directive and in the UK Regulations are effective and provide reduce the risk of exposure to hazardous vibration. There is concern however about the adequacy of the Whole-Body Vibration (WBV) workplace exposure limits, especially in regard to the adoption in the UK Regulations of only one of the two measurement metrics. More research may lead to an improved means for assessment of hazardous WBV exposure in particular from regular jolts and jars and individual shocks as well as to continuous vibration.

Some outcomes from this study include the following:

1. The regulatory duty placed on manufacturers to provide data on the emitted vibration levels for their plant and equipment has proved to be beneficial in reducing exposure in the UK, especially for HAV. The adoption of similar mandatory requirements in accordance with the approach of the EU Machinery Directive should be considered because it would drive improvements in the quality of tools and enable employers to select the lowest reasonably practicable vibration equipment for their worker’s use.

2. The regulatory duty of employers to limit hazardous vibration exposure for their employees has shown to be beneficial in the UK. Inclusion of workplace exposure limits similar to the UK Vibration Regulations could be considered for Australian Work Health and Safety (WHS) regulations, in the longer term. These limits could be

included initially as non-mandatory guidance in the proposed code of practice for HAV and WBV. This would help employers prepare for any future mandatory requirements and increase the awareness of the extent of the vibration exposure and of the means for reducing that exposure. This code could include the documentation developed by the UK Health and Safety Executive (HSE), and identify an action level which triggers management action to reduce vibration exposure.

3. Health monitoring guidelines for both HAV and WBV have been developed in the UK by HSE. These could be used as the basis for similar health monitoring guidelines for managing HAV and WBV in the workplace. Such health monitoring guidelines should include guidance for employers regarding concerns about vulnerable groups such as pregnant women as well as the potential for damage from vibration on the foot (similar to HAV).

4. To enable the measurement of HAV in Australia consistent with international practice, the current Australian Standard, dated 1988 should be rescinded and the current, International Standards Organisation (ISO) standard for HAV should be adopted without amendment as an Australian Standard.

5. There is a clear link between back pain and exposure to excessive WBV, particularly for the users of heavy equipment in the construction, mining and transport industries.

6. The potential for hazardous vibration exposure is higher in the agriculture, mining and construction industries, and any future guidance should target these industries.

Glossary of terms relating to Human Vibration

The following provides a brief explanation of some of the terms and acronyms used in relation to assessment of vibration exposure for those in the workplace

HAV- vibration transmitted to the body via the hand and arm; usually from use of hand tools

HAV exposure limit- based on m/s^2 A(8) calculated on three orthogonal axes a_{hwx}, a_{hwy}, a_{hwz} as defined in ISO standard 5349-1(2001)

HSE- Health and Safety Executive (UK)

m/s^2 A(8)- daily exposure value normalised to an eight-hour reference period A(8), expressed as the square root of the sum of the squares (r.m.s.) (total value) of the frequency-weighted acceleration values.

PCBU- Person Conducting a Business or Undertaking as described in the Safe Work Australia Model WHS legislation [www.safeworkaustralia.gov.au]

SEG- similar exposure group

VDV- vibration dose value based on 4th power of the acceleration signal and the units are $m/s^{1.75}$ (used for WBV only)

WBV- vibration transmitted to the body via the feet and legs or via the bottom for a seated person hand; usually from vibrating platforms or vehicle movements

WBV exposure limit- based on m/s^2 A(8) or VDV as the highest (r.m.s) value of the frequency-weighted accelerations, determined on three orthogonal axes ($1.4a_{wx}$, $1.4a_{wy}$, a_{wz} for a seated or standing worker) in accordance with ISO2631-1(1997)

WHS- Work Health and Safety as described in the Safe Work Australia Model WHS legislation [www.safeworkaustralia.gov.au]

Preface

This study aims to review the current situation relating to the establishment and effectiveness of limits to vibration exposure in the workplace. It is undertaken in direct response a recommendation from the Safe Work Australia study on "National Hazard Exposure Worker Surveillance (NHEWS) – Exposure to vibration and the provision of vibration control measures in Australian workplaces" [Safe Work Australia, 2010] for an investigation of:

"...whether or not it would be beneficial for Australia to adopt the minimum health and safety requirements of the EU Directive on vibration in regulations or codes of practice".

There are three distinct parts to this project and this report addresses the first two parts. The third part on exposure measurement research will be addressed in a separate associated report. The requirements of each three parts are specified in the contract as:

1. An analysis of the implementation and effectiveness of EU Directive 2002/44/EC:

   The purpose of this part of the project is to identify:
   - the extent of implementation of this Directive;
   - the success or otherwise of this Directive;
   - any implementation issues with this Directive; and
   - any data /published exposure studies based on implementation of this Directive.

The analysis is to be based on published reports on the implementation of this Directive (especially implementation in UK), evidence that the approaches have led to any decrease in vibration exposure and/or health effects and suggested improvements that can be made to the current regulatory frameworks.

2. A literature review that will focus on published measurements of HAV and WBV exposures to identify:
   - evidence that vibration exposure can cause disease and injury;
   - where hazardous vibration exposures may be occurring in industry; and
   - gaps in the research.

The critical analysis should identify: which industries and/or work tasks result in exposure to potentially harmful levels of HAV and HBV; are the exposures measured using appropriate equipment; is there evidence that amendments to plant and equipment design standards for vibrating equipment lead to reduced vibration exposure for workers; are the exposures measured considered to be representative of real world exposures; is there evidence to suggest that workers are exposed to HAV and WBV at levels which are known to have adverse health effects; where and how should further research on HAV and WBV exposure in Australia be carried out; and factors which may affect susceptibility to vibration related injury and disease such as health status, climate, heat/cold.

The requirements for the third part, which is subject to a separate report, are specified in the contract as:

3. The development of a research plan and methodology for an Australian vibration exposure measurement research study.

This part of the report aims to draw upon the findings of the first two parts of this project plus experience to date on vibration measurement exposure in Australia. The following emphases are to be considered in the development of the plan:

- be targeted at industries and work tasks which are identified as having the highest potential for HAV and WBV which could result in adverse health effects;
- be undertaken in 'real world' settings where possible;
- use measurement methodologies consistent with the Australian and International ;
- be undertaken in a manner which will allow comparison with EU/UK action levels and exposure limits and where available manufacturers specifications for the vibration emission of equipment;
- if possible consider the effects of control measures in reducing exposure; and
- include a worker survey instrument to record any potential health effects (self-reported).

The report should include recommendations on:

- number of workplaces to be visited;
- industry sectors to be targeted;
- work tasks to be measured type/number;
- assessment whether 'low vibration' tools result in lowered exposure in under normal work conditions if possible;
- measurement protocols; and
- methods to be used for calculation of exposures against EU action levels and exposure limits.

1 Analysis of the implementation and effectiveness of EU Directive 2002/44/EC

1.1 EU Directives dealing with vibration

European Union (EU) Directives are processed through the European Parliament and the Council of the EU. The directives are legal documents and must be complied with by the introduction of national legislation within the member countries. Enforcement of the requirements for a Directive is the responsibility of the member country. EU Directives are the basis of legal duties imposed on employers and manufacturers in each member country and in the UK have been implemented in the Control of Vibration at Work Regulations and for Provision and Use of Work Equipment Regulations. There are two EU Directives that are relevant to human vibration
:

- Machinery Safety Directive, 2006/42/EC, applicable since Dec 2009; and
- Physical Agents (Vibration) Directive 2002/44/EC of June 2002.

1.2 Machinery Safety Directive, 2006/42/EC

The Machinery Directive 2006/42/EC replaces the former Directive 98/37/EC. It does not introduce radical changes but clarifies and consolidates the provisions of the Directive with the aim of improving its practical application. The intention of this Directive is that the member country legislation requires manufacturers to consider safety in the design of plant and machinery and that vibration emission is reduced to as low as possible:
"1.5.9 Vibrations

Machinery must be designed and constructed in such a way that risks resulting from vibrations produced by the machinery are reduced to the lowest level, taking account of technical progress and the availability of means of reducing vibration, in particular at source.

> *The level of vibration emission may be assessed with reference to comparative emission data for similar machinery."*

This Directive effectively establishes the overall duty of care of manufacturers to design plant and equipment to minimise vibration emission levels. Trade of products to and from Europe means the regulations introduced in the EU member countries requiring compliance with this Directive have wider benefit than just within the member country. This is particularly relevant to Australia due to the high level importation of plant and equipment.
The manufacturer is required to declare values measured according to an ISO test code if one exists or to clearly describe the test procedure used. If the hand transmitted value is less than 2.5 m/s^2 (in accord with the exposure action value for HAV in the EU vibration Directive) there should be a statement to say that the threshold has not been exceeded. If the value is greater, then the measured value must be quoted along with the

uncertainty of measurement. For mobile machinery, in addition to the hand transmitted value, the whole body vibration transmission must be declared (along with the uncertainty of measurement) if it is greater than 0.5 m/s^2 (in accord with the exposure action value for WBV in the EU vibration Directive).

Freely available databases make the information on declared values for machinery widely available. These should encourage the purchaser to select the item with the lowest vibration level that meets their requirements. For example the Centralised European Hand-Arm Database contains data on vibrations of about 2,500 electric hand tools [available from www.oshweb.com/owd/owd01.nsf/s/430-01]. A similar database contains data in vibration for mobile plant [available from www.vibration.db.umu.se/HkvSok.aspx?lang=en].

While it is tempting to use the declared results to estimate HAV or WBV this can be misleading. By its very nature, a standard ISO test prescribes the test conditions and so does not give accurate data on the typical tool or machine usage. This is highlighted in the guidance on the Directive [EC 2010]:

"Operating conditions have a strong influence on the vibrations transmitted by machinery. Measurement of vibrations should therefore be carried out under representative operating conditions."

Recent HSE reports from Heaton and Hewitt [2011a, 2011b] assess the standard ISO tests for powered lawn mowers and hedge trimmers for repeatability and ease of use and where possible for reproducibility. Both these reports urge caution in the use of declared values for assessing the hand-arm vibration levels in use and indicate some doubt about the value for rank ordering units on the basis of the declared vibration data. However, it should be noted that such problems will occur whenever the outcomes from a standard ISO test procedure are used as representative of a wider range of applications.

The implementation of the Machinery Directive has been a positive encouragement for good practice in equipment design for plant and equipment manufactured and imported into European countries. The requirement for manufacturers to declare values has led to careful consideration of the design of the product with the result that reductions in HAV or WBV have been achieved and this can be used as a marketing advantage. One example is shown in Figure 1.1 for a European manufactured chain saw that clearly states 'low vibration' as one of the five main promotional features for this item. For the same product on the Australian website [http://www.stihl.com.au/STIHL-Products/Chain-saws/Professional-Chain-saws/21775-1573/MS-261.aspx] it does state that it has an 'anti-vibration system' but only as one of 8 dot points listing features. Fabian Gwosdz from the European operations of Stihl identified that the production of low noise and low vibration tools must not compromise performance or weigh [private communication, Buy Quiet seminar, Paris, 2011].

Some early models of chain saws with improved noise and vibration features were not marketing successes due to the higher weight and slower cutting performance which are critical features for professional use. The companies have learnt and are now developing techniques to incorporate lower noise and vibration while maintaining performance and hence acceptance by the professionals. Overall the Machinery Directive appears to have led to improved the design of plant and equipment in Europe, thereby reducing the vibration emissions and this should in the long term reduce the hazard from tasks involving vibration exposure.

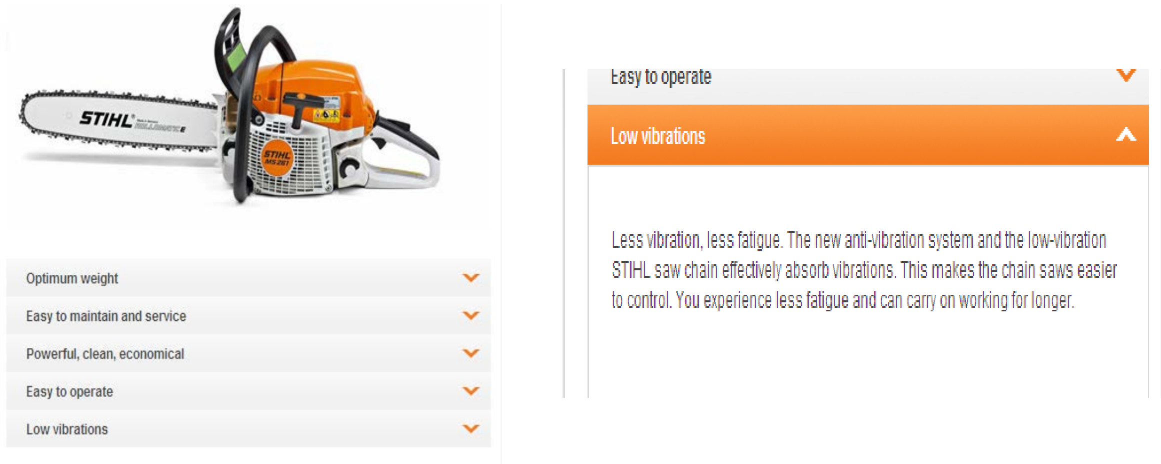


Figure 1.1 Example of advertising from European manufacturer of chain saws that includes low vibration as one of 5 key features. [From www.stihl.com/professional-forestry-work-stihl-ms261-advantages.aspx]

1.3 Physical Agents (Vibration) Directive 2002/44/EC

The Physical Agents (Vibration) Directive contains three main sections which cover general aspects, workplace exposure limit values, obligation of employers and miscellaneous provisions. The aim of the Directive is to provide the minimum requirements for the protection of workers from health risks of hazardous exposure to mechanical vibration. The Directive allows for non application to workers in air and sea transport
"..*where it is not possible to comply with the exposure limit value despite the technical and/or organisation measures taken".*

The Directive does not apply to the non-work environment such vibration from leisure activities. While the Machinery Directive encourages improved design to reduce vibration emissions the Vibration Directive elaborates the employer responsibilities in controlling the vibration exposure of employees.

The approach to limiting the risk for employees is to prescribe a workplace exposure action value and an exposure limit value for both HAV and WBV. Measurement is required to show compliance with these limits, although the usual approach to 'similar exposure groups' (SEG) in the workplace allows for assessment for workers undertaking similar work tasks.

The Vibration Directive requires the measurements to be made in accordance with the procedures in the relevant international standards, namely ISO 5349-1 and ISO 2631-1 for HAV and WBV respectively. These standards prescribe the measurement procedures, the data to be obtained and the frequency weighting factors to be applied. It should be noted that Australian Standard 2670.1 [2001] is a direct adoption of ISO 2631-1 for WBV. However, the current Australian Standard for HAV, AS 2763 is from 1988 and is not in accordance with current technology or practices. Adoption of ISO 5349-1 as an Australian Standard would ensure that measurement and assessment of HAV in Australia is in accord with international best practice.

The assessments of exposure in the Vibration Directive are a based on daily exposure normalised to a working day of 8 hours. For HAV the root of the mean of the sum of the squares (rms) of the frequency weighted values of acceleration in the x, y and z directions for the worse hand are normalised for 8-hour exposure. For WBV the assessment is for the worst axis and most commonly this is for the vertical movement i.e. the z-axis. The assessment is either in terms of the frequency weighted r.m.s. or the vibration dose value (VDV). The VDV is only used for WBV and is based on research that showed a 4^{th} power relationship between vibration magnitude and discomfort. The VDV has an important role by providing a better indication of those rides with a high proportion of shock or "jolts and jars".

It is up to the member states to choose which of these assessment methods to adopt in their legislation. The action and limit values from the EU Physical Agents (Vibration) Directive are reproduced below in Table 1.1. Employers are obliged to minimise the risks of exposure to vibration but once the "action level" is exceeded they must minimise the exposure and introduce health surveillance. Exceedance of the "limit value" requires immediate action to reduce the exposure below the limit value.
Flow charts showing the processes to be followed according to the EU Directive are reproduced in Figure 1.2 to Figure 2.4 [extracted from Mansfield, 2005].

Table 1.1: Workplace exposure limit values and action values from EU Physical Agents (Vibration) Directive.

	Exposure Action Value	Exposure Limit Value
Hand-arm vibration	2.5 m/s^2(A8)	5 m/s^2(A8)
Whole-body vibration	0.5 m/s^2(A8)	1.15 m/s^2(A8)
	9.1 $m/s^{1.75}$ VDV	21 $m/s^{1.75}$ VDV

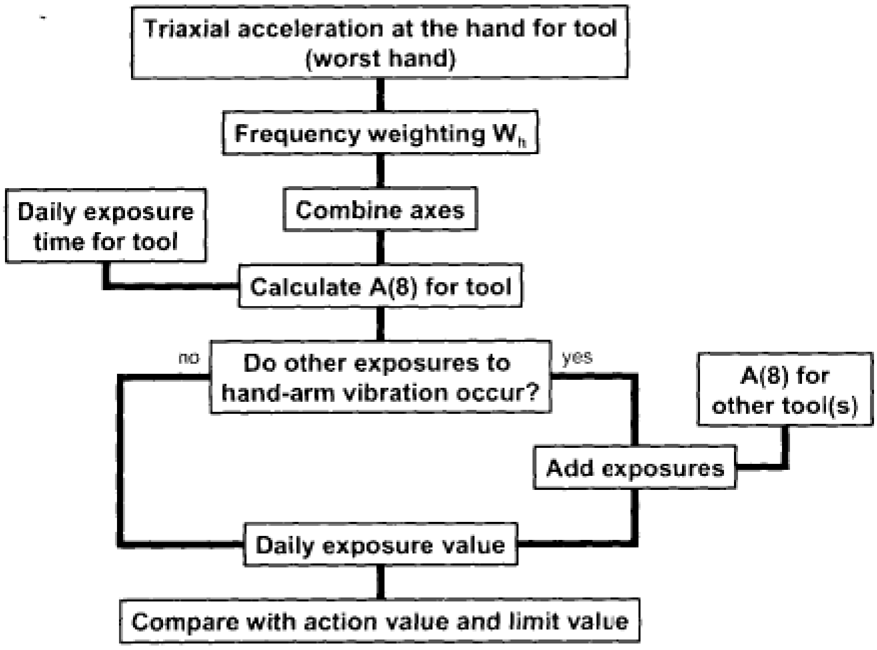


Figure 1.2 Method for assessing hand-arm vibration according to the EU Directive 2002/44/EC [from Mansfield, 2005]

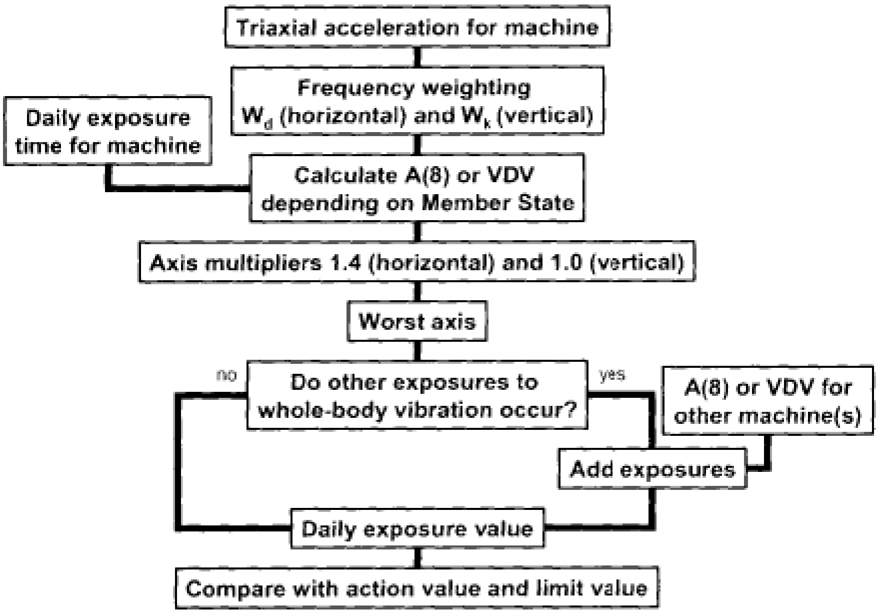


Figure 1.3 Method for assessing whole-body vibration according to the EU Directive 2002/44/EC [from Mansfield, 2005]

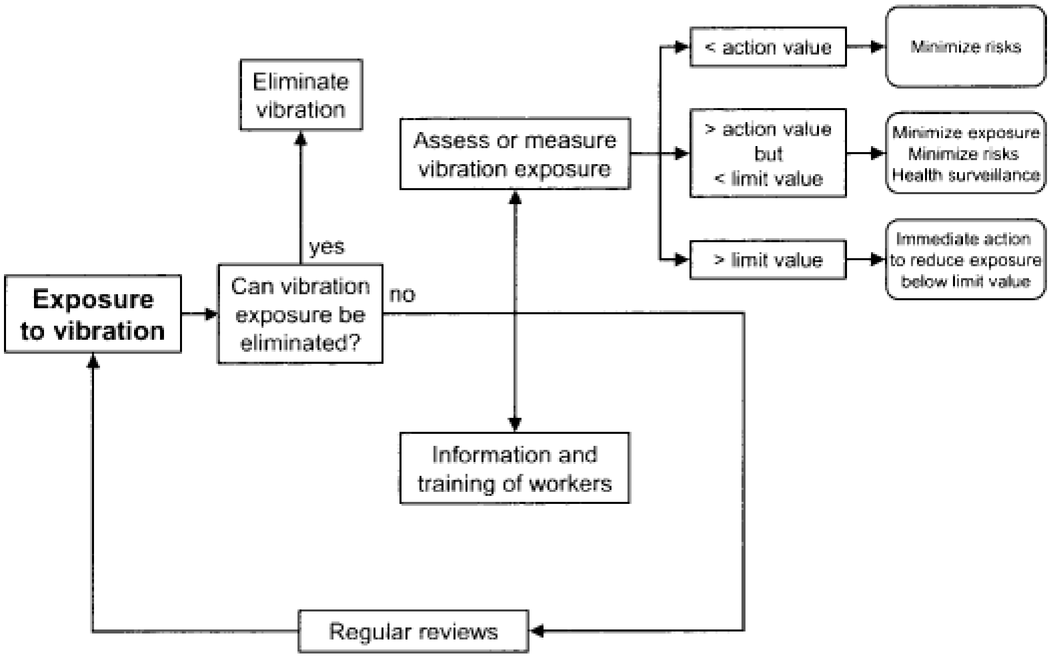


Figure 1.4 Obligations for employers according to the EU Directive 2002/44/EC [from Mansfield, 2005]

2 Implementation of legislation in United Kingdom dealing with vibration in the workplace

Each of the member countries of the EU are obliged to implement the EU Directive dealing with human vibration into legislation. In the UK this was achieved in 2005 by the Control of Vibration at Work Regulations (2005 see Annex A). This legislation defines the action levels and exposure limits identical with those in the EU Directive for the r.m.s. values, i.e. in terms of m/s^2(A8) but does not define the alternative limits for WBV assessments in terms of VDV.

To support the implementation of these regulations the HSE maintains an extensive website on vibration matters [www.hse.gov.uk/vibration/index.htm]. This website is a valuable resource for employers, occupational hygienists and workers. Figure 2.1 shows the type of information for HAV and similar pages of information sources are available for WBV. It is clear that the HSE considers easy access to information and guidance is important to encourage compliance with the requirements of the legislation.

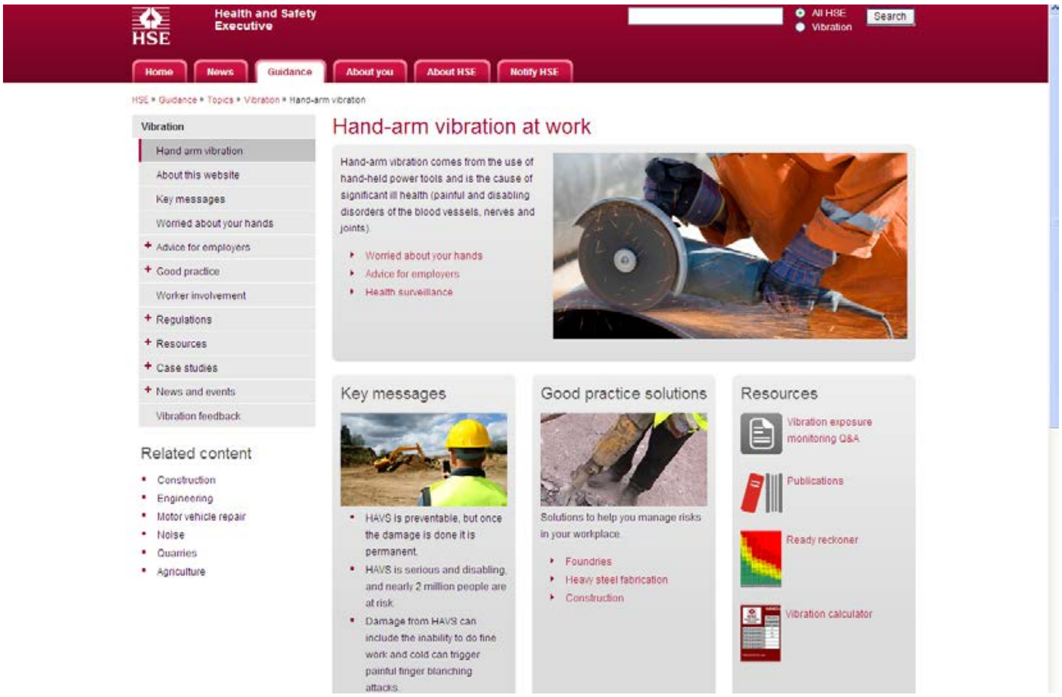


Figure 2.1 Example from HSE website [http://www.hse.gov.uk/vibration/hav/index.htm]

The specific duties for an employer in the Control of Vibration at Work Regulations include:

- assessment of the exposure to both hand-arm and whole body vibration;
- identification of the measures to eliminate or reduce risks from exposure to vibration to protect employees from risks to their health;
- a prioritised action plan for managing the risks and controlling exposure to hand-arm vibration;
- ensuring that control measures to reduce vibration are properly applied;
- provision of information, training and health surveillance; and

- review of the work environment that may affect exposures to vibration.

An effective regulatory regime in Australia should incorporate similar duties. In regard to enforcement, the HSE states that:

"Inspectors will act to prevent damage to employee's health where duty holders are failing to comply with the law."

The HAV link on the website includes examples of this enforcement. In one case a company was fined for non compliance following two improvement notices and in the second example the company acted upon an Improvement Notice which required

"the completion of a suitable risk assessment, introduction of appropriate controls and provision of suitable information, instruction and training to employees."'

Both the HAV and WBV links provide generic guidance on how to reduce vibration exposure. The HAV link includes more detail solutions with actual case studies over selected industry sectors.
In the HSE document on controlling the risk from HAV [HSE,2005] the controls suggested include:

- alternative work methods such as mechanise or automate the work;
- equipment selection such as lowest vibration tools that will do the job;
- purchasing policy for replacing old equipment and tools;
- workstation design aimed at minimising the load on the employee's hands;
- maintenance to prevent avoidable increases in vibration;
- work schedules to limit the time of exposure; and
- clothing to keep the hands warm.

For WBV, the control measures in the document on Control back-pain risks from:

- whole-body vibration [HSE, 2005] include:
- train and instruct operators and drivers;
- choose machinery suitable for the job;
- maintain machinery and roadways; and
- other measures include limiting time of exposure and considering groups particularly at risk such as pregnant women.

The regulatory framework for work health and safety legislation in the UK is similar to the Australian context and the UK. HSE is one of the more advanced and experienced agencies in Europe in relation to the adoption of the vibration Directives. Therefore this report focuses on the implementation and evaluation of the UK vibration at work legislation.

2.1 Process for implementation of the Vibration Directives in the UK

2.1.1 Hand Arm Vibration Regulatory Controls

Since 2005, the HSE has worked with industry to raise awareness and provide guidance and assistance. The initial emphasis was on HAV exposure in view of the stronger dose response relationship for HAV and the widespread use offhand operated plant and equipment in the UK that has vibration emission. The goal for 90% compliance with the HAV exposure limit was 2010 and in July 2010 the HAV exposure limits became binding under the legislation. The timetable for the HSE is outlined on their website as:

- From April 2008 to March 2010 we are embedding messages on noise and HAV.
- From April 2006 to March 2007 we focused on hand-arm vibration at work.

And the three key messages that underline their promotion are:

- HAVS is preventable, but once the damage is done it is permanent.
- HAVS is serious and disabling, and nearly 2 million people are at risk.
- Damage from HAVS can include the inability to do fine work and cold can trigger painful finger blanching attacks.

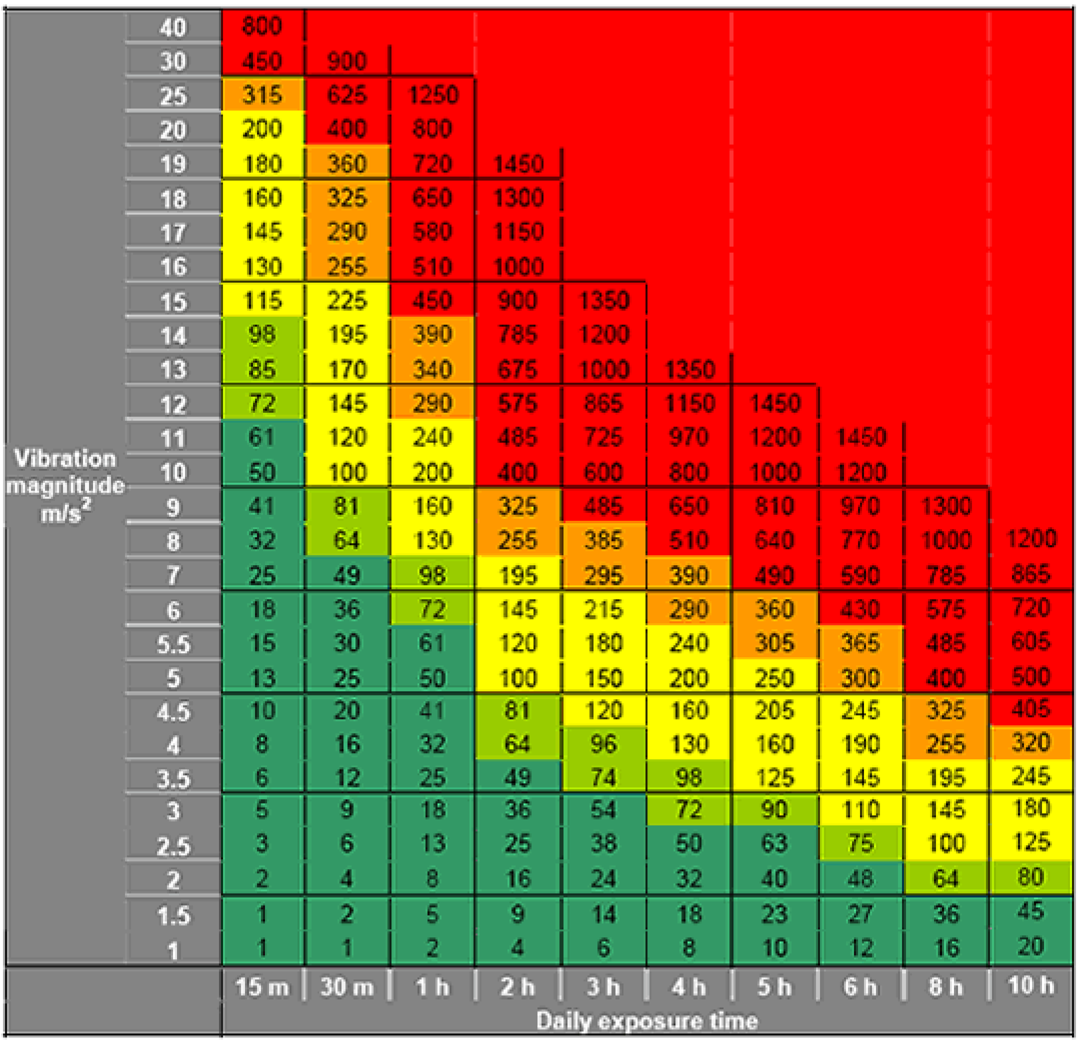
Note that the finger blanching (white finger) may be more readably noticeable in the colder UK climate than may be the case in Australia however the underlying damage still occurs.

The HSE initially encouraged industry to comply with the exposure limits by freely providing much information and guidance. Meetings and seminars around the country were an important means to get the key messages across and to give as much support as possible to industry. Case studies and good practice guidelines are available on the website which is also a resource for frequently asked questions, publications, a vibration calculator and a 'ready reckoner'.

The vibration calculator is an Excel spreadsheet but the ready reckoner is a graphic presentation as reproduced below in Figure 2.1. This is a similar approach to the ready reckoner on the HSE site for occupational noise exposure. A total of 100 points represents the exposure action value while a total of 400 points represents the exposure limit value. The tabular representation highlights the balance between time versus vibration magnitude as for example it is easy to see that an exposure to 8 m/s^2 accumulates 32 points for an exposure of 15 minutes compared with 130 points for one hour (i.e. above the action level) and 510 points for four hours (i.e. well above the exposure limit).

For any workplace where there is the potential for exposure to excess HAV, a health surveillance system must be implemented. A screening questionnaire is part of this health surveillance and an example of such a questionnaire is provided for those companies that do not have ready access to occupational hygienists.

Brereton [2011b] comments that large reductions in HAV exposure have been achieved in the UK by choice of machinery and reduction of the time of use. The success of the implementation of the regulations is shown by reduced incidence of exposure above the limiting value. The HSE is now focussing on encouraging industry to take the necessary steps to reduce the HAV exposures below the action level. Consequently the HSE guidance on "*health surveillance for HAVS should be revised in the light of experience gained since 2005*" Brereton [2011b] as this provides the opportunity to prioritise where further efforts should be applied.



Vibration magnitude m/s²	15 m	30 m	1 h	2 h	3 h	4 h	5 h	6 h	8 h	10 h
40	800									
30	450	900								
25	315	625	1250							
20	200	400	800							
19	180	360	720	1450						
18	160	325	650	1300						
17	145	290	580	1150						
16	130	255	510	1000						
15	115	225	450	900	1350					
14	98	195	390	785	1200					
13	85	170	340	675	1000	1350				
12	72	145	290	575	865	1150	1450			
11	61	120	240	485	725	970	1200	1450		
10	50	100	200	400	600	800	1000	1200		
9	41	81	160	325	485	650	810	970	1300	
8	32	64	130	255	385	510	640	770	1000	1200
7	25	49	98	195	295	390	490	590	785	865
6	18	36	72	145	215	290	360	430	575	720
5.5	15	30	61	120	180	240	305	365	485	605
5	13	25	50	100	150	200	250	300	400	500
4.5	10	20	41	81	120	160	205	245	325	405
4	8	16	32	64	96	130	160	190	255	320
3.5	6	12	25	49	74	98	125	145	195	245
3	5	9	18	36	54	72	90	110	145	180
2.5	3	6	13	25	38	50	63	75	100	125
2	2	4	8	16	24	32	40	48	64	80
1.5	1	2	5	9	14	18	23	27	36	45
1	1	1	2	4	6	8	10	12	16	20
	Daily exposure time									

Figure 2.2 Hand Arm Vibration Ready Reckoner [extracted from www.hse.gov.uk/vibration/hav/readyreckoner.htm]

2.1.2 Whole Body Vibration Regulatory Controls

As there is a clear link between excessive hazardous whole body vibration and musculoskeletal injury much of the education in regard to the WBV regulatory controls has emphasised actions relating to overall reduction of musculoskeletal injury. The guidance on WBV from the HSE website is less extensive than for HAV but does include the key elements with advice to employers, general guidance on control measures and an Excel based exposure calculator. In the paper on the revision of HSE guidance [2011b] Brereton states that the existing guidance provides "*reassurance to many people exposed to WBV during transport while at work but unlikely to be exposed above the exposure action value and at minimal risk of back problems*". As WBV is not seen by the HSE to be a major source on its own of occupational injury in the UK, it has a lower priority for review of the information currently provided.

The table of typical exposures on the HSE website for a range of off-road vehicles highlights the risk of excess exposure for that industry sector and there is an emphasis on following good practice to minimise this risk. However, the HSE studies have shown that those working in off–road machinery or those who have strained postures are more likely to have increased risk of back pain and much of the guidance is similar to that for reducing musculoskeletal injury.

The situation in Australia may well place a higher priority on WBV as there is extensive potential exposure the WBV in the mining and construction industry from heavy vehicle and mobile plant operation over rough and uneven surfaces. Particularly in the mining industry, heavy vehicles and mobile plant are operated over rough terrain and for long shifts thus increasing the risk of hazardous exposure. This type of activity can lead to high continuous vibration levels as well as substantial shock type vibration or "jolts and jars" from rough surfaces and from operation of the plant.

There is the potential for both vibration and shock for workers in fast boats. These are used in the leisure industry to provide excitement for those seeking a thrill. They are also used by enforcement agencies, rescue organisations and the Defence Force when there is a need to complete a mission in minimum time period and despite the sea state. This means the boat cannot always proceed at slow speed or along the waves to minimise the shock. Unlike the situation in Australia, the UK HSE does not have responsibility over the maritime environment and so has little injury data or guidance information on the extent of such exposure or injury.

2.2 Evaluation of the Effectiveness of the UK Vibration Regulations

In regard to outcomes Brereton [2011,b] reported that "*It is too soon to see any impact of the regulations because of the long latency of HAVS".* However there has been a significant reduction since both the Machinery and Vibration Regulations have been implemented. Brereton [2011,b] presented Figure 2.3 which shows the payments for "*Industrial Injuries Disablement Benefit (IIDB) is paid for disabling cases of HAVS in specified industries and for Carpal Tunnel Syndrome (CTS) associated with exposure to vibration.*" This chart shows the main fall in payments began around 2000. There is a small increase in HAVS in 2007, but from that year the basis for a claim can include the neurological part of HAVS while previously it was for vascular injury only.

Australian data [private communication Safe Work Australia, April 2012] on compensation claims for carpal tunnel and vibration white finger show a doubling in the number of claims between 1997 and 2010. If there was a similar drop in the number of claims to that observed in the UK, the estimate of the saving in terms of economic cost is over $100 million. Additional comments by Brereton are that in the UK they have noted large reductions in HAV exposures "*where duty holders have taken action in accordance with the directive*" and that they have *"seen the vibration emissions of hand-held power tools fall - and at least as importantly, seen the availability of (and demand for) high vibration models greatly reduce"* So this would indicate that the combination of the enforcement of the requirements for declaration of vibration levels coupled with the implementation of the regulations relating to vibration in the workplace have had some effect.

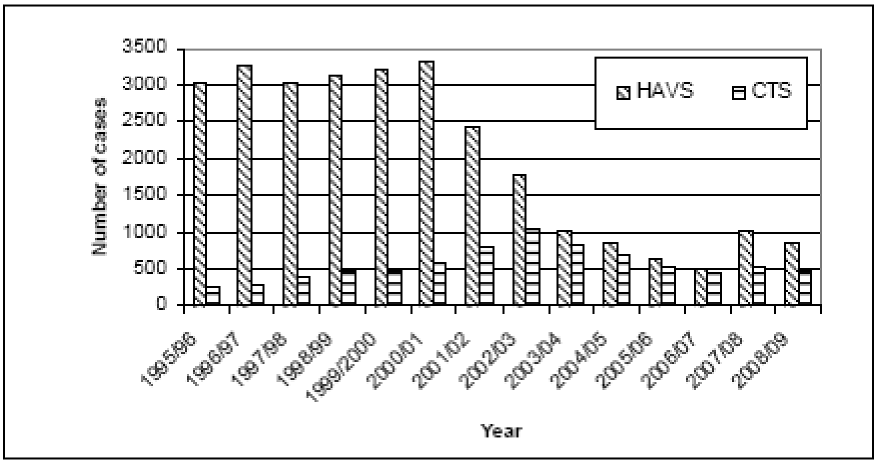


Figure 2.3 New payments under UK Industrial Injuries Disablement Benefit for HAV syndrome and carpal tunnel syndrome [Brereton 2011]

The HSE has acknowledged the "*difficulty in complying with the exposure limit value for some industries*" for HAV and has taken a practical approach to encourage that the industries do "*all that is reasonably practicable*". Advice from HSE [Brereton, 2012] is that the workplaces where compliance is difficult are foundries and to a lesser extent shipbuilding and stone masonry. In these workplaces there has been a move to the use of modern low vibration tools and an outcome of multi-skilling is that the times of exposure can be reduced via task sharing. It is clear that HSE efforts to provide advice and education at all levels are an important part of this encouragement.

In terms of regulatory effectiveness in preventing WBV injury, Brereton reported that the HSE has had "*very few cases of whole-body vibration injury reported to HSE*" and that when investigated, they have found "*ergonomic issues to be at least as important a contributor to back pain as WBV*". This illustrates the difficulty any policy agency will have in measuring the effectiveness of regulatory controls for WBV alone. It should also be noted that the situation for WBV in Australia may well be different due in particular to the more extensive mining, construction and farming industries.

Brereton does note that the exception to this is whole body injury for those in fast vessels when it is the high levels of shock that are transmitted into the craft as the vessels bounce across the waves at high speed. Control measures such as reduction in speed will compromise the achievement of the mission. Burgess and Harrap [2009] have reviewed the effects of such shocks and the options for specially designed seats to mitigate the shock entering into the body. The HSE does not have an enforcement role in the maritime industry and also the Vibration Directive [2002] has a specific exemption in regard to air and sea transport:

"In compliance with the general principles of health and safety protection for workers, Member States may, in the case of sea and air transport, derogate from Article 5(3) in duly justified circumstances with respect to whole-body vibration where, given the state of the art and the specific characteristics of workplaces, it is not possible to comply with the exposure limit value despite the technical and/or organisation measures taken."

2.3 Summary

The similarity between the regulatory framework for work health and safety legislation in the UK and the Australian context indicates that the experiences from the UK can provide valuable guidance.

The implementation of legislation in the UK addressing the Machinery Directive has shown the benefits of the requiring manufacturers to provide data on the vibration levels for their plant and equipment, especially in relation to reduction of HAV. In the Australian context, a similar emphasis on the duty of manufacturers to declare vibration levels would enable PCBUs to select the lowest vibration equipment practicable for their worker's use.

Also in the manner of the UK Vibration regulations, a duty of the employers in limiting hazardous exposure to vibration by their employees could be specifically included in the model Work Health and Safety Regulations. The experience from the HSE has shown the importance of devoting considerable effort in providing information and advice to industry before and after the introduction of the regulations relating to exposure limits.

The information should not only discuss the regulatory requirements but also the range of control measures that are available to reduce exposure. So as a first step towards including a regulatory duty in Australia, the development of a Code of Practice would prepare employers for potential future mandatory requirements and increase the awareness of the extent of the exposure and of the means for reducing that exposure. In parallel with this, steps should be taken to replace the current outdated Australian Standard for the measurement of HAV and endorse the relevant ISO standard as an Australian Standard. This will ensure there are no barriers to requiring that measurements for HAV undertaken in Australia are in accord with the current best practice in the EU.

For HAV it appears from UK industry reports that the incidence of exposures above the limiting values has reduced and the focus is now on the reduction to below the action level. There appears to be less of a risk of ill health from WBV in the UK and consequently this has a lower priority for the HSE. The situation in Australia may well be different due to the extent of potential exposure from extensive use of vehicles and mobile plant in the agriculture, mining and construction industries over rough surfaces and for long time periods. The risks of injury from shock in the maritime industry are of concern but not within the jurisdiction of the HSE. Again the situation in Australia differs in that work in the maritime and enforcement industries are within the scope of the Model Work Health and Safety Regulations.

3 Evidence vibration exposure can cause disease and injury

3.1 Effects of Hand Arm Vibration

As part of their work, personnel can be exposed to vibration that is generated by a tool or item of plant that is held in the hand. Due to the force applied by the hand to hold and control the tool there can be a transmission of the vibrational energy via the hand into the arm and then to the body and is referred to 'hand arm vibration' (HAV). HAV with low magnitude and/or short duration may just cause annoyance or discomfort. Exposure to higher levels of HAV and/or for longer periods can result in various forms of damage of which the most commonly known one is referred to as "vibration-induced white finger".
In one of the first books dealing comprehensively with human vibration, Griffin [1990] provided a summary table of the five types of disorders associated with HAV:

- Vascular Disorders (e.g. 'white finger')
- Bone and Joint Disorder
- Peripheral Neurological Disorders
- Muscle Disorders
- Other Disorders of the whole body and central nervous system

As the most commonly reported visual effect is vibration white finger, generally these disorders are discussed in two groupings: Vascular and Non Vascular.

Griffin also provided a conceptual illustration of the factors influencing the cause and effect relationships and this is reproduced as Figure 3.1

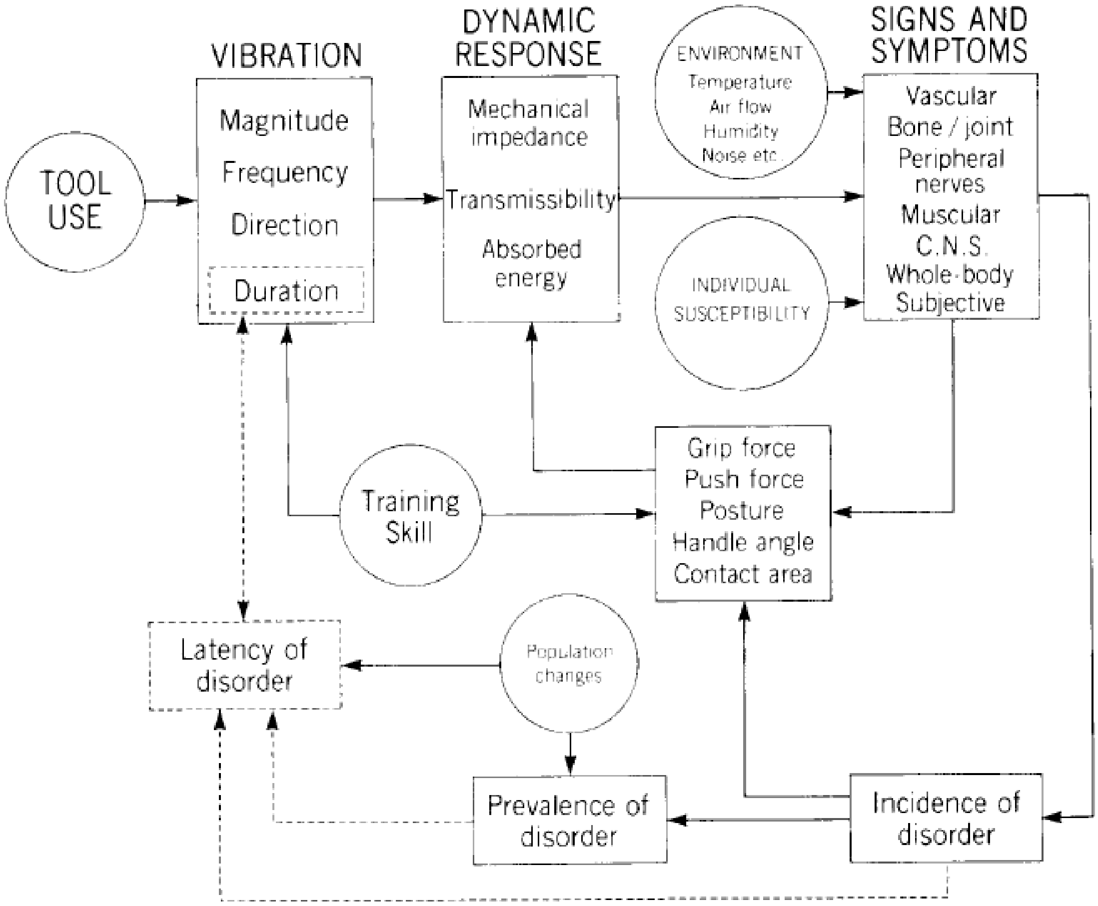


Figure 3.1 Conceptual illustration of the factors influencing the cause effect relationships for HAV [Griffin, 1990]

3.1.1 Vascular effects - Vibration induced white finger

Vibration induced white finger is also known as Raynaud's disease. In the 1800s Raynaud identified a whitening of the fingers believed to be the result of decreased blood supply. The name Primary Reynaud's disease is used when it arises from an unknown cause while the term Secondary Raynaud's disease is used when it is caused by some known factor and occupational vibration exposure is just one of the possible causes. The first link with occupational exposure was made by Alice Hamilton in 1918 following her study on the hands of stone cutters. In their follow up study on stonecutters in the same quarries in 1984, Taylor et al reported an 80% prevalence of vibration white finger and commented that over the 60 years there had been no change in the design of the air hammers and that their measured values were *"outside the recommended limits".*

The extent of the damage increases with continued exposure to vibration and it is important to note that the effects are triggered by cold. A medical consultation in a warm environment may not show the effect or may not show the full extent of the vascular damage. There can be considerable discomfort when the blood returns to the fingers after blanching. In severe cases the tips of the fingers can take on a blue black appearance which, due to the lack of blood supply, can become permanent. Some studies show that some improvement in vibration white finger will occur once the occupational exposure is removed [for example Bovzeni, 2008].

3.1.2 **Non Vascular effects**

Mansfield [2005] discusses a number of non vascular effects related to HAV exposure and in summary these include:

Neurological effects such as numbness and tingling in the fingers which are considered to be the first signs of HAV. Carpal tunnel syndrome can also be observed in those exposed to HAV.

Bone and Joint disorders which are quite extensive and include Kienbock's disease (damage to the lunate bone of the wrist) and osteoarthritis.

Muscular disorders such as loss of grip strength, inflammation of the tendons or synovial sheaths causing tendonitis or tenosynovitis, painful swelling of the extensor tendon sheaths of the thumb (de Quervain's disease) or the flexor tendons of the finger ('trigger finger").

Disorders remote from the hand/arm may be reported as secondary effects from the HAV. For example, there is some indication that vibration can be a non auditory contributor to hearing damage and the link is suggested as a sympathetic response in the cochlea to the vascular effects in the hand. Lower back pain caused by vibration transmitted via the arm to the lumbar spine has been reported. Similarly abdominal injuries can be caused by pressing the torso against the tool to increase the force or to assist control of the item. Here the vibration is transmitted directly into the abdomen and not via the hand/arm. "Vibration white foot" which shows similar effects as "vibration white finger" has been shown to arise from standing on a vibrating surface. This is a possibly emerging issue especially for the Australian mining industry and is discussed in a later section of this report.

3.2 Signs of Hand Arm Vibration Effects

The 2011 HSE UK [HSE,2011] brochure gives guidance to employers on when there should be concerns about excessive occupational HAV exposure and summarises the early signs as :

- tingling and numbness in the fingers;
- not being able to feel things properly;
- loss of strength in the hands; and
- the fingers going white (blanching) and becoming red and painful on recovery (particularly in the cold and wet, and probably only in the tips at first).

And suggests the effects can be:

- pain, distress and sleep disturbance;
- inability to do fine work (e.g. assembling small components) or everyday tasks (e.g. fastening buttons);
- reduced ability to work in cold or damp conditions (i.e. most outdoor work) which would trigger painful finger blanching attacks; and
- reduced grip strength which might affect the ability to do work safely.

An initial screening questionnaire was developed for UK HSE [undated] as an Appendix to their guide to employers and is reproduced as Figure 3.2. This provides a simple screening tool which can be implemented by the employer. It helps to identify the important features to be noted but there is no clear indication of how many “Y” answers are needed to provide the trigger for a proper medical surveillance.

A more formal guidance for medical surveillance by a suitably qualified health care professional is given in Annex F of the HAV Good Practice Guide [ISVR, 2006] which was prepared under contract to the European Union. This summarises the key points that should be checked under a series of 8 headings including case history, physical examination, clinical tests, blood and urine analysis and investigations for vascular, neurological, muscle strength and radiological investigations. This Annex F is reproduced as Annex B of this report.

Have you ever used hand-held vibrating tools, machines or hand-fed processes in your job? Y/N

If YES:
(a) list year of first exposure..

(b) when was the last time you used them?..
(detail work history overleaf)

1 Do you have any tingling of the fingers lasting more than 20 minutes after using vibrating equipment? Y/N

2 Do you have tingling of the fingers at any other time? Y/N

3 Do you wake at night with pain, tingling, or numbness in your hand or wrist? Y/N

4 Do one or more of your fingers go numb more than 20 minutes after using vibrating equipment? Y/N

5 Have your fingers gone white* on cold exposure? Y/N

**Whiteness means a clear discoloration of the fingers with a sharp edge, usually followed by a red flush.*

6 If Yes to 5, do you have difficulty rewarming them when leaving the cold? Y/N

7 Do your fingers go white at any other time? Y/N

8 Are you experiencing any other problems with the muscles or joints of the hands or arms? Y/N

9 Do you have difficulty picking up very small objects, eg screws or buttons or opening tight jars? Y/N

10 Have you ever had a neck, arm or hand injury or operation? Y/N

If so give details..

11 Have you ever had any serious diseases of joints, skin, nerves, heart or blood vessels? Y/N

If so give details..

12 Are you on any long-term medication? Y/N

If so give details..

OCCUPATIONAL HISTORY

Dates **Job Title**

....

Figure 3.2 Initial screening checklist for those employees at risk of exposure to excess HAV [HSE, undated]

3.3 Effects of Whole Body Vibration (WBV)

Whole body vibration occurs when a person is standing or seated on a surface that is vibrating. The vibration is transmitted through the body and to the head. So for a person seated in a truck on a bumpy road the transmission path is from the road through the vehicle suspension system to the seat and then via the driver's body and skeleton and through to the skull. It is important to note that there are two different aspects to considerations of WBV. The aspect most commonly considered when discussing WBV is the substantially continuous vibration that may be experienced when driving along a grooved road or if the vehicle has a rough engine. The other aspect is a sudden short duration vibration referred to as a shock or 'jarring' which can occur when a vehicle goes over a single deep hole or a fast boat slams across a high wave. If the vehicle or boat was travelling at a slower speed or the road surface was smoother and the sea state lower the magnitude of the shock to the body would not be as great. However in most cases these sudden jolts and jars are unexpected so the driver does not have the warning or the opportunity to prepare for the shock.

Most people experience WBV in their daily life. Some form of WBV and shock is fun; for example the jumping castle at the fun fair and the promotion of the excitement from fast boat rides on the ocean. Low level vibration is experienced when in a car or bus on suburban roads. When the vibration increases then discomfort can occur so vehicle manufacturers aim to minimise this as vehicle comfort is considered to be a marketing advantage. It is when the magnitudes of vibration and shock are high and there is an increase in the duration of exposure and/or the number of shocks that health effects are of concern.

Back pain is the most commonly reported effect of excess WBV. Therein lies the problem as back pain can be caused by many factors for which WBV is just one. As there are many possible causes of back pain it is challenging to show clearly the link between WBV and back pain. However, addressing WBV will offer the opportunity to reduce costly back related musculoskeletal compensation claims, especially in those industries where the workers have such exposure, namely the agriculture, mining and construction.

In the introduction to the section in his book on WBV, Griffin [1990] stated that:

"The relationship between whole body vibration and health is an area where both the limitations of available data and the difficulties in obtaining new data allow much room for argument."

Unfortunately, despite continuing investigation since that time there is still no clear dose response relationship. Mansfield [2005] discusses the difficulties of establishing the definite link between WBV and injury. The review by Stayner, [2001], states that:

"The literature shows that LBP, or 'lumbar syndrome' can be associated with occupations, but not specifically with WBV. Only one study has been found which was so structured that vibration magnitude could be assessed independently of time. In many cases, posture or manual handling is probably more important than vibration exposure."

The report by Darby et al [2010] examines the combination of vibration and ergonomics and states:

"The exact cause of back pain is often unclear but back pain is more common in jobs that involve driving, especially over long distances or over rough ground. Driving exposes the vehicle's occupants to whole-body vibration that may include the shocks and jolts that are believed to increase the likelihood of injury or pain in the lower back. However drivers may also be exposed to other risk factors for lower-back pain such as poor posture while driving and manual handling while loading and unloading goods."

The HSE UK brochure [HSE,2011b] gives guidance to employers on when there should be concerns about excessive occupational WBV, refers to back pain as the symptom and the summarises the possible causes which include:

- poor design of controls, making it difficult for the driver to operate the machine or vehicle easily or to see properly without twisting or stretching;
- incorrect adjustment by the driver of the seat position and hand and foot controls, so that it is necessary to continually twist, bend, lean and stretch to operate the machine;
- sitting for long periods without being able to change position;
- poor driver posture;
- repeated manual handling and lifting of loads by the driver;
- excessive exposure to whole-body vibration, particularly to shocks and jolts; and
- repeatedly climbing into or jumping down from a high cab or one which is difficult to get in and out of.

Dealing with all these risk factors including excessive vibration and shock can lead to reduced musculoskeletal injury. An intervention study by Tiemessen et al [2009] aimed at reducing WBV exposure involved 126 drivers who were exposed to WBV above the action limit. The range of vehicles included those typically found in the construction industry. One group received no intervention and the second group were provided with information and a brochure on how to reduce WBV exposure. The grouped findings at the end of the study were somewhat disappointing as there was "*a minimal but not significant decrease*" for the drivers who received the intervention. However the authors found that overall there was not good compliance by the drivers. From further analysis it was shown that "*for those drivers who were more than 50% compliant with the set agreements, a reduction in WBV exposure was seen in 63% of the drivers*".

An additional outcome was a better understanding of WBV by management and a number of the companies involved in the project introduced new company policy specifically addressing reduction in WBV exposure. The findings of this study highlight the difficulties in changing behaviour in a workforce and the importance of good quality and appropriate information as well as management support and motivation for the participation. If all these come together reductions in WBV can be achieved.

3.4 Signs of Whole Body Vibration Effects

As discussed above the primary effect of WBV is damage to the spine and this results in back pain. The difficulty in clearly identifying the cause of the pain and relating it to WBV exposure is the reason for the lack of epidemiological data that shows a dose response relationship. The incidence of back pain is high in the workforce and it can be related to many different types of activities which may or may not be related to WBV. Despite the increased attention to WBV, there has been no substantial gain in fully understanding WBV since the studies of Wikstrom, [1994] who undertook a review and concluded that "*years of exposure to whole-body vibrations may contribute to injuries and/or disorders of the lower back*".

In more recent studies Seidel [2005] proposed that the structure of the skeleton should be further investigated and that future research should consider: "*(1) the nonlinearity of biodynamics, (2) the effects of WBV in x- and y-axes, (3) the strength of the spine for shear, (4) the contact parameters between the seat and man, (5) the significance of postures and muscle activity, and (6) material properties of spinal structures*."

This highlights the need for a multidisciplinary approach to the problem is required to show how the vibration can affect the spine. The additional benefits of such research will be that once more is known about the mechanism, there is greater potential for developing effective control measures.

One effect that can be clearly shown is when there is immediate damage after a shock. An example of the effect on the spine can be seen from the animation of the skeleton from the website of a seat manufacturer and two stills from this video are shown in Figure 3.3. An example of damage to the spine which has been identified immediately after a high level shock in a fast vessel is shown in Figure 3.4. [Price, 2010].

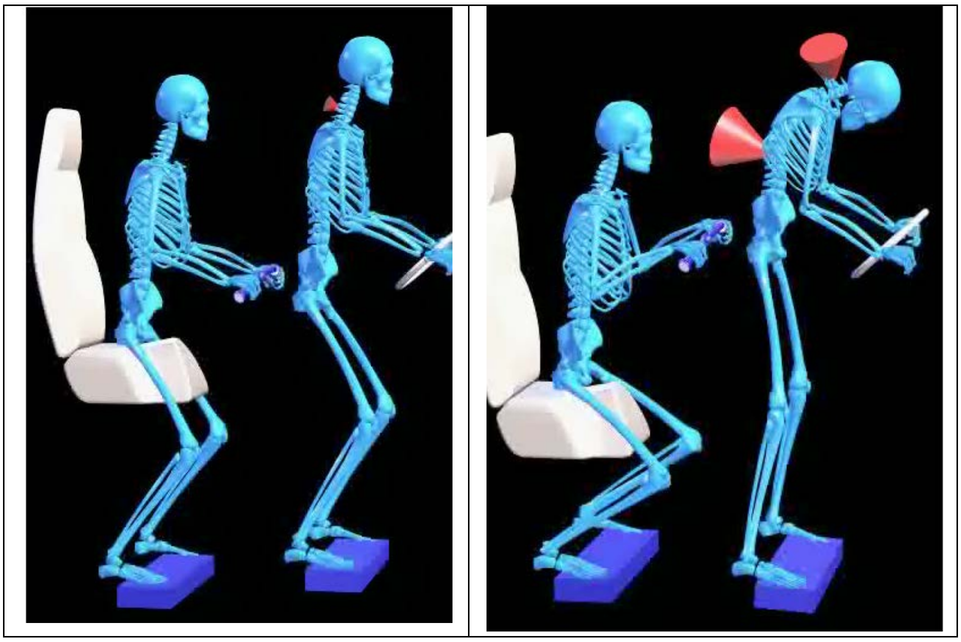


Figure 3.3 Two images from a video showing the comparison of the effect of a shock on the spine for an unsupported and a supported skeleton [extracted from www.ullmandynamics.com/downloads]

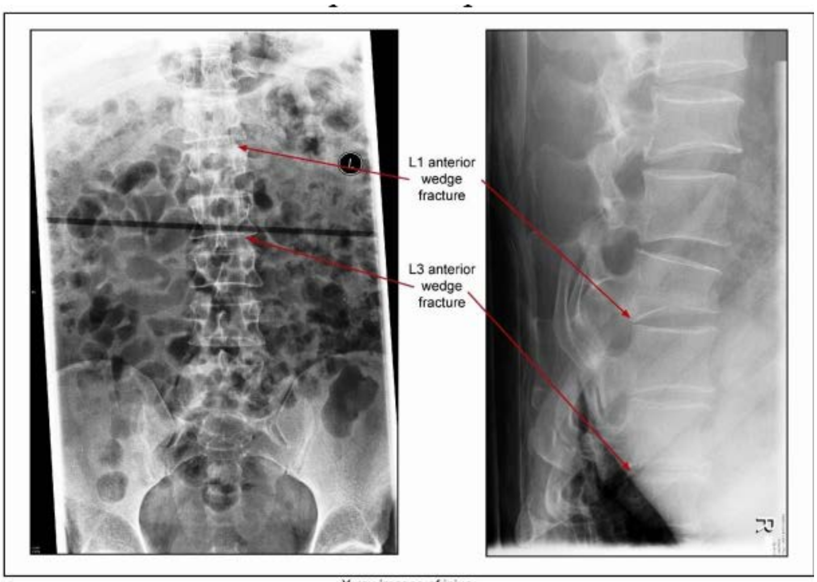


Figure 3.4 X rays showing spinal damage following a large shock experienced by a passenger in a fast vessel [Price 2010]

It is more common even when jolts and jars are the main source of WBV, that the damage and symptoms occur after some period of exposure and not instantaneous. Like many other workplace hazards, the symptoms of early damage may reduce overnight, and it is only after continued exposure that the pain becomes chronic and the worker seeks attention.

Due to the lack of a clear method to specifically related to workplace factors and back pain, general health monitoring is more appropriate than formal health surveillance [HSE, 2011b]. The approach to such monitoring is essentially the same as for manual handing and using the HSE guidance involves:

- considering the method and frequency of monitoring when planning and implementing control measures;
- consulting employees so that they are fully aware of the monitoring procedures, understand they are in place to help protect their health and that they know their part in them;
- encouraging employees to report symptoms they may be suffering as early as possible to stop any further aggravation. having a system in place to do this on a regular basis, such as a brief simple questionnaire, can improve the likelihood that you get this information in the format most useful to you;
- a body map can help a person to pinpoint where they are feeling the symptoms and they can be asked to describe the sensations they are feeling; and
- asking employees whether their work caused the problem and whether they can identify what specific task caused the pain.

Even at low levels WBV can also lead to effects on the psychomotor, physiological and psychological systems of the body. Health monitoring guidance provided in Ontario [2005] includes consideration of these aspects in addition to back pain:

- Abdominal pain
- General feeling of discomfort, including headaches
- Chest pain
- Nausea
- Loss of equilibrium (balance)
- Muscle contractions with decreased performance in
- Precise manipulation tasks
- Shortness of breath
- Influence on speech

However, there is no clear dose response relationship between these effects and WBV as there are many other factors in the workplace that can lead to similar effects. Consequently the major focus in relation to prevention of injury from WBV is on reduction of musculoskeletal injury.

4 Locations of hazardous vibration exposures in industry

4.1 Hand Arm Vibration - Priority Industries

Hazardous exposure to hand arm vibration originates from a vibration transmitted into the hand and arm. Most commonly this interface is at the hand but it can also occur at the wrist or lower arm if that part of the body is in contact with the vibrating object. Some vibration is produced on activation of the tool or the item of plant and this level of vibration can be either increased or decreased during the operation of the tool on the work piece. There can be considerable variability in the amount of vibration from the same tool depending on the particular task and the way the tool is being used. The factors that affect the generated vibration at the tool include the maintenance of the tool, attachments on the tool, type of material being worked on, reaction from the work piece, orientation of the tool to the work piece etc. The extent of the transmission of this vibration into the hand and arm then depends on the nature of the interface between the hand (or arm) and the tool or vibrating surface. If the tool is being firmly gripped the transmission into the hand and arm will be more effective. A firm grip can be required to simply hold the tool if it is heavy or used in an awkward position. A firm grip can also be necessary to control the operation of the tool. It is relevant to note that there have been reports of symptoms of HAV injury from dentists who need to firmly grip their tools for the precise work they undertake [Rytkönen E, et al 2006]. Although the vibration levels generated by the tools themselves are low a long work history and tight "pinch-gripping" of the tool are proposed as being the reasons for the incidence of the injuries.

Thus hazardous vibration exposure depends not just on the vibration level of the tool but the way it is being used, the effectiveness of the transmission path of the vibration from the tool to the hand and arm, the time of use as well as other physiological factors relating to the person such as temperature of the hands, quality of the circulation etc. An EU-OSHA [2008] report on human vibration grouped the main types of tools that lead to hazardous exposure as percussive/roto-percussive tools and rotative tools plus a third group classified as '*alternative*" such as wood finishing tools. Figure 4.1 [EU-OSHA, 2008] provides a visual guidance to the types of tools that are considered to be the main sources of excessive exposure. Those working with any of these tools have increased risk of experiencing hazardous HAV exposure. The data in this Figure corresponds with the findings from the Safe Work Australia vibration exposure surveillance study [Safe Work Australia, 2010] in which Table 4 showed that the highest, i.e. 36%, who reported exposure to vibration identified workshop and worksite tools and equipment.

Thus the main industry sectors where hazardous exposures for HAV could occur would be in Construction, Manufacturing and Mining with additional exposed groups within Agriculture and Forestry. These are included in the priority and national industry groups identified in draft National Strategy [Safe Work Australia 2012]

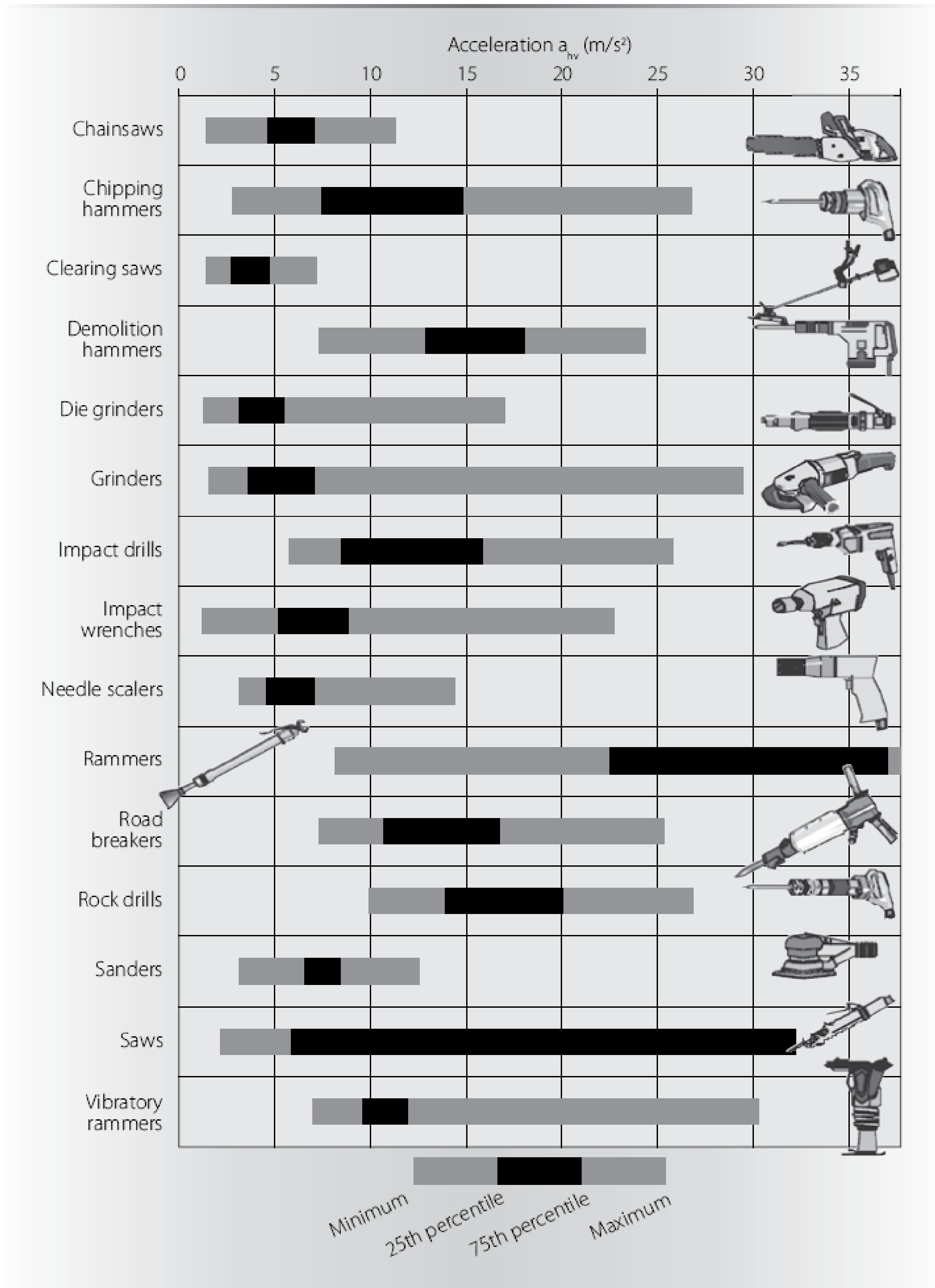


Figure 4.1 Examples of vibration magnitude for some common tools [EU-OSHA, 2008]

4.2 Whole Body Vibration - Priority Industries

Hazardous exposure to whole body vibration originates from a vibration transmitted into the body via an interface for a standing or seated person. One form of exposure is generated from the engine and transmitted via the seat for drivers and passengers within mobile plant and vehicles. The amount of this type of vibration depends on the operation of the engine of the mobile equipment and how effectively that vibration is transmitted into the person. Another main form of exposure related to the vibration generated by the movement of the vehicle over rough roads and the speed of that movement. Thus vehicles and trucks which operate on reasonably good quality road surfaces at moderate speed and are well maintained are not likely to lead to excessive exposure. There is higher potential for hazardous vibration exposure by mobile plant operated at speed on rough surfaces as encountered in mining, construction and agriculture.

Another vibration related hazard from mobile plant arises from jolts and jars which is not a continuous vibration but a shock or jerk. This can be caused by the operation of the mobile plant over uneven surfaces where the sudden movements are transmitted to the cabin of the vehicle. The magnitude of the jolt depends on the track surface and the speed the vehicle goes over the track. Jolts can also be caused by the action or movement of part of the plant itself such as dumpers when loads are being dropped and diggers where the jolts and jars can be caused when the digging tool needs to apply impact.

The EU-OSHA [2008] report on human vibration provided a visual guidance to the types of mobile plant that may lead to WBV, as shown in Figure 4.2. The accompanying data showing comparison with the EU exposure values indicated that while mobile plant could lead to exposures greater than the action values, only the classes of scrapers and finishers would lead to exposures exceeding the limiting values.

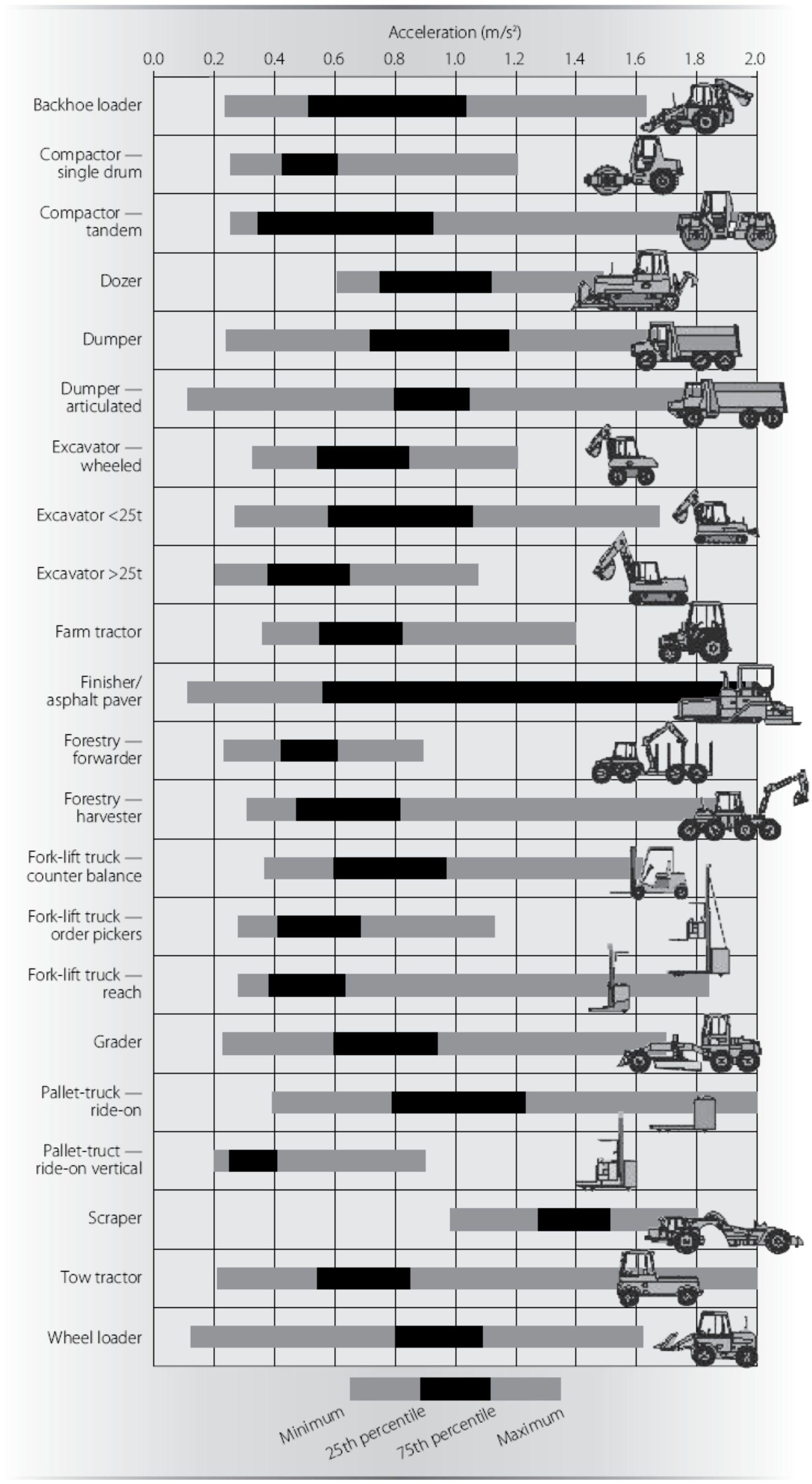


Figure 4.2 Examples of vibration magnitude for some common mobile machines [EU-OSHA, 2008]

Although the EU-OSHA study [2008] indicated that vehicles that are used on off road surfaces for long periods of time, such as agricultural and forestry vehicles, would rarely lead to excessive exposures this may not be the same in the Australian context. The importance of the mining and construction sector in Australia leads to a greater concern about hazardous WBV exposures than may be the case in the UK and the EU. The charts shown in Figure 4.3 are from measurements in Australia by Foster [unpublished] and contrast the assessment of exposure via the two methods described in the ISO standard, namely the rms. (m/s^2) and the VDV ($m/s^{1.75}$) but compared with the caution and health risk zones rather than the limits in the EU Directive. This data highlights the variability in the workplace exposure limits for different types of mobile plant and even more importantly the difference in assessment of hazardous exposure using the two metrics.

Figure 4.4 [McPhee et al, 2009] is based on extensive measurements in mining industry in Australia and shows the typical time of exposure before reaching the caution and likely health hazard zones based on the guidance in AS 2670 [2001]. Again this highlights the wide range in exposure for personnel in the same type of mobile plant. However, the important point to note is the mean time period of exposure before reaching the caution zone. Some of the time periods are less than an hour and all of these time periods are less than the 12 hours shift length which is common for mine workers in Australia. Some improvements in the equipment, seating etc on new mobile plant have been made over the decade since this report. However, not all mobile plant can be fitted with suspension seating due to the small cabin size and the means of operation and recent measurements by Foster [unpublished] have continued to show hazardous exposures for many working in the mining and construction industry, as shown in Figure 4.3.

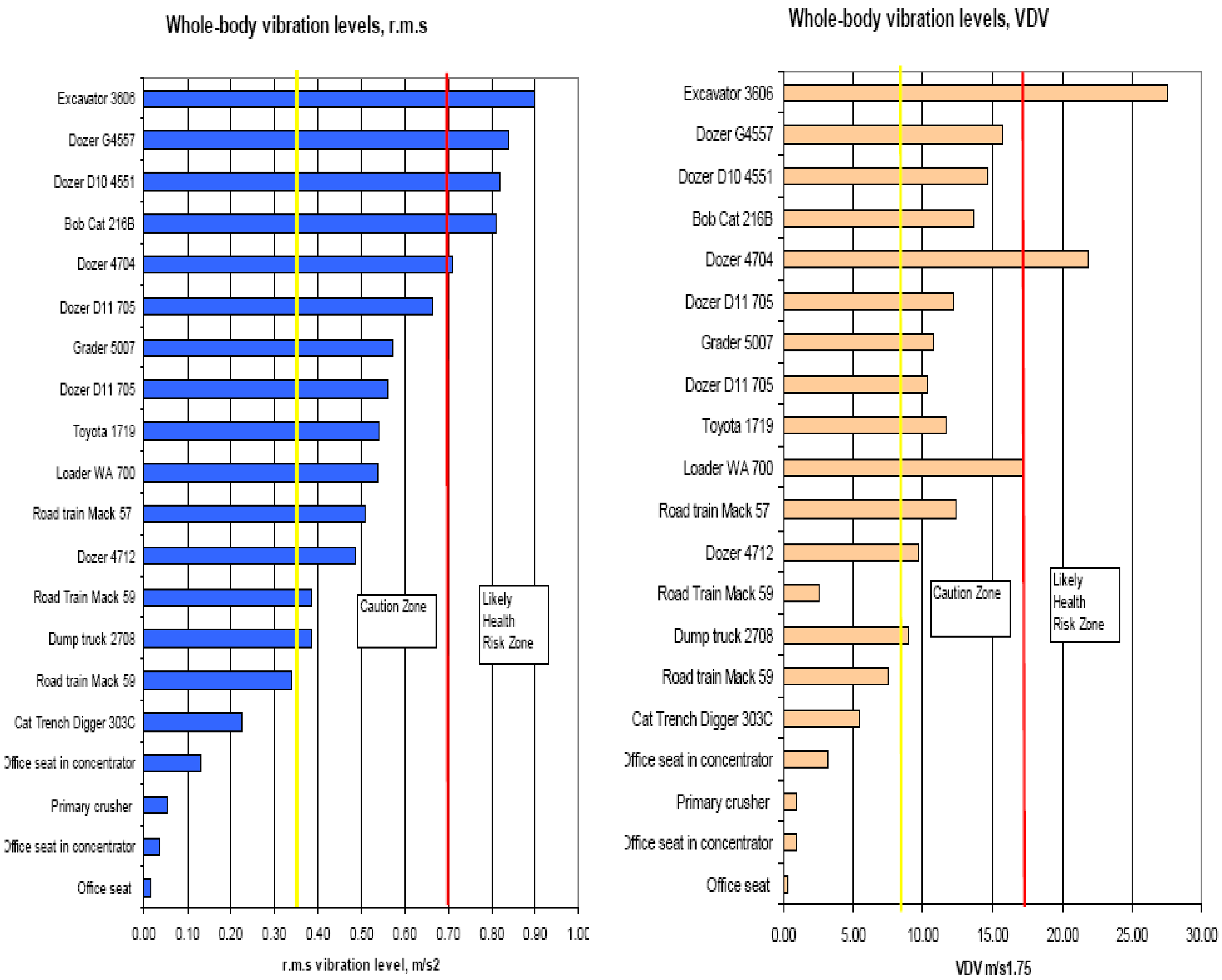


Figure 4.4 Examples of vibration magnitude in terms of two metrics for a range of mobile plant [Foster, unpublished]

Thus the mining and construction industries in Australia have a high risk of hazardous exposure in view of the data already available and the consideration of the long shifts that are typical of these industries. Much of this high exposure may be from jolts and jars, i.e. short duration but repeated shocks. The potential for hazardous vibration exposure also exists for agriculture as workers can spend long periods in vehicles over rough ground and for the enforcement agencies, including the Defence Force, as their primary goal is to complete a mission over rough land or sea in a short time.

Typical times to reach zones for open-cut and underground vehicles

Vehicle Type		AS 2670-2001 Time to Caution Zone (hours)	AS2670-2001 Time to Likely Health Risk Zone (hours)
Open-cut mines			
Dump truck (transporting material)	Mean Range	9 hours 4-19 hours	24 hours 17 to >24 hours
Loader (loading material)	Mean Range	4 hours 48 minutes to 8 hours	13 hours 4 to >24 hour
Track dozer pushing	Mean Range	5 hours 1-11 hours	11 hours 4 to >24 hours
Tractor dozer ripping & pushing	Mean Range	2 hours 36 minutes to 4 hours	9 hours 13-14 hours
4WD personnel carrier (driver)	Mean Range	3 hours 2-5 hours	14 hours 8 to 19 hours
4WD personnel carrier (passenger)	Mean Range	2 hours 1.5 to 2 hours	7 hours 6 to 8 hours
Grader	Mean Range	4 hours 1 to 8 hours	16.hours 5 to >24 hours
Underground mines			
4WD personnel carrier (driver)	Mean Range	5 hours 3 to 10 hours	18 hours 12 to >24 hours
4WD personnel carrier (passenger)	Mean Range	2 hours 1 to 4 hours	7 hours 4 to 14 hours
Equipment transport without suspension	Mean Range	24 minutes 7 minutes to 2 hours	2 hours 26 minutes to 8 hours
Load hall dump Type 1	Mean Range	2 hours 1 to 4 hours	8 hours 5 to 16 hours
Load hall dump Type 2	Mean Range	46 minutes 17 minutes to 4 hours	3 hours 1 to 9 hours
Rail personnel carrier (driver)	Mean Range	2 hours 1 to 5 hours	9 hours 5 to 20 hours
Rail personnel carrier (passenger)	Mean Range	3 hours 2 to 4 hours	10 hours 7 to 14 hours

Figure 4.3 Examples of time periods to reach the caution and likely health risk zones based on AS 2670-2001 guidance for a range of mobile plant in mining [McPhee et al, 2009]

5 Gaps in knowledge

5.1 Vibration White Foot

There is some evidence that symptoms similar to 'vibration white finger' can occur in the toes and foot. In a case study, Thompson et al [2010] reports on a 54-year-old miner (from North America) who experienced blanching and pain in his toes. The worker had operated vehicle-mounted bolting machines for many years and so experienced vibration transmission into his feet over long periods. A more recent study by House et al [2011] investigated cold induced vasospasms in the hands and feet for a group of construction workers in North America. These showed that around 30% had non-severe and a similar proportion had severe vasospasms in the feet and toes which correlated with those who experienced similar levels of vasospasms in the hands. Mansfield [2005] refers to anecdotal reports of 'vibration white toe' and comments that while there have been studies of vibration thresholds for toes relating to diabetes studies these have not been for feet supporting a body.

The risks for vibration white foot are high in the mining industry where workers can spend long hours standing or seating with some pressure on their foot in areas where there is high vibration. This can be from underground drilling machines which can generate by the nature of their operation high levels of vibration in the surrounding environment. Exposure can also be for the operator of plant that uses vibration to achieve the task such as for the coal washing plant or shaker sieves for sorting aggregate, gravel etc the gravel extraction industries.

At this time there is no guidance on vibration exposure limits on the appropriate method of measurement. There is not a high awareness of the potential for this problem and so it is rarely being assessed. For those cases where it is being investigated the limits for HAV are being used due to the lack of any other guidance.

5.2 Whole Body Vibration Exposure Limits

As discussed by Mansfield [2005] there is general agreement that the methods and limits in the EU Directive for assessment of risk from HAV 'correspond with "*generally accepted best practice*" but the same cannot be said for the assessment of risk from WBV. The concerns about the WBV include the use of the data only from the worst axis of vibration, the choice between r.m.s. and VDV, the limitation to r.m.s. for declarations via the Machinery Directive and the lack of a clear dose-effect relationship that can be used as the basis for the exposure limits.

In their review paper on the EU Directive, Nelson and Brereton [2005] summarised that the establishment of the WBV exposure and action limits *"were agreed, taking into account current understanding of the risks to health from vibration exposure (as documented in annexes to ISO 5349-1 and ISO 2631-1) and also the practicability or cost of achieving exposures below these values. The exposure limit value for whole-body vibration was set at 0.63 ms^{-2} A(8) in the original proposal. During discussions in the Social Questions Working Group this was shown to be unachievable in many work activities and was raised to 1.15 ms^{-2} A(8) in the final agreed version of the Directive"*

The impression from many undertaking measurements in the workplaces [private communications] is that the workplace exposure limit for WBV in the EU Directive is indeed too high and the value does need to be reviewed with a lower value established. The data that is now becoming available following the introduction of the EU Directive may well assist with the development of a robust dose-response relationship for WBV. The data to date from the EU-OSHA [2010] report shows the range of mobile plant for which the vibration exposure of the driver is under the current exposure limit, of 1.15 m/s^{-2} but would be well above the originally proposed 0.63m/s^{-2} limit.

In view of the uncertainty on the value for the workplace exposure limit, there is a high risk of musculoskeletal injury for those continuing to be exposed below the current limit. The experience with HAV showed that the manufacturers responded to the exposure limits by improving the design of tools to reduce the HAV exposure. If a similar approach could be adopted with regard to WBV the incidence of musculoskeletal injury in industries with HAV exposure may be reduced.

An additional concern from those undertaking measurements in the field is the accuracy of the WBV data, especially if it is reported in terms of VDV as that metric has a greater response to bumps. For the measurements, the sensor pad is either put on the seat or against the back rest. The movements of the person while seated and especially while getting on and off can lead to bumps on the sensor which will register in the data acquisition. The extent to which this may corrupt data needs further investigation particularly in cooperation with the manufacturers of the instrumentation.

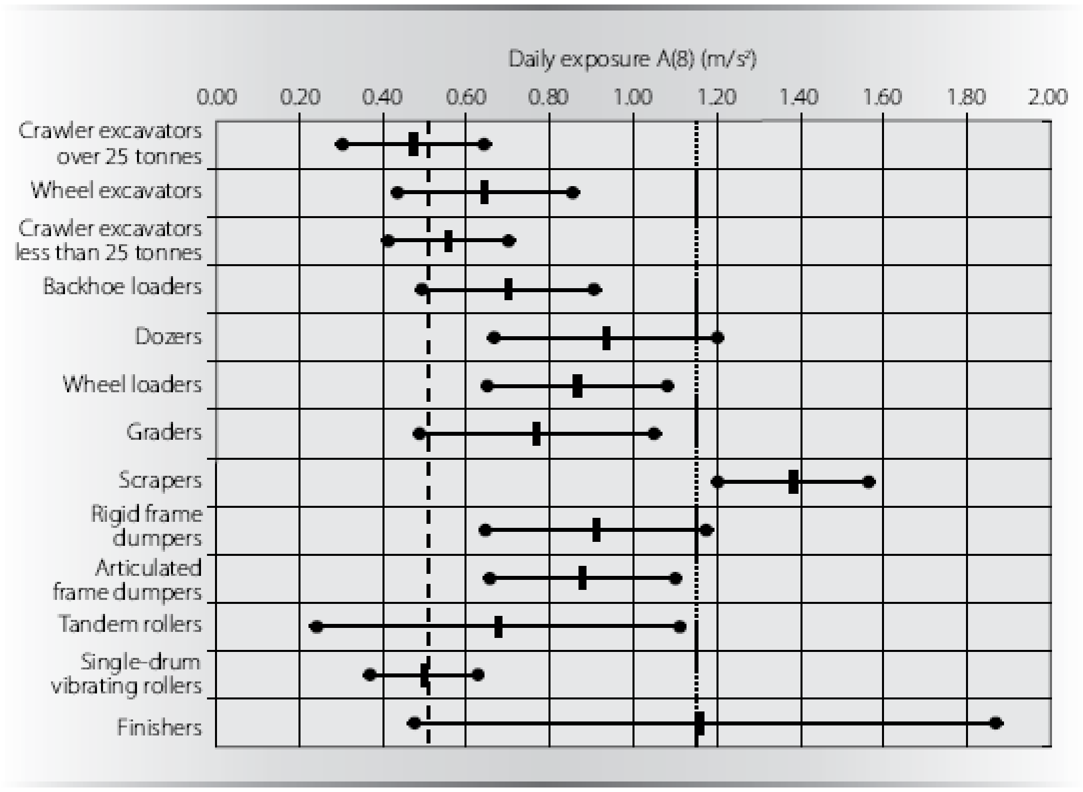


Figure 5.1 Examples of daily exposure for some common mobile machines [EU-OSHA, 2008]

5.3 Assessment of Shock

A major source of WBV in mining, construction and agriculture is from shocks and jolts to the body. The mechanism for the production of shock differs to that for a more continuous vibration as from the operation of a motor, machine or engine. In the analysis of measurement data the shocks present as an initial sharp acceleration and a follow on oscillatory movement before there is a return to the rest state. The greater the damping in the system the greater the reduction of the magnitude of each oscillation and the faster the return to the rest state. Crest factor can be determined from detailed signal analysis and high values of crest factor indicate large excursions above the average level.

The EU Directive allows for the assessment of WBV in terms of either frequency weighted rms or the vibration dose value (VDV). By its nature the assessment in terms of r.m.s. will lead to an averaging of the signal. The VDV has been developed following research that showed a 4^{th} power relationship between vibration magnitude and discomfort. The VDV will provide a better indication when the signals has high crest factor, i.e. when there have been shocks during the measurement period.

Since the release of the EU Directive in 2002, Part 5 of the ISO series of standards on WBV has been released. This standard [ISO 2631-5, 2004] provides methods for evaluation of vibration containing multiple shocks. The methods are not simple and require more analysis that can be achieved with the commercially available human vibration meters. The aim is to quantify the effects of shocks on the body and to assess the effects on the body from analysis of the lumbar spine response. The dose in terms of equivalent static compressive stress, S_{ed}, is calculated from the accelerometer data, the model of the lumbar spine and the time of exposure per day. The guidance for adverse health effects is provided in terms of lifetime exposure. When S_{ed} is <0.5 MPa there is a low probability of adverse health effects and when S_{ed} is >0.8 MPa there is a high probability. It is important to note that the assessment method in ISO 2631-5 is based on the assumption that the person:

"is seated in an upright position and does not voluntarily rise from the seat during the exposure"

The work in this area is coming from the military, for example the paper by Alem et al [2004] found that:

"Results have shown that the new standard is more sensitive to cross-country rough terrain signatures than WBV methods, but produces similar predictions for ride signatures obtained over paved or secondary roads. The data analysis demonstrates the applicability of the new ISO 2631-5 standard to tactical ground vehicles, especially in the vertical axis"

The gaps in knowledge in this area were summarised by Price [2011] who identified the competing methods for assessing shock exposure and the limiting values and the need for a decision by the committees of the ISO. He acknowledged that there were challenges when dealing with such international organisations and that it was essential that those concerned participated in the process to achieve the goal. He emphasised that the incidence of injury for personnel on high speed boats is not declining as there had been 13 marine incidents investigated over period 2008-2010 involving lower back compression factors associated with shock and vibration on high speed craft [MAIB, 2010]. It is hoped that the outcomes of this work by the ISO will lead to an improved method of assessing the risk of hazardous shock exposure.

5.4 Vibration and Pregnancy

The EU-OSHA [2010] report raises concern about the effect of hand arm and WBV on pregnant women. It does not give any specific guidance but says:

"Therefore, the authors emphasise the need to inform occupational physicians about women's exposure to vibration and the need to take specific measures to limit women's exposure and to prohibit it during pregnancy."

At this time very little quantitative data is available for the effects of vibration on pregnant women. A literature review by Van Dyke [2010] showed that concerns about effects of WBV on pregnancy were mentioned before the 1990s and included increased risks of abortions, menstrual disturbances and anomalies of (uterine) positions and that at that time there was no guidance for a safe limit. Studies in recent years have included animal studies have shown similar concerns. A series of studies on workers in Poland showed that "*vibration was one of the noxious factors most frequently reported and was associated with abnormal pregnancy outcomes*". Similarly Joubert [2009] concluded from a study of the effects of professional driving on pregnancy that :

"From the evidence to date it can be reasonably inferred that exposure to prolonged whole-body vibration while operating a vehicle shows unclear and weak evidence of adverse reproductive outcomes in males or females. The limited research and anecdotal evidence that does however exist should not be ignored and can be considered as the strongest indicator so far that adverse reproductive effect could be present and should be investigated further."

So while there is evidence and concern about the effect of WBV on pregnancy there is no clear damage risk level and the guidance remains as recommending caution. In the interim it would be wise for employers to be advised to limit exposure to vibration as much as possible for pregnant women and this should be included in a health monitoring guideline and/or code of practice.

5.5 Anti-Vibration Gloves

Anti-vibration gloves are proposed in many guides as one way to reduce HAV exposure. Since the late 1980s there has been concern about the effectiveness of anti-vibration gloves, especially when it was discovered that in some situations the gloves were found to amplify the vibration at some frequencies. In 1996 ISO 10819 was introduced to standardise a method of measurement and acceptance criteria. This standard was adopted as AS/NZS 2161.9 [2002] as part of the suite of standards dealing with Occupational Protective Gloves.

While it is important to have a prescribed measurement procedure, this standard includes acceptance criteria for description as 'anti-vibration glove'. Gloves which have been designed to pass the acceptance criteria may not provide the protection necessary to reduce the exposure for the worker. This is mentioned in a note in the standard as "The *fulfilment of these criteria does not imply that the use of such gloves removes the hazard of Vibration exposure*."

In a paper on protective equipment for HAV, [Chatten, 2010] expressed doubts about the effect of ant-vibration gloves and went further to say "*A pair of good quality industrial gloves will often provide equal levels of protection.*" Further studies are being undertaken in Europe to assess the effectiveness of anti-vibration gloves across a range of tools. The outcome of these studies will give better guidance on when gloves can be considered as appropriate personal protection.

As the selection of the gloves which may reduce the vibration exposure is complex the HSE guidance on controlling HAV for the worker states:

> “Gloves can be used to keep hands warm, but should not be relied upon to provide protection from vibration.”

6 Summary

The dose response relationship between excess HAV and the presence of vascular effects, i.e. 'vibration white finger', is well established. For WBV but there is a strong link with musculoskeletal damage in particular from shock and from jolts and jars. Thus national prevention efforts addressing the priority area of musculoskeletal disorders in the proposed National Strategy [Safe Work Australia 2012], should include control of WBV, particularly for the users of heavy equipment in the construction, mining and transport industries.

The health monitoring guidance for HAV and WBV that has been developed in the UK and other countries can be used as the basis for the development of health monitoring guidelines. These can be used by as a screening aid to assist with the identification of those employees of greater risk of hazardous exposure. The gaps in knowledge indicate that any health monitoring guidelines should include concerns about the effects of vibration on pregnancy and the effects of vibration on the foot (similar to HAV). Employees are most likely to experience hazardous vibration in the construction, mining and transport industries and these correspond with the national priority industries identified in the proposed National Strategy.

7 References

Alem N, Ernest Hiltz E, Breaux-Sims A and Bumgardner B, 2004 *Evaluation of New Methodology for Health Hazard Assessment of Repeated Shock in Military Tactical Ground Vehicles* Symposium on "Habitability of Combat and Transport Vehicles: Noise, Vibration and Motion", Prague, Czech Republic, 4-7 October (available from , http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA446928)

AS 2670.1, 2001 Evaluation of human exposure to whole-body vibration - General requirements, Standards Australia

AS 2763, 1988 Vibration and shock - Hand-transmitted vibration - Guidelines for measurement and assessment of human exposure, Standards Australia

AS/NZS 2161.9, 2002, Occupational protective gloves Part 9: Method of measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand, Standards Australia

Bovenzi M, 2008 A follow up study of vascular disorders in vibration-exposed forestry workers Int Arch Occup Environ Health (2008) 81:401–408

Brammer AJ. Peterson D ,. 2004 *Standard Handbook of Biomedical Engineering and Design, Chapter 10 Vibration, Mechanical Shock, And Impact*, McGraw-Hill (available from http://unhas.ac.id/tahir/BAHAN-KULIAH/BIO-MEDICAL/NEW/HANBOOK/Vibration__Mechanical_Shock__And_Impact.pdf)

Brereton P., 2011a Impact of European Directive 2002/44/EC on the risk of developing Hand-arm vibration syndrome in Great Britain, 12 Int Conference on Hand Arm Vibration, Ottawa, Canada, 13-17 June

Brereton P., 2011b *Control of Occupational Risks from Vibration: Revision of HSE Guidance*, UK Conference on Human Response to Vibration, Buxton, UK. 20-22 September

Burgess M Harrap M (2010) *Fast Vessels in Heavy Seas – a 'shocking' experience!* Journal of Health, Safety and Environment, 26(2), pp101-107

Chatton C, 2010, *Hand in Glove - PPE specific to Hand-arm Vibration (HAV)* Health and Safety International, July (available from http://www.hsimagazine.com/article.php?article_id=457)

EC 2002 DIRECTIVE 2002/44/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:177:0013:0019:EN:PDF

EC 2010 *Guide to the application of the machinery Directive* European Commission for enterprise and industry, 2006/42/EC, available from http://ec.europa.eu/enterprise/sectors/mechanical/files/machinery/guide_application_directive_2006-42-ec-2nd_edit_6-2010_en.pdf

EU-OSHA 2008 *Workplace exposure to vibration in Europe – an expert review*, European Agency for Safety and Health at Work

Griffin, M J 1990 *Handbook of Human Vibration*, Academic Press

Hamilton, A 1918 *The effect of Air Hammers on the hands of Stone cutters* Bureau of Labour Statistics Report No236 (see www.youtube.com/watch?v=zo6d3xQ6780)

Heaton R & Hewitt S., 2011a *RR884 Hand-arm vibration of horticultural machinery Part 1* Health and Safety Executive, UK

Heaton R & Hewitt S., 2011b *RR894 Hand-arm vibration of horticultural machinery Part 2* Health and Safety Executive, UK

House R, Jiang D, Thompson A, Eger T, Krajnak K, Sauvé J, Schweigert M., 2011 *Vasospasm in the feet in workers assessed for HAVS* Occup Med (Lond). Mar;61(2):115-20. Epub 2010 Dec 31.

HSE, 2011a Control the risks from Hand Arm Vibration Advice for employers www.hse.gov.uk/pubns/indg175.pdf

HSE, 2011b *Control back-pain risks from whole-body vibration* Advice for employers http://www.hse.gov.uk/pubns/indg242.pdf

HSE, undated “Initial screening questionnaire for workers using handheld vibrating tools, hand-guided vibrating machines and hand-fed vibrating machines” www.hse.gov.uk/vibration/hav/advicetoemployers/inscrquest.pdf (accessed Feb 2012)

ISO 10819 1996 Mechanical vibration and shock -- Hand-arm vibration -- Method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand, International Standards Organisation

ISO 2631-1:1997 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration - Part 1: General requirements* International Standards Organisation Plus amendment 1 2010

ISO 2631-5 2004 Mechanical vibration and shock - Evaluation of human exposure to whole body vibration - Part 5 method for evaluation of vibration containing multiple shocks, International Standards Organisation

ISO 5349-1:2001 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements International Standards Organisation

ISO 5349-2:2001 Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 2: Practical guidance for measurement at the workplace International Standards Organisation

ISVR, 2006, HAV Good Practice Guide , V7.7, Report on contract VC/2004/0341 for the European Commission Directorate General Employment, Social Affairs and Equal Opportunities. Available from wwwnew.isvr.soton.ac.uk/hrv/VIBGUIDE/HAV%20Good%20practice%20Guide%20V7.7%20English%20260506.pdf

Joubert D 2009 *Professional Driving and Adverse Reproductive Outcomes: The Evidence to Date and Research Challenges* The Open Occupational Health & Safety Journal, 1, 1-6 (available from www.benthamscience.com/open/toohsj/articles/V001/1TOOHSJ.pdf)

M Darby P R Heaton M Mole [2010] "*Whole-body vibration and ergonomics of driving occupations Road haulage industry*" Health and Safety Executive research report 777

MAIB 2011, Report on the investigation of injury to a passenger on board a Delta 8.5m RIB River Thames, London, Marine Accident Investigation Branch, Department Transport, UK (available from www.maib.gov.uk/cms_resources.cfm?file=/Delta_RIB_Report.pdf)

Mansfield N 2005 *Human Response to Vibration*, CRC Press

McPhee, B., Foster, G., and Long, A., 2009, *Bad Vibrations: a Handbook on Whole-Body Vibration Exposure in Mining*: The Joint Coal Board Health and Safety Trust, Sydney (available from www.fosterohs.com/links.htm)

Nelson C and Brereton P, 2005 *The European Vibration Directive* Industrial Health 43, 472–479

Ontario, 2005 *Whole Body Vibration* Occupational Health Clinics for Ontario Workers Inc.

Price, B, 2011, *Human Injury Metric Standards and High Speed Planing Craft* NavseaConference, Pananma City Division, March 15 (available from www.navalengineers.org/SiteCollectionDocuments/2011%20Proceedings%20Documents/MACC2011/43_Blankenship%20MACC_Price_NSWCPCD_05252011_V3.pdf)

Rytkönen E, Sorainen E, Leino-Arjas P, Solovieva S, 2006 *Hand-arm vibration exposure of dentists* Int Arch Occup Environ Health. Jun;79(6):521-7. Epub 2006 Jan 18.

Safe Work Australia, 2010 National Hazard Exposure Worker Surveillance: Vibration exposure and the provision of vibration control measures in Australian Workplaces, Commonwealth of Australia.

Safe Work Australia, 2012 Australian Work Health and Safety Strategy 2012–2022:Healthy, Safe and Productive Working Lives, Commonwealth of Australia.

Seidel, H., 2005 "On the relationship between whole-body vibration exposure and spinal health risk". Industrial Health, 43(3): 361-377

Statutory Instrument No 1093, 2005 *The Control of Vibration at Work Regulations 2005* United Kingdom Government Legislation (available from www.legislation.gov.uk/uksi/2005/1093/contents/made)

Stayner RM 2001 Whole body vibration and shock a literature review extension of a study over travel of seat suspensions, Health and Safety Executive contract research report 333

Taylor W, Wasserman D, Behrens V, Reynolds D and Samueloff S, 1984 "Effect of the air hammer on the hands of stonecutters. The limestone quarries of Bedford, Indiana, revisited." Br J Ind Med. 41(3): 289–295.

Thompson AM, House R, Krajnak K, Eger T, 2010. *Vibration-white foot: a case report* Occup Med (Lond).;60(7):572-4. Epub 2010 Aug 3.

Tiemessen, I.J.H., Hulshof, C.T.J., and Frings-Dresen, M.H.W., 2009 Effectiveness of an occupational health intervention program to reduce whole body vibration exposure: An evaluation study with a controlled pretest-post-test design. American Journal of Industrial Medicine, 52(12): 943-952.

UK 2005 *The Control of Vibration at Work Regulations* Statutory Instruments No 1093 available from http://www.legislation.gov.uk/uksi/2005/1093/introduction/made
Van Dyke, P., 2010 "A Literature Review of Air Medical Work Hazards and Pregnancy". Air Medical Journal, 29(1): 40-47.

Wikstrom, B.O.,1994 "*Health-Effects Of Long-Term Occupational Exposure To Whole-Body Vibration - A Review*". International Journal Of Industrial Ergonomics, 14(4)(1994): 273-292.

8 Bibliography

Further reading on Hand Arm Vibration

Appleton, B., "Control of noise and hand-arm vibration". Foundry Trade Journal, 181(3652)(2008): 52.

Astrom, C., "Hand-arm vibration syndrome (HAVS) and musculoskeletal symptoms in the neck and the upper limbs in professional drivers of terrain vehicles - A cross sectional study". APPLIED ERGONOMICS, 37(6)(2006): 793-799.

Besa, A.J., "Characterisation of the mechanical impedance of the human hand-arm system: The influence of vibration direction, hand-arm posture and muscle tension". International Journal Of Industrial Ergonomics, 37(3)(2007): 225-231.

Bovenzi, M., "Exposure-response relationship in the hand-arm vibration syndrome: an overview of current epidemiology research". International Archives Of Occupational And Environmental Health, 71(8)(1998): 509-519.

Bovenzi, M., "The European Directive 2002/44/CE on the protection of workers against risks arising from mechanical vibration | La Direttiva Europea 2002/44/CE sulla protezione dei lavoratori contro i rischi da vibrazioni meccaniche". Medicina del Lavoro, 93(6)(2002): 551-560. (Abstract only)

Bovenzi, M., "A case-control study of occupational exposures and systemic sclerosis". International Archives Of Occupational And Environmental Health, 77(1)(2004): 10-16.

Bovenzi, M., "Health effects of mechanical vibration". Giornale Italiano di Medicina del Lavoro ed Ergonomia, 27(1)(2005): 58-64.

Bovenzi, M., "Health risks from occupational exposures to mechanical vibration". Medicina del Lavoro, 97(3)(2006): 535-541.

Bovenzi, M., "A prospective cohort study of exposure-response relationship for vibration-induced white finger". Occupational And Environmental Medicine, 67(1)(2010): 38-46. (Have this one)

Bovenzi, M., "A longitudinal study of peripheral sensory function in vibration-exposed workers". International Archives Of Occupational And Environmental Health, 84(3)(2011): 325-334.

Brereton, P., "A programme to examine risk of injury from exposure to hand-arm and whole-body vibration at work". Inter-Noise 96 - The 1996 International Congress On

Noise Control Engineering, 25th Anniversary Congress - Liverpool, Proceedings, Books 1-6, 1996): 1713-1718

Brereton, P., "Impact of european Directive 2002/44/ec on the risk of developing hand-arm vibration syndrome in great britain". Canadian Acoustics - Acoustique Canadienne, 39(2)(2011): 108-109. (Abstract only)

Burke, F.D., "An assessment of the effects of exposure to vibration, smoking, alcohol and diabetes on the prevalence of Dupuytren's disease in 97,537 miners". Journal Of Hand Surgery-British And European Volume, 32E(4)(2007): 400-406.

Burstrom, L., "Comparison of different measures for hand-arm vibration exposure". Safety Science, 28(1)(1998): 3-14.

Burstrom, L., "Relationship between hand-arm vibration exposure and onset time for symptoms in a heavy engineering production workshop". Scandinavian Journal Of Work Environment & Health, 32(3)(2006): 198-203.

Burstrom, L., "Vibrotactile Perception and Effects of Short-Term Exposure to Hand-Arm Vibration". Annals Of Occupational Hygiene, 53(5)(2009): 539-547.

Burstrom, L., "White fingers, cold environment, and vibration - exposure among Swedish construction workers". Scandinavian Journal Of Work Environment & Health, 36(6)(2010): 509-513.

Burstrom, L., "A follow-up study of welders' exposure to vibration in a heavy engineering production workshop". Journal Of Low Frequency Noise Vibration And Active Control, 29(1)(2010): 33-39.

Cameron, I., "New vibration laws focus attention on machine ergonomics". Diesel Progress International Edition, 25(1)(2006): 34. (Abstract only)

Carlsson, I., "Hand injuries and cold sensitivity: Reliability and validity of cold sensitivity questionnaires". Disability And Rehabilitation, 30(25)(2008): 1920-1928.

Cederlund, R., "Hand-arm vibration exposure influences performance of daily activities". Disability And Rehabilitation, 23(13)(2001): 570-577.

Chao, P.C., "Assessment of Combined Effects From Exposure to Cold Stress, Hand-arm Vibration and Noise". Epidemiology, 22(1)(2011): S256-S257.

23. Cherniack, M., "The hand-arm vibration international consortium (HAVIC): Prospective studies on the relationship between power tool exposure and health effects". Journal Of Occupational And Environmental Medicine, 49(3)(2007): 289-301.

Chetter, I.C., "The hand arm vibration syndrome: a review". Cardiovascular Surgery, 6(1)(1998): 1-9.

Coggins, M.A., "Evaluation of Hand-Arm and Whole-Body Vibrations in Construction and Property Management". Annals Of Occupational Hygiene, 54(8)(2010): 904-914.

Cooke, R., "Hand-arm vibration syndrome from exposure to high-pressure hoses". Occupational Medicine-Oxford, 51(6)(2001): 401-409.

Dale, A.M., "Evaluation of anti-vibration interventions for the hand during sheet metal assembly work". Work - A Journal Of Prevention Assessment & Rehabilitation, 39(2)(2011): 169-176. (Abstract only)

De Capua, C., "A virtual assistant for safety measurements evaluating the worker hand-arm exposure to percussion machines vibration". 2007 IEEE Symposium On Virtual Environments, Human-Computer Interfaces And Measurement Systems, 2006; 58-62.

De Capua, C., Meduri, A., and Morello, R., "A hand-arm vibration meter monitoring the percussion exposure for health risk prevention applications". 2009 IEEE International Workshop on Medical Measurements and Applications, MeMeA 2009, 2009): 45-50. (Abstract only

Dong, R.G., "An evaluation of the standardized chipping hammer test specified in ISO 8662-2". Annals Of Occupational Hygiene, 48(1)(2004): 39-49.

Dong, R.G., "A method to quantify hand-transmitted vibration exposure based on the biodynamic stress concept". Proceedings Of The Institution Of Mechanical Engineers Part H-Journal Of Engineering In Medicine, 221(H8)(2007): 847-861.

Edwards, D.J., "Exposure to hand-arm vibration: implications of new statutory requirements". Building Research And Information, 33(3)(2005): 257-266.

Edwards, D.J., "Analysis of hand-arm vibration risk to highway utilities maintenance and repair operatives". Automation In Construction, 19(5)(2010): 580-587.

Elms, J., "A screening questionnaire for HAVS?". Occupational Medicine-Oxford, 55(2)(2005): 139-141.

Gillmeister, F., "Exact recording of the real hand-arm-vibration exposure time at Workplaces". Human Vibration: Effects on Health - Performance - Comfort, 20022007): 113-120.

Goglia, V., "Influence on operator's health of hand-transmitted vibrations from handles of a single-axle tractor". Annals Of Agricultural And Environmental Medicine, 13(1)(2006): 33-38.

Govindaraju, S.R., "Nerve damage occurs at a wide range of vibration frequencies". International Journal Of Industrial Ergonomics, 38(9-10)(2008): 687-692.

Griffin, M.J., "Negligent exposures to hand-transmitted vibration". International Archives Of Occupational And Environmental Health, 81(5)(2008): 645-659.

Harada, N., "Effects of room temperature, seasonal condition and food intake on finger skin temperature during cold exposure test for diagnosing hand-arm vibration syndrome". Industrial Health, 36(2)(1998): 166-170.

Heaver, C., Goonetilleke, K.S., Ferguson, H., and Shiralkar, S., "Hand-arm vibration syndrome: A common occupational hazard in industrialized countries". Journal of Hand Surgery: European Volume, 36(5)(2011): 354-363.

House, R., "Current perception threshold and the HAVS Stockholm sensorineural scale". Occupational Medicine-Oxford, 59(7)(2009): 476-482.

House, R., "Upper extremity disability in workers with hand-arm vibration syndrome". Occupational Medicine-Oxford, 59(3)(2009): 167-172.

House, R., Krajnak, K., Thompson, A., and Jiang, D., "Effect of hand-arm vibration and proximal neuropathy on current perception threshold measurement in the fingers". Canadian Acoustics - Acoustique Canadienne, 39(2)(2011): 68-69.

House, R.A., "Noise-induced Hearing Loss in Construction Workers Being Assessed for Hand-arm Vibration Syndrome". Canadian Journal Of Public Health-Revue Canadienne De Sante Publique, 101(3)(2010): 226-229.

Jetzer, T., "Review of legal suits involving hand-arm vibration". Canadian Acoustics - Acoustique Canadienne, 39(2)(2011): 114-115. (Abstract only)

Kaulbars, U., "Overview - Human exposure to hand-arm-vibration". Human Vibrations, 18212004): 87-95.

Kowalski, P., "Whole-Body and Hand-Arm Vibration in In-House Transport". Archives Of Acoustics, 35(2)(2010): 183-190.

Lander, L., "Nerve conduction studies and current perception thresholds in workers assessed for hand-arm vibration syndrome". Occupational Medicine-Oxford, 57(4)(2007): 284-289.

Leventhall, G., "The EU Physical Agents Vibration Directive". Noise and Vibration Worldwide, 33(2)(2002): 9-12.

Lundstrom, R., "Exposure-response relationship between hand-arm vibration and vibrotactile perception sensitivity". American Journal Of Industrial Medicine, 35(5)(1999): 456-464.

Machado, M., "Occupational vibration effects on workers health and quality of life". SHO2010: International Symposium On Occupational Safety And Hygiene, 2010): 304-308.

Malchaire, J., "Neurological and functional effects of short-term exposure to hand-arm vibration". International Archives Of Occupational And Environmental Health, 71(4)(1998): 270-276.

Mansfield, N.J., "The European vibration Directive - How will it affect the dental profession?". British Dental Journal, 199(9)(2005): 575-577.

Mason, H.J., "Exposure assessment in health assessments for hand-arm vibration syndrome". Occupational Medicine-Oxford, 61(5)(2011): 374-376.

Mattioli, S., "A case report of vibration-induced hand comorbidities in a postwoman". BMC Musculoskeletal Disorders, 122011).

McCallig, M., "Evaluating worker vibration exposures using self-reported and direct observation estimates of exposure duration". Applied Ergonomics, 42(1)(2010): 37-45.
Middleton, S., "A study of occupational noise and hand-arm vibration exposure to employees in multidisciplinary organisation". Epidemiology, 18(5)(2007): S118-S119.

Mirbod, S.M., "Proposal for hand arm vibration exposure limits adopted for Japanese workers operating hand held vibrating tools". International Archives Of Occupational And Environmental Health, 69(6)(1997): 418-422.

Mirbod, S.M., "Assessment of hand-arm vibration exposure among traffic police motorcyclists". International Archives Of Occupational And Environmental Health, 70(1)(1997): 22-28.

Mohr, D., "The noise and vibration occupational health and safety ordinance I and II". Human Vibration: Effects on Health - Performance - Comfort, 20022007): 3-28. (Abstract only)

Monarca, D., et al., "Safety and health of workers: Exposure to dust, noise and vibrations". Acta Horticulturae, 8452009): 437-442.

Nataletti, P., "Occupational Exposure to Mechanical Vibration: The Italian Vibration Database for Risk Assessment". International Journal Of Occupational Safety And Ergonomics, 14(4)(2008): 379-386. (Abstract only)

Nelson, C.M., "The European vibration Directive". Industrial Health, 43(3)(2005): 472-479. (Abstract only)

Nitti, R., De Santis, P., and Nataletti, P., "Assessment of hand-arm vibration exposure by means estimation methodologies: Comparison between vibration databases (ispesl) and information provided by tool manufacturers". Canadian Acoustics - Acoustique Canadienne, 39(2)(2011): 106-107.

Paddan, G.S., "Effect of arm support on force at a hand-held joystick during exposure to vertical seat vibration". Inter-Noise 96 - The 1996 International Congress On Noise Control Engineering, 25th Anniversary Congress - Liverpool, Proceedings, Books 1-6, 1996): 1731-1735.

Palmer, K.T., "Risk of hand-arm vibration syndrome according to occupation and sources of exposure to hand-transmitted vibration: A national survey". American Journal Of Industrial Medicine, 39(4)(2001): 389-396.

Palmer, K.T., "Exposure to hand-transmitted vibration and pain in the neck and upper limbs". Occupational Medicine-Oxford, 51(7)(2001): 464-467.

Pelmear, P.L., "Impact vibration and hand-arm vibration syndrome". Journal Of Occupational And Environmental Medicine, 39(11)(1997): 1092-1096.

Pelmear, P.L., "Directive EU Directive on physical agents - Vibration". Journal Of Low Frequency Noise Vibration And Active Control, 21(3)(2002): 131-139. (Abstract only)

Pettersson, H., Burström, L., and Nilsson, T., "The effect on the temporary threshold shift in hearing acuity from combined exposure to authentic noise and hand-arm vibration". International Archives Of Occupational And Environmental Health, 2011): 1-7.

Phillips, J.I., "Rock drills used in South African mines: a comparative study of noise and vibration levels". Annals Of Occupational Hygiene, 51(3)(2007): 305-310.

Poole, K., "Disability in the Upper Extremity and Quality of Life in hand-arm vibration syndrome". Disability And Rehabilitation, 27(22)(2005): 1373-1380.

Poole, K., "Uptake and quality of health surveillance for noise and hand-arm vibration". Occupational Medicine-Oxford, 61(5)(2011): 354-356.

Santos, J.A., "Hand-arm vibration risk assessment". DYNA, 83(4)(2008): 214-220. (Abstract only)

Sauni, R., "Dose-Response Relationship Between Exposure to Hand-arm Vibration and Health Effects among Metalworkers". Annals Of Occupational Hygiene, 53(1)(2009): 55-62.

Sauni, R., "Vibration-induced white finger syndrome and carpal tunnel syndrome among Finnish metal workers". International Archives Of Occupational And Environmental Health, 82(4)(2009): 445-453.

Thompson, A., "Hand-arm vibration syndrome with concomitant arterial thrombosis in the hands". Occupational Medicine-Oxford, 56(5)(2006): 317-321.

Thompson, A., "Assessment of the hand-arm vibration syndrome: thermometry, plethysmography and the Stockholm Workshop Scale". Occupational Medicine-Oxford, 57(7)(2007): 512-517.

Thompson, A.M.S., "Vibration-white foot: a case report". Occupational Medicine-Oxford, 60(7)(2010): 572-574.

Thonnard, J.L., "Short-term effect of hand-arm vibration exposure on tactile sensitivity and manual skill". Scandinavian Journal Of Work Environment & Health, 23(3)(1997): 193-198.

van Rijn, R.M., "Associations between work-related factors and specific disorders of the shoulder - a systematic review of the literature". Scandinavian Journal Of Work Environment & Health, 36(3)(2010): 189-201.

Vergara, M., "Hand-transmitted vibration in power tools: Accomplishment of standards and users' perception". International Journal Of Industrial Ergonomics, 38(9-10)(2008): 652-660.

Virokannas, H., "Dose-Response Relation Between Exposure to 2 Types of Hand-Arm Vibration And Sensorineural Perception Of Vibration". Occupational And Environmental Medicine, 52(5)(1995): 332-336.

Wahlstrom, J., "Musculoskeletal symptoms among young male workers and associations with exposure to hand-arm vibration and ergonomic stressors". International Archives Of Occupational And Environmental Health, 81(5)(2008): 595-602.

Wang, L., "The study on hand-arm vibration syndrome in China". Industrial Health, 43(3)(2005): 480-483.

Wasserman, D.E., "Manufacturing and the New ANSI S2.70-2006 Hand-Arm Vibration Exposure Standard". Human Factors And Ergonomics In Manufacturing, 18(6)(2008): 658-665.

Widia, M., "The effect of vibration on muscle activity using electric drill". 2009
Wiegand, J., "Exposure of hand-arm-vibrations by hand-guided woodworking machines". Human Vibration: Effects on Health - Performance - Comfort, 20022007): 85-98. (abstract only)

Wigley, R.D., "Contribution of vibration to musculoskeletal disorders in New Zealand". Internal Medicine Journal, 37(12)(2007): 822-825.

Yoo, C., "Occupational hand-arm vibration syndrome in Korea". International Archives Of Occupational And Environmental Health, 78(5)(2005): 363-368.

Further reading on Whole Body Vibration

Abbate, C., "Affective correlates of occupational exposure to whole-body vibration - A case-control study". Psychotherapy And Psychosomatics, 73(6)(2004): 375-379.

Barrero, L.H., "Validity of self-reported mechanical demands for occupational epidermiologic research of musculoskeletal disorders". Scandinavian Journal Of Work Environment & Health, 35(4)(2009): 245-260.

Beazant, G., "Europe wages war on bad vibes". Professional Engineering, 18(14)(2005): 23. (Abstract only)

Bogadi-Sare, A., "Whole-body vibration syndrome - A medical problem requiring more attention". Arhiv za Higijenu Rada i Toksikologiju, 44(3)(1993): 269-279.

Bovenzi, M., "Low back pain disorders and exposure to whole-body vibration in the workplace". Seminars In Perinatology, 20(1)(1996): 38-53.

Bovenzi, M., "The European Directive 2002/44/CE on the protection of workers against risks arising from mechanical vibration | La Direttiva Europea 2002/44/CE sulla protezione dei lavoratori contro i rischi da vibrazioni meccaniche". Medicina del Lavoro, 93(6)(2002): 551-560.

Bovenzi, M., "Health risks from occupational exposures to mechanical vibration". Medicina del Lavoro, 97(3)(2006): 535-541.

Bovenzi, M., Rui, F., D'Agostin, F., and Negro, C., "The role of the occupational health physician in the implementation of the European and Italian regulations on mechanical vibrations at work | I compiti del medico competente alla luce della direttiva Europea

2002/44/CE sulle vibrazioni meccaniche e del decreto applicativo 187/2005". Giornale Italiano di Medicina del Lavoro ed Ergonomia, 28(3)(2006): 241-244.

Channamallu, R.R., "Dynamic Lumbar Tracking With Occupational Whole-Body Vibration Exposure". Proceedings Of The Asme International Mechanical Engineering Congress And Exposition 2008, VOL 2, 2009): 643-644.

Da Silva, M.E., "Effects of different frequencies of whole body vibration on muscular performance". Biology Of Sport, 23(3)(2006): 267-282.

d'Errico, A., "Medium- and long-term reproducibility of self-reported exposure to physical ergonomics factors at work". Applied Ergonomics, 38(2)(2007): 167-175.

Dupuis, H., "Medical and occupational preconditions for vibration-induced spinal disorders: Occupational disease no. 2110 in Germany". International Archives Of Occupational And Environmental Health, 66(5)(1994): 303-308.

Eger, T., Salmoni, A., Cann, A., and Jack, R., "Whole-body vibration exposure experienced by mining equipment operators". Occupational Ergonomics, 6(3-4)(2006): 121-127.

Fallentin, N., "Evaluation of physical workload standards and guidelines from a Nordic perspective". Scandinavian Journal Of Work Environment & Health, 272001): 1-52.
Griffin, M.J., "Predicting the hazards of whole-body vibration - Considerations of a standard". Industrial Health, 36(2)(1998): 83-91.

Griffin, M.J., "Minimum health and safety requirements for workers exposed to hand-transmitted vibration and whole-body vibration in the European Union; a review". OCCUPATIONAL AND ENVIRONMENTAL MEDICINE, 61(5)(2004): 387-397

Hagberg, M. and Jonsson, A., "Combinations of exposure to vibration, noise and ergonomic stressors in the swedish work force affect musculoskeletal health outcomes". Canadian Acoustics - Acoustique Canadienne, 39(2)(2011): 26-27. (Abstract only)

Hinz, B., "Models of European drivers - new ways of the assessment of health risks caused by long-term whole-body vibration". Human Vibration: Effects on Health - Performance - Comfort, 20022007): 349-386. (Abstract only)

Howard, B., Sesek, R., and Bloswick, D., "Typical whole body vibration exposure magnitudes encountered in the open pit mining industry". Work, 34(3)(2009): 297-303.

Hulshof, C.T.J., "Evaluation of an occupational health intervention programme on whole-body vibration in forklift truck drivers: a controlled trial". Occupational And Environmental Medicine, 63(7)(2006): 461-468.

Kasin, J.I., "Whole Body Vibration in Helicopters: Risk Assessment in Relation to Low Back Pain". Aviation Space And Environmental Medicine, 82(8)(2011): 790-796.

Khorshid, E., "Measurement of whole-body vibration exposure from speed control humps". Journal Of Sound And Vibration, 304(3-5)(2007): 640-659.

Leventhall, G., "The EU Physical Agents Vibration Directive". Noise and Vibration Worldwide, 33(2)(2002): 9-12.

Ljungberg, J.K., "Stress, subjective experience and cognitive performance during exposure to noise and vibration". Journal Of Environmental Psychology, 27(1)(2007): 44-54.

Ljungberg, J.K., "Combined exposures of noise and whole-body vibration and the effects on psychological responses, a review". Journal Of Low Frequency Noise Vibration And Active Control, 27(4)(2008): 267-279. . (Abstract only)

Ljungberg, J.K., "Psychological effects of combined noise and whole-body vibration: a review and avenues for future research". Proceedings Of The Institution Of Mechanical Engineers Part D-Journal Of Automobile Engineering, 224(D10)(2010): 1289-1302. (Abstract only)

Majd, F.F., "The Evaluation of Whole-Body Vibration Level in Hand-Held Pneumatic Tools (Rock Drill) by "Pneurop Cagi Test Code" Method". Journal Of Low Frequency Noise

Majd, F.F. and Nassiri, P., "The evaluation of whole-body vibration level in hand-held pneumatic tools (rock drill) by "pneurop cagi test code" method". Canadian Acoustics - Acoustique Canadienne, 36(3)(2008): 50-51.

Majd, F.F. and Nassiri, P., "The evaluation of whole-body vibration level in hand-held pneumatic tools (Rock drill) by "Pneurop cagi test code" method". Journal Of Low Frequency Noise Vibration And Active Control, 28(3)(2009): 217-221.

Mani, R., "The effect of occupational whole-body vibration on standing balance: A systematic review". International Journal Of Industrial Ergonomics, 40(6)(2010): 698-709.

Matsumoto, Y., "A review of standards for evaluation of vibration in living environment and studies of human perception of whole-body vibration". Environmental Vibrations: Prediction, Monitoring, Mitigation and Evaluation (ISEV 2005), 2005): 599-606. (Abstract only)

McCallig, M., "Evaluating worker vibration exposures using self-reported and direct observation estimates of exposure duration". Applied Ergonomics, 42(1)(2010): 37-45.

McPhee, B., "Ergonomics in mining". Occupational Medicine, 54(5)(2004): 297-303.

Melo, R.B., "Risks Associated With Exposure to Whole Body Vibration: Impact Of Different Assessment Procedures". Sho2009: International Symposium On Occupational Safety And Hygiene, 2009): 291-294.

Milosavljevic, S., et al., "Exposure to whole-body vibration and mechanical shock: A field study of quad bike use in agriculture". Annals Of Occupational Hygiene, 55(3)(2011): 286-295.

Mohr, D., "The noise and vibration occupational health and safety ordinance I and II". Human Vibration: Effects on Health - Performance - Comfort, 20022007): 3-28. (Abstract only)

Morrison, K.W., "Whole-body vibration: It may be a occupational hazard. Why do so few safety proffessionals know anything about it?". Safety and Health, 180(4)(2009): 54-58. (Abstract only)

Nataletti, P., "Occupational Exposure to Mechanical Vibration: The Italian Vibration Database for Risk Assessment". International Journal Of Occupational Safety And Ergonomics, 14(4)(2008): 379-386. (Abstract only)

Neitzel, R., "Occupational vibration and noise exposures in forestry workers". Proceedings Of The Society Of American Foresters, 2000 National Convention, 2001: 504-506.

Nelson, C.M., "Implementation of the physical agents (vibration) Directive in the UK". Contemporary Ergonomics 2003, 2003): 94-101.

Nelson, C.M. and Brereton, P.F., "The European vibration directive". INDUSTRIAL HEALTH, 43(3)(2005): 472-479. (Abstract only)

Newell, G., "Survey Of Heavy Equipment Operators Whole-Body Vibration Profiles". Contemporary Ergonomics 2008, 2008): 203-208. (Abstract only)

Ozkaya, N., "Whole-Body Vibration Exposure - A Comprehensive Field-Study". American Industrial Hygiene Association Journal, 55(12)(1994): 1164-1171.

Pal, B.K. and Dewan, A., "Role of ergonomics on environmental protection and industrial safety". Journal of Mines, Metals and Fuels, 57(10)(2009): 335-342.

Paschold, H.W., "Whole-body vibration knowledge survey of US occupational safety and health professionals". Journal Of Safety Research, 40(3)(2009): 171-176.

Pelmear, P.L., "Directive EU Directive on physical agents - Vibration". Journal Of Low Frequency Noise Vibration And Active Control, 21(3)(2002): 131-139.

Pinto, I. and Stacchini, N., "Uncertainty in the evaluation of occupational exposure to whole-body vibration". Journal of Sound and Vibration, 298(3)(2006): 556-562.

Quintana, S., et al., "Exposure of excavator operators to noise and vibration". Acoustics Bulletin, 35(3)(2010): 35-38.

Rakheja, S., "Biodynamics of the human body under whole-body vibration: Synthesis of the reported data". International Journal Of Industrial Ergonomics, 40(6)(2010): 710-732.

Rodean, S., "Health And Safety Study About The Exposure Of Workers To Whole Body Vibration Inside An Auto Vehicle". Annals Of Daaam For 2009 & Proceedings Of The 20th International Daaam Symposium, 202009): 1501-1502.

Santos, B.R., "A laboratory study to quantify the biomechanical responses to whole-body vibration: The influence on balance, reflex response, muscular activity and fatigue". International Journal Of Industrial Ergonomics, 38(7-8)(2008): 626-639.

Sato, T., Maeda, S., and Yano, T., "Effects of noise exposure on whole-body vibration perception threshold". Huanan Ligong Daxue Xuebao/Journal of South China University of Technology (Natural Science), 35(SUPPL.)(2007): 108-111.

Seidel, H., "Selected health risks caused by long-term, whole-body vibration". American Journal Of Industrial Medicine, 23(4)(1993): 589-604.

Seidel, H., "On the relationship between whole-body vibration exposure and spinal health risk". Industrial Health, 43(3)(2005): 361-377. (Abstract only)

Siciliano, E. and Nori, L., "Risk of exposure to mechanic vibrations: Lights and shadows | D. LGS. 187/2005 - Rischio vibrazioni meccaniche - Luci ed ombre". Giornale Italiano di Medicina del Lavoro ed Ergonomia, 28(3)(2006): 348-350.

Silva, L.F., "Combined exposure to noise and vibration and its effects on worker's hearing". Revista De Saude Publica, 39(1)(2005): 9-17.

Tak, S., "The Estimated National Burden of Physical Ergonomic Hazards Among US Workers". American Journal Of Industrial Medicine, 54(5)(2011): 395-404.

Tiemessen, I.J.H., "Two way assessment of other physical work demands while measuring the whole body vibration magnitude". Journal Of Sound And Vibration, 310(4-5)(2008): 1080-1092.

Tiemessen, I.J.H., Hulshof, C.T.J., and Frings-Dresen, M.H.W., "Effectiveness of an occupational health intervention program to reduce whole body vibration exposure: An evaluation study with a controlled pretest-post-test design". American Journal Of Industrial Medicine, 52(12)(2009): 943-952.

Tuchsen, F., "The impact of self-reported exposure to whole-body-vibrations on the risk of disability pension among men: a 15 year prospective study". BMC Public Health, 102010).

Uchikune, M., "Measurement and evaluation of whole-body vibrations". Environmental Health Risk II, 82003): 143-149.

Uchikune, M., "Vibration evaluation from the effects of whole-body vibration". Environmental Health Risk III, 92005): 287-293. (Abstract only)

Vandergrift, J.L., Gold, J.E., Hanlon, A., and Punnett, L., "Physical and psychosocial ergonomic risk factors for low back pain in automobile manufacturing workers". Occupational And Environmental Medicine, 2011).

Wasserman, D.E., "Occupational vibrations: Are you at risk?". Journal of the Mine Ventilation Society of South Africa, 56(2)(2003).

Wikstrom, B.O., "Health-Effects of Long-Term Occupational Exposure to Whole-Body Vibration - A Review". International Journal Of Industrial Ergonomics, 14(4)(1994): 273-292.

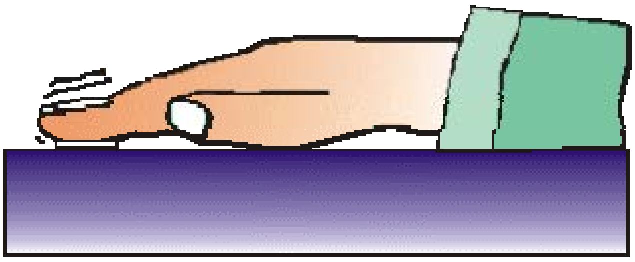
Yates, J.P. and McGill, S.M., "The effect of vibration and posture on the progression of intervertebral disc herniation". Spine, 36(5)(2011): 386-392.

9 Appendix A

2005 No. 1093
HEALTH AND SAFETY
The Control of Vibration at Work Regulations 2005
http://www.legislation.gov.uk/uksi/2005/1093/pdfs/uksi_20051093_en.pdf

10 Appendix B

HEALTH SURVEILLANCE TECHNIQUES



Health surveillance may consist of an evaluation of the case history for a worker in conjunction with a physical examination conducted by a doctor or suitably qualified health-care professional.

Questionnaires for hand-arm vibration health surveillance are available from various sources (e.g. the VIBGUIDE section of: http://www.humanvibration.com/EU/EU_index.htm).

F.1 The case history

The case history should focus on:

- family history,
- social history, including smoking habit and alcohol consumption.
- work history, including past and current occupations with exposure to hand-arm vibration, previous jobs with exposure to neurotoxic or angiotoxic agents and any leisure activities involving the use of vibrating tools or machines.
- personal health history.

F.2 The physical examination

A physical examination should look in detail at the peripheral vascular, neurological, and musculoskeletal systems, and should be performed by a qualified physician

F.3 Clinical tests

In general, clinical tests do not provide reliable proof of vibration injury, however, they may be helpful to exclude other causes of symptoms similar to those of hand-arm vibration syndrome or to monitor progression of injury.

Tests for the peripheral vascular system include the Lewis-Prusik test, the Allen test, and the Adson test.

Tests for the peripheral nervous system include the evaluation of manual dexterity (e.g. coin recognition and pick up), the Roos test, the Phalen's test and the Tinel's sign (for carpal tunnel compression).

F.4 Vascular investigations

The vascular assessment of the hand-arm vibration syndrome is mainly based on cold provocation tests: assessing changes in finger colour, recording recovery times of finger skin temperature, and measuring finger systolic blood pressure. Other non- invasive diagnostic tests, such as Doppler recording of arm and finger blood-flow and pressure, may also be useful.

F.5 Neurological investigations

The neurological assessment of the hand-arm vibration syndrome includes several tests:

- Vibration perception thresholds
- Tactile sensitivity (gap detection, monofilaments)
- Thermal perception thresholds
- Nerve conduction velocities in the upper and lower limbs.
- Electromyography.
- Fingertip dexterity (Purdue pegboard).

F.6 Muscle strength investigations

The evaluation of muscle force in the hand can be performed by means of a dynamometer to measure grip strength and a pinch gauge to measure pinch strengths.

F.7 Radiological investigations

X-rays of the shoulders, elbows, wrists and hands for a radiological diagnosis of bone and joint disorders are usually required in those countries in which vibration-induced osteoarthropathy in the upper limbs is recognised as an occupational disease.

F.8 Laboratory tests

Blood and urine analyses may be necessary in some case to distinguish vibration injury from other vascular or neurological disorders.

Further reading:

ISO 13091-1:2001 Mechanical vibration — Vibrotactile perception thresholds for the assessment of nerve dysfunction — Part 1: Methods of measurement at the fingertips

ISO 14835-1:2005 Mechanical vibration and shock — Cold provocation tests for the assessment of peripheral vascular function — Part 1: Measurement and evaluation of finger skin temperature

ISO 14835-2:2005 Mechanical vibration and shock — Cold provocation tests for the assessment of peripheral vascular function — Part 2: Measurement and evaluation of finger systolic blood pressure