Hazard Identification

Preventing HAVS in the Workplace

Identifying workplace risk of hand-arm vibration syndrome

By Christopher A. Janicak

HAND-ARM VIBRATION SYNDROME (HAVS) is one of the most ignored and damaging occupational diseases, according to some workplace injury experts (Center for Workplace Health Information). It is estimated that 1.45 million U.S. workers use vibrating tools and their use is responsible for the majority of hand-arm-vibration-related occupational illnesses reported each year [CDC(a)].

Hand-arm vibration is defined as the transfer of vibration from a tool to a worker's hand and arm. The amount of hand-arm vibration (HAV) is characterized by the acceleration level of the tool when grasped by the worker and in use; it is typically measured on the handle of a tool while in use to determine the acceleration levels transferred to the worker [CDC(b) 19].

Hand-Arm Vibration Syndrome

The direct physical transmission of vibration from a mechanical object to the hand and arms can cause HAVS, also known as Raynaud's phenomenon, vibration-induced white finger and traumatic vasopastic disease (Weeks, et al 258). For segmental vibration to the hands, accelerations from 1.5g to 80g and frequencies from 8Hz to 500Hz are of concern (Eastman Kodak 223). One g represents the gravitational acceleration of objects on earth at a rate of 9.8 m/s^2 or 1g, while a hertz is the SI unit of frequency, equal to one cycle per second. The condition is primarily characterized by numbness, tingling and blanching (loss of normal color) of the fingers (Weeks, et al 259). Additional health effects include sensory and motor disturbances exhibited by loss of finger coordination and dexterity, clumsiness and inability to perform intricate tasks (Cederlund, et al 570). It is this exposure to hand-arm vibration over a long period which may lead to a HAVS.

Development of HAVS depends on many factors, including the level of acceleration (vibration energy) produced by the tool; the length of time the tool is used each day; the cumulative number of months or years the worker has used the tool; and the ergonomics of tool use. Factors that affect the response to vibration include grip force around the tool, gloves worn, body position and the axial force exerted on the tool. Of these factors, grip force and axial force are the most important [CDC(b) 28].

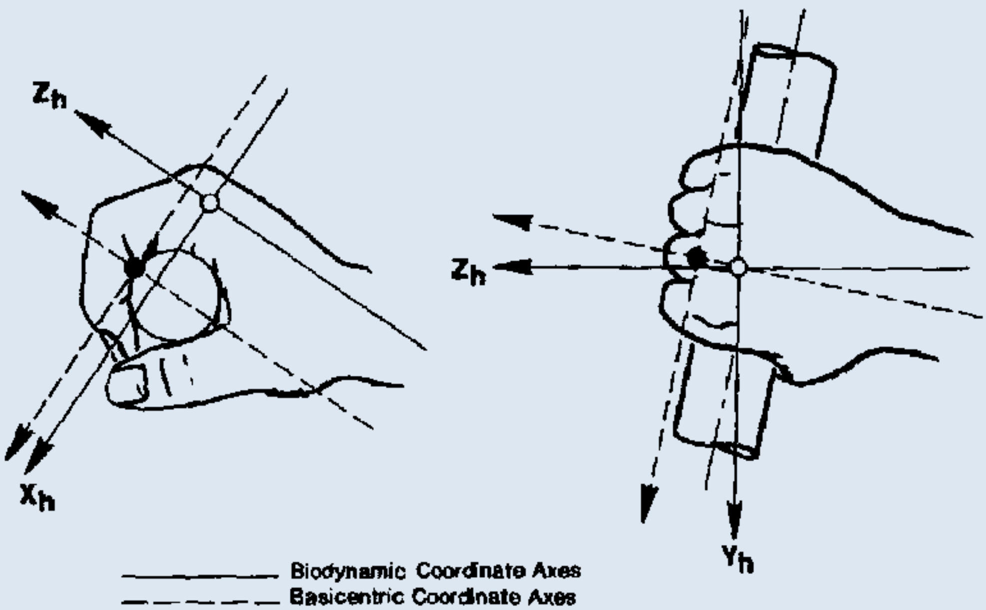
The time exposure necessary may range from one month to 30 years because of variations in the transfer of energy and the variable physiological response of individuals (Pelmear and Leong 291).

Prevalence in the Workplace

The prevalence of HAVS in worker populations that have used vibrating tools has ranged from six percent to 100 percent [CDC(b) 55]. Industries with the largest

Christopher A. Janicak, Ph.D., CSP, ARM, *is an associate professor of safety in the Dept. of Safety Sciences at Indiana University of Pennsylvania. He has published extensively in the area of occupational safety and has authored two books in safety statistics and safety metrics. Janicak earned a Ph.D. in Research Methodology from Loyola University; an M.S. in Industrial Technology (industrial safety concentration) from Illinois State University; and a B.S. in Health and Safety Studies from the University of Illinois at Urbana-Champaign.*

Figure 1
Coordinate System for the Hand



Source: CDC(b) 16.

numbers of workers likely exposed to vibrating hand tools or other sources of segmental vibration are construction, farming, and truck and automobile manufacturing (Weeks, et al 260).

The prevalence and severity of HAVS usually increases as the acceleration level and duration of use increases [CDC(c)]. Many studies have shown strong evidence of a positive association between high-level exposure to HAV and vascular symptoms of HAVS [CDC(c)]. These studies are of workers with high levels of exposure—such as forestry workers, stone drillers, stonecutters and carvers, shipyard workers or platers—who were typically exposed to HAV acceleration levels of $5m/s^2$ to $36m/s^2$. The typically cross-sectional studies examined the relationship between workers with high levels of exposures to HAV and a nonexposed control group [CDC(c)]. Substantial evidence exists that as intensity and duration of exposure to vibrating tools increase, the risk of developing HAVS increases [CDC(c)]. Evidence also exists that an increase in symptom severity is associated with increased exposure [CDC(c)]. As intensity and duration of exposure are increased, the time from exposure onset and beginning of symptoms is shortened [CDC(c)].

Sources of Exposure to Vibration on the Job

The most significant sources of HAV are pneumatic tools (air compressed and electrical)—for example, grinders, sanders, drills, fettling tools, impact wrenches, jackhammers and riveting guns. Users of chainsaws, brush saws, hedge cutters and grass trimmers are also at risk (Pelmear and Leong 291). The tools most commonly associated with HAVS are powered hammers, chisels, chain saws, sanders, grinders, riveters, breakers, drills, compactors, sharpeners and shapers [CDC(b) 31]. It is also evident that adverse health effects can result from almost any vibrating source in contact with the hands if the vibration is sufficiently intense from oscillatory or impact sources over the frequency range from 4Hz to 5000Hz for a critical period of time (Pelmear and Leong 295).

The Centers for Disease Control and Prevention (CDC) examined five factors that influence the vibration acceleration levels of hand tools in the workplace [CDC(b) 26-27]. These factors included the type of tool, effects of tool operation, tool maintenance, work cycles and effects of the coupling between the tool and the operator's hand. Impact tools were found to produce significantly higher vibration levels than nonimpact tools. Materials designed to isolate the vibrating tool from the operator's hand were found to reduce exposure levels. The operation characteristics of the tools indicate that those which use a reciprocating piston (e.g., chipping hammer) tend to produce higher vibration levels that are then transmitted to the operator. The weights of the tools also influence the amount of vibration transmitted to the operator's hand [CDC(b) 26]. Heavier tools tend to direct lower vibration levels to the hands than lighter tools.

Tools that were not properly maintained were found to produce greater vibration levels than those that were properly maintained [CDC(b) 27]. Lack of maintenance caused tools to become out of balance, and tools that require the use of vibration dampening pads must be inspected to ensure that the pads are properly maintained. Work cycles, conditions and incentives can significantly affect the time-averaged vibration levels [CDC(b) 27]. As one would expect, as the length of time a person uses a vibrating piece of equipment increases, the risk for HAVS increases as well.

Finally, the manner in which the operator's hand makes contact with the vibrating tool also has a significant influence on the amount of vibration transmitted from the tool to the operator. While the degree of coupling between the hand and the tool will affect the amount of vibration energy transmitted to the hand, it will not significantly affect the amount of vibration produced by the tool [CDC(b) 28].

Measuring HAVS

Vibration is measured in units of acceleration, typically m/s^2. Accelerometers are used to measure HAV exposure acceleration of the tool at the point where the handle of the equipment contacts the hand at the base of the third digit. NIOSH has established specific guidelines with regard to the placement of the accelerometers along the three axes for various pieces of equipment. The three axes from which vibration levels are measured are identified as X, Y and Z (shown in Figure 1). Coordinate system for the hand is defined in ANSI S3.34-1986, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand. The X axis projects forward from the hand when it is in the normal anatomical position. The Y axis is perpendicular to the X axis so that when the hand is gripping a cylindrical handle, the Y axis is parallel to the handle. The Z axis is defined as the longitudinal axis of the third metacarpal.

Accelerometers are also to collect vibration data that can be stored and analyzed through data-logging equipment or computer software.

The individual vibration accelerations obtained for the three axes can be combined to derive an overall root mean square acceleration for the particular piece of equipment. The example in Figure 2 demonstrates the calculation of the overall total root mean square acceleration for a piece of equipment, its effective time-weighted average and maximum allowable time [CDC(b) 26].

Exposure Limits

Three consensus standards exist in the U.S. for the control of HAVS. These are American Conference of Governmental Industrial Hygienists (ACGIH), American National Standards Institute (ANSI) and International Organization for Standardization (ISO). The first HAV standard in the U.S. was introduced by ACGIH in 1984 (Wald and Stave 83). Weighted triaxial acceleration measurements are obtained over a third-octave band vibration frequency range of 5.6Hz to 1250Hz. Table 1 summarizes the maximum vibration recommended by ACGIH along any one axis based on hours of exposure (Wald and Stave 84).

ANSI daily exposure limits have established zones for daily exposure time based on the obtained root mean square acceleration intensity and the vibration frequency in third-octave bands (Figure 3) (Wald and Stave 85).

In ISO 5349, the daily exposure to vibration is expressed in terms of energy-equivalent frequency-weighted acceleration for a period of four hours $(a_{h,w})_{eq(4)}$ in m/s^2r.m.s), according to the following equation (Bovenzi 50.6):

$$(a_{h,w})_{eq(4)} = (T/4)^{1/2}\, a_{(h,w)eq(T)}$$

where T is the daily exposure time expressed in hours and $a_{(h,w)eq(T)}$ is the energy-equivalent frequency-weighted acceleration for the daily exposure time T. The standard provides guidance to calculate $a_{(h,w)eq(T)}$ if a typical workday is characterized by several exposures of different magnitudes and durations.

Figure 2

NIOSH Acceleration Calculations

$A_{total} = (X^2 + Y^2 + Z^2)^{1/2}$

Effective TWA $= (\Sigma(A_T^{\,2} \times T)/T_{Total})^{1/2}$

Maximum Allowable Time $= (4/\text{Effective TWA})^2 \times 8$

A worker was exposed to the following task (assume eight-hour workday):

60 minutes using a chipping hammer which produced a vibration where the three axes acceleration measured:
$X = 9.0\ m/s^2$; $Y = 8.9\ m/s^2$; $Z = 8.7\ m/s^2$

40 minutes using a power drill which produced a vibration where the three axes acceleration measured:
$X = 1.2\ m/s^2$; $Y = 1.0\ m/s^2$; $Z = 1.1\ m/s^2$

The total rms acceleration for the chipping hammer is determined to be:

$A_{total} = (9.0^2 + 8.9^2 + 8.7^2)^{1/2}$
$A_{total} = 15.4\ m/s^2$

The total rms acceleration for the power drill is determined to be:

$A_{total} = (1.2^2 + 1.0^2 + 1.1^2)^{1/2}$
$A_{total} = 1.9\ m/s^2$

The Effective TWA for the exposure is:

Effective TWA $= [\{(15.4^2 \times 60)+(1.9^2 \times 40)\}/100]^{1/2}$
Effective TWA $= 12.0\ m/s^2$

The maximum allowable time allowed for this exposure is:

Maximum Allowable Time $= (4/12.0)^2 \times 8$
Maximum Allowable Time = 0.89 hours

Table 1

ACGIH Exposure Limits

Hours of Exposure	Maximum Frequency in Any One Direction
4 to <8 hrs.	$4\ m/s^2$
2 to <4 hrs.	$6\ m/s^2$
1 to 2 hrs.	$8\ m/s^2$
<1 hr.	$12\ m/s^2$

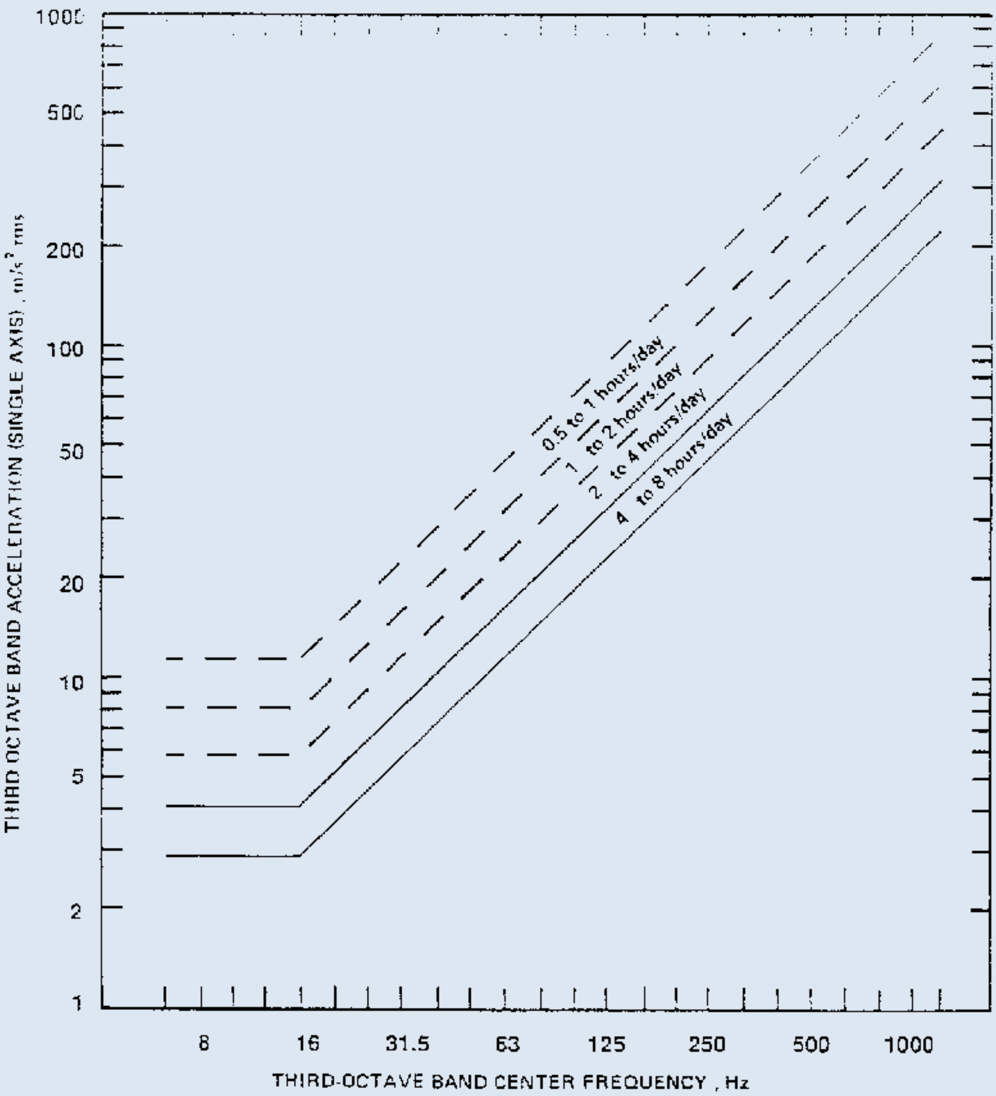
Assessing the Degree of HAVS

There are no reliable, objective diagnostic tests for HAVS (Weeks, et al 259). The available tests may differentiate affected from unaffected workers on a group basis, but they have poor validity on an individual basis (Weeks, et al 259). Examples of tests used to identify HAVS include peripheral vascular function and neurological function, as well as radiographs of the fingers and hands.

A grading system for severity of HAVS was first proposed by Taylor and Pelmear, and was recently

Figure 3

ANSI Exposure Limits



revised to take into account the fact that injuries to nerves and blood vessels appear to develop independently (Weeks, et al 259). The Taylor and Pelmear Stages of Vibration Syndrome are eight stages ranging from Stage 00 with no symptoms or work interference to Stage 04, in which the worker is forced to change occupations due to the severity of the symptoms and the hands exhibit a blanched appearance year-round (Table 2) (Taylor and Pelmear xxi).

Another classification system for determining the degree of incapacitation due to this condition is the Stockholm Workshop Scale (Table 3) (Wald and Stave 95). This scale for cold-induced Raynaud's phenomenon in the HAVS is a modification of the Taylor-Pelmear scale, which separates the vascular from the neurological and musculoskeletal components (Gemne, et al 275). To use the scale, each hand is evaluated along with each finger. Each stage is designated (0 to 4), each hand (left or right) and number of fingers (one to five).

Control Measures

Preventing and controlling exposure to HAV in the workplace should follow the same process as other hazards: Implement engineering controls as a first approach, followed by administrative controls and PPE. NIOSH recommends that engineering controls, medical surveillance, work practices and PPE be used to help reduce exposure to vibrating hand tools and to help identify HAVS in its early stages among workers likely to be at risk [CDC(a)].

Engineering Controls

Engineering controls should consist of the redesign of power hand tools to minimize the vibration generated or transmitted during operation. Mechanical isolation and damping should be used to reduce the acceleration of the vibration transmitted to the hand and arm (Weeks, et al 262). An example of an engineering strategy involves reengineering production processes to eliminate the use of handheld tools that vibrate.

Where job redesign is not feasible, direct intervention by means of reducing tool vibration should be attempted [CDC(a)]. In some cases, manufacturers of equipment that commonly pose vibration hazards have redesigned the tools to reduce to acceptable levels the vibration levels transmitted from the equipment to the operator.

Medical Surveillance & Worker Education

Workers who are required to use vibrating tools should be instructed on the hazards of such use, symptoms of HAVS and procedures to report such symptoms immediately. Once reported, employers should ensure that employees obtain proper medical assistance from health professionals who are knowledgeable in HAVS. The number of vibration syndrome cases reported is small because physicians have failed to diagnose the syndrome and workers tend not to report it [CDC(a)].

Work Practices

Some tools, such as grinders, can cause greater vibration levels to impinge on the hand when wear is uneven or their alignment slips. While insufficient information is available to recommend a safe exposure duration, it is known that the severity of HAVS is related to the extent and duration of continuous exposure to vibration [CDC(a)]. Additional practices should be employed, such as wearing adequate clothing to keep the body temperature stable and normal, since a low body temperature reduces blood flow to the extremities and therefore may trigger an attack of HAVS [CDC(a)].

Because tools that were once considered safe with regard to the level of vibration they generate may increase in vibration levels over time, a maintenance program should be developed to ensure that vibrating hand tools are carefully maintained according to manufacturers' recommendations [CDC(a)].

PPE

Many types of gloves help maintain body warmth and some designs may attenuate vibration as well; however, this may be limited to only some of the higher frequencies found in vibrating hand tools [CDC(a)]. Although gloves alone are not recommended as a method of reducing vibration transfer to the hands, they will help keep hands warm, which helps to reduce the severity of HAVS.

A common workplace method used to control exposure to harmful vibration is to provide workers with antivibration gloves. ISO 10819 specifies the amplitude of vibration transmissibility that must be achieved for a glove to be classified as an antivibration glove (Reynolds and Stein 310). When used properly, this method can reduce vibration levels transmitted to the hand to levels below what is considered dangerous. However, in some situations, workers are exposed to harmful vibration levels despite wearing the appropriate PPE. It is also believed that factors such as hand size, grip strength and glove type may adequately protect one person, but not necessarily another worker in the same situation.

Table 2

Taylor & Pelmear Stages of Vibration Syndrome

Stage	Condition of Fingers	Work & Social Interference
00	No tingling, numbness or blanching of fingers	No complaints
OT	Intermittent tingling	No interference with activities
ON	Intermittent numbness	No interference with activities
TN	Intermittent tingling and numbness	No interference with activities
01	Blanching of a fingertip with or without tingling and/or numbness	No interference with activities
02	Blanching of one or more fingers beyond tips, usually during winter	Possible interference with nonwork activities; no interference at work
03	Extensive blanching of fingers; during summer and winter	Definite interference at work and home, and with social activities; restriction of hobbies
04	Extensive blanching of most fingers; during summer and winter	Occupation usually changed because of severity of signs and symptoms

Table 3

Stages of the Stockholm Workshop Scale

Description	Grade	Stage
No attacks		0
Occasional attacks affecting only the tips of one or more fingers	Mild	1
Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers	Moderate	2
Frequent attacks affecting all phalanges of most fingers	Severe	3
Frequent attacks affecting all phalanges of most fingers with trophic skin changes in the fingertips	Very severe	4

Case Studies Demonstrating Workplace Vibration Control

Over the years, employers and manufacturers have successfully implemented controls to reduce worker exposure to HAVS. These measures have included redesigning job tasks, changing the tools and incorporating PPE into the job.

Example 1: Vibration Reduction of Demolition Hammers

A useful reference implementing HAVS control measures has been written by the U.K. Health and Safety Commission and the Health and Safety Executive (HSE). These agencies are responsible for regulating almost all risks to safety and health arising from work activity in Britain. An HSE book, entitled *Vibration Solutions: Practical Ways to Reduce the Risk of Hand-Arm Vibration Injury,* analyzes 51 case studies dealing with vibration and its control. It provides guidance for managers and shows that vibration problems can be solved in many ways. The case studies offer real examples of how companies have reduced workplace vibration. One example of how employers have successfully reduced the exposure to HAVS is described here:

> It is possible to reduce the vibration from electric demolition hammers by mounting the tools in a frame attached to a balancing rig to take the weight of the tool and ease tool movement. The tool and frame assembly is then attached to a superstructure via a counterbalance. This allows the tool to be moved across the work piece with ease, reducing the forces required to do the job. This technique has been shown to reduce the vibration from these types of tool from $12 m/s^2$ to approximately $6 m/s^2$. The counterbalance reduces risks associated with the manual handling of the tool. Training is required to ensure the operators avoid holding the high-vibration parts of the tool (i.e., the shaft of the tamping foot and the throttle handle of the tool). To achieve this, either a foot-operated throttle or locking throttle is required to avoid contact with the tool during operation (HSE 4).

Example 2: Vibration Reduction Through the Use of Antivibration Gloves

In this study, vibration levels for a variety of hand tools used in sawmills were tested to determine the effectiveness of gel foam and sorbothane in reducing vibration levels. Gel foam and sorbothane are two common vibration attenuation materials found in antivibration gloves. This study was conducted by the Workers' Compensation Board of British Columbia. The four hand tools examined were a chainsaw bucker, a 10-inch Walter grinder, a seven-inch Makita grinder and a five-inch Makita grinder. For each piece of equipment, baseline vibration levels were obtained at the handle followed by vibration levels at the handle with the vibration attenuation material placed between the handle and the sensor. Results were mixed. The gel foam was most effective in reducing the vibration levels at the dominant axis on the chainsaw bucker with a 40-percent reduction in vibration levels; however, the sorbothane material was found to increase the vibration levels transmitted to the operator using the grinders (Zinck 32). A manufacturers' study had also substantiated an amplification of vibration levels with certain materials, particularly at lower vibration frequencies (Zinck 44).

Conclusion

While use of vibrating tools is relatively commonplace throughout industry, identifying, controlling and preventing workplace HAVS hazards may not be. Identification of potential hazards includes workers engaged in the use of handheld tools such as grinders, chippers and jackhammers. Through the use of vibration meters and accelerometers, the SH&E professional can determine the vibration exposure levels for various tasks and compare them to acceptable exposure limits. As discussed, ACGIH, ANSI and ISO standards can serve as vibration limits. Prevention and control strategies involve engineering approaches, administrative controls and the use of PPE, all of which, when used properly, can be effective in protecting workers. ■

References

American National Standards Institute (ANSI). ANSI S3.34-1986, Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand. New York: ANSI, 1986.

American Conference of Government Industrial Hygienists (ACGIH). *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* Cincinnati: ACGIH, 1998.

Bovenzi, M. "Hand Transmitted Vibration." *Encyclopaedia of Occupational Health and Safety, 4th ed.* J.M. Stellman, ed. 4 vols. Geneva, Switzerland: International Labour Office, 1998: 50.1-50.15.

Cederlund, R. et al. "Hand-Arm Vibration Exposure Influences Performance of Daily Activities." *Disability and Rehabilitation.* 23(2001): 570-577.

Center for Workplace Health Information. "Hand-Arm Vibration Ignored, Misdiagnosed." *CTD News.* October 1995.

Centers for Disease Control and Prevention (CDC)(a). "Vibration Syndrome." Current Intelligence Bulletin No. 38. DHHS (NIOSH) Publication No. 83-110. Washington, DC: U.S. Government Printing Office, 1983.

CDC(b). "Criteria for a Recommended Standard: Occupational Exposure to Hand-Arm Vibration." DHHS (NIOSH) Publication No. 89-106. Washington, DC: U.S. Government Printing Office, 1989.

CDC(c). "Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-Related Musculoskeletal Disorders of the Neck, Upper Extremity and Low Back." DHHS (NIOSH) Publication No. 97-141. Washington, DC: U.S. Government Printing Office, 1997. <http://www.cdc.gov/niosh/ergtxt5.html>.

Eastman Kodak Co. *Ergonomic Design for People at Work: Vol. 1.* New York: Van Nostrand Reinhold, 1983.

Gemne, G., et al. "The Stockholm Workshop Scale for the Classification of Cold-Induced Raynaud's Phenomenon in the Hand-Arm Vibration Syndrome (revision of the Taylor-Pelmear scale)." *Scandinavian Journal of Work Environment and Health.* 13(1987): 275-278.

Health and Safety Executive (HSE). "Hand-Arm Vibration in the Cast Stone Industry: Reducing the Risk." HSE Information Sheet MISC493. Caerphilly, England: HSE, 2003.

International Standards Organization (ISO). ISO 5349, Guidelines for the Measurement and Assessment of Human Exposure to Hand-Transmitted Vibration. Geneva, Switzerland: ISO, 1986.

Pelmear, P. and D. Leong. "Review of Occupational Standards and Guidelines for Hand-Arm (Segmental) Vibration Syndrome (HAVS)." *Applied Occupational and Environmental Hygiene.* 15(2000): 291-302.

Reynolds, D. and J. Stein. "Evaluation of the Test Procedures for the Testing of Antivibration Gloves Per ISO Standard 10819." *Proceedings of the 8th International Conference on Hand-Arm Vibration, Umea, Sweden.* June 1998: 309-322.

Taylor, W. and P.L. Pelmear. *Vibration White Finger in Industry.* London: Academic Press, 1975.

Wald, P.H and G.M. Stave. *Physical and Biological Hazards of the Workplace.* New York: John Wiley and Sons Inc., 2002.

Weeks, J.L. et al, eds. *Preventing Occupational Disease and Injury.* Washington, DC: American Public Health Assn., 1991.

Zinck, K. *The Evaluation of Human Vibration Measurements and the Effectiveness of Different Vibration Reduction Strategies in a Sawmill.* Richmond, British Columbia: Workers' Compensation Board of British Columbia, Finding Solutions Program, 1999.

Your Feedback

Did you find this article interesting and useful? Circle the corresponding number on the reader service card.

RSC#	*Feedback*
31	Yes
32	Somewhat
33	No