Human Vibration Guide

Introduction

1. Purpose

a. This guide may be useful to industrial hygienists, safety professionals and technicians in understanding the need to perform human vibration exposure assessments including a discussion of the occupational exposure limits, collection of vibration measurements and determination of vibration magnitudes, and understanding conditions that require control measures.

   This guide provides general hazard and health effects information; a way to prioritize work tasks needing further investigation concerning worker exposure to whole body vibration and hand arm vibration; methods for determining an estimate of a worker's vibration exposure, and a reference containing control methods to minimize whole body and hand arm vibration exposures.

2. Human Vibration Background Information

a. Vibration occurs when the body oscillates due to external and internal forces per reference (a). Occupational exposures to vibration can be divided into two categories, Hand Arm Vibration (HAV) and Whole-Body Vibration (WBV). The pathway of the vibration is contingent on the workplace and work performed; including workplace design, equipment use and maintenance, personal protective equipment, and gripping force. Vibration can enter one or more body parts for instance, in one or both hands, and transmit through the hand to the arm and shoulder. As outlined in reference (b), dynamic vibration transmitted to the hands, arms, shoulders, and body occurs when in contact with vibrating objects such as powered hand tools (e.g., chain saw, electric drill, chipping hammer) or equipment (e.g., wood planer, punch press, packaging equipment). Whole-Body vibration occurs when standing or sitting in vibrating environments (e.g., operating a helicopter or driving a truck over bumpy roads) or when using heavy vibrating equipment that requires whole-body involvement (e.g., jackhammers).

b. Occupational exposure to continuous or dynamic vibration is an ergonomic hazard of concern in the workplace. The risk of exposure is increased with high vibration equipment and prolonged or regular use of the equipment per reference (a).

c. Habitual use of powered hand tools and equipment has been linked to severe and irreversible patterns of diseases affecting blood vessels, nerves, bones, joints, muscles, or connective tissues of the hand and forearm. In addition, vibration is frequently a source of discomfort and possibly reduced proficiency per reference (c). Certain groups of power tools account for 20-50% of HAV exposures in the workplace. Two-and-a-half million U.S. workers are exposed daily per reference (b) however, good management can control and reduce vibration hazards and risks. Ultimately, the goal is to control the vibration hazard to ensure worker health and improve efficiency per reference (a).

d. A study by Blackman (2019) surveyed 884 active-duty Navy aircrew personnel that operated the gunner seats of the MH-60S helicopter, and 96.6% identified that they experienced back pain per reference (d). Additionally, as discussed in reference (e), 89% of the flying events during the study exceeded the American Conference of Governmental Industrial Hygienists (ACGIH) action level (AL), while 22% exceeded the Threshold Limit Value (TLV) of reference (f). The National Institute of Occupational Safety and Health (NIOSH) studied hand-arm vibration on foundry and shipyard workers who had never used vibrating hand tools. Eighty-three percent of foundry workers and 64% of shipyard workers that were exposed to vibration had some form of vibration syndrome with initial symptoms appearing in less than a year. Coinciding with the ACGIH TLV recommendations to control vibration exposure, the industrial hygienist should be familiar with the use of anti-vibration tools, equipment and gloves, early signs and symptoms of vibration exposure, and the application of a medical surveillance program as needed.

e. Vibration investigations have been acquired from academic studies, the Department of Defense (DoD), and other regulatory agencies to understand better the health hazards related to vibration exposures. The Human Vibration Technical Guidance intends to assist in providing information on resulting health conditions, occupational exposure limits, sampling equipment, procedures and determination of vibration magnitudes, exposure assessments and controls used to assess and limit health effects associated with vibration.

3. Health Effects

a. Vibration exposure is a broad classification that includes Hand Arm Vibration (HAV) and Whole-Body Vibration (WBV). HAV is localized or segmental, where the vibration originates at the hands and transmits along the arms via vibrating hand tools. WBV occurs when the body comes in contact with a vibrating surface such as machinery or vehicles. Both HAV and WBV are associated with various health concerns, including irreversible conditions.

b. Hand Arm Vibration.

(1) Raynaud's syndrome. One of the most prominent vascular disorders associated with

exposure to HAV is Raynaud's Disease. Also known as dead or white finger or vibration-induced white finger. Raynaud's disease can be divided into two classifications, primary or secondary. Primary Raynaud's cases develop spontaneously in the general population (about 15% of total cases). Secondary Raynaud's phenomenon is associated with underlying diseases and occupational exposures incurred during the use of handheld power tools. Per reference (e), Primary and Secondary Raynaud's symptoms present identically. Symptoms of Raynaud's include:

(a) Tingling or numbness in one or more fingers. Symptoms progress to include whitening or blanching in the fingertips, which is often painful. Blanching is when little to no blood flow circulates to the affected body part causing the skin to turn white. Blanching of the skin is often referred to as a "Raynaud's attack." Blanching can advance and often travels from fingertips to the finger's base. Blanching subsides from minutes to an hour when blood returns to the fingers. Blood return can be hastened by warming or massage and is often painful.

(b) Prolonged exposure to vibration and cold can accelerate symptoms or trigger a "Raynaud's attack." In addition, an associated neurological condition known as vibratory neuropathy, may appear alone or in conjunction with Raynaud's Disease.

(c) The sensory changes are due to damage of nerve endings in the fingers and can be responsible for the tingling or numbness of the fingers that occurs during a "Raynaud's Attack" as discussed in reference (g).

(d) Severe prolonged or repeated Raynaud's can lead to hypoesthesia (see below), tissue damage, skin sores, and decay of body tissues.

(2) Hypoesthesia. Hypoesthesia is when the sensation of touch, temperature sensitivity, and manual dexterity is lost over time. Symptoms can last year-round with an increase in severity during the winter months. Ergonomic factors such as arm position and grip force may contribute to the progression of hypoesthesia. Please note that temporary tingling or numbness is not a characteristic of vascular or neurological disorders associated with prolonged vibration exposure per references (a), (e), and (h).

(3) Carpal-tunnel syndrome (CTS). Epidemiological research in workers has also shown that vibrating tools combined with repetitive movements, forceful gripping, and awkward postures may increase the risk of CTS as cited in reference (a). Workers with prolonged exposure to vibration may develop muscular weakness, pain in the hands and arms, and diminished grip strength.

(4) Wrist and elbow arthritis and hardening of soft tissue (ossification) mainly at the elbow, have been found in miners, road construction workers, and metal-working

operators using percussive tools. Other work-related disorders have been reported in vibration-exposed workers, such as inflammation of tendons (tendonitis) and their sheaths in upper limbs and Dupuytren's contracture, a disease of the fascial tissues of the palm per reference (a).

c. Whole-Body Vibration. WBV is associated with several adverse health effects. According to reference (a) the United States Army Aeromedical Research Laboratory (USAARL) has identified that WBV can potentially cause headaches, speech disturbances, respiratory complaints, abdominal pain, and the urge to urinate and defecate, depending on the frequency. WBV does not have one specific target organ and has an association with various health problems per reference (g). Long-term exposure to WBV can result in a range of biomechanical and physiological changes, including spinal injuries and motion sickness. The combination of ergonomic and WBV while operating military aircraft, vehicles, or heavy equipment may further strain the musculoskeletal system, causing muscle fatigue leading to musculoskeletal disorders as explained in reference (i). Additional studies have found that aviators and aircrew personnel commonly experience back-related health concerns due to vibration experienced in flight. Military and civilian personnel in these settings who experience extended periods of sitting in combination with WBV often complain of lower back pain, spinal discomfort, and intervertebral disc problems, according to references (d) and (i). Symptoms may be localized, radicular (radiating from the spine to the back, hip, and leg), and referred (originating in one part of the body but felt in another part of the body) including leg, buttock, and back pain with numbness and muscle spasms; complications from these conditions can decrease concentration and situational awareness. The USAARL displays the physical effects of WBV dependent on frequencies ranging from less than 1 hertz to 25 hertz in Table 1.

Table 1
Examples of Known Whole-Body Effects
(Adapted from USAARL Human Response Effects to Whole-Body Vibration in Aviation: A Brief Review and MIL-STD-1472H)

Vibration Frequency	Effect	Reference
< 1 Hz	Motion Sickness	ISO 2631-1, 1997; Dupuis & Zerlett, 1986
2-6 Hz	Hyperventilation	Dupuis & Zerlett, 1986
4 – 10 Hz	Resonant frequency of the torso, peak transmissibility to the head; increased colon pressure; respiratory complaints; abdominal pain; increased torque in spinal support muscles; jaw resonance; chest pain; general discomfort	Dupuis & Zerlett, 1986; White et al., 1963; Magid & Coermann, 1960; White et al., 1963; Seroussi et al., 1986
10 – 18 Hz	Urge to urinate and defecate	Dupuis & Zerlett, 1986
13 – 20 Hz	Headache; speech disturbance; increased muscle tension	Dupuis & Zerlett, 1986; Magid & Coermann, 1960
20 -25 Hz	Decreased visual acuity	Dupuis & Zerlett, 1986

4. Recommended Occupational Exposure Limits

Currently, the ACGIH, the American National Standards Institute (ANSI), the International Standards Organization (ISO), and the DoD have established occupational exposure limits (OELs) for HAV and WBV, discussed in references (f), and (j-p). The recommended daily eight-hour vibration exposure values for HAV are presented in Table 2. The recommended daily eight-hour vibration exposure values for WBV are presented in Tables 3 and 4.

a. Hand Arm Vibration, A(8): The daily vibration exposure [eight-hour energy equivalent total value A(8)] is defined as the amount of HAV a worker is exposed to during an eight-hour workday; taking into account the magnitude and duration of vibration. The A(8) daily vibration exposure is derived from the magnitude of the vibration [(vector sum/frequency weighted root mean square (rms) acceleration for the X, Y, and Z axes)] and the daily exposure duration (trigger time) per reference (j).

(1) HAV A(8) Single Exposure. The A(8) for a single piece of equipment can be calculated using the following equation:

$$A(8) = a_{hv}\sqrt{\frac{Tv}{T0}}$$

where :
a_{hv} = the vector sum/frequency weighted acceleration sum in m/s^2
T_v = trigger time/actual duration of worker exposure in hours
T_0 = the reference time/duration of workday in hours (usually eight hours)

(2) HAV A(8) Multiple Exposures. If vibration exposure consists of several operations with differing vibration magnitudes, use the guidelines outlined in reference (j) to determine the partial vibration exposures; ensure to calculate the magnitude and duration for each source. The cumulative overall daily vibration exposure $A_t(8)$ can be calculated from the partial vibration exposure values using the equation below:

$$At(8)=\surd((A_1 8)^2+(A_2\ 8)^2+(A_3 8)^2\ldots$$

where:
$A_t(8)$ = the cumulative overall daily vibration exposure in m/s^2
$A_1(8), A_2(8), A_3(8)$,…= partial vibration exposure values for the different vibration sources

(3) HAV OELs. The *At(8)* can be compared to the AL/Daily Exposure Action Level (DEAV) and TLV/DELV for assessment and evaluation purposes.

Table 2
HAV OELs
(Adapted from ACGIH, MIL-STD-1472H, ISO 5439, and ANSI S2.70)

Source	**Action Level/Daily Exposure Action Value (m/s^2)**	**Threshold Limit Value/ Daily Exposure Limit Value (m/s^2)**
ACGIH	2.5	5.0
ANSI S2.70	2.5	5.0
ISO 5349	2.5	5.0
MIL-STD 1472H	2.5	5.0

b. The ACGIH AL for HAV- concurs with the ANSI, ISO, and DoD DEAV of 2.5 m/s^2. The ACGIH TLV concurs with ANSI, ISO and DoD stated DELV of 5.0 m/s^2. The AL/DEAV is a measure of daily operator vibration exposure, which, if exceeded, requires controls to be implemented to reduce associated risks, preferably below 2.5m/s^2. The TLV/DELV is the measure of daily operator vibration exposure that must not be exceeded in an eight-hour workday per references (a), (f), (q), and (r).

c. Whole-Body Vibration. Daily WBV exposure is determined by calculating the A(8) and the vibration dose value (VDV). The daily vibration exposure [eight-hour energy equivalent total value A(8)] is defined as the amount of WBV a worker is exposed to during an eight-hour working day; the A(8) daily vibration exposure is derived from the overall cumulative weighted rms acceleration magnitude for the each of the axes (X, Y, or Z) and duration of mechanically induced WBV per reference (f).

(1) WBV A(8) single exposure. The A(8) can be calculated using the following equation:

$$A(8) = a_{wbv}\sqrt{\frac{Tj}{T0}}$$

where:
a_{wbv} = the overall weighted rms acceleration for the X, Y, or Z-axis in m/s^2
T_j = the actual duration of worker exposure in hours
T_0 = the reference time/duration of workday in hours (8 hours)

(2) WBV vibration dose value single exposure. The VDV is an alternative measure of vibration exposure; using the VDV is preferable when measuring transient vibration or vibration containing shocks or jolts, being that the A(8)/weighted rms method may underestimate the true exposure. The VDV should be calculated in addition to the A(8)/rms method when the crest factor is greater than nine. The crest factor can be obtained when performing real time measurements with a vibration meter.

The VDV is a cumulative value; it increases with measurement duration. VDV is assessed using the measurement duration and the actual total time a worker is exposed to a vibration source daily per references (f), (q), (s), and (t). The VDV can be calculated using the following equation:

$$VDV = k_l\left(\int_0^T [a_{wl}(t)^4]dt\right)^{1/4}$$

where:

k_l = the multiplying factor for direction l (k =1.4 for l = x or y; k = 1.0 for l = z)
a_{wl} = the frequency weighted acceleration in m/s^2
t = the total measurement period in minutes
d = the daily duration of exposure to the vibration in minutes

NOTE: VDV should NOT be applied for exposures greater than eight hours

(3) WBV A(8) multiple exposures. If vibration exposure consists of several operations with differing vibration magnitudes, use the guidelines outlined in ANSI S2.72/ISO 2631 per references (k), (l), and (m) to determine the partial vibration exposures; ensure to calculate the $A_t(8)$ daily vibration exposure for the X, Y, and Z axes. The overall weighted rms accelerations along the X, Y, and X axes should be used to compare against the AL/DEAV and TLV/DELV. The cumulative overall daily vibration exposure $A_t(8)$ can be calculated from the partial vibration exposure values for the X, Y, and Z axes individually using the equation below:

$$At(8)=\sqrt{((A_1 8)^2+(A_2\ )^2+(A_3 8)^2 \ldots}$$

where:
$A_t(8)$ = the overall daily vibration exposure in m/s^2 for the axis with the highest total
$A_1(8), A_2(8), A_3(8), \ldots$ = partial vibration exposure values for the different vibration sources (calculated for the X, Y, and Z axes separately)

(4) Vibration dose value multiple exposures. In addition, if more than one source of WBV and VDVs are available, the total VDV for each the X, Y, and Z axes is calculated using the equation:

$$VDV_t = (VDV4_1 + VDV4_2 + VDV4_3 \ldots)^{1/4}$$

where:
VDV_t = the overall daily VDV in $m/s^{1.75}$ for the axis with the highest total
$VDV_1, VDV_2, VDV_3, \ldots$ = partial VDVs for the different vibration sources (calculated for the X, Y, and Z axes separately)

(5) WBV $A_v(8)$ vector sum. The overall weighted rms accelerations may not differ greatly along the X, Y, and Z axes, when they are similar the combined motion of all three axes should be calculated using the following equation:

$$Av = \left([1.4a_{wx}]^2 + \left[1.4a_{wy}\right]^2 + [1.4a_{wz}]^2\right)^2$$

NOTE: The vector sum method can be used for single or multiple WBV exposures.

d. WBV OELs. The axis with the highest total should be used to compare against the AL/DEAV and TLV/DELV for assessment purposes.

Table 3
WBV OELs
(Adapted from ACGIH, ANSI S2.72, ISO 2631, and MIL-STD-1472H)

Source	**Action Level Lower Limit of the Health Guidance Caution Zone (m/s^2)**	**Threshold Limit Value/ Upper Limit of the Health Guidance Caution Zone (m/s^2)**
ACGIH	0.4331	0.8661
ANSI S2.72	0.43	0.87
ISO 2631	0.43	0.87
MIL STD 1472H	0.43	0.87

Table 4
WBV OELs Using Vibration Dose Value (VDV)
(Adapted from ACGIH and ISO 2631)

Source	**Action Level/Lower Limit of the Health Guidance Caution Zone ($m/s^{1.75}$)**	**Threshold Limit Value/ Upper Limit of the Health Guidance Caution Zone ($m/s^{1.75}$)**
ACGIH	8.5	17
ISO 2631	8.5	17

e. When using the A(8) value to determine exposures, the ACGIH AL for WBV is 0.4331 m/s^2, overall in concurrence with the ANSI, ISO, and DoD DEAV of 0.43 m/s^2. The ACGIH TLV is 0.8661 m/s^2 overall in concurrence with the ANSI, ISO, and DoD stated DELV of 0.87 m/s^2. The AL/DEAV is a measure of daily operator or occupant WBV exposure, which, if exceeded, requires the implementation of controls to reduce associated risks, preferably below 0.4331 m/s^2. Controls/mitigations are recommended for whole-body daily vibration exposures which occur within 24 hours and fall between the AL and TLV. The TLV/DELV is the measure of daily operator or occupant WBV exposure that must not be exceeded within 24 hours; always in reference to an eight-hour workday per references (f), (q), (s), and (t).

f. If using the VDV to determine exposure levels, the ACGIH/ISO 2631 WBV AL in any direction is 8.5 $m/s^{1.75}$. The ACGIH TLV/ISO 2631 WBV exposure limit in any direction is 17 $m/s^{1.75}$. The AL is a measure of daily operator or occupant WBV exposure for the exposure period, which, if exceeded, requires the implementation of controls to reduce associated risks, preferably below 8.5 $m/s^{1.75}$. Controls/mitigations are recommended for WBV exposures that fall between the AL and TLV/ISO exposure limits. The TLV/ISO exposure limit is a measure of operator or occupant WBV exposure that must not be exceeded in any direction for the exposure duration per references (f), (q), (s), and (t).

Sampling Equipment/Procedures and Determination of Vibration Magnitudes

1. Sampling Equipment

a. There are varying manufacturers of vibration measurement equipment; establish an understanding of the types of equipment and what each is designed to measure. Ensure that the measurement system considered for purchase is for WBV or HAV and not building or general vibration. The following is a list of the components of a human vibration measurement system.

(1) Meter. The computer/base/brain of the unit. Meters come in various styles, have a display, and are set to measure in three directions (X, Y and Z axes). Some meters may also measure the frequency of the vibration, an essential measurement for weighting.

(2) Cables. Responsible for transferring the signal from the sensor to the meter. Cables may be shielded or unshielded or even double shielded. Shielding is necessary to reduce interference from outside sources.

(3) Accessories. Vary from manufacturer to manufacturer and may include various mounting aids. These aids may include screw pots, bands or even beeswax.

(4) Calibrator. Accelerometers must be calibrated before and after each use. Calibrators typically have a surface that moves at a specific speed. Some calibrators may allow the user to set the speed. Some allow the frequency to be set as well. The usual level of calibration is between 1 m/s2 to 10 m/s2. The frequency can vary between 16 – 640 Hz. The weight of the accelerometer must be considered. Each accelerometer must be attached to the calibrator and calibrated in each of the three axes. Screws, bands, and even beeswax can be used to affix sensors to the calibrator. Some accelerometers, such as seat pads, may come with an attachment that fixes firmly to the calibrator, and the accelerometer is moved to meet the alignment required for each axis.

(5) Hand-arm vibration accelerometers. This sensor has a tri-axial piezoelectric accelerometer. This accelerometer has mounting brackets or set screws to allow the accelerometer to be placed either on the equipment or on the operator’s hand. The operator's hand is the most effective location to mount it and ensure the sensor is between the operator's hand and the tool's grip to be operated. In general appearance, it is a small cube with the letters X, Y, and Z on three of its faces. The sensor may be enclosed in a case of some type to make mounting more effective.

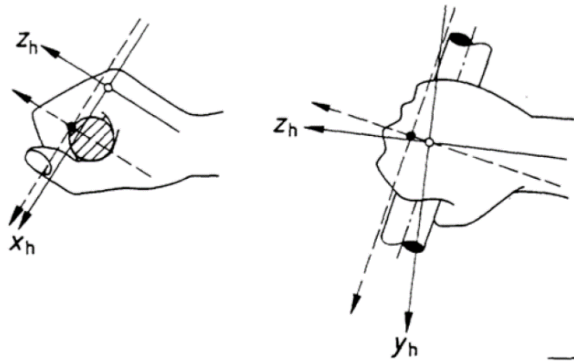
(6) Whole-body vibration accelerometers. The WBV accelerometer has a three-axis (X, Y, and Z) piezoelectric accelerometer. It is contained in a round disc that is mounted on the operator’s seat. It can also be mounted on the operator's seatback if comfort levels are to be established.

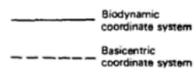
2. Measurement Directions

a. HAV measurements. HAV measurements are taken in three directions or axes (X, Y, and Z). These are orthogonally directed, as depicted in Figure 1. The sum of these measurements is used to calculate the daily vibration exposure, A(8). The system's origin lies in the head of the third metacarpal, and the longitudinal axis of that bone defines the Z (hand) axis. The X-axis projects forward from the origin when the hand is in the standard anatomical position (palm facing forward). The Y-axis passes through the origin and is perpendicular to the X-axis. When the hand is gripping a cylindrical handle, the coordinate system shall be rotated so that the Y-axis is parallel to the axis of the handle. In “handgrip" position (a), the hand adopts a standardized grip on a cylindrical bar of radius 2 cm. In "flat palm" position (b), the hand presses down onto a spherical surface of radius 5 cm.

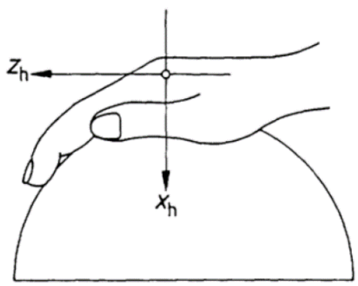
Figure 1
HAV Measurement Positions
(Adapted from ANSI S2.70)

(b) Handgrip Position



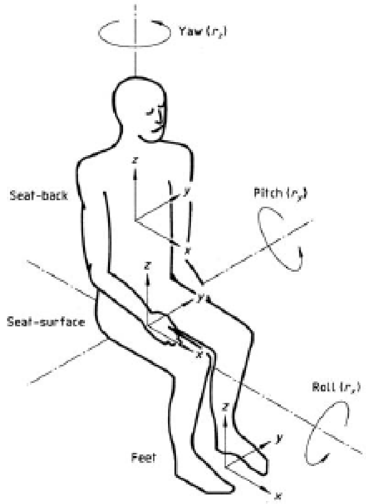


(a) Flat Palm Position

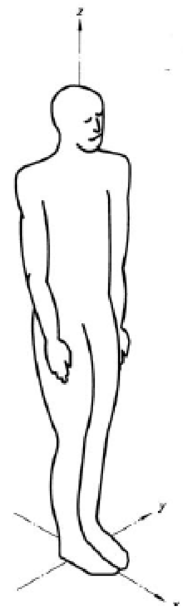


b. <u>WBV measurements</u>. WBV measurements are taken in three directions or axes (X, Y, and Z). These are orthogonally directed, as depicted in Figure 2. Unlike HAV, the axis with the highest rms is used to calculate the A(8). The X-axis is measured from posterior to anterior positions. The Y-axis is measured laterally through the body, while the Z-axis is measured vertically from the body's base through to the top of the head.

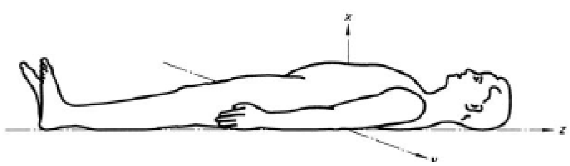
Figure 2
WBV Measurement Directions
(Adapted from ANSI S2.72)



(a) Seated Position



(b) Standing Position



(c) Recumbent Position

c. Determination of Vibration Magnitude. Calculating vibration exposure requires determining the vibration magnitude of the equipment in use by the worker. The primary resources used to determine equipment exposure magnitudes include:

(1) Manufacturer's vibration measurements. Manufacturer's literature will often have data available in the user's manual or on their website. These are the most straightforward measurements to obtain, though not the most accurate. Measurements are taken in a laboratory under ideal conditions and do not account for the condition of the equipment, the different styles of operation, the anthropometric differences between operators, or other variables.

(2) In use measurement of tools with a vibration meter. Usage of a vibration meter can be time-consuming; however, it will return the most accurate and precise value of vibration magnitude. Multiple tests with various test subjects should be performed, and an average of these results used as the vibration magnitude.

(3) Public databases of measured vibration levels. A few public databases are available that have both manufactured measured (laboratory-produced) and live measured vibration levels (tested under working conditions). These databases contain vibration magnitude measurements on various handheld tools and mobile equipment. Examples include the DoD Human Vibration Exposure Database and the Physical Agents Portal (PAF) – Tuscany Region.

(4) Vibration magnitude tool-type charts. There are several industry-accepted publications that list vibration magnitude measurements for commonly used powered hand tools and equipment, including the U.S. Army TG356 Vibration Pocket Guide, E.U. Good Practice Guide HAV V7.7 and the OPERC/Birmingham City University Hand-Arm Vibration Wall Chart, see references (a), (q), and (u).

NOTE: For detailed information on using the above resources, refer to the U.S. Army TG356 Vibration Pocket Guide.

d. Hand Arm Vibration Measurement Procedures.

(1) Calibrate equipment. Each sensor must be calibrated in the X, Y, and Z axes at the beginning and end of the sampling day. Recalibrate the instrument immediately if it is dropped or treated harshly to ensure the accuracy of measurements.

(2) Mount accelerometers. Accelerometers must be mounted thus that they are firmly positioned on the surface the machine operator will be using. Accelerometers used with an adaptor must firmly contact the tool. The sensor should not be mounted on gloves or the arms. The meter may be placed on the arm or waist. ISO 5349-2, see reference (n), Table A-1 has examples of accelerometer mounting locations on many standard tools.

(3) Measure vibration magnitude. The worker must operate the tool as normal. Do not simulate work; measure actual work. If the tool is used with two hands, measurements must be taken on each hand and the higher measurement used for the calculation of vibration magnitude. Measurements should be taken on the vibrating surface as close to the center as possible. Whenever possible, the one-third

octave band vibration of the equipment should be measured in the X, Y, and Z axes. Readings are taken in m/s^2.

(4) Determine "trigger time" (exposure duration). Trigger time is the amount of time personnel are actively operating machinery/tools.

(5) Recording measurement data. HAV exposure data should be recorded in DOEHRS-IH under the process or SEG samples module on the vibration sample form.

e. Whole-Body Vibration Measurement Procedures.

(1) Calibrate equipment. Calibrate each sensor in the X, Y, and Z direction/axis at the beginning and end of the sampling day at a minimum. If the instrument is dropped or handled harshly, it should be recalibrated to ensure accuracy. WBV sensors are typically mounted in a pad. There may be a need to use a jig of some sort to mount the pad on the calibrator. Calibrators may come with an attachment for calibrating seat pads.

(2) Mount accelerometer. The accelerometer is typically embedded in the seat pad. It may operate wirelessly, store data internally, or require a cable to attach to a meter.

(3) Measure vibration magnitude. Measure the test subject for a long enough duration to ensure statistical precision and to capture the entire variation of vibration effects common to the task or the exercise. Place the accelerometer at the point where vibration enters the body. For example, when measuring a recumbent individual, take measurements at three points, the pelvis, the back, and the head. Take vibration measurements on the surface where the feet are most often placed for standing individuals. There are three areas to place the accelerometer, the feet, the seat surface, and the seatback for a seated individual. The vibration measurements for WBV are based on the weighted RMS vibration acceleration.

(4) Recording measurement data. WBV exposure data should be recorded in the Defense Occupational and Environmental Health Registry System-Industrial Hygiene (DOEHRS-IH) under the process or Similar Exposure Group (SEG) samples module on the vibration sample form.

f. Frequency Weighting. Vibration in the frequency range of 10 Hz to 1000 Hz affects humans the most. Most meters have a frequency weighting system that takes this into account and will filter or otherwise attenuate those frequencies to arrive at the measurements that most affect workers.

g. Environmental Effects on Measurement. There are a few environmental and equipment interferences that can affect vibration measurement. Likewise, there are solutions to attenuate these effects.

(1) Accelerometer cable noise.

(a) Ground loops. Sometimes electrical currents flow in the shielding around the accelerometer cables, caused by both the accelerometer and the meter being grounded. This ground loop can be broken by electrically isolating the accelerometer mounting stud with a mica washer.

(b) Triboelectric noise. The internal noise generated by the flexing or vibrating of the accelerometer cable. Be sure to tape or otherwise mount cables as close to the accelerometer as possible. Do not bend or compress the cables.

(c) Electromagnetic noise. Occasionally, the equipment to be measured can create an electromagnetic field that can affect the cable. A double-shielded cable should alleviate this in all but the most extreme cases.

(2) Heat and humidity. Vibration measurements are not usually affected by these conditions except in the most extreme circumstances.

3. Exposure Assessment

a. Evaluate and assess processes involving HAV and WBV to determine if harmful vibration exposures may occur. Identify HAV by taking note of vibrating objects such as hand tools or equipment which transfer dynamic vibration to the hand, arms, and body. WBV can be found in environments where the worker is standing or sitting while operating heavy equipment or vehicles per reference (a).

b. According to reference (f), while the industrial hygienist may use OELs as a guide in controlling HAV and WBV exposure, they should not regard OELs as defining a distinct boundary between safe and dangerous levels. It is impossible to specify an OEL to protect all workers for all work situations (e.g., high force exertions, cold environments, and unusual postures. Note that risk for illness and injury is different for each person and process. For example, exposure to cold conditions and smoking tobacco products can increase the chances of experiencing vibration-induced health effects by constricting the blood vessels and reducing finger circulation.

c. Worker exposure should remain below the ANSI, ISO, and ACGIH DELV/TLV for the corresponding exposure time in hours and the measured vibration acceleration in m/s^2. for HAV and WBV require immediate action to reduce the exposure. ANSI, ISO, and ACGIH assume an 8-hour workday for HAV and WBV exposure and should not exceed 24 hours for WBV, if most employees will not experience vibration symptoms within the ANSI, ISO, and ACGIH suggested acceleration rates and corresponding exposure times.

4. HAV Exposure Health Risk Levels

a. As discussed in references (f) and (j), utilize the 8-hour ANSI, ISO, and ACGIH DELV/TLV acceleration rate calculation to help identify low, moderate, and high potential health risks, refer to Table 5. At less than 2.5 m/s^2, the worker's potential health risk is low. Between 2.5 – 5.0 m/s^2, the health risk is considered moderate. However, HAV exposure is significant enough to produce signs and symptoms of vibration exposure in some individuals in this range. Levels at 5.0 m/s^2 or higher, a more significant proportion of workers will experience signs and symptoms of HAV exposure.

Table 5
HAV Exposure Health Risk Levels
(Adapted from ANSI S2.72, ISO 5349, and ACGIH)

HAV	
Health Risk Level	**ACGIH TLV AL**
	A(8) (m/s^2)
Low	< 2.5
Moderate	2.5 - 5.0
High	> 5.0

5. WBV Exposure Health Risk Boundaries

a. Utilize the 8-hour ACGIH acceleration rate calculation to help identify upper and lower boundaries for potential health risks; refer to Table 6. At less than 0.43 m/s^2, the worker's potential health risk is low. Between 0.43 – 0.87 m/s^2, the health risk is considered moderate. In this range, vibration exposure is significant enough to produce signs and symptoms of WBV exposure in some individuals. Levels at 0.87 m/s^2 or higher, a higher proportion of workers will experience signs and symptoms of WBV exposure.

Exposures in the lower and upper boundary range of 0.25 – 0.5 m/s2 for WBV have potential health risks.

Table 6
WBV Exposure Health Risk Boundaries
(Adapted from ACGIH and ISO 2631-1)

WBV		
Health Risk Boundary	ACGIH 8hr TLV AL	ACGIH 24hr TLV AL
	A(8) (m/s^2)	A(8) (m/s^2)
Lower Boundary (Curve B/AL)	0.43	0.25
Upper Boundary (Curve A/TLV)	0.87	0.5

NOTE: Please see the MIL-STD 1472G, ISO 2631-1, ANSI S2.70, and ACGIH-TLV (2021) references (j-p) for additional charts and tables on HAV and WBV DELV/TLV and DEAV/AL levels for corresponding exposure times and acceleration values, respectively.

6. Control Measures

When HAV or WBV values are equal to or greater than the DEAV/AL, take action to reduce worker vibration exposures to levels below the ANSI/ISO and ACGIH DELV/TLV. Control measures should be realistic, represent the process and workers' needs and reduce worker exposure without impeding workflow or adding to the potential harm of the worker. Include steps to adapt controls for workers at particular risk of injury (e.g., those who are more susceptible to vibration injury and show signs of developing injury at exposures below the exposure action value). Utilize the hierarchy of controls to reduce occupational HAV and WBV exposure.

7. HAV Workplace Control Measures

a. Elimination/Substitution. When possible, eliminate the process or select a method that results in the lowest vibration exposure possible. Elimination may involve mechanization, automation of tasks or substitution of alternative work processes (e.g., Jigs) per reference (a).

b. Administrative Controls.

(1) Training. There are several training topics to be addressed with workplace supervisors and workers. First, the early signs and symptoms of HAV should be familiar to all supervisors and workers. Second, training should identify processes that may result in HAV injuries. Third, in each HAV-related process, training should include the proper use of vibration-producing equipment and measures to eliminate or reduce HAV exposure. Finally, training should address the personal health factors that escalate the health effects of HAV (e.g., smoking or preexisting medical conditions like peripheral circulatory disorders) per references (f) and (k).

(2) Work schedules. Supervisors may implement work schedules to limit continuous worker exposure to vibration hazards, including establishing 10-minute breaks to allow recovery and blood recirculation to affected extremities. In addition, shop supervisors should supervise newly implemented work schedules to ensure that workers do not return to the old work schedule per reference (a).

(3) Maintenance. Ensure vibrating power tools and equipment are regularly maintained and calibrated when appropriate. Routine care and maintenance will reduce the likelihood of unnecessary vibration (e.g., follow manufacturer's recommendations for maintenance of parts, keep cutting tools sharp, replace worn parts) per reference (a).

c. Engineering Controls.

(1) Workstation design. Based on best practices from reference (a), redesigning the workstation layout can help control HAV exposure by avoiding ergonomic stressors such as awkward postures and gripping/pushing forces perpetuating the vibration hazard. The industrial hygienist may recommend custom tools to control another tool's location and motion to relieve a tool's static load. Similar aids such as incorporating anti-vibration mounts can help avoid the need to hold vibrating surfaces. When contact is necessary, the industrial hygienist may recommend anti-vibration handles to reduce the vibration. It is vital to select anti-vibration handles that do not increase the HAV hazard. Incorrect selection of this type of handle may escalate hand vibration. Anti-vibration handle recommendations should align with the endorsement of the tool manufacturer to ensure proper selection.

(2) Equipment selection. Equipment selection is vital for the safe and proper execution of a process. Inadequate tools may prolong the duration of the process, exposing the

worker to vibration for an extended period. The workplace should utilize tools that do not exert too much or too little power and provide ergonomically correct factors such as weight and handle design to reduce HAV and forceful exertion.

(3) Tool attachments and accessories (e.g., drill attachments, saw blades, and abrasives for grinders and sanders) will need to be carefully selected to ensure the best functionality of the tool. Evaluate the effectiveness of handles or other parts of a tool wrapped in rubber, vibration stifling material, or other added resilient materials. While the resilient materials may improve comfort, improper use or application of resilient material could increase vibration acceleration. Refer to the manufacturer for suggested vibration resilient materials and attachments, when possible, per reference (a)

(4) Cold exposure and prolonged exposure to vibration can accelerate symptoms or trigger a "Raynaud's attack." When possible, avoid using tools that may cause hands to be cold when in contact or handling them, such as steel. As discussed in reference (a), keep cold exhaust air away from fingers and hands for pneumatic tools. Avoid outdoor work during cold weather when possible. When workers must be outdoors during cold weather, consider using equipment with heated handles and/or PPE (see below) (e.g., chainsaws with heated handles to help keep the hands warm).

d. Personal protective equipment. Personal protective equipment (PPE) is the final option for protection against hazards at work and should only be considered a long-term means of control after all other options have been investigated. PPE options to reduce the effects of HAV exposure primarily consist of anti-vibration gloves and warm clothing. Gloves marketed as 'anti-vibration' should be labeled with the ANSI S2.73/ISO 10819 standard, indicating they have been tested and found to meet the requirements to reduce vibration above 150Hz. However, anti-vibration gloves do not provide significant risk reduction at frequencies below 150Hz per reference (a). If temperatures require the use of warm clothing and gloves during potential HAV exposure, ensure that they are assessed for good fit insulation and keep moisture away from the body.

8. WBV Control Measures

Implementation of control measures is necessary to reduce the effects of vibration frequencies on all parts of the body per reference (k).

a. Administrative controls.

(1) Training. Train workplace supervisors and workers using the same guidelines as described for HAV (See paragraph on training under HAV). Additionally, skilled workers have a reduced risk of vibration exposure per reference (v).

(2) Work schedules. Supervisors should implement work schedules to limit continuous worker exposure time to vibration hazards, as needed. (See paragraph on work schedules under HAV).

(3) Maintenance. Ensure routine care and maintenance of vehicles to reduce the likelihood of unnecessary vibration exposures (e.g., check the condition of tires and vehicle suspension, ensure proper load for vehicle design and general vehicle maintenance) per reference (v).

(4) Workplace practices. Make efforts to decrease vehicle speed to reduce additional vibration caused by accelerated vehicle movement. When possible, operate vehicles on a smooth surface to reduce vibration (e.g., level gravel or dirt). Vehicle drivers should sit in a neutral and upright position. Their entire back should be in contact with the backrest and lumbar support. Their heads should rest against the headrest to maintain support and reduce vibration and potential motion sickness per reference (k).

b. Engineering controls.

(1) Workstation design and equipment selection. Control heavy equipment exposures can by evaluating workstation design and equipment selection. When applicable, introduce the use of seat/cabin suspensions (See paragraphs on workstation design and equipment selection under HAV) per reference (v).

c. Personal protective equipment.

(1) If temperatures require the use of warm clothing and gloves during potential WBV exposure, ensure that they are assessed for a good fit, insulation, and ability to keep moisture away from the body.

9. Medical surveillance

a. Implementing a Medical Surveillance (MS) program is critical due to the severity and irreversible effects of vibration exposure and can be used to monitor and evaluate the effectiveness of mitigation programs. Medical surveillance is needed when exposures at/or above the action level of 2.5 m/s^2 occur 30 days or more per year, when there is a clear link between vibration exposure and notable adverse health effects, and there is a high risk of adverse health effects related to vibration exposure in the workplace per reference (j).

b. The MS program should include a preplacement examination of all new workers and an initial examination of all current workers exposed to vibration. Documentation of work histories should consist of any prior exposure to HAV and WBV. It is vital to maintain a longitudinal record of medical records and work histories for all Navy personnel exposed to a vibration hazard. The industrial hygienist will utilize DOEHRS-IH to document vibration exposure and the need for MS Workers should consult their medical provider if they experience prolonged symptoms related to vibration exposure. In addition, occupational health physicians should be trained in the clinical examination and identification of vibration syndrome.

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