HAND–ARM VIBRATION

TLVs

The TLVs shown in Table 1 refer to component acceleration levels and durations of exposure that represent conditions under which it is believed that nearly all workers may be exposed repeatedly without progressing beyond Stage 1 of the Stockholm Workshop Classification System for Vibration-induced White Finger (VWF), also known as Raynaud's Phenomenon of Occupational Origin (Table 2). Since there is a paucity of dose–response relationships for hand–arm vibration syndrome (HAVS), these recommendations have been derived mainly from epidemiological data from forestry, mining, and metal-working occupations. These values should be used as guides in the control of hand–arm vibration exposure; because of individual susceptibility, they should not be regarded as defining a boundary between safe and dangerous levels.

It should be recognized that control of hand–arm vibration syndrome (HAVS) from the workplace cannot occur simply by specifying and adhering to a given TLV. The use of 1) antivibration tools, 2) antivibration gloves, 3) proper work practices that keep the worker's hands and remaining body warm and also minimize the vibration coupling between the worker and the vibration tool are necessary to minimize vibration exposure, and 4) a conscientiously applied medical surveillance program are ALL necessary to rid HAVS from the workplace.

TABLE 1. TLVs for Exposure of the Hand to Vibration in Either X_h, Y_h, or Z_h Directions

Total Daily Exposure Duration[A]	Values of the Dominant,[B] Frequency-Weighted, RMS, Component Acceleration Which Shall Not Be Exceeded a_K, (a_{Keq})	
	m/s^2	g[C]
4 hours and < 8	4	0.40
2 hours and < 4	6	0.61
1 hours and < 2	8	0.81
< 1 hour	12	1.22

[A] The total time vibration enters the hand per day, whether continuously or intermittently.
[B] Usually one axis of vibration is dominant over the remaining two axes. If one or more vibration axes exceed the Total Daily Exposure, then the TLV has been exceeded.
[C] $g = 9.81\ m/s^2$.

Notes for Table 1

1. The weighting network provided in Figure 1 is considered the best available frequency weight acceleration components. However, studies suggest that the frequency weighting at higher frequencies (above 16 Hz) may not incorporate a sufficient safety factor, and caution must be applied when tools with high-frequency components are used.[(1–7)]
2. Acute exposures to frequency-weighted, root-mean-square (rms), component accelerations in excess of the TLVs for infrequent periods of time (e.g., 1 day per week or several days over a 2-week period) are not necessarily more harmful.[(4,5–8)]
3. Acute exposures to frequency-weighted, rms, component accelerations of three times the magnitude of the TLVs are expected to result in the same health effects after between 5 and 6 years of exposure.[(6,8)]
4. To moderate the adverse effects of vibration exposure, workers should be advised to avoid continuous vibration exposure by cessation of vibration exposure of approximately 10 minutes per continuous vibration hour.[(3–6,9–11)]
5. Good work practices should be used and should include instructing workers to employ a minimum

TABLE 2. Stockholm Workshop HAVS Classification System for Cold-induced Peripheral Vascular and Sensorineural Symptoms

Vascular Assessment

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

Note: Separate staging is made for each hand, e.g., 2L(2)/1R(1) = Stage 2 on left hand in 2 fingers; Stage 1 on right hand in 1 finger.

Sensorineural Assessment

Stage	Symptoms
0SN	Exposed to vibration but no symptoms
1SN	Intermittent numbness, with or without tingling
2SN	Intermittent or persistent numbness, reducing sensory perception
3SN	Intermittent or persistent numbness, reducing tactile discrimination and/or manipulative dexterity

Note: Separate staging is made for each hand

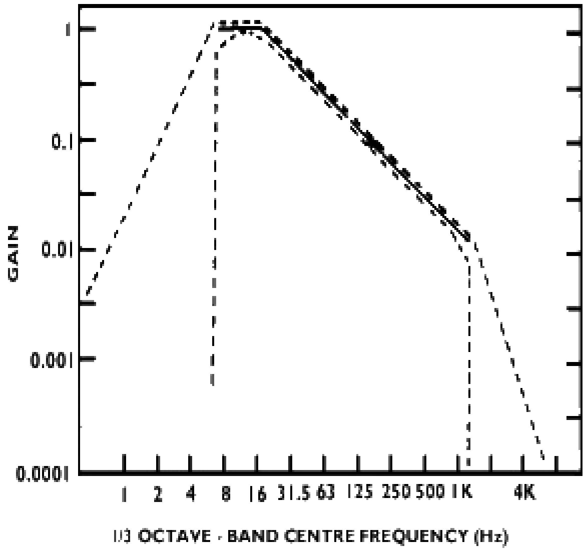

FIGURE 1. Gain characteristics on the filter network used to frequency-weight acceleration components (continuous line). The filter tolerances (dashed lines) are those contained in ISO 5349 and ANSI S3.34-1986.

hand grip force consistent with safe operation of the power tool or process, to keep the body and hands warm and dry, to avoid smoking, and to use antivibration tools and gloves when possible. As a general rule, gloves are more effective for damping vibration at high frequencies.(4–6)

6. A vibration measurement transducer, together with its device for attachment to the vibration source, should weigh less than 15 grams and should possess a cross-axis sensitivity of less than 10%.(4–6,9–11)
7. The measurement by many (mechanically underdamped) piezoelectric accelerometers of repetitive, large displacement, impulsive vibrations, such as those produced by percussive pneumatic tools, is subject to error. The insertion of a suitable, low-pass, mechanical filter between the accelerometer and the source of vibration with a cutoff frequency of 1500 Hz or greater (and cross-axis sensitivity of less than 10%) can help eliminate incorrect readings.
8. The manufacturer and type number of all apparatus used to measure vibration should be reported, as well as the value of the dominant direction and frequency-weighted, rms, component acceleration.(3,5,6,12,13)

Continuous, Intermittent, Impulsive, or Impact Hand–Arm Vibration

The measurement of vibration should be performed in accordance with the procedures and instrumentation specified by ISO 5349 (1986)(14) or ANSI S3.34-1986(15) and summarized below.

The acceleration of a vibration handle or work piece should be determined in three mutually orthogonal directions at a point close to where vibration enters the hand. The directions should preferably be those forming the biodynamic coordinate system but may be a closely related basicentric system with its origin at the interface between the hand and the vibrating surface (Figure 2) to accommodate different handle or work piece configurations. A small and lightweight transducer should be mounted so as to accurately record one or more orthogonal components of the source vibration in the frequency range from 5 to 1500 Hz. Each component should be frequency-weighted by a filter network with gain characteristics specified for human-response vibration measuring instrumentation, to account for the change in vibration hazard with frequency (Figure 1).

Assessment of vibration exposure should be made for EACH applicable direction (X_h, Y_h, Z_h) since vibration is a vector quantity (magnitude and direction). In each direction, the magnitude of the vibration during normal operation of the power tool, machine, or work piece should be expressed by the rms value of the frequency-weighted component accelerations, in units of meters per second squared (m/s^2), or gravitational units (g), the largest of which, a_K, forms the basis for exposure assessment.

For each direction being measured, linear integration should be employed for vibrations that are of extremely short duration or vary substantially in time. If the total daily vibration exposure in a given direction is composed of several exposures at different RMS accelerations, then the equivalent, frequency-weighted component acceleration in that direction should be determined in accordance with the following equation:

$$(a_{K_{eq}}) = \left[\frac{1}{T}\sum_{i=1}^{n}(a_{K_1})^2 T_i\right]^{1/2}$$

$$= \sqrt{(a_{K_1})^2 \frac{T_1}{T} + (a_{K_2})^2 \frac{T_2}{T} + \cdots (a_{K_n})^2 \frac{T_n}{T}}$$

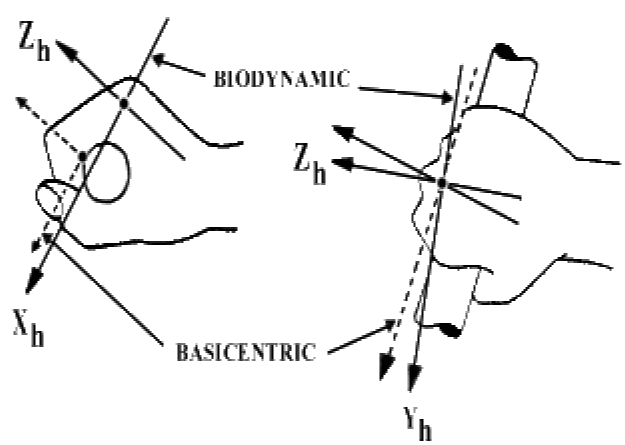

FIGURE 2. Biodynamic and basicentric coordinate systems for the hand, showing the directions of the acceleration components (ISO 5349 and ANSI S3.34–1986).

where: $T = \sum_{i=1}^{n} T_i$

T = total daily exposure duration

a_{Ki} = *ith* frequency-weighted, rms acceleration component with duration T_i

These computations may be performed by commercially available human-response vibration measuring instruments.

DOCUMENTATION

Introduction

In the United States, an estimated 8 million workers were exposed to occupational vibration. About 1 million were exposed to "hand–arm vibration" from hand-held vibratory tools,[16] such as pneumatic impact and rotary tools, gasoline-powered chainsaws, and electrical tools such as grinders.

Since the beginning of the 20th century, hand–arm vibration arising from the use of hand-held vibratory tools has been known to give rise to a condition known as hand–arm vibration syndrome (HAVS), also known as Raynaud's Phenomenon of Occupational Origin, vibration white finger (VWF), or dead finger/hand. In U.S. industry, a substantial prevalence of HAVS[9] has been associated with the use of pneumatic tools,[5] gasoline-powered chainsaws in forestry,[4–6] and with electrically driven, rotating tools in grinding.[4–6] In these industrial situations, HAVS attacks on a worker's fingers appeared to last 0.5 to 1 hour and were induced by exposure to cold, usually in a damp working environment and mainly in the winter. During these attacks, the fingers were numb (sensory loss) and blanched; with the return of circulation, pain was usually experienced. The number and severity of the blanching attacks increased with increasing vibration exposure time. In advanced cases, the attacks occurred in the summer as well as in the winter. With prolonged and continuous use of certain hand-held vibratory tools, ulceration of the terminal phalanges and skin and tissue necrosis (gangrene) has eventually occurred.

White finger unrelated to vibration appears to have occurred normally in the community at a 6% to 8% prevalence.[4–6] This condition was first described by Maurice Raynaud in 1862[17] and has been known as Primary Raynaud's Disease or constitutional cold finger, emphasizing a hereditary factor in the etiology. White finger has also been associated with one or more of the following disease categories: connective tissue diseases; trauma lacerations and fractures of the hands or fingers; neurovascular compression; occlusive vascular disease dysglobulinemias; drug intoxication; neurogenic disorders; and thoracic outlet and shoulder girdle compression syndromes. Vinyl chloride exposures, at concentrations 100 or more times the TLV–TWA, have also been associated with white fingers (see TLV Documentation for Vinyl chloride). In work situations where hand-held vibratory tools are in use, all efforts should be made to exclude the above medical conditions and Primary Raynaud's Disease in the differential diagnosis. This would allow a degree of certainty in the diagnosis of pure cases of HAVS of occupational origin. In advanced cases of HAVS, irreversible changes occurred in the digital arteries of the fingers, producing a decrease in lumen and a reduction in blood supply.[18]

Background

As early as 1918, studies of Raynaud's Phenomenon in the U.S. were reported among stone cutters[19,20] using vibrating hand tools and were further studied by Hamilton,[21] Rothstein,[22] Edsall,[23] and Leake.[24] Very few studies in the U.S. were reported until 1946 when Dart[25] described the effects of vibrating hand tools on 112 workers in the aircraft industry. He noticed these workers complained of pain, swelling, and increased vascular tone in the hands as well as tenosynovitis. Once again, there was an absence of occupational vibration studies in North America until the early 1960s when Ashe et al.[26] and Ashe and Williams[27] reported that Raynaud's Phenomenon had been clinically diagnosed in Canadian hardrock miners. Surprisingly, however, Pecora[28] conducted a questionnaire survey at the same time in the United States and concluded that HAVS in the U.S. "... may have become an uncommon occupational disease approaching extinction."

The lack of occupational hand–arm vibration studies in the U.S. continued until 1974 when the U.S. National Institute for Occupational Safety and Health (NIOSH) vibration studies group reported that there were an estimated 8 million workers exposed to occupational vibration in U.S. industries.[16] These estimates were based on a 40-worksite survey from the multiplicity of U.S. industries. Also in 1974, Williams, who had collaborated with Ashe in the early 1960s, and Byrne completed a study for NIOSH.[29] This study was an attempt to determine the quality, quantity, and availability of suitable HAVS health records from which NIOSH might later conduct extensive epidemiological studies. Although this study was not exhaustive, the results indicated that of the sparse, suitable records available for an epidemiological HAVS study in the U.S., the records of those companies employing workers who almost exclusively use hand tools were the best. Particularly disturbing, however, were Williams'[29] reports of informal talks with some workers whose hands appeared blanched. Many of these workers told him that they knew they had Raynaud's Phenomenon, but they lived with it and tolerated it because they feared loss of employment should they report the malady.

During the period 1978–1980, NIOSH conducted a series of on-site epidemiological, medical, and engineering field studies[9,12,30] of pneumatic chipping and grinding hand tool workers in foundries and a shipyard. The results indicated a 47% prevalence of HAVS (2-year mean latent period) in foundries and 19% (16.8-year mean latent period) in the shipyard.[9] Vibration acceleration levels approaching 2400 g_{rms} on the chipping hammer chisels and 30 g_{rms} on chipping hammer handles were measured.[12] Thus, it appeared that Pecora's[28] claim that HAVS was approaching extinction in the U.S. was incorrect.

Assessment

To estimate the severity of the white finger condition, a grading system was developed by Taylor and Pelmear.[4] Based on a questionnaire, occupational health history, history of social impairment (as a direct consequence of HAVS), and the degree of interference with hobbies, the white finger sufferer is placed into one of the categories listed in Table 3.

As vibration exposure time increases, the number of HAVS attacks has also tended to increase. At first, the attacks occurred mainly in the winter, especially during the early morning while performing domestic chores at home, when exposed to the elements on the way to work (e.g., driving a motorcycle or touching a cold steering wheel), or during morning rest periods at work. Employees working outside in all seasons (e.g., forestry workers) appeared to be most prone to early morning attacks. Workers have reported interference with leisure activities such as gardening, fishing, bathing, car washing, car maintenance, or woodworking. All of these activities had one common factor: a reduced environmental temperature that triggered or initiated an attack of HAVS.

The first signs of the phenomenon were intermittent tingling and/or numbness in the fingers. In Stage 1, the blanching process began in one or more fingertips with no interference with activities. In Stage 2, blanching continued, usually with numbness, and there was a limitation of activities and hobbies. In Stage 3, there was extensive blanching in both summer and winter with a definite cessation of hobbies and interference with work particularly in outside jobs (forestry), especially in winter; difficulty in undertaking fine work such as electronics; difficulty in handling and picking up small coins; difficulty in doing and undoing items of clothing (buttons); and clumsiness of the fingers with increasing stiffness of the finger joints. In the final grading (Stage 4), the severity of the HAVS and the interference with work, social activities, and hobbies was such that the subject changed his or her occupation. The fingers were extensively blanched and, in some instances, were beginning to approach tissue necrosis (gangrene) and acrocyanosis.

TABLE 3. Stage Assessment for Vibration-Induced White Finger (Taylor–Pelmear Classification System, 1975)

Stage	Condition of Digits	Work and Social Interference
OO	No tingling, numbness, or blanching of digits	No complaints
OT	Intermittent tingling	No interference with activities
ON	Intermittent numbness	No interference with activities
OTN	Intermittent tingling and numbness	No interference with activities
01	Blanching of one or more fingertips with or without tingling and numbness	No interference with activities
02	Blanching of fingers beyond tips, usually confined to winter	Slight interference with home and social activities; no interference at work
03	Extensive blanching of digits; frequent episodes in summer as well as in winter	Definite interference at work, at home, and with social activities; restriction of hobbies
04	Extensive blanching of most fingers; frequent episodes in summer and in winter	Occupation changed to avoid further vibration exposure because of severity of signs and symptoms

The above sequence of increasing stages arose from the cumulative effect of vibration transmitted to the hands from the regular, prolonged use of vibrating tools found in certain processes of industry. The length of the initial symptom-free period of vibration exposure (i.e., from first vibration exposure to the first appearance of a white fingertip) has been known as the "Latent Period." It has been related to the intensity of the vibration exposure; the shorter the latent period, the more severe the resulting HAVS if vibration exposure continues. The Taylor–Pelmear system was replaced by the Stockholm Workshop HAVS Classification System used in this TLV, (Table 2) in recognition that the neurological and peripheral vascular components of HAVS may develop independently.[31]

Despite a considerable amount of research, little was known about how white finger attacks were caused. In the severest forms, there were advanced changes in the arteries of the fingers. Neither was it known with precision, what vibration parameters were responsible for the resulting vibration-induced white fingers.

Control of HAVS from the Workplace

Control of HAVS in the workplace cannot occur simply by specifying and adhering to a given TLV. The use of all of the following is recommended:[3,10,11,32]

1. Workers should use antivibration tools together with antivibration gloves
2. Workers should adhere to the work code of practice (given below).
3. Each worksite is advised to have a conscientiously applied medical surveillance program with personnel trained in HAVS detection and practices.
4. TLVs and standards should be used.

In an effort to alleviate the HAVS problem, one tool type (gasoline-powered chainsaw) was redesigned using special antivibration (A/V) mounted handles that significantly reduced acceleration levels. This resulted in a falling prevalence of HAVS in vibration-exposed populations in at least two countries (England and Sweden).

Several A/V glove designs were available.[3,10,11,32] A study of their effectiveness in controlling and reducing vibration impinging upon workers' hands and fingers was not done extensively.

In an effort to inform occupational hygienists, doctors, nurses, etc., of the HAVS problem, NIOSH prepared Current Intelligence Bulletin No. 38 and a 30-minute videotape (No. 177); both are entitled "Vibration Syndrome."[10]

Recommended Code of Work Practices[3,10,11,32]

1. Define the vibratory tool areas within the worksite.
2. Determine vibration exposure times and introduce work breaks to avoid constant, continued vibration exposure.
3. If possible, measure the vibration levels of tools to obtain dosage data.
4. Clinically monitor the progress of HAVS deterioration in a vibration-exposed population where HAVS is already established. Monitoring should include measuring the severity and number of increasing attacks and occurrences in summer as well as in winter. Remove those workers with moderate to severe HAVS symptomatology from further vibration exposure.
5. Through a specialized preplacement medical examination, exclude those workers with a previous history of blood circulation abnormalities (in particular, Primary Raynaud's Disease) prior to employment using hand-held, vibratory tools. Continue these specialized medical examinations on an annual basis for exposed workers.
6. The use of multiple pairs of warm A/V gloves by workers is recommended, especially where workers use vibratory tools in cold environments. Do not allow hands to become chilled. Gloves not only keep the hands warm but also reduce callus formation and prevent hand lacerations. Antivibration gloves are recommended because conventional gloves serve to filter out only some of the higher vibration frequencies (depending on the glove material design) and not the lower frequencies where much of the energy usually occurs.
7. Reduce smoking while using vibrating hand tools.
8. Let the tool do the work by grasping it as lightly as possible, consistent with safe work practices. Rest the tool on a support or the workpiece as much as possible. Operate the tool only when necessary and at minimum speed (and impact force) to reduce vibration exposure.
9. If workers develop symptoms of tingling or numbness, or signs of white or blue fingers, they should promptly be examined by a physician knowledgeable about HAVS.
10. Encourage vibrating hand-tool manufacturers to add vibration damping and isolation devices to present and/or future products.
11. Warnings should be placed on vibrating tools.

Recommendation

Historically, because of the paucity of workplace information, standards and guidelines for hand–arm vibration were based principally on subjective data (numbness, pain, discomfort, etc.) and not pathology.[3,7]

Based upon the work of Brammer, Taylor, and others,[4–6,8] the TLVs given in Table 1 provide combinations of frequency-weighted, rms, component accelerations, and durations of exposure to which it is believed nearly all persons may be repeatedly exposed without persistent adverse health effects. They are based on epidemiological studies of workers occupationally exposed to vibration and on extensive clinical experience in the forestry, metalworking, and mining industries. The values should be used only as guides in the control of vibration exposure and should not be regarded as defining fine lines between safe and hazardous exposures, because of the following:

1. Factors influencing source intensity and exposure duration (e.g., work practices, operator skill, tool maintenance).
2. The degree of mechanical coupling between the source of vibration and the hands, which is influenced by hand gripforce and push or pull forces and work practices.
3. Individual susceptibility to HAVS, which is affected by predisposing disease and prior injury to the fingers.
4. Tool design and type.

All tools exhibit their own characteristic "fingerprints" or vibration spectra. It has been found that the weighting network provided in Figure 1 is considered effective when the worker uses tools whose vibration spectra contain principally lower frequencies. However, recent studies suggest that the frequency weighting (above 16 Hz) may not incorporate a sufficient safety factor, and caution must be applied when tools with high-frequency components are used (e.g., high-speed grinders, etc.).[1,2]

Additional Guidelines

In addition to this TLV, there are two "consensus" standards for HAVS. These are the International Standards Organization (ISO) 5349[33] and the American National Standards Institute (ANSI) S3.34-1986.[34] In 1989, NIOSH published recommendations for an occupational hand–arm vibration standard.[11]

The TLV, the ISO 5349, and the ANSI S3.34 all utilize the "weighting" curve shapes shown in Figure 2. The NIOSH criteria document does not utilize this weighting curve; rather, NIOSH chose to recommend "medical monitoring" as the basis of its document with the recommendation that both weighted and unweighted triaxial vibration measurements be made and correlated with the medical findings. NIOSH chose not to recommend an exposure limit until more epidemiological or medical data are published.[11]

History of the Hand Arm Vibration TLVs

See Table 4.

TABLE 4. History of the HAV TLVs

1984: *Proposed*	Dominant axis, frequency-weighted, rms acceleration: 4 – 8 hours: 4 M/s^2 2 – 4 hours: 6 M/s^2 1 – 2 hours: 8 M/s^2 < 1 hour: 12 M/s^2
1986: Adopted	
1990: *Proposed*	
1992: Adopted	Revised text
1996: Revised	Removed TLV table note regarding medical examinations

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