ERGONOMICS

Ergonomics is the term applied to the field that studies and designs the human–machine interface to prevent illness and injury and to improve work performance. It attempts to ensure that jobs and work tasks are designed to be compatible with the capabilities of the workers. ACGIH® recognizes that some physical agents play an important role in ergonomics. Force and acceleration are addressed, in part, in the Hand–Arm Vibration (HAV) and Whole-Body Vibration (WBV) TLVs®. Thermal factors are addressed, in part, in the TLVs® for Thermal Stress. Force is also an important causal agent in injuries from lifting. Other important ergonomic considerations include work duration, repetition, contact stresses, postures, and psychosocial issues.

STATEMENT ON WORK-RELATED MUSCULOSKELETAL DISORDERS

ACGIH® recognizes work-related musculoskeletal disorders (MSDs) as an important occupational health problem that can be managed using an ergonomics health and safety program. The term musculoskeletal disorders refers to chronic muscle, tendon, and nerve disorders caused by repetitive exertions, rapid motions, high forces, contact stresses, extreme postures, vibration, and/or low temperatures. Other commonly used terms for work-related musculoskeletal disorders include cumulative trauma disorders (CTDs), repetitive motion illnesses (RMIs), and repetitive strain injuries (RSIs). Some of these disorders fit established diagnostic criteria such as carpal tunnel syndrome or tendinitis. Other musculoskeletal disorders may be manifested by nonspecific pain. Some transient discomfort is a normal consequence of work and is unavoidable, but discomfort that persists from day to day or interferes with activities of work or daily living should not be considered an acceptable outcome of work.

Control Strategies

The incidence and severity of MSDs are best controlled by an integrated ergonomics program. Major program elements include:

- Recognition of the problem,
- Evaluation of suspected jobs for possible risk factors,
- Identification and evaluation of causative factors,
- Involvement of workers as fully informed active participants, and
- Appropriate health care for workers who have developed musculoskeletal disorders.

General programmatic controls should be implemented when risk of MSDs is recognized. These include:

- Education of workers, supervisors, engineers, and managers;
- Early reporting of symptoms by workers; and
- Ongoing surveillance and evaluation of injury, health and medical data.

Job-specific controls are directed to individual jobs associated with MSDs. These include engineering controls and administrative controls. Personal protection may be appropriate under some limited circumstances.

Among engineering controls to eliminate or reduce risk factors from the job, the following may be considered:

- Using work methods engineering, e.g., time study, motion analysis, to eliminate unnecessary motions and exertions.
- Using mechanical assists to eliminate or reduce exertions required to hold tools and work objects.
- Selecting or designing tools that reduce force requirements, reduce holding time, and improve postures.
- Providing user-adjustable workstations that reduce reaching and improve postures.
- Implementing quality control and maintenance programs that reduce unnecessary forces and exertions, especially associated with nonvalue-added work.

Administrative controls reduce risk through reduction of exposure time and sharing the exposure among a larger group of workers. Examples include:

- Implementing work standards that permit workers to pause or stretch as necessary but at least once per hour.
- Re-allocating work assignments (e.g., using worker rotation or work enlargement) so that a worker does not spend an entire work shift performing high-demand tasks.

Due to the complex nature of musculoskeletal disorders, there is no "one size fits all" approach to reducing the incidence and severity of cases. The following principles apply to selecting actions:

- Appropriate engineering and administrative controls will vary from industry to industry and company to company.
- Informed professional judgment is required to select the appropriate control measures.
- Work-related MSDs typically require periods of weeks to months for recovery. Control measures should be evaluated accordingly to determine their effectiveness.

Nonoccupational Factors

It is not possible to eliminate all musculoskeletal disorders via engineering and administrative controls. There are individual and organizational factors that may influence the likelihood that an individual will experience musculoskeletal disorders. Some cases may be associated with nonoccupational factors such as:

- Rheumatoid arthritis
- Endocrinological disorders
- Acute trauma
- Obesity
- Pregnancy
- Age
- Gender

- Level of physical condition
- Previous injuries
- Diabetes
- Recreational/leisure activities

The recommended TLV® may not provide protection for people with these conditions and/or exposures. Engineering and administrative actions can help eliminate ergonomic barriers for persons with predisposing conditions and thus help to minimize disability.

Chronology of the Statement

1995: *Proposed* "Lifting Statement"
1996: Adopted with name change to "Musculoskeletal Statement"
2000: Editorial changes
2004: Editorial changes

HAND ACTIVITY LEVEL

Although work-related musculoskeletal disorders can occur in a number of body regions (including the shoulders, neck, low back, and lower extremities), the focus of this TLV® is on the hand, wrist, and forearm.

The TLV® shown in Figure 1 is based on epidemiological, psychophysical, and biomechanical studies and is intended for "mono-task" jobs performed for four or more hours per day. A mono-task job involves performing a similar set of motions or exertions repeatedly, such as working on an assembly line or using a keyboard and mouse. The TLV® specifically considers average hand activity level or "HAL" and peak hand force and represents conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects.

HAL is based on the frequency of hand exertions and the duty cycle (distribution of work and recovery periods). HAL can be determined by trained observers based on exertion frequency, rest pauses and speed of motion using the rating scale shown in Figure 2. HAL also can be calculated from an analysis of the work method, force, and posture using information on hand exertion frequency and on duty cycle (work time/(work + rest time)) x 100% as described in Table 1 and in the *Documentation*.

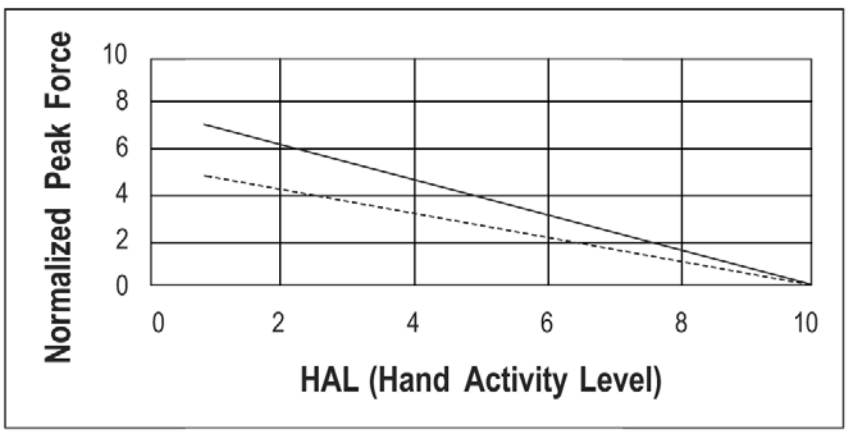

FIGURE 1. The TLV® for reduction of work-related musculoskeletal disorders based on "hand activity" or "HAL" and peak hand force. The top line depicts the TLV®. The bottom line is an Action Limit for which general controls are recommended.

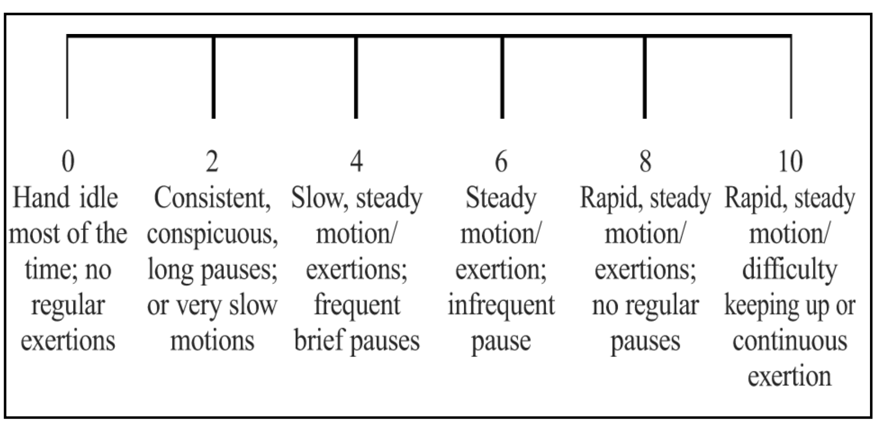

FIGURE 2. Hand Activity Level (0 to 10) can be rated using the above guidelines.

TABLE 1. Hand Activity Level (0 to 10) is Related to Exertion Frequency and Duty Cycle (% of work cycle where force is greater than 5% of maximum)

		Duty Cycle (%)				
Frequency (exertion/s)	Period (s/exertion)	0–20	20–40	40–60	60–80	80–100
0.125	8.0	1	1	—	—	—
0.25	4.0	2	2	3	—	—
0.5	2.0	3	4	5	5	6
1.0	1.0	4	5	5	6	7
2.0	0.5	—	5	6	7	8

Notes:

1. Round HAL values to the nearest whole number.
2. Use Figure 2 to obtain HAL values outside those listed in the table.

Peak hand force is the peak force exerted by the hand during each regular work cycle. Peak force can be determined with ratings by a trained observer, rated by workers using a Borg-like scale (see TLV® *Documentation* for definition), or measured using instrumentation, e.g., strain gauges or electromyography. In some cases, it can be calculated using biomechanical methods. These methods are intended to measure recurring peak forces; random force peaks associated with noise that occur less than 10% of the time are disregarded. Peak hand force is normalized on a scale of 0 to 10, which corresponds to 0% to 100% of the posture specific strength for the applicable population (males, females, young, old, office workers, factory workers, etc.):

Normalized Peak Force = (Peak force / Posture specific referent strength) $\times$ 10

The solid line in Figure 1 represents those combinations of force and hand activity level associated with a significantly elevated prevalence of musculoskeletal disorders. Appropriate control measures should be utilized so that the force for a given level of hand activity is below the upper solid line in Figure 1. It is not possible to specify a TLV® that protects all workers in all situations without profoundly affecting work rates. Therefore, an action limit is prescribed at which point general controls, including surveillance, are recommended.

Examples

1. Select a period of the job that represents an average activity. The selected period should include several complete work cycles. Videotapes may be used for documentation purposes and to facilitate rating of the job by others.
2. Rate the Hand Activity Level using the scale shown in Figure 2. Independent rating of jobs and discussion of results by three or more people can help produce a more precise rating than individual ratings.
3. Observe the job to identify forceful exertions and corresponding postures. Evaluate postures and forces using observer ratings, worker ratings, biomechanical analysis, or instrumentation. Normalized peak force is the required peak force divided by the representative maximum force for the posture multiplied by 10.

Consideration of Other Factors

Professional judgment should be used to reduce exposures below the action limits recommended in the HAL TLVs® if one or more of the following factors are present:

- sustained non-neutral postures such as wrist flexion, extension, wrist deviation, or forearm rotation;
- contact stresses;
- low temperatures; or
- vibration.

Employ appropriate control measures any time the TLV® is exceeded or an elevated incidence of work-related musculoskeletal disorders is detected.

LIFTING

These TLVs® recommend workplace lifting conditions under which it is believed nearly all workers may be repeatedly exposed, day after day, without developing work-related low back and shoulder disorders associated with repetitive lifting tasks. There are individual and organizational risk factors that may influence the likelihood that an individual will experience low back and shoulder disorders.

Lifting TLVs®

The TLVs® consist of three tables with weight limits, in kilograms (kg), for two-handed, mono-lifting tasks within 30 degrees of the sagittal [neutral] plane. A mono-lifting task is one in which the loads are similar and the starting and destination points are repeated, and this is the only lifting task performed during the day. Other manual material-handling tasks such as carrying, pushing, and pulling are not accounted for in the TLV®, and care must be exercised in applying the TLVs® under these circumstances.

These TLVs® (Tables 1 through 3) are presented for lifting tasks defined by their durations, either less than or greater than 2 hours per day, and by their frequency, expressed in number of lifts per hour, as qualified in the *Notes* to each table.

In the presence of any factor(s) or working condition(s) listed below, professional judgment should be used to reduce weight limits below those recommended in the TLVs®:

- High-frequency lifting: > 360 lifts per hour.
- Extended work shifts: lifting performed for longer than 8 hours per day.
- High asymmetry: lifting more than 30 degrees away from the sagittal plane.
- Rapid lifting motions and motions with twisting (e.g., from side to side).
- One-handed lifting.
- Constrained lower body posture, such as lifting while seated or kneeling.
- High heat and humidity (*see* Heat Stress and Heat Strain TLVs®).
- Lifting unstable objects (e.g., liquids with shifting center of mass or lack of coordination or equal sharing in multi-person lifts).
- Poor hand coupling: lack of handles, cut-outs, or other grasping points.
- Unstable footing (e.g., inability to support the body with both feet while standing).
- During or immediately after exposure to whole-body vibration at or above the TLV® for Whole-Body Vibration (*see* the current *TLV® Documentation* for Whole-Body Vibration).

Instructions for Users

1. **Read the *Documentation* for the Lifting TLVs®** so you understand the basis for these TLVs® and their limitations.
2. **Classify task duration** as less than or equal to a cumulative 2 hours per day or greater than a cumulative 2 hours per day. Task duration is the total length of time that a worker performs the task in 1 day.

TABLE 1. TLVs® for Lifting Tasks:
≤ 2 Hours per Day with ≤ 60 Lifts per Hour
OR
>2 Hours per Day with ≤ 12 Lifts per Hour

Vertical Zone	Horizontal Zone[A] Close: < 30 cm	Horizontal Zone[A] Inter-mediate: 30 to 60 cm	Horizontal Zone[A] Extended:[B] > 60 to 80 cm
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	16 kg	7 kg	No known safe limit for repetitive lifting[D]
Knuckle height[E] to below shoulder	32 kg	16 kg	9 kg
Middle shin to knuckle height[E]	18 kg	14 kg	7 kg
Floor to middle shin height	14 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]

Footnotes for Tables 1 through 3:

A. Distance from midpoint between inner ankle bones and the load.
B. Lifting tasks should not start or end at a horizontal reach distance more than 80 cm from the midpoint between the inner ankle bones (Figure 1).
C. Routine lifting tasks should not start or end at heights that are greater than 30 cm above the shoulder or more than 180 cm above floor level (Figure 1).
D. Routine lifting tasks should not be performed for shaded table entries marked "No known safe limit for repetitive lifting." While the available evidence does not permit identification of safe weight limits in the shaded regions, professional judgment may be used to determine if infrequent lifts of light weights may be safe.
E. Anatomical landmark for knuckle height assumes the worker is standing erect with arms hanging at the sides.

TABLE 2. TLVs® for Lifting Tasks
>2 Hours per Day with > 12 and ≤ 30 Lifts per Hour
OR
≤ 2 Hours per Day with > 60 and ≤ 360 Lifts per Hour

Vertical Zone	Horizontal Zone[A]		
	Close: < 30 cm	**Inter-mediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	14 kg	5 kg	No known safe limit for repetitive lifting[D]
Knuckle height[E] to below shoulder	27 kg	14 kg	7 kg
Middle shin to knuckle height[E]	16 kg	11 kg	5 kg
Floor to middle shin height	9 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]
See Notes in Table 1.			

TABLE 3. TLVs® for Lifting Tasks
>2 Hours per Day with > 30 and ≤ 360 Lifts per Hour

Vertical Zone	Horizontal Zone[A]		
	Close: < 30 cm	**Inter-mediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] from 30 cm above to 8 cm below shoulder height	11 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]
Knuckle height[E] to below shoulder	14 kg	9 kg	5 kg
Middle shin to knuckle height[E]	9 kg	7 kg	2 kg
Floor to middle shin height	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]
See Notes in Table 1.			

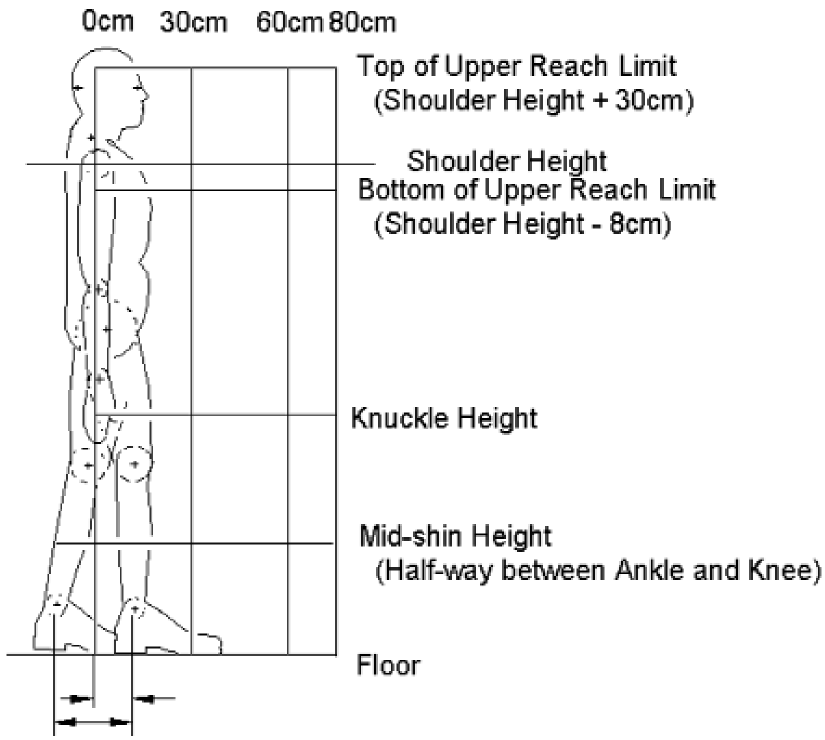

FIGURE 1. Graphic representation of hand location.

3. **Determine the lifting frequency** as the number of lifts a worker performs per hour.
4. **Use the TLV® table that corresponds to the duration and lifting frequency of the task**.
5. **Determine the vertical zone** (Figure 1) based on the location of the hands at the start of the lift.
6. **Determine the horizontal zone of the lift** (Figure 1) by measuring the horizontal distance from the midpoint between the inner ankle bones to the midpoint between the hands at the start of the lift.
7. **Determine the TLV®** in kilograms for the lifting task, as displayed in the table cell that corresponds to the vertical and horizontal zones in the appropriate table, based upon frequency and duration.
8. **Consider load control at destination.** If the load is placed at the destination in a controlled fashion (i.e., slowly or deliberately placed), repeat Steps 5 through 7 using the destination point instead of the start. The TLV® is represented by the lower of the two limits.

HAND–ARM (SEGMENTAL) VIBRATION

The TLVs® 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 VWF, these recommendations have been derived from epidemiological data from forestry, mining, and metal working. 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✩	Values of the Dominant,★ Frequency-Weighted, rms, Component Acceleration Which Shall not be Exceeded a_K,($a_{K_{eq}}$) m/s²	g$^{\Delta}$
4 hours and less than 8	4	0.40
2 hours and less than 4	6	0.61
1 hour and less than 2	8	0.81
less than 1 hour	12	1.22

✩The total time vibration enters the hand per day, whether continuously or intermittently.

★Usually one axis of vibration is dominant over the remaining two axes. If one or more vibration axes exceeds the Total Daily Exposure, then the TLV® has been exceeded.

g^{Δ} = 9.81 m/s².

Notes for Table 1:

1. The weighting network provided in Figure 1 is considered the best available to 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.
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.
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 5 to 6 years of exposure.

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 trophic 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 two fingers: stage 1 on right hand in one 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.

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4. To moderate the adverse effects of vibration exposure, workers should be advised to avoid continuous vibration exposure by cessation of vibration exposure for approximately 10 minutes per continuous vibration hour.
5. Good work practices should be used and should include instructing workers to employ a minimum hand grip force consistent with safe operation of the power tool or process, to keep their 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.
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%.
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 cut-off 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.

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)[1] or ANSI S3.34-1986[2] 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 record accurately 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 root-mean-square (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

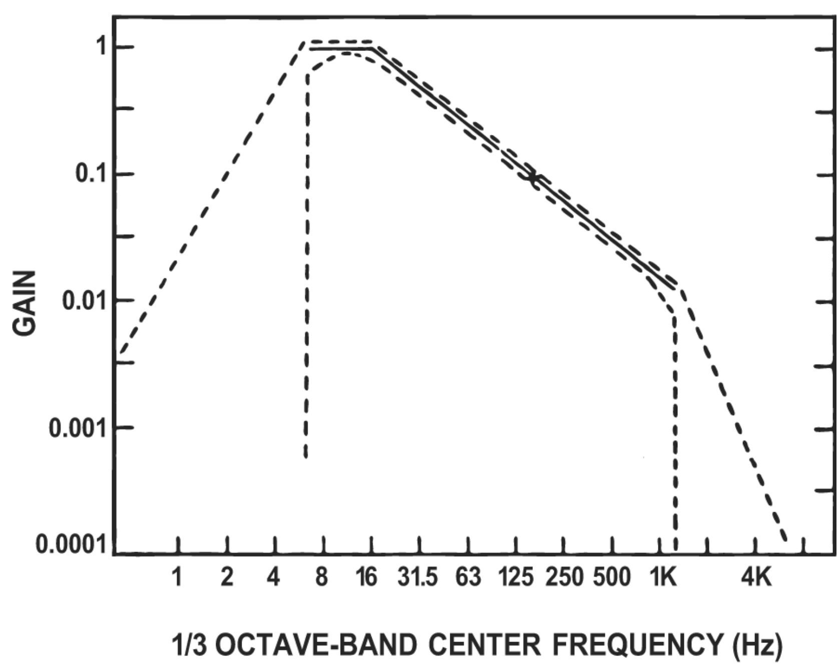

FIGURE 1. Gain characteristics on the filter network used to frequency-weight acceleration components (continuous line). The filter tolerances (dashed lines) are those contained in ISO 5349 and ANSI S3.34-1986.

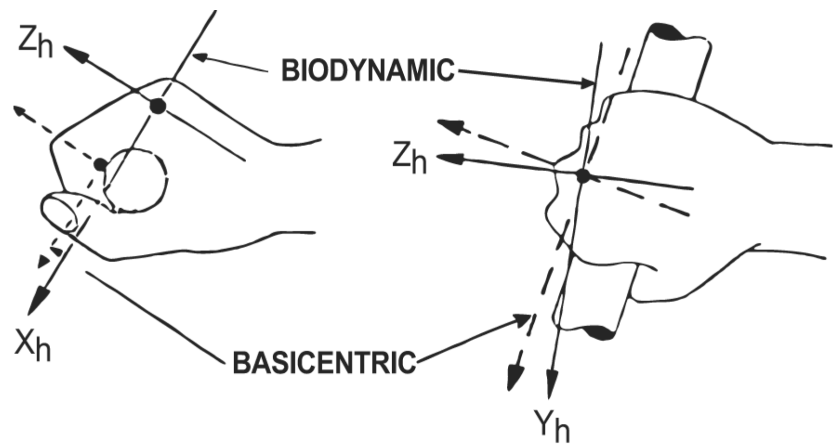

FIGURE 2. Biodynamic and basicentric coordinate systems for the hand, showing the directions of the acceleration components (ISO 5349[1] and ANSI S3.34–1986[2]).

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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:

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

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

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

T = total daily exposure duration

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

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

References

1. International Standards Organization: ISO 5349 (1986): Guide for the Measurement and the Assessment of Human Exposure to Hand Transmitted Vibration. ISO, Geneva (1986).
2. American National Standards Institute: ANSI S3.34-1986: Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand. ANSI, New York (1986).

WHOLE–BODY VIBRATION

The TLVs® in Figures 1 and 2 (tabulated in Tables 1 and 2) refer to mechanically induced whole-body vibration (WBV) acceleration component root-mean-square (rms) magnitudes and durations under which it is believed that nearly all workers may be exposed repeatedly with minimum risk of back pain, adverse health effects to the back, and inability to operate a land-based vehicle properly. The biodynamic coordinate system to which they apply is displayed in Figure 3. These values should be used as guides in the control of WBV exposure, but because of individual susceptibility, they should not be regarded as defining a boundary between safe and dangerous levels.

Notes:

1. Vibration acceleration is a vector with magnitude expressed in units of m/s^2. The gravitational acceleration, g, equals 9.81 m/s^2.
2. Figures 1 and 2 each show a family of daily exposure time–dependent curves. They indicate that human vibration resonance occurs in the 4 to 8 Hz frequency range for the z axis and in the 1 to 2 Hz frequency range for the x and y axes, where the axes are defined in Figure 3.
3. WBV measurements and equivalent exposure time calculations for interrupted exposures, where the rms acceleration levels vary appreciably over time, should be made according to ISO 2631 or ANSI S3.18-1979.[1,2]
4. The TLV® is valid for vibration crest factors of 6 or less. Crest factor is defined as the ratio of peak to rms acceleration, measured in the same direction, over a period of 1 minute for any of the orthogonal x, y, and z axes. The TLV® will underestimate the effects of WBV and must be used with caution when the crest factor exceeds 6.
5. The TLV® is not intended for use in fixed buildings (see ANSI S3.29-1983),[3] in off-shore structures, or in ships.
6. A summary of WBV measurement and data analysis procedures follows:[4]
   a. At each measurement point, three orthogonal, continuous, rms acceleration measurements are simultaneously made and recorded for at least 1 minute along the biodynamic coordinates shown in Figure 3.
   b. Three very light-weight accelerometers, each with a cross-axis sensitivity of less than 10%, are perpendicularly mounted to a light-weight metal cube and placed in the center of a hard rubber disc (per SAE, J1013).[5] The total weight of the disc, cube, accelerometers, and cables should not exceed 10% of the total weight of the object to be measured. Measurements are made by placing the instrumented rubber disc on the top of the driver's seat, under the driver's buttocks, as the vehicle is operated.
   c. For each axis, a $^1/_3$ octave band (1 to 80 Hz), separate Fourier spectrum analysis is required for comparison to Figure 1 or Figure 2, as appropriate.

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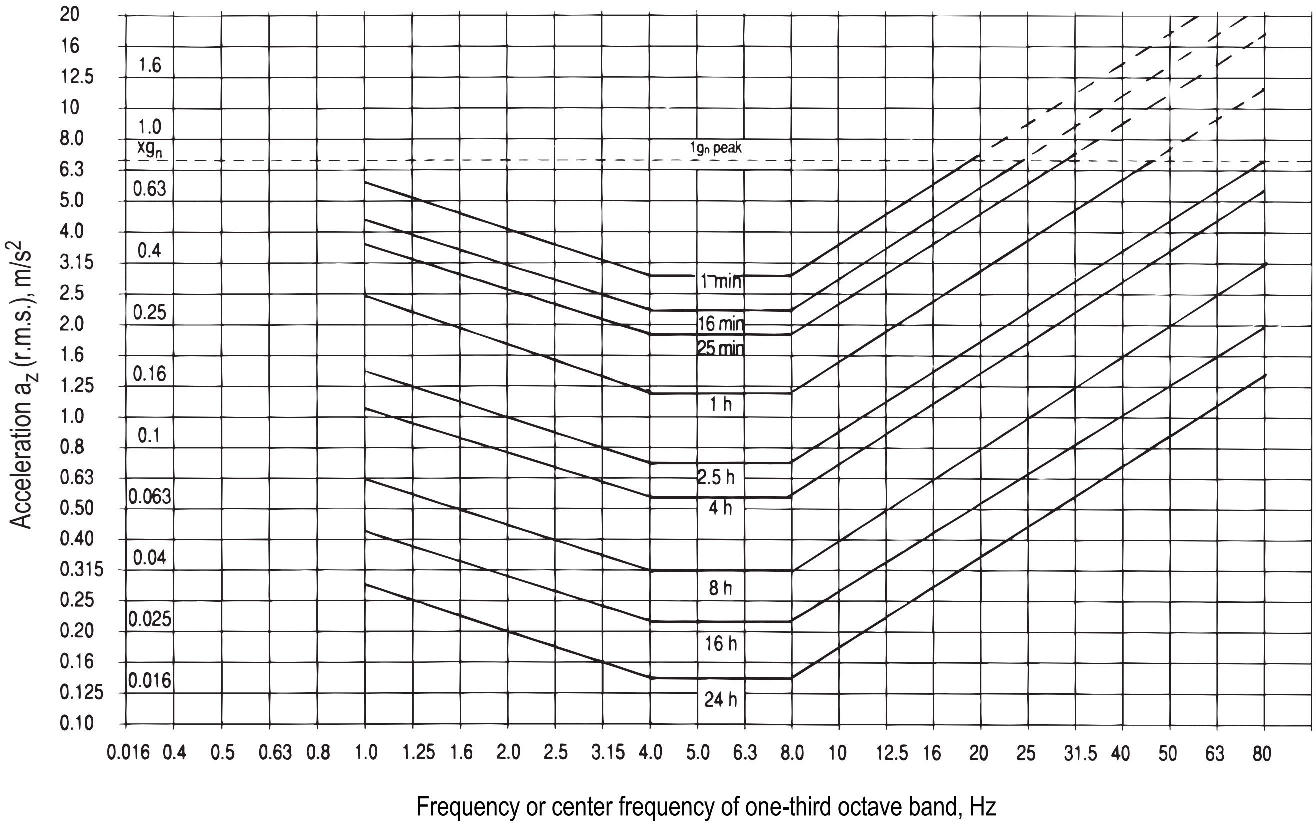

FIGURE 1. Longitudinal (a_z) acceleration TLVs® as a function of frequency and exposure time. Adapted from ISO 2631.[1]

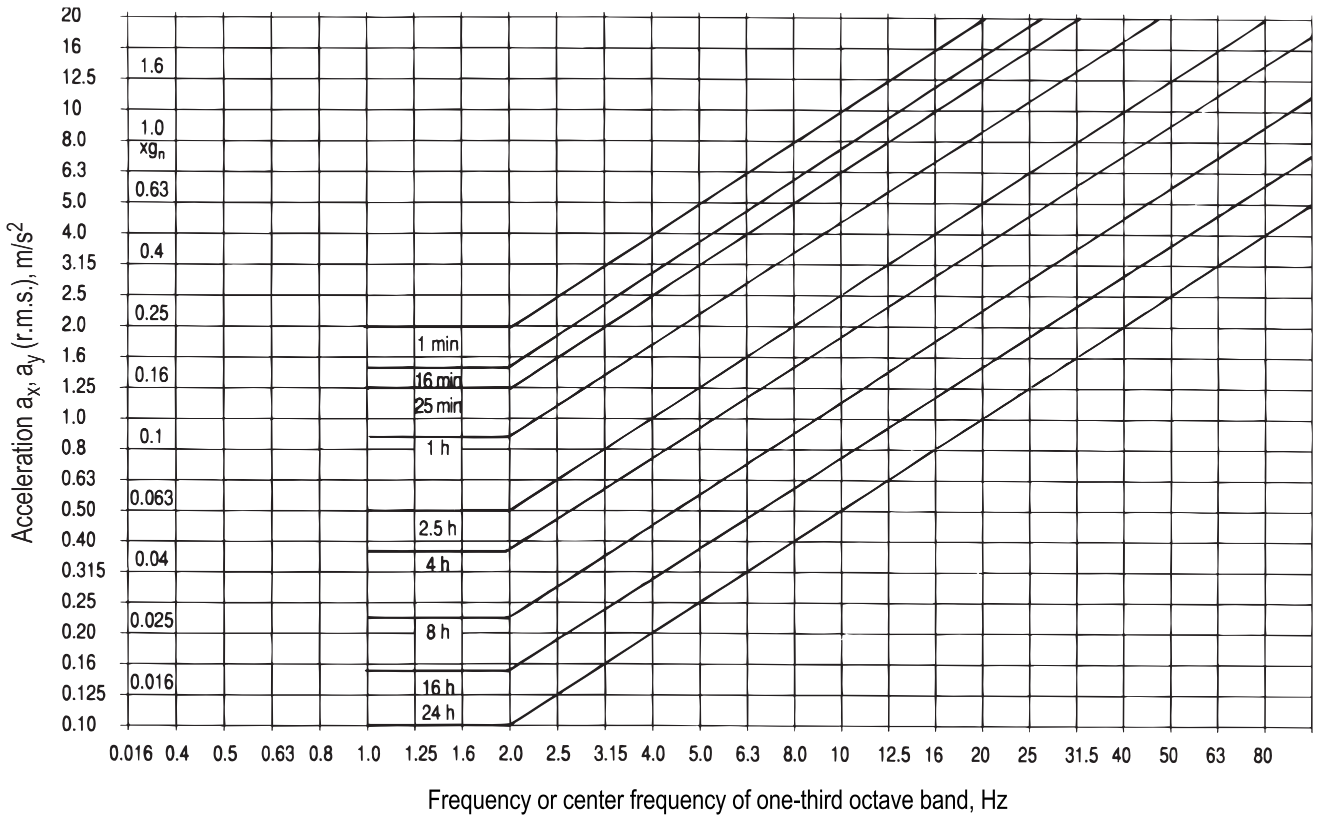

FIGURE 2. Transverse (a_x,a_y) acceleration TLVs® as a function of frequency and exposure time. Adapted from ISO 2631.[1]

TABLE 1. Numerical values for vibration acceleration in the longitudinal, a_z, direction [foot-to-head direction] [see Figure 1]. Values define the TLV® in terms of rms value of pure (sinusoidal) single-frequency vibration or of rms value in one-third-octave band for distributed vibration. (Adapted from ISO 2631)

	Acceleration, m/s²								
Frequency Hz	**Exposure times 24 h**	**16 h**	**8 h**	**4 h**	**2.5 h**	**1 h**	**25 min**	**16 min**	**1 min**
1.0	0.280	0.383	0.63	1.06	1.40	2.36	3.55	4.25	5.60
1.25	0.250	0.338	0.56	0.95	1.26	2.12	3.15	3.75	5.00
1.6	0.224	0.302	0.50	0.85	1.12	1.90	2.80	3.35	4.50
2.0	0.200	0.270	0.45	0.75	1.00	1.70	2.50	3.00	4.00
2.5	0.180	0.239	0.40	0.67	0.90	1.50	2.24	2.65	3.55
3.15	0.160	0.212	0.355	0.60	0.80	1.32	2.00	2.35	3.15
4.0	0.140	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
5.0	0.140	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
6.3	0.140	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
8.0	0.140	0.192	0.315	0.53	0.71	1.18	1.80	2.12	2.80
10.0	0.180	0.239	0.40	0.67	0.90	1.50	2.24	2.65	3.55
12.5	0.224	0.302	0.50	0.85	1.12	1.90	2.80	3.35	4.50
16.0	0.280	0.383	0.63	1.06	1.40	2.36	3.55	4.25	5.60
20.0	0.355	0.477	0.80	1.32	1.80	3.00	4.50	5.30	7.10
25.0	0.450	0.605	1.0	1.70	2.24	3.75	5.60	6.70	9.00
31.5	0.560	0.765	1.25	2.12	2.80	4.75	7.10	8.50	11.2
40.0	0.710	0.955	1.60	2.65	3.55	6.00	9.00	10.6	14.0
50.0	0.900	1.19	2.0	3.35	4.50	7.50	11.2	13.2	18.0
63.0	1.120	1.53	2.5	4.25	5.60	9.50	14.0	17.0	22.4
80.0	1.400	1.91	3.15	5.30	7.10	11.8	18.0	21.2	28.0

TABLE 2. **Numerical values for vibration acceleration in the transverse, a_x or a_y, direction [back-to-chest or side-to-side] [see Figure 2]. Values define the TLV® in terms of rms value of pure (sinusoidal) single-frequency vibration or of rms value in one-third-octave band for distributed vibration. (Adapted from ISO 2631)**

	Acceleration, m/s²								
	Exposure times								
Frequency Hz	24 h	16 h	8 h	4 h	2.5 h	1 h	25 min	16 min	1 min
1.0	0.100	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.0
1.25	0.100	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.0
1.6	0.100	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.0
2.0	0.100	0.135	0.224	0.355	0.50	0.85	1.25	1.50	2.0
2.5	0.125	0.171	0.280	0.450	0.63	1.06	1.6	1.9	2.5
3.15	0.160	0.212	0.355	0.560	0.8	1.32	2.0	2.36	3.15
4.0	0.200	0.270	0.450	0.710	1.0	1.70	2.5	3.0	4.0
5.0	0.250	0.338	0.560	0.900	1.25	2.12	3.15	3.75	5.0
6.3	0.315	0.428	0.710	1.12	1.6	2.65	4.0	4.75	6.3
8.0	0.40	0.54	0.900	1.40	2.0	3.35	5.0	6.0	8.0
10.0	0.50	0.675	1.12	1.80	2.5	4.25	6.3	7.5	10.0
12.5	0.63	0.855	1.40	2.24	3.15	5.30	8.0	9.5	12.5
16.0	0.80	1.06	1.80	2.80	4.0	6.70	10.0	11.8	16.0
20.0	1.00	1.35	2.24	3.55	5.0	8.5	12.5	15.0	20.0
25.0	1.25	1.71	2.80	4.50	6.3	10.6	15.0	19.0	25.0
31.5	1.60	2.12	3.55	5.60	8.0	13.2	20.0	23.6	31.5
40.0	2.00	2.70	4.50	7.10	10.0	17.0	25.0	30.0	40.0
50.0	2.50	3.38	5.60	9.00	12.5	21.2	31.5	37.5	50.0
63.0	3.15	4.28	7.10	11.2	16.0	26.5	40.0	45.7	63.0
80.0	4.00	5.4	9.00	14.0	20.0	33.5	50.0	60.0	80.0

d. If the rms acceleration of any of the spectral peaks equals or exceeds the values shown in Figure 1 or Figure 2 for the relevant time periods, then the TLV® is exceeded for that exposure time. The axis with the highest spectral peak intersecting the curve with the shortest exposure time dominates and determines the permissible exposure.

7. The total-weighted rms acceleration for each axis can be calculated using Equation 1 with the appropriate axis weighting factors taken from Table 3. For the x axis (analogous equations and definitions apply to the y and z axes), the equation is:

$$A_{wx} = \sqrt{\Sigma (W_{fx} A_{fx})^2} \qquad (1)$$

where: A_{wx} = total weighted rms acceleration for the x axis
W_{fx} = weighting factor for the x axis at each 1/3 octave band frequency from 1 to 80 Hz (Table 3)
A_{fx} = rms acceleration value for the x axis spectrum at each 1/3 octave band frequency from 1 to 80 Hz

8. If the vibration axes have similar acceleration magnitudes as determined by Equation 1, the combined motion of all three axes could be greater than any one component and could possibly affect vehicle operator performance.[1,2] Each of the component results determined by Equation 1 may be

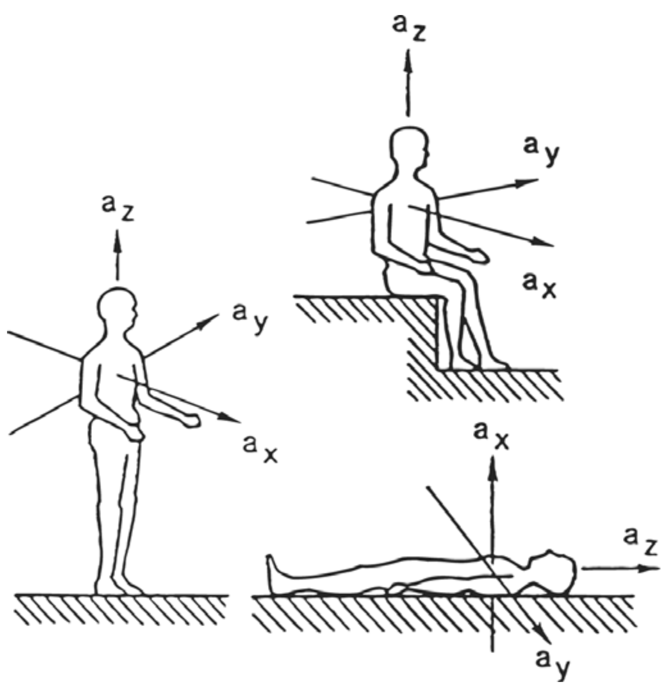

FIGURE 3. Biodynamic coordinate system acceleration measurements (adapted from ISO 2631). a_x, a_y, a_z = acceleration in the direction of the x, y, and z axes; x axis = back-to-chest; y axis = right-to-left; z axis = foot-to-head.

used in Equation 2 to find the resultant, which is the overall weighted total rms acceleration, A_{wt}:

$$A_{wt} = \sqrt{(1.4\,A_{wx})^2 + (1.4\,A_{wy})^2 + (A_{wz})^2} \qquad (2)$$

The factor of 1.4 multiplying the x and y total, weighted rms acceleration values is the ratio of the values of the longitudinal and transverse curves of equal response in the most sensitive human response ranges.

The Commission of the European Communities now recommends 0.5 m/s^2 as an action level for an 8 hour per day overall weighted total rms acceleration. This may be compared with the results of Equation 2.

9. Short-duration, high-amplitude, multiple-vibration shocks may occur with crest factors greater than 6 during the workday, in which cases the TLV® may not be protective (Note 4). Other methods of calculation that include the “4th power concept” may be desirable in these instances.[6]

TABLE 3. Weighting Factors Relative to the Frequency Range of Maximum Acceleration Sensitivity[A] for the Response Curves of Figures 1 and 2 (Adapted from ISO 2631)

	Weighting factor for	
Frequency Hz	Longitudinal z Vibrations [Figure 1]	Transverse x,y Vibrations [Figure 2]
1.0	0.50	1.00
1.25	0.56	1.00
1.6	0.63	1.00
2.0	0.71	1.00
2.5	0.80	0.80
3.15	0.90	0.63
4.0	1.00	0.5
5.0	1.00	0.4
6.3	1.00	0.315
8.0	1.00	0.25
10.0	0.80	0.2
12.5	0.63	0.16
16.0	0.50	0.125
20.0	0.40	0.1
25.0	0.315	0.08
31.5	0.25	0.063
40.0	0.20	0.05
50.0	0.16	0.04
63.0	0.125	0.0315
80.0	0.10	0.025

[A] 4 to 8 Hz in the case of $\pm a_z$ resonance vibration.
1 to 2 Hz in the case of $\pm a_y$ or a_x resonance vibration.

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10. WBV controls may include the use of "air-ride" suspended seats, suspended cabs, maintenance of vehicle suspension systems, proper tire inflation, and remote control of vibrating processes. Seats with arm rests, lumbar support, an adjustable seat back, and an adjustable seat pan are also useful.
11. The following good work practices may also be useful for workers operating vehicles:[7,8]
    a. Avoid lifting or bending immediately following exposure.
    b. Use simple motions, with minimum rotation or twisting, when exiting a vehicle.

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