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Whole-Body Vibration

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Introduction

Whole-body Vibration (WBV) concerns the transfer of relatively low frequency environmental vibration to the human body through a broad contact area. These frequencies are in the range of 0.5 to 80 Hz (ISO, 1). Transmission occurs through the feet when standing, the buttocks when sitting (most common scenario), or the entire body length when reclining in contact with the vibrating surface. WBV exposures exist in many occupational settings.

The body as a whole and individual organs have natural frequencies that can resonate when receiving vibration energy at the natural frequency. Resonance of the body or its parts due to WBV is suspected to cause adverse health effects, primarily with chronic exposure. Presently, most of the evidence supporting this relationship is epidemiological. Direct medical evidence is scarce, especially when compared to the greater amounts of data available for hand-arm vibration (HAV) illnesses that occur at higher frequency ranges. HAV exposures occur with higher vibration frequencies applied to the fingers and hands using powered hand tools, resulting in known adverse health effects such as "white finger" (Janicak, 35).

Standards are available for reference in the US. However, there are no specific regulations mandating identification, monitoring and control of WBV, such as within OSHA standards (OSHA). In Europe, WBV monitoring and exposure limits have been addressed in mandatory standards and directives.

WBV monitoring is somewhat similar to the methodology used for occupational noise. Accelerometers are used in placed of a microphone and recording the direction of vibration waves is critical. WBV is measured as oscillation about a fixed point in m/s^2 and noise energy, rapid variations in air pressure, is measured and recorded in decibels. Measurement of WBV entails the collection of much more data than with noise monitoring, increasing the requirements for sophistication of instruments and methods of data logging.

A survey of US safety and health professionals was conducted in May 2006 to determine knowledge and awareness of WBV. Analysis of the data revealed a relatively low knowledge of the topic. Of those responding to the survey, 69.5% self-reported less than a basic understanding of WBV (Paschold, 56).

Many positive steps can be undertaken to eliminate or reduce harmful WBV exposure. These methods can include engineering re-design, procedural changes, or employee training. However, before these corrective actions can be undertaken, identification and assessment of WBV exposure is needed.

Basics of Vibration

WBV is caused by the transmission of environmental vibration waves to the human body. A wave in its simplest form is depicted in Figure 1. Frequency is characterized by wavelength and displacement (power) by amplitude. In reality, we not normally exposed to a vibration of a pure simple single wave; exposures are to a multitude of simultaneous waves of differing frequency, magnitude and direction.

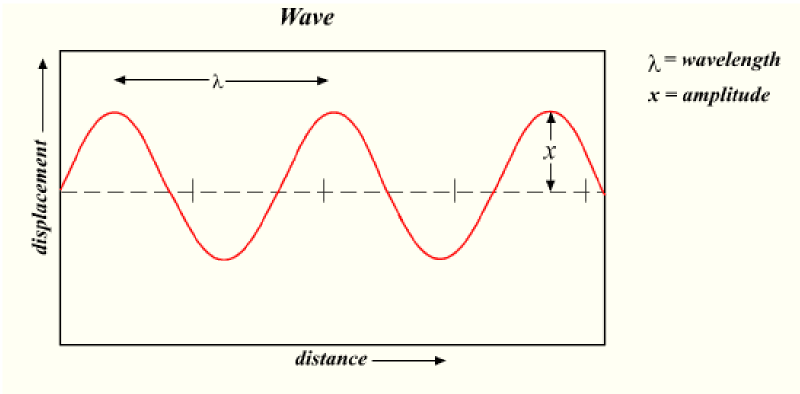

Figure 1. A simple wave. (Paschold, 53)

As previously stated, the frequency range of concern for WBV is between 0.5 and 80 Hz. Motion sickness is associated with frequencies below 1 Hz (Mansfield, 7). HAV frequencies of concern are between 5 and 1500 Hz (Bruce, Bommer & Moritz, 478). Higher yet frequencies are recorded for sound and ultrasound exposure and are shown in Figure 2.

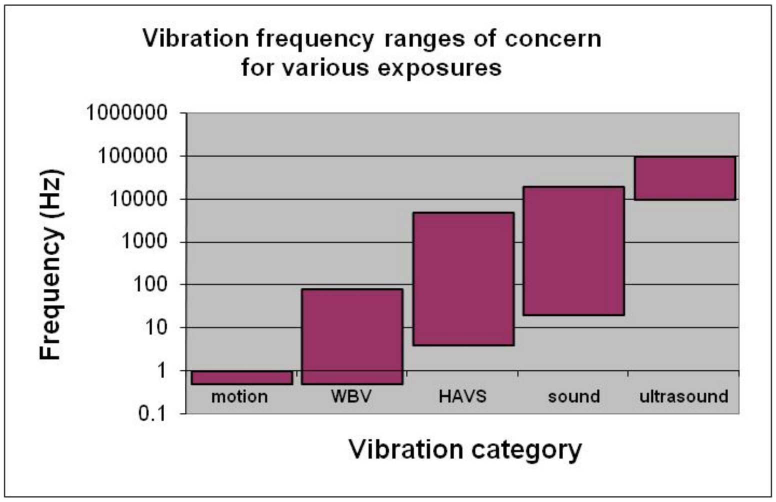

Figure 2. Frequency ranges for various exposures.

WBV Health Effects

The transmission of WBV to the human body at the natural frequency of the body as a whole or its parts will result in resonance. This is a condition in which the body or a part of the body will vibrate at a magnitude greater than the applied vibratory force. In response, muscles will contract in a voluntary or involuntary manner and cause fatigue or a reduction in motor performance capacity (Chaffin & Andersson, 379-380). This response may be considered adverse in the occupational realm; however, WBV is seen as means to achieve body strengthening as a part of an exercise regimen. WBV platforms are now popular and in widespread use for athletic training (Cardinal & Rittweger, 12)

Many adverse health effects are linked to WBV. These include interference with or irritation to the lungs, abdomen, or bladder (Kroemer & Grandjean, 347-348). Also, ISO 2631-1 (1997) (13) assumes WBV adversely affects the digestive, genital/urinary, and female reproductive systems. Effects of WBV on vision were reported as early 1965 by Dennis (245) and later by others.

The most profound adverse health effect is lower back pain (LBP). In a review of 19 WBV studies, NIOSH (6-33), reported 15 studies to support positive association between WBV exposure and LBP. With this, NIOSH assigned its highest ranking descriptor of "strong evidence" to the WBV-LBP relationship. Numerous subsequent studies support the LBP relationship with WBV in specific industry studies, for example:

- Heavy construction: Kittusamy & Buchholz (2004)
- Forklift operation: Hoy, et al. (2005)
- Vehicle operators: Schwarze, et al. (1998)
- Professional drivers: Bovenzi, et al. (2006)
- Farmers: Solecki (2007)

Belgium, Germany, Netherlands, and France acknowledge WBV exposure with resultant LBP as a compensation-qualifying occupational disease. These countries differ significantly in their criteria regarding compensation relative to exposure in excess of standard limits (Hulshof, 185, 191, 192).

About 8 million US workers have occupational vibration exposure. Of these, an estimated 6.8 million are exposed to WBV and the remainder HAV (Bruce, 475; ACGIH®, WBV-5). These estimates of WBV exposure are based on a study published in 1974 (Wasserman, 43).

WBV Standards and Regulations

Standards and regulations for WBV include:

- International Organization for Standardization ISO 2631-1 (1997)
- British Standards Institution BS 6841 (1987)
- American National Standards Institute ANSI S3.18-2002 ISO 2631-1-1997, and
- American Conference of Governmental Industrial Hygienists (ACGIH®) Documentation of the Threshold Limit Values for Physical Agents (2001) and 2007 TLVs® and BELs®

- European Directive 2002/44/EC
- United Kingdom – The Control of Vibration at Work Regulations 2005 (CVWR)

The origin of WBV standards was in Europe. The ISO WBV standard started development in 1966 and was initially published in 1974. About this time, the United Kingdom disagreed with ISO 2631 on technical issues and initiated its own standard, ultimately resulting in BS 6841 (Griffin, 417, 442, 443).

In the US, both ANSI and ACGIH® adopted the ISO WBV standard for measurement and suggested exposure action and limit values. ACGIH® reported in its 2001 publication that neither NIOSH nor OSHA had issued WBV standards (WBV-6). A contemporary search of NIOSH and OSHA websites confirmed that this has not changed.

The European Directive issued in 2002 served to establish the methods for WBV monitoring and setting action and limit values for the control of occupational vibration across Europe (Nelson, 442). The European Directive 2002/44/EC (Mansfield, 193) and the CVWR of 2005 set the action level limit at 0.50 m/s^2 based on an 8-hour daily exposure and the daily exposure limit at 1.15 m/s^2.

With regard to human comfort, magnitudes of WBV less than 0.315 m/s^2 are generally 'not uncomfortable" (ISO, 25).

WBV monitoring

Vibration is measured using an accelerometer to detect the vibrations which is connected to an electronic instrument to amplify, analyze, and store vibration data. WBV monitoring equipment can be assembled from components or purchased as an integrated instrument.

ISO 2631-1 (1997) provides information on WBV monitoring. WBV is measured in a 3-axis coordinate system. When seated, the axes represent vibrations as x – fore and aft, y – side to side, and z – vertical. These are shown in Figure 3.

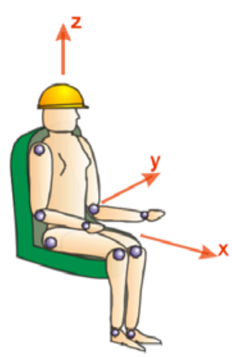

Figure 3. X, y, and z axes seated coordinate system. (EU, 37)

The vibration is measured with a tri-axial accelerometer placed at the interface between the vibrating surface and the human body. For seated measurement, the accelerometer is placed between the seat and ischial tuberosities (ISO, 4). Seat pad accelerometers are commercially available and designed for relatively comfort during monitoring. These pads are slightly pliable and measure 9¼ inches in diameter slightly less than ½ inch thick at the center. Care must be taken to assure proper alignment of the seat pad accelerometer with the x, y, and z-axis system. Figure 3 shows the placement of an accelerometer seat pad. The accelerometer is connected via cable to the vibration monitor, which is secured from movement in a location where it is not likely to be damaged.

Figure 4. Placement of a seat pad accelerometer on a driver's seat.

Vibration is measured as distance moved about a point. With simple addition, the positive and negative distances traveled from the reference point would cancel each other and equal zero. For this reason, vibration is measured by the root-mean-square (r.m.s.) using units of m/s^2 which are the square of individual vibration wave values reduced by the square root.

Measurement duration is should be long enough to a reasonable statistical precision of measurement for a typical exposure and may require separate analysis of variable exposures during work tasks (ISO, 5). Some limitations of measurement duration may exist due to data logging capacity of the instrument.

The monitoring analysis will include a crest factor, which identifies shock vibrations. The crest factor is defined as "the modulus of the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration signal to its r.m.s. value" (ISO, 6). If these crest values are high, over 9, the basic WBV evaluation method may not be suitable to determine the vibration severity on humans. It is then recommended to present the WBV findings using the vibration dose value (VDV).

VDV is a fourth power cumulative dose method that is more sensitive to shocks in the monitored vibration. It is calculated as:

$$VDV = \left(\int_0^T a_w^4(t)\,dt \right)^{\frac{1}{4}}$$

The VDV exposure values set b 2/44/EC are an exposure action value of 9.1 $m/s^{1.75}$ VDV and a l . These exposure values may be used if a country chooses.

As with noise monitoring, weighting is applied to frequencies for WBV. Two weightings are prescribed by ISO during seated exposure monitoring. For the vertical z-axis, a W_k weighting is used and W_d is applied to the x and y directions (ISO, 2 & 10). These weightings can be easily set and applied in a WBV personal vibration monitor.

Health assessment of WBV exposure is made with respect to each axis. However, if the r.m.s. values for two or more axes are similar, a vector sum may be used to determine potential health risk (ISO, 13). ISO 2631-1 (1997) does not explicitly state how similar the values must be. These values can then be compared with regulations such as the European Direction or CVWR to evaluate potential health risk and required remedial actions. When the three axes are combined, the x-axis and y-axis are weighted by a factor of k=1.4 and the z-axis by k=1.0.

During the summer of 2007, WBV data was collected in a pilot study of automated residential solid waste collection trucks. Summary data is from a 20-minute period of time during which the truck was on the road driving or idling. The z-axis has the highest value of 0.64 m/s^2 and indicates this exposure to be above the action level and below the exposure limit. High crest factor values indicate significant shock vibration during monitoring. However, the VDV_z value is below the 9.1 $m/s^{1.75}$ VDV action level. The WBV values are summarized in Table 1.

Table 1. WBV values during solid waste truck operation.

WBV value	x-axis	y-axis	z-axis	xyz
Aeq - m/s^2	0.18	0.21	0.64	0.75
VDV - $m/s^{1.75}$	1.91	2.18	5.89	6.36
Crest Factor	12	13	13	11

Figure 5 graphically presents the vibration data during this period. An approximate 7-minute period of idling is apparent at time beginning approximately 11:07, with the balance showing a z-axis dominated WBV exposure when driving.

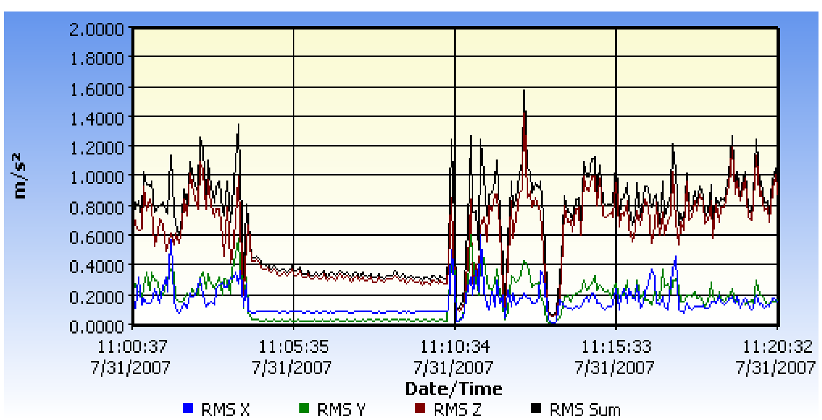

Figure 5. Graphic presentation of WBV for residential solid waste truck driving and idling.

WBV is relatively unknown in the US

Based on a knowledge and awareness survey of WBV, 69.5% of the responding US safety and health professional self-reported less than a basic understanding of WBV (Paschold, 56). Participants were asked to self-rate their WBV knowledge on a 5-point scale based on:

1. None, couldn't identify
2. Awareness but without a depth of understanding, few
3. Basic understanding, about half, limited
4. Most aspects lacking some detail issues, very well
5. Clearly, completely, competently, comprehensively.

The responses (approximately 2,600) were tabulated as Knowledge Level (KL_{1-5}), none of which averaged greater than 2.00. The highest knowledge areas were "ability to define or explain WBV" – 1.94 and "identify WBV sources" – 1.92. Knowledge and awareness of WBV standards was generally very low (Paschold & Sergeev, 27-29). Question responses (KL_{1-5}) are summarized in Table 2.

Table 2. Summary of responses to WBV knowledge study

Questions asked	(KL_{1-5})
Define or explain WBV?	1.94
Describe WBV health effects?	1.84
Identify WBV illness trend?	1.63
Identify WBV sources?	1.92
Monitor WBV levels?	1.59
Know ISO 2631-1 (1997) standard?	1.22
Know BS 6841 (1987) standard?	1.10
Know ANSI S3.18 – 2002 ISO 2631-1 (1997) standard?	1.36
Know ACGIH® TLV® for physical agents standard?	1.53

Clearly, knowledge of WBV topics is not very strong in the US. A limited survey of health and safety professionals in the United Kingdom revealed much higher knowledge levels regarding the CVWR and WBV (Edwards, 270). This can most likely be attributed to the U.K. implementation of a WBV standard as law, as opposed to the US where OSHA does not include WBV.

WBV suggested remedies

Safety and health professionals must use a systematic approach to recognize or anticipate, evaluate and control the hazard. As demonstrated through the knowledge survey, the inability of safety professional to recognize and evaluate WBV may hamper remediation efforts.

WBV may be eliminated with the following suggestions:

- Re-design equipment, vehicles, or roads to eliminate the vibration, or
- Completely remove employees from WBV environments.

WBV reduction or isolation may be achieved by:

- Purchasing newer equipment,
- Using transportation alternatives instead of truck,
- Reducing vehicle speeds,
- Installing vibration dampeners on equipment and vehicles,
- Maintaining equipment, and
- Streamlining jobs,

Other control methods may include:

- Job rotation to reduce individual exposure time,
- Training and rules that:
  - Prohibit jumping from large vehicles to the ground,
  - Require proper mirror adjustments and usage to prevent excessive turning,
  - Enforce strict lower speed limits, etc.,
- Employee WBV training.

Conclusions

The US safety and health professional community does not presently have strong knowledge or awareness of the WBV topic. WBV is prevalent in US occupations, with many workers exposed. Increased knowledge through professional education or implementation of OSHA-based WBV standards should increase awareness and attendant remedial actions.

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