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HAND-ARM VIBRATION EXPOSURE GUIDELINES IN THE UNITED STATES WITH SPECIAL REFERENCE TO THE ACGIH® TLV®

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Abstract

According to NIOSH there may be as many as 1.5 million people exposed to hand-arm vibration, HAV. Many of these workers will have sufficient exposure to HAV and concomitant ergonomic factors to develop chronic vascular, nerve or muscle injuries. In the US, the ANSI S2.70-2006 and the ACGIH® TLV® provide guidance for controlling the risk of injuries associated with HAV. The ANSI S2.70-2006 standard is based on consensus of affected parties. The TLV® is a scientific standard based only on health considerations using published data. The ACGIH® has placed the hand-arm vibration TLV® on its “under study” list. A review of selected literature suggest that possible updates to the TLV® might include a new TLV® based on an equal energy curve, inclusion of higher frequencies, inclusion of multiple axes of vibration exposure in exposure calculations, changes in frequency weightings, consideration of concomitant ergonomic stresses, and action and ceiling limits.

1. Introduction

Hand-arm vibration exposure has been shown to affect nerves, muscles, arteries, muscles and bones. This paper examines the prevalence of vibration exposure and current regulations. It is particularly concerned with the existing ACGIH® TLV®. The TLV® is under study by the ACGIH TLV® Physical Agents Committee for possible revision.

2. Exposure

While it is difficult to estimate the exact exposure to hand arm vibration, it is possible to estimate the number of people who work in industries and occupations where vibrating tools might be used. NIOSH [1] estimated that the there were 1.25

million people in occupations that used vibrating tools. Using 2004 Bureau of Labor Statistics Data, Dong [2] estimated that there may still be more than 1.5 million people who are exposed to hand-arm vibration for more than one hour per day. It can be argued that out-sourcing of US jobs will lead to reduced exposures. It also can be argued that tools have improved since the 1983 NIOSH estimate so the exposure intensities and associated health impairments may also have decreased.

3. Current Standards & Guidelines

3.1 US Federal Standards

Presently Occupational Safety and Health Administration, OHSA, does not have a standard that specifically addresses hand-arm vibration. The National Institute for Occupational Safety and Health, NIOSH, did published a criteria document in 1989 that included a comprehensive review of the literature, but it did not recommend an exposure limit for hand-arm vibration [3]. NIOSH was unable to show a satisfactory dose-response relationship between hand-arm vibration exposures and disorders based on the available studies and did not recommend an exposure limit. They recommend exposure and health monitoring along with engineering controls. They also specifically recommended against use the ISO 5349 standard [measurement procedures that considers frequencies from 6.3-1,250Hz with a -6dB/octave weighting for frequencies greater than 16Hz. Instead they recommended unweighted measurements through 5,000Hz. In the absence of a recommended exposure limit, the OSHA did not promulgate a standard.

OSHA does have a General Duty Clause that says employers must provide a place of employment that is free of recognized hazards that are likely to cause death or serious physical harm to his employees [20]. ANSI S2.70-2006 (see below) could have an impact future General Duty Citations. According to OSHA [4] “industry consensus standards may be evidence that a hazard is "recognized" and that there is a feasible means of correcting such a hazard.”

3.2 State Regulations and Guidelines

Only the State of Washington has attempted to implement a standard for control of hand-arm vibration exposure. The Washington vibration standard was part of an ergonomic standard that addressed a number of workplace factors believed to contribute to chronic hand, wrist and forearm injuries. It instructed the user to get the information from the manufacturer or to download it from a web-based database maintained by the Swedish National Institute for Working Life. The vibration measurements in the NIWL data are based on ISO 5349-1. The Washington standard specified an 8-hour energy-equivalent frequency- weighted acceleration caution limit and hazard limit of 2.5 m/s^2 and 5 m/s^2 respectively. The vibration standard along with the entire ergonomic initiative was repealed by referendum shortly after it was implemented, but it remains only as a guideline.

3.3 ANSI S2.70-2006

The American National Standards Institute, ANSI, is a non governmental body. ANSI is the U.S. representative to the International Organization for Standardization (ISO). ANSI standards are based on "consensus" of affected parties. Use of consensus standards is voluntary; however, the OSHA General Duty Clause forces their consideration or consideration of something more protective.

Some important features of the ANSI S2.70-2006 are its scope, its measurement guidelines and the recommended limits. First the scope broadly addresses many chronic hand-wrist-forearm disorders: "adverse health effect, such as hand-arm vibration syndrome (HAVS) and other conditions of the upper extremities, such as carpal tunnel syndrome. Second the ANSI standard specifies how vibration measurements should be performed using ISO 5349. Exposures are calculated as a vector sum of three orthogonal axes and expressed as an 8-hour equivalent exposure. Third the ANSI standard recommends a Daily Exposure Action Value of $2.5 m/s^2$ and a Daily Exposure Limit Value (8-hour equivalent exposure) of $5.0 m/s^2$. This recommendation is derived from the dose-response relationship included in Annex C.3 of ISO 5349. The dose is expressed as an equivalent 8-hour exposure and the response as the number of years for 10% of the population to develop finger blanching. Neither the ANSI nor the ISO standard provides specific references to support the dose-response relationship.

3.4 International Standards

The ISO 5349 and EU Directive 2002/44/EC affect American employers and manufacturers. First many American companies do business in Europe and other parts of the world governed by these standards. Second, the vibration measurement and reporting procedures recommended by the IOS 5349 are widely used. And Third, Both the ACGIH® TLV® and ANSI S2.70-2006 refer to the exposure response relationship described in the Annex of the ISO standard.

3.5 The American Conference of Governmental Industrial Hygienist, ACGIH®

ACGIH® is a private, not-for-profit, nongovernmental corporation whose members are industrial hygienist or other safety professionals dedicated to promoting health and safety within the workplace. ACGIH® is not a standards setting body. It considers itself a scientific organization and it establishes committees that to review existing published, peer-reviewed scientific literature that is used to publish exposure guidelines called Threshold Limit Values® or TLVs®. Scientific Committee members must adhere to strict rules regarding conflict of interest and bias. ACGIH® members must set aside their personal and company interests and consider only the available science in the interest of worker health. ACGIH does not consider the cost that TLVs® might have on an employer, employee or manufacturers. The use of TLVs® is voluntary. TLVs® are reviewed annually and a list of the TLVs® that are under study for possible revision are is published each year in the ACGIH® Threshold Limit Value book [5]. Hand-arm vibration is on the 2006 Physical Agents Under Study list.

The TLV® for hand-am vibration specifies exposure limits that are intended to prevent nearly all workers from 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" [5,6]. The TLV® specifies vibration measurements using, as closely as possible, a "biodynamic" coordinate system located in the center of the first knuckle of the third digit with the z-axis in alignment with the third metacarpal. The TLV® specifies that frequencies be weighted according to ISO 5349 and reported as a time-weighted average for the exposure period.

In contrast to the other reviewed standards, the TLV® considers only the dominate axis. If the three orthogonal axes are equal, then the vector sum will be 72% greater than any single axis. If the dominant axis is twice as great as the vector sum of the other two axes, the vector sum of all axes will be 23% greater than the dominant axis. As the difference between the dominant axis and the vector sum of the other two axes becomes greater, the effect of the vector sum becomes less. It is important though that the major axis be correctly identified.

The TLV® for hand-arm vibration range from $4 m/s^2$ for 4-8 hours to $12 m/s^2$ for less than one hour. These values are less than the $5.0 m/s^2$ limits recommended by ANSI S2.70-2006 and the state of Washington, but they are greater than the $2.5 m/s^2$ action limits. The TLV® is based on a single dominant axis, so it can be assumed that the vector sum of all three axes is up to 70% greater in many cases.

3.5.1 Possible TLV® enhancements

The current TLV® documentation does not rationalize the use of only the dominate axis. This may reflect the fact that many tools, such as reciprocating chipping hammers or pavement breakers, tend to have one conspicuous axis. It also may reflect the cost of instrumentation for simultaneous tri-axial measurements in the 1980s. The low cost of necessary instrumentation, the elimination of possible errors trying to identify a dominant axis of vibration and the alignment of the TLV® with other standards argue for the use of a vector sum.

The documentation for the current TLV® is not specific about the basis for the current TLV® recommendations. The main reference appears to be that of Brammer [7,8]. It his work, Brammer used the results of several epidemiological studies to examine exposure-response relationships for the prevalence of white finger versus exposure time, and average latency versus component acceleration. Based on these arguments Brammer proposes that the threshold is between 1 and $2.9 m/s^2$ for the appearance of white fingers in 10% of the susceptible population in 25-30 years. Pelmear and Leong [9] that Stage 1 vibration- induced white finger will proceed to Stage 3 and possibly Stage 4 if exposure continues. The goal must be to prevent Stage 1 vibration-induced white finger altogether. Studies of other health responses to hand-arm vibration suggest that the exposure response-relationship needs to consider other outcomes and exposure factors. The most recent study used by Brammer [7,8] to examine the exposure response relationship for vibration-induced white finger was 1971. The relationship between hand-arm vibration and health responses may not have changed, but the equipment and procedures for measuring exposure and responses has improved considerably. The Brammer model needs to be updated with current literature and additional outcomes.

There is growing concern about disorders besides vibration induced white finger. Lundborg, Dahlin, et al. [10] were able to induce epineurial edema in the sciatic nerve in mice with 82Hz exposures at $26 m/s^2$ for 4 hours per day after five days. This shows that vibration acts directly on nerve tissues. Necking [11] reported morphological changes in abductor pollicis brevis muscle in 20 patients suffering from HAVS. The number of fibers demonstrating centrally located nuclei was correlated with the cumulative vibration exposure time, while the number of angulated fibers was correlated with the total exposure time. These results show that vibration acts directly on muscles as well as nerves.

There is growing evidence that that vibration may be a co-factor with ergonomic factors of musculoskeletal disorders. Armstrong et al. [12] reported an odds ration of 5.6 for risk of carpal tunnel syndrome among persons performing highly repetitive jobs versus low repetitive jobs. The risk of carpal tunnel syndrome was doubled again for workers who were exposed to both high repetition and vibration. Bovenzi et al. [13] reported that risk of carpal tunnel syndrome increased by a factor of 1.3 with each unit increase of A(8) and by 1.09 with each increase unit in Strain index. Bovenzi, Giannini, et al. [14] reported ergonomic factors along with vibration exposure also were a factor in peripheral nerve injuries in forestry workers. High levels of paresthesias observed among dental hygienists appear to be attributable to several pathophysiological mechanisms, including, sensory nerve demyelination at the carpal tunnel and intrinsic to the digits, and dysfunction of fingertip mechanoreceptors. In its comprehensive review of the literature, the NRC-IOM [15] the contribution of vibration to chronic hand, wrist and forearm disorders along with the contributions of other ergonomic factors such as repeated and sustained forces and stressful postures. Armstrong, Marshall, et al [12] found that use of hammer and chipping tools and grinders were associated with medium to high repeated exertions, forces and postures. Eight hour equivalent vibration exposures weighted using the ISO 5349 ranged from $3.3 m/s^2$ for grinders to $8.5 m/s^2$ for reciprocating scaling hammers. A model is needed that can be used to understand and predict the combined effects of vibration and ergonomic co-factors.

The current ISO 5349 frequency weighting can be traced back to psychophysical studies by [16]. NIOSH [3] believes that the measurement grossly underestimates the HAVS-producing effects from tools that vibrate at high frequencies and argued for use of un-weighted measurements for frequencies from 6.3 to 5,000Hz along each axis of a biodynamic reference system. They also noted that use of this method would simplify the measurement process. Dong, Welcome, et al [17] also at NIOSH reported that vibration power absorption, VPA, for the palm and hand matched the ISO 5349 weighting, but the VPA for the fingers during combined grip and push was much higher than the ISO values for frequencies in excess of 25Hz. Combined griping and pushing is a common exertion for using hand tools. Lundborg, Dahlin, et al. [10] were able to induce epineurial edema in the sciatic nerve in mice with 82Hz exposures at 26m/s^2 for 4 hours per day after five days. Using the ISO 5349 weighting, this exposure would be -7.0dBs. Griffen, Bovenzi, et al. [18] examined the exposure response relationship between white finger and vibration exposures over time using both weighted and un-frequency weightings. Poorer predictions were obtained when the currently recommended frequency weighting was employed than when accelerations at all frequencies were given equal weight. This sample of studies suggests the need for either modification or elimination of frequency weightings.

There is a growing body of literature about vibration related disorders occurring in dentist who use high frequency dentist drills. Cherniack, Brammer, et al. [19] conducted a cross-sectional study of vibrotactile perception thresholds (VPT) among dentists, dental technicians, and dental hygienists, using rotary devices and ultrasonics among 94 experienced dental hygienists. Akesson, Lundborg, et al. [20] compared vibration exposed groups of 30 dentists and 30 dental hygienists who used low and high speed hand pieces and ultrasonic scalers with vibration unexposed groups of 30 dental assistants and 30 medical nurses (all women). The two groups exposed to vibration had significant impairments of vibrotactile sensibility, strength, and motor performance, as well as more frequent sensorineural symptoms. There was no increase of vascular symptoms of the hands in the groups exposed to vibration. Rytkonen, Sorainen, et al [21] measured vibration in 22 dental hand pieces during normal work using the ISO 5349 weighting. The highest vibration levels were in the frequency range above 1,250Hz. At the weighting factor for accelerations at 1,250Hz would be -19.2dB. This sample of studies supports both an exposure response relationship for vibration and peripheral nerve disorders and using a flat weighting that includes frequencies in excess of 1,250 Hz.

4. Conclusions

There is evidence that as many as 1.5 million people may be exposed to hand-arm vibration. The current ANSI S2.70-2006 consensus standard and ACGIH® TLV® provide guidance for measuring and managing hand arm vibration exposures. Both of these documents draw on recommendations from ISO 5349 for measurement and reporting procedures. The ACGIH® has placed the hand-arm vibration TLV® on its “under study” list. A review of selected literature suggest that possible updates to the TLV® might include a new TLV® based on an equal energy curve, inclusion of higher frequencies, inclusion of multiple axes of vibration exposure in exposure calculations, changes in frequency weightings, consideration of concomitant ergonomic stresses, and action and ceiling limits.

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