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Vibration Level Characterization from a Needle Gun Used on U.S. Naval Vessels

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Public Health
Department of Environmental and Occupational Health
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ABSTRACT

United States (U.S.) Navy sailors are exposed to a very large number of hazards, both chemical and physical. Occupational vibration from pneumatic air tools is one of the potential exposure hazards. There are very limited data as to the exposures to one type of tool, a needle gun or needle scaler, used by the sailors.

The purpose of this study was to characterize the vibration levels generated by a needle gun used in the U.S. Navy. The design of the study evaluated the difference pressure had on the acceleration levels generated from the needle scaler. Five subjects were used in the evaluation of the tool. Each subject was required to hold the tool for twenty seconds activated without contact and activated on a surface and at two different pressures, 60 and 80 pound per square inch (psi). Each subject repeated each of the conditions three times for a total of 12 measurements. Each subject was also required to hold the tool in hand without the tool activated. The measurements were collected from an accelerometer on the needle gun following ISO 5349-1:2001 and ISO 5349-2:2001 methods.

Significant differences were observed individually in pressure ($p<0.0001$), contact ($p<0.0001$)), and subjects ($p<0.001$). In addition, there was a significant interaction between contact and pressure ($p<0.001$). It was concluded that U.S. Navy sailors are not likely at significant risk to Hand-Arm Vibration Syndrome for lifetime exposures to hand transmitted vibration.

SYMBOLS AND ABBREVIATIONS

$a_{\mathrm{hw}}(t)$	instantaneous single-axis acceleration value of the ISO frequency-weighted hand-transmitted vibration at time t, in meters per second squared (m/s^2);
a_{hw}	root-mean-square (rms) single-axis acceleration value of the ISO frequency-weighted hand-transmitted vibration, in m/s^2
$a_{\mathrm{hw}x}$, $a_{\mathrm{hw}y}$, a_{hwz}	values of a_{hw}, in m/s^2, for the axes denoted x, y and z respectively
a_{hv}	vibration total value of the ISO frequency-weighted rms acceleration; it is the root-sum-of squares of the a_{hw} values for the three measures axes of vibration in m/s^2
$a_{\mathrm{hv(eq,\ 8h)}}$	daily vibration exposure (8-h energy equivalent vibration total value), in m/s^2
$a_{\mathrm{hv(DEAV)}}$	vibration total value for a time $\mathrm{T_v}$ other than 8 h that will result in a DEAV of 2.5 m/s^2
$a_{\mathrm{hv(DELV)}}$	vibration total value for a time $\mathrm{T_v}$ other than 8 h that will result in a DELV of 5.0 m/s^2
$A(8)$	a convenient alternative term for the daily vibration exposure $a_{\mathrm{hv(eq,\ 8h)}}$
DEAV or EAV	Daily Exposure Action Value – A(8) is equal to 2.5 m/s^2
DELV or ELV	Daily Exposure Limit Value – A(8) is equal to 5.0 m/s^2
D_{y}	group mean total (lifetime) exposure duration, in years
HAVS	Hand-arm vibration syndrome
HTV	Hand-transmitted vibration
rss	root sum of squares – the square root of the sum of the squares of the x, y, and z axes.
T	total daily duration of exposure to the vibration a_{hv}
T_0	reference duration of 8 h (28,800 s)
W_{h}	frequency-weighting characteristic for hand-transmitted vibration

INTRODUCTION

The general United States worker may be exposed to a myriad of hazards, both physical and chemical. Occupational vibration is one of the many physical hazard exposures. It is found in landscaping (mowing lawns and trimming shrubs), tree cutting, driving heavy construction equipment, or using any assortment of hand power tools (i.e., jackhammers, grinders, needle guns, etc.) (NIOSH, 1989). Eight to ten million Americans are exposed to occupational vibration where two million of these are exposed to hand-arm vibration alone (Wasserman, 2001).

Occupational vibration is categorized into hand-arm vibration (HAV) and whole body vibration (WBV). “Whole body vibration affects the entire human body, and is usually transmitted in a sitting or standing position from a vibrating seat or platform” (Wilder, D. E. Wasserman, J. Wasserman, 2002, p. 80). Hand-arm vibration focuses on the hand-arm unit alone and is transmitted to the hand via a power tool (Wilder et al., 2002).

Hand-arm and whole-body vibration each elicit different health effects (Wilder et al., 2002). Whole body vibration primarily affects the lower back region (Wilder et al., 2002). The primary health effect currently associated with hand-arm Hand-Arm Vibration Syndrome (HAVS)(Wilder et al., 2002). Vibration white finger is also known by other names, such as vibration-induced Raynaud’s phenomenon (Pelmear, Taylor & Wasserman, 1992), secondary Raynaud’s phenomenon (Griffin, 1990), Raynaud’s Phenomenon of Occupational Origin, and vibration white finger (VWF) (Bruce, Bommer, & Moritz, 2003). The prevalence and severity of HAVS usually increases with the magnitude of acceleration of the power tool and the duration of time the tool is used (NIOSH 1989).

United States Navy sailors, like their American worker counterparts, are exposed to hand-transmitted vibration (C. R. Wilhite, personal communication, July 12, 2006). A typical example is the use of a compressed air power tool called a needle gun or needle scaler. The needle scalers are used to remove rust and/or coatings from the substrate, usually a steel bulkhead, deck or railing. Needle scalers are used extensively during periods when the ship was in port.

The exposure levels to these tools have not been fully characterized and the exposure levels are unknown. In 1999, Paddan, Haward, Griffin, & Palmer published some limited hand transmitted vibration data on several tools from surveys conducted around the United Kingdom. They conducted sampling on three needle scalers and found a range between 10.9 to 28.7 meters per second per second (m/s^2) (Paddan et al., 1999).

Currently, the U.S. does not have a regulatory standard for occupational vibration. However, the U.S. has three health and safety guidance documents published by: American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) for Hand-Arm Vibration (2006), the American National Standards Institute (ANSI) S2.70-2006 American National Standard Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand (2006), and the National Institute for Occupational Safety and Health (NIOSH) Criteria For a Recommended Standard: Occupational Exposure to Hand-Arm Vibration (1989). The international community also has published similar guidelines:

- International Standards Organization (ISO) 5349-1:2001 Mechanical vibration - Guidelines for the measurement and the assessment of human exposure to hand-transmitted vibration (2001).
- European Directive 2002/44/EC - On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration)(2002).Member states were required to comply with the Directive by 6 July 2005.

The occupational exposure limits published by most of the standards are prefaced with a disclaimer indicating that the “etiology of these disorders is not well [understood]” (ANSI S3.34-1986, 1986, p. 1). ANSI’s older hand-transmitted vibration standard (1986) goes on to state “that because of several confounding factors, Appendix B [of ANSI S3.34-1986, Latent Period for Hand-Transmitted Vibration] shall not be construed to be a general guide to permissible exposures to vibration transmitted to the hand” (p. 1). NIOSH (1989) indicates that there are many variables that affect the acceleration of the transmitted vibration to the hand and therefore has not established a recommended exposure limit. The ISO 5349-1 (2001) publication states that the standard “does not define the limits of safe vibration exposure” (p. 1) and therefore does not provide an exposure limit.

The European Directive (2002), ACGIH TLV for Hand-Transmitted Vibration (2006), and the new ANSI S2.70 standard (2006) have established an occupational exposure limit for hand-transmitted vibration. The European Directive for occupational vibration (2002) suggests a numerical value for vibration with the exposure action limit (EAL) of 2.5 m/s^2 (rms) and an exposure limit value (ELV) of 5.0 m/s^2 (rms). The European Directive (2002) derived these values from the ISO 5349 (1986) standard. The ANSI S2.70 (2006) standard defines the daily EAV “represents the health risk threshold to hand-transmitted vibration (p. 11)." At the EAV and above, abnormal signs & symptoms will become prevalent. The daily ELV is considered a high health risk and the prevalence of symptoms will be more prevalent in the exposed population (ANSI, 2006). The new ANSI S2.70 standard (2006) for hand-transmitted vibration has also adopted the same European Directive (2002) ELV and EAV.

The current ACGIH TLV for Hand-Transmitted Vibration (2006) is similar to the ISO 5349 (1986) hand-transmitted vibration standard. The ACGIH TLV for hand-transmitted vibration (2006) is based on the dominant frequency-weighted, single axis acceleration and on a four hour exposure. The ANSI S2.70 (2006) and the European Directive (2002) vibration levels are based on an equal energy model (root sum of squares for each of the orthogonal axes of the hand) and standardized to an eight hour exposure.

LITERATURE REVIEW

Background

At the beginning of the 20th century, physicians began to document health effects generated from vibrating equipment/tools. One of the first documented occurrences of occupational injury from vibration appeared in 1907 when the United Kingdom Departmental Committee on Compensation for Industrial Diseases identified “neurosis” (p.74) in workers that was caused by vibration from pneumatic tools (Griffin, 1997). In 1911, the Italian physician, Giovanni Loriga, identified Raynaud’s phenomenon in workers that used pneumatic hammers on stone and marble (Bovenzi, 1998a). And in the United States, Alice Hamilton observed Raynaud’s phenomenon caused by vibration of pneumatic tools used in stone cutting in 1918 (Pelmear et al., 1992). In 1960, Louis Pecora et al. (1960) stated “that Raynaud’s phenomenon of occupational origin may not be completely eradicated but that it may have become an uncommon occupational disease approaching extinction in [the United States]” (p. 82).

From the time occupational vibration was first identified as a health hazard, more and more sources of hand-transmitted vibration have been identified. Besides vascular related adverse health effects (e.g., VWF), other conditions have been linked to hand-transmitted vibration, which include sensineural and musculoskeletal effects (Pelmear et al., 1992). Since the turn of the twentieth century, the scientific community has commonly assumed the vibration frequency range of significance is between 8 – 1000 Hz (Griffin, 1990).

Health Effects of Hand-Transmitted Disorders

The ANSI S2.70 standard (2006) defines hand-transmitted vibration as “the mechanical vibration that, when transmitted to the human hand-arm system, may entail risks to worker health and safety, in particular vascular, bone or joint, neurological and muscular”[disorders] (p. vi). Hand-transmitted vibration is vibration that is transmitted to the hand by some type of rotating and/or percussive hand held tool (Bovenzi, 1998a). Workers that use rotating and/or percussive tools are found in mining, construction, forestry, shipbuilding, and landscaping, among others (ISO 5389-1, 2001).

The target organs for hand-transmitted vibration using hand-held power tools include the skin vasculature of the fingers, sensory nerves of the hand, and components of the “locomotor apparatus of the hand-arm system" (Pelmear et al., 1992). The primary health effect currently associated with hand-transmitted vibration is vibration white finger (VWF), Raynaud’s phenomenon of occupational origin, or hand-arm vibration syndrome (HAVS) (Pelmear et al., 1992). The prevalence of hand-arm vibration syndrome (HAVS) in the U.S. for worker populations that use vibrating tools ranges from 6 to 100% with an average of about 50% (NIOSH, 1989). There are also other disorders associated with hand-transmitted vibration from different types of tools other than vascular disorders (VWF). Griffin separates the disorders into five separate categories: vascular disorders, bone and joint disorders, peripheral neurological disorders, muscle disorders, and other disorders (e.g., of the whole-body and central nervous system) (Griffin, 1990).

Vibration white finger is the commonly known health effect associated with hand-transmitted vibration. Environmental factors can increase the prevalence of this disorder.

Bovenzi (1998b) demonstrated that different geographic areas are more or less susceptible to VWF based on temperature. Colder climates had a higher prevalence of VWF compared to warm climates (Bovenzi, 1998b). Symptoms associated with VWF include tingling, numbness, blanching of the fingers, cyanosis (a bluish or purplish discoloration due to deficient oxygenation of the blood) and gangrene (Griffin, 1990).

The actual HAVS mechanisms caused by hand-transmitted vibration are not clear (Wilder, et al., 2002). Some of the factors that lead to the development of HAVS are characteristics of the vibrating tool (vibration magnitude, direction and frequency; and duration of tool use), the type and condition of the tool, environmental factors, biodynamic factors, ergonomic factors, and individual factors (ISO 5349-1, 2001).

There has been extensive research conducted on vascular disorders associated with vibrating tools. NIOSH published a document in 1997 that provided a critical review of epidemiological evidence associated with Hand Arm Vibration Syndrome (Bernard, 1997). From 20 epidemiological studies, Bernard concluded that “there is substantial evidence that as intensity and duration of exposure to vibrating tools increase, the risk of developing HAVS increases” (1997, p. 5c-9).

In addition to VWF, Carpel Tunnel Syndrome (CTS) has also been linked with exposures to hand-transmitted vibration, however, not by itself (Bernard, 1997). Mild numbness and tingling is common in both HAVS and CTS. But the vascular injury to the hand in hand-transmitted vibration is different than the nerve compression in CTS (Pelmear & Leong, 2000).

Disorders associated with hand-transmitted vibration are not only linked to the vascular system of the hand but also there is evidence with chronic problems with bone and joints, peripheral neurological system, muscular system of the hand, among other disorders (Griffin, 1990). The mechanisms for each of the disorders is also not clearly understood (Pelmear et al., 1992).

Diagnosis of Hand-Transmitted Vibration Disorders

There is no definitive, objective diagnostic test for the vascular disorders associated with hand transmitted vibration (NIOSH, 1989). Physicians rely on the subjective report from the worker. This makes the diagnosis and classification difficult for the physicians (NIOSH, 1989). Although none of the diagnostic tests for vascular disorders due to hand transmitted vibration are considered the "gold standard," some of these tests can be useful in the assessment in conjunction with the subjective medical evaluation (Griffin, 1990, p. 592). Some of the diagnostic tests include: Doppler studies, plethysmography, finger systolic pressure measurements. There are also similar diagnostic tests for sensineural effects (Physical and Biological Hazards, Wilder, 2002).

The medical community has devised assessment methods to determine the degree of HAVS once it is diagnosed. In 1968, Taylor and Pelmear devised a classification system that was used until 1986 when their classification system was modified by the Stockholm Scale (Wasserman, 2001). The Stockholm Scale separated vascular and sensineural effects and also evaluated both hands (Pelmear, et al., 1992). The three scales are found in Tables 1 through 3.

Table 1. Taylor–Pelmear Stages of VWF (Pelmear et al., 1992, Table 3-1, p. 28)

Stage	Condition of Digits	Work and Social Interference
0	No blanching of digits	No complaints.
OT or ON	Intermittent tingling, numbness, or both.	No interference with activities.
1	Blanching of one or more fingertips with or without tingling and numbness.	No interference with activities.
2	Blanching of one or more fingers with numbness; usually confined to winter.	Slight interference with home and social activities. No interference at work.
3	Extensive blanching. Frequent episodes, summer as well as winter.	Definite interference at work, at home, and with social activities. Restriction of hobbies.
4	Extensive blanching; most fingers; frequent episodes, summer and winter.	Occupation changed to avoid further vibration exposure because of severity of symptoms and signs.

Table 2**.** Stockholm Workshop Scale for the Classification of Cold-Induced Raynaud's Phenomenon in HAVS (Pelmear et al., 1992, Table 3-2, p. 29)

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 fingertips

Table 3**.** Stockholm Workshop Scale for the Classification of Sensorineural Effects of HAVS (Pelmear et al., 1992, Table 3-3, p. 29)

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

Physics and Terminology

In order to understand how vibration affects the body and how vibration is measured, it is important to understand some of the physics and terminology involved with vibration. For the purposes of this discussion, vibration is the oscillatory movement of a solid or tool; the motion can be periodic (sinusoidal) or random, and either intermittent or continuous (Soule, 1973). “The simplest form of periodic vibration is called pure harmonic motion which is a function of time and that can be represented by a sinusoidal curve” (Soule, 1973, p. 339). Three components are related mathematically to pure harmonic motion: displacement from an equilibrium position, velocity or rate of change in displacement, and acceleration or vector quantity expressed as rate of change in velocity (Bruce et al., 2001). Acceleration is the critical component when considering occupational vibration measurement since it believed that the force from the acceleration is responsible for adverse health effects (Bruce et al., 2001). Equation 1 represents acceleration mathematically.

$$a = -\omega^2 X \sin(\omega t) = a_{\text{peak}} \sin(\omega t) \tag{1}$$

Where: a = acceleration (m/s^2)
a_{peak} = maximum acceleration
f = frequency (Hz or cycles/s)
t = time (s)
ω = angular frequency or $2\pi f$
X = maximum displacement (m)
**adapted from The Industrial Environment: Its Evaluation and Control, NIOSH, 1974, p. 339*

Vibration is defined as a vector quantity; it has magnitude and direction (Wasserman, 2001). Describing occupational vibration exposure levels is difficult. Peak vibration levels are useful when the waveform is purely sinusoidal; however, most occupational vibrations are not pure sinusoid waveforms and are complicated with varying frequencies (Bruce et al., 2003). Root-mean-square (rms) values are the primary unit for occupational vibration because the rms values are proportional to the energy content of the vibration (Soule, 1973). Root-mean square values were the preferred method to describe severity of HTV exposures; it was a common measure in engineering fields and was a convenient term for measurement and analysis (Griffin, 1990). Root-mean-square acceleration for an ISO frequency-weighted, single axis is defined in Equation 2 below:

$$a_{hw(rms)} = \sqrt{\frac{1}{T}\int_0^T a_{hw}^2(t)dt} \qquad (2)$$

Where: *a* is the rms single axis acceleration of the ISO frequency-weighted hand-transmitted vibration in m/s^2
t is time in seconds
T is the measurement time period.
**from ANSI S2.70-2006,(2006, Eq. 3, p. 4)*

The direction component of vibration transmitted to the hand is described in three directions (*x*, *y*, and *z*) of an orthogonal coordinate system. Additionally, vibration is also transmitted through rotational axes: pitch, roll and yaw. The linear axes (*x, y*, and *z*) are used and explained by two coordinate systems typically associated with hand transmitted vibration: biodynamic and the basicentric coordinate systems. The biodynamic system is referenced from the third metacarpal of the hand and defines motions in *x*, *y*, and *z* axes (Wilder et al., 2002). Measurements for occupational vibration are not traditionally obtained directly from the hand but are taken from the tool handle, making the tool the reference point for the basicentric coordinate system (See Figure 1). It is an approximation of the biodynamic coordinate system.

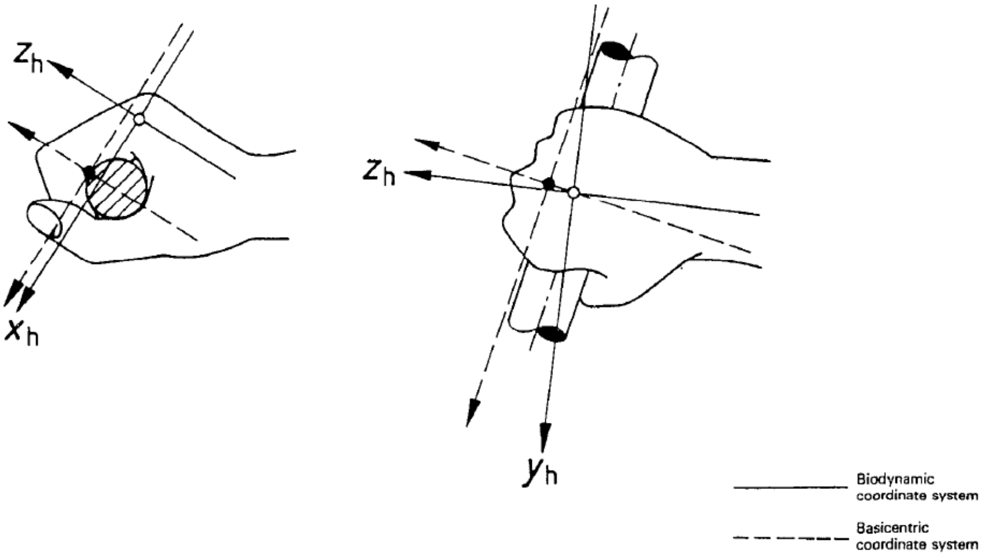


Figure 1. Description of Biodynamic and Basicentric Orthogonal Coordinate Axis Systems (*diagram from ANSI S2.70-2006, Figure 1(a), p. 6)*

In 2001, the ISO 5349 (1986) was revised to change reporting requirements from a dominant, ISO frequency-weighted, single axis acceleration to a root sum of squares acceleration (a_{hv}) (ISO 5349-1, 2001). The European Union Directive (2002) followed by requiring the measurement and reporting criteria of the ISO 5349 (2001). In 2006, ANSI updated their 1986 standard for hand-transmitted vibration to meet the measurement and reporting criteria of the ISO 5349 standard (2006). The current ACGIH TLV (2006) and the NIOSH Criteria Document (1989) for hand-transmitted vibration both still use the dominant, ISO frequency-weighted, single-axis measurements.

The vibration generated by the tool has direction and is quantifiable, but the direction and magnitude also vary with the frequency component of the vibration transmitted to the hand. The vibration frequency unit is expressed in Hertz (Hz). A frequency weighting has been used in several vibration standards and is based on subjective sensations tolerated at varying frequencies (Griffin, 1997). The frequencies evaluated ranged between 10 and 300 Hz for hand-transmitted vibration (NIOSH, 1989). The frequency weightings currently used in ANSI, ACGIH, and ISO have been extrapolated from the vibration sensations and are not health based (Griffin, 1997). The frequency range for each of the standards (ISO 5349-1, 2001; ACGIH, 2006; & ANSI S2.70, 2006) is between 5.6 and 1400 Hz. The composite frequency weighting used for hand-transmitted vibration by ANSI, ISO and ACGIH has not been linked to any one specific disorder; however there are certain frequencies have been linked to specific disorders (Griffin, 1990). The frequency weighting is illustrated below in Figure 2.

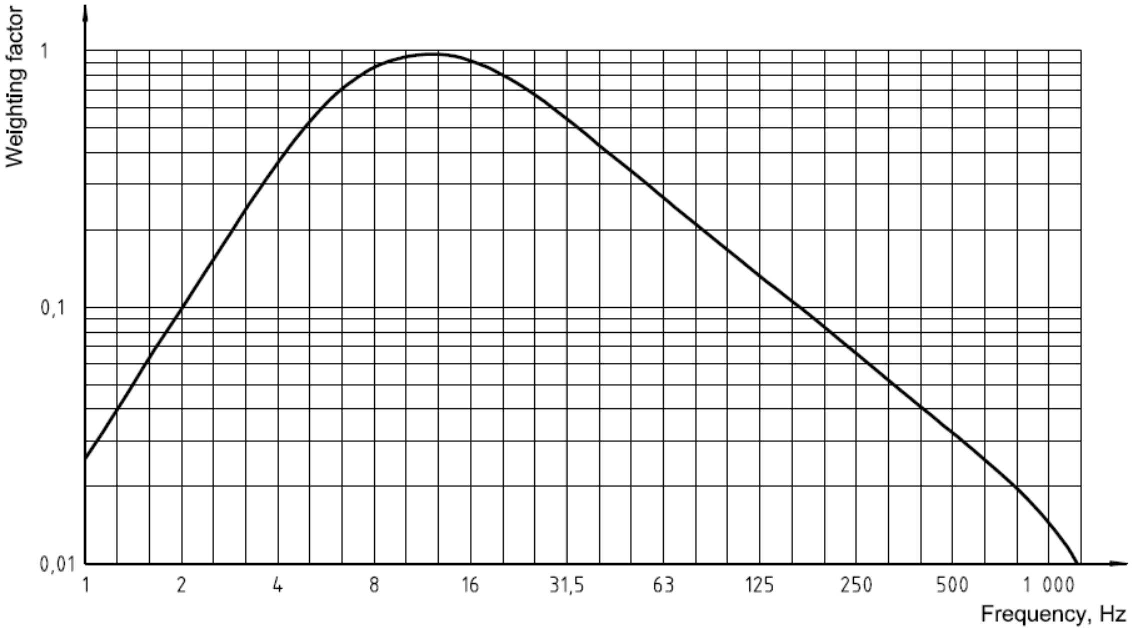


Figure 2. Frequency weighting used by ANSI, ISO, and ACGIH (From ISO 5349-1:2001(E), Figure A.1, p. 9).

The NIOSH Criteria Document for HAV (1989) disagreed with the frequency weighting and suggested that it underestimates the health effects produced from the high frequencies (NIOSH, 1989). NIOSH (1989) also goes on to state that unweighted frequency acceleration values provides a better means of assessing health risk with hand-transmitted vibration. Bovenzi (1998b) indicated that there is not enough evidence to support the theory that unweighted acceleration values are a more representative measure of risk for vascular disorders than the ISO frequency-weighted accelerations.

Another topic important to the understanding of occupational vibration is the concept of resonance. Wasserman (2001) defines resonance as "the tendency of a mechanical system (or the human body) to act in concert with externally generated vibration and to internally amplify the input vibration and exacerbate its effects" (Chapter 105, Section 1.6, para. 1).   The maximum acceleration can be transmitted to the hand-arm system at its resonant frequency. The resonant frequency range of the hand-arm system is between 150 – 300 Hz (Bruce et al., 2003).

Since the acceleration levels are gathered from the tool, an important question must be answered: how much is energy is absorbed by the hand? Several factors affect how the vibration is transmitted to the hand and fingers which includes the vibration magnitude, direction, and frequency, hand coupling to the tool, hand-arm posture, environmental conditions, and duration of exposure (Griffin, 1990, p. 609).   There is still a tremendous amount information that must be discovered to fully understand how vibration causes injury.

Occupational Standards and Guidelines for Hand-Transmitted Vibration

Several organizations have put forth health and safety standards or guidelines for the control of the vibration produced by powered hand tools. The United States has published the following guidance on hand-transmitted vibration:

- ACGIH TThreshold Limit Value for Hand-Arm Vibration, 2006,

- ANSI S2.70-2006 American National Standard Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand and,
- NIOSH Criteria For a Recommended Standard: Occupational Exposure to Hand-Arm Vibration, 1986.

The U.S. Occupational Safety and Health Administration (OSHA) has not developed regulatory standards for the control of HAV.

The American Conference of Governmental Industrial Hygienists (ACGIH) developed a threshold limit for hand-transmitted vibration that ACGIH believes that will protect nearly all workers from progressing to Stage 1 of the Stockholm Workshop Scale for the Classification of Cold-Induced Raynaud's Phenomenon in HAVS (see Table 2)(ACGIH, 2006). The ACGIH guideline requires that measurements be collected in accordance with ISO 5349 (1986) or ANSI S3.34 (1986). Both the ISO 5349 (1986) and the ANSI S3.34 (1986) standards are based on the dominant axis, frequency-weighted, rms accelerations. Both the ISO and ANSI standards have been revised in 2001 and 2006, respectively considers root sum of squares for each of the three basicentric or biodynamic axes.

Guidance for hand-transmitted vibration in the United States Navy sailors is found in OPNAV Instruction 5100.23G (2005). The U.S. Navy guidance document instructs personnel to refer to the ACGIH TLV for Hand-Arm Vibration (2006) for two exposure scenarios. The first is for high vibration tools, such as, percussive-type tools (impact wrenches, carpet strippers, chain saws), percussive tools (jack hammers, needle scalers/guns, riveting or chipping hammers), and other high vibration tools where the usage exceeds 30 minutes total per day. The second is for moderate vibration tools such as, grinders, sanders, jigsaws, where the usage exceeds 2 hours total per day.

ANSI recently updated the standard for hand-transmitted vibration in May 2006: American National Standard – Guide for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand, ANSI S2.70-2006. The ANSI standard is very similar to the current ISO 5349 (2001) and European Commission (2002) standards in that it requires the determination of the root sum of squares, frequency-weighted, rms acceleration (a_{hv}). The ANSI S2.70 standard (2006) also identifies both parts of the ISO 5349 (2001) and ISO 8041 (2005) (Human Response to Human Vibration – Measuring Instrumentation) as "indispensable for the application" of the ANSI S2.70 standard. One difference between the ISO 5349 (2001) and the ANSI S2.70 standard (2006) is that new ANSI standard prescribes a Daily Exposure Action Value (DEAV) and a Daily Exposure Limit Value (DELV). Each of the values are based on an eight hour work day where the DEAV is equal to 2.5 m/s^2 and the DELV is equal to 5.0 m/s^2. The DEAV represents a point at which symptoms of HAVS may begin to appear and the DELV are expected to be at high risk for developing HAVS (ANSI, 2006). The ANSI standard (2006) also presents a plot, Figure 3, which illustrates the location of the health risk zones based on duration of tool use and the root sum of squares acceleration value (a_{hv}).

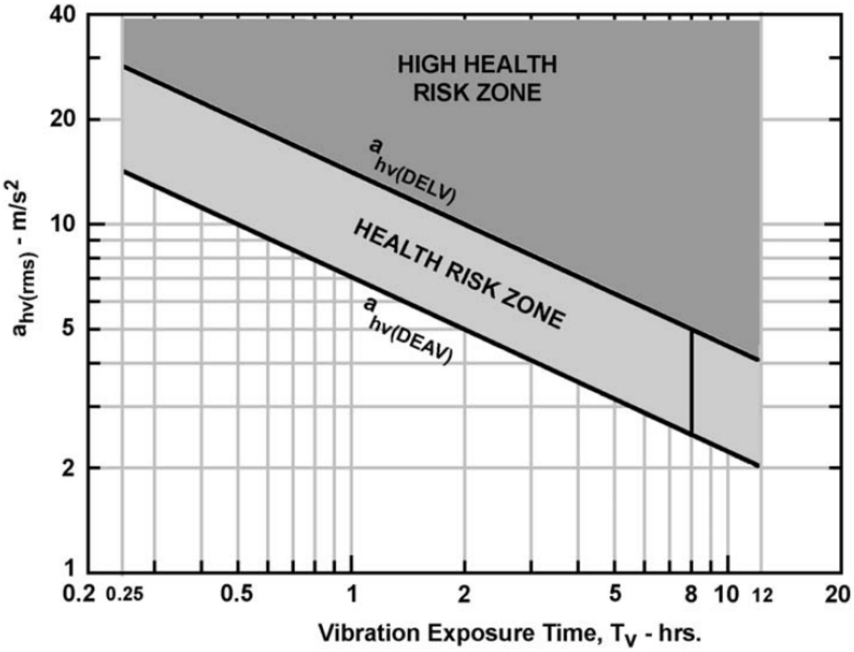


Figure 3. ANSI Health Risk Zones for DEAV and DELV (*ANSI S2.70-2006, Figure A.1, p. 12*)

In the international community, the International Organization for Standardization (ISO) has developed a consensus standard for hand transmitted vibration:

- ISO 5349-1:2001 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – General Requirements
- ISO 5349-2:2001 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Practical guidance for measurement at the workplace

The ISO 5349 (1986) was changed in 2001 to measure the root sum of squares for the *x, y,* and *z* axes acceleration values instead of reporting the rms acceleration of the dominant axis. The new ISO 5349 standard (2001) recognized that not all power tools are dominated by a single direction of vibration magnitude.

The current ISO standard for exposures to hand-transmitted vibration, ISO 5349 (2001), is divided into two parts. Part 1 provides information on the health effects related to hand-transmitted vibration, the relationship between vibration exposure and effects on health, factors likely to influence the effects of human exposure to hand-transmitted vibration in working conditions, and specific guidance on preventative measures for hand transmitted vibration. Part 2 gives specific guidelines on how to measure vibration on hand-held vibrating and percussive tools. This standard takes into consideration the frequency of the vibration, magnitude, duration of exposure per day and the cumulative exposure to date (ISO 5349-1, 2001). However, the ISO 5349 (2001) standard does not prescribe a safe limit for hand-transmitted vibration exposures. The standard does indicate that the information it provides “should protect the majority of the workers against serious health impairment associated with hand-transmitted vibration” (ISO 5349-1, 2001, p. vi)

Although the ISO 5349 standard does not provide occupational exposure limits, it does provide a way of predicting 10% prevalence of HAVS in a population that uses vibrating hand tools. The ISO 5349 standard (2001) indicates that Equation (3) below “can be used to define exposure criteria designed to reduce the health hazard of hand transmitted vibration in a group of occupationally exposed persons” (p. 16). For example, an eight hour daily exposure of 10 m/s^2 would indicate that 10% of that particular exposed group would develop finger blanching or HAVS in 2.77 years.

$$D_y = \frac{31.8}{A(8)^{1.06}} \qquad (3)$$

Where $A(8)$ is the daily vibration exposure and D_y is the group mean total (lifetime) exposure in years
**from ANSI S2.70(2006, Eq. A.4, p. 13)*

The ISO 5349-2 standard describes guidance on the measurement methods and data collection. Both the ANSI S2.70 standard (2006) and the NIOSH Criteria Document (1989) provide information regarding measurement and data collection.

The Europeans have recently taken a step forward in setting a regulatory health standard for hand-transmitted vibration that includes exposure limits. All countries part of the European Commission were required to comply with the requirements set forth in the European Directive 2002/4/EC (2002) regarding the minimum requirements for protecting the health of workers from hand transmitted vibration by July 6, 2005. The European Directive prescribes a daily Exposure Action Value (EAV) and a daily Exposure Limit Value (ELV). Both the EAV and the ELV consider time of exposure. The 8-hour acceleration value for the EAV is 2.5 m/s^2 and for the ELV it is 5.0 m/s^2 (European Directive, 2002). The equations for calculating the EAV and the ELV based on time are described below with Equation (4) and (5), respectively (Griffin, 2004).

$$a_{\mathrm{action}} = 2.5\left[\frac{8}{t_{\mathrm{h}}}\right]^{\frac{1}{2}} \tag{4}$$

$$a_{\mathrm{limit}} = 5.0\left[\frac{8}{t_{\mathrm{h}}}\right]^{\frac{1}{2}} \tag{5}$$

Where t_{h} is the exposure duration express in hours.

The ELV and EAV have also been adopted by the new ANSI S2.70 Standard (2006). The European Directive requires measurements to be collected in accordance with ISO 5349-1 (2001).

Griffin (2004) and the new ANSI S.2.70 (2006) standard use an equation from ISO 5349, Equation (3) above, to predict HAVS in 10% of a population exposed to vibration of the hand for the EAV and the ELV values of the European Directive. There is a 10% chance of HAVS for an ELV exposed worker in 5.8 years and 12 years for the EAV.

Hand-Transmitted Vibration Measurements

The test tool for the study was a compressed air-powered needle gun. The needle gun is considered a percussive tool and measurement challenges are associated with these types of tools. The ISO 5349-2 standard (2001) gives practical guidance in measurement collection.

The ISO 5349-2 standard (2001) suggests the following considerations when collecting measurements with percussive tools: proper selection of accelerometer, proper placement of the accelerometer, proper connections between the vibration instrument and the accelerometer, and placement of the cable. The ISO 5349-2 standard (2001) also suggests that a mechanical filter be used with percussive tools that should not alter the frequency response characteristics of the instrumentation. The filter is to be used to reduce high frequencies and prevent mechanical overloading of the integrated circuit piezoelectric accelerometer (ISO 5349-2, 2001).

ISO 5349-2 (2001) suggests that the selection criteria for the accelerometer should allow it to tolerate the range of anticipated vibration magnitudes and have stable characteristics. The accelerometer should also be stable in the environment (i.e., temperature, humidity) tested and the weight should not interfere with the vibration characteristics of the tool.

Placement of the accelerometer is also important and can vary. The ISO 5349-2 standard (2001) recommends that placement of the accelerometer be at or near the surface of the hand near the vibration entry point of the hand or near the middle of the palm. In most practical cases, the accelerometer cannot be placed on the hand without interfering with the worker's grip on the tool. The accelerometer should be placed near either side of the hand from the grip position (ISO 5349-2, 2001).

There are also various ways to mount the accelerometer to the tool. The most common method is to securely tighten a clamp around the accelerometer and tool. There are other ways of securing the accelerometer on the tool as well: screwed or welded mountings, glue or adhesive mountings, clamp mountings, hand-held adaptors (ISO 5349-2, 2001).

Another important aspect in the measurement of hand-transmitted vibration concerns the cable between the accelerometer and the instrument. If the cable is not secured to the vibrating surface near its connection, this may cause interference with the measurement. Additionally, improper or faulty connections between the cable, acceloremeter, and the instrument can also contribute to unreliable acceleration values (ISO 5349-2, 2001).

Other possibilites for measurement error include DC-shifts. Griffin (1990) describes this phenomenon as "an erroneous instantaneous change in the DC signal produced by some accelerometers and their signal conditioning in response to mechanical shock" (p.811). The ISO 5349-2 standard (2001) states that the DC-shift can occur in the accelerometer and cause a mechanical overloading of the piezoelectric electronics. The ISO 5349 standard for hand-transmitted vibration indicate that a mechanical filter should be used between the accelerometer and the percussive tool. The ISO 5349-2 standard (2001) cautions the user that the mechanical filter may increase the accelerations of the nonpercussive axes. Smeatham, Kaulbars, and Hewitt (2001) suggest that a thin sheet of resilient material will suffice to reduce the DC-shift with lightweight accelerometers; less than two grams.

Studies Associated with Needle Scalers and Hand-Transmitted Vibration

There are few studies on the characterization of needle scalers with regard to vibration. The British Human Factors Research Unit, Institute of Sound and Vibration Research, and Medical Research Council evaluated vibration associated with several different types of tools in 1999 (Paddan, Haward, Griffin, & Palmer). This study evaluated vibration by using a finger ring that was held securely against the tool and fitted with three separate accelorometers to measure each of the mutual orthoganol axes (Paddan et al., 1999). The researchers sampled for a five second period and used the ISO 5349 (1986) frequency-weighting for the measurements. The study gathered 10 triaxial measurements from three needle scalers. The dominant axis was determined to be the y axis (percussive axis) for all but one measuement from the needle scalers. This study also included a spectral analysis of the acceleration across the frequency range evaluated. Pressure from the compressor supplying air to the tool was not noted in the survey. The researchers calculated the root sum of squares (rss) for all ten measurements. The mean rss accelerations for tools 1 and 2 in the cleaning modes was approximately 17 m/s^2. The results of this study are summarized below in Table 4. The rss values in Table 4 for the *x*, *y*, and *z* axes were not part of the report; but were calculated for comparison purposes to the data collected for this research study.

Table 4. Needle Gun Vibration Measurements from HSE Contract Research Report 234/1999

			Frequency-weighted Vibration Accelerations (rms m/s^2)			
Tool #	Operation	Handle	*x*	*y*	*z*	rss
1	free run	main body	4.31	18.77	3.89	19.65
	cleaning	main body	3.99	13.35	6.48	15.37
	cleaning	main body	4.70	12.77	3.73	14.11
	cleaning	main body	4.05	12.64	4.94	14.16
2	free run	main body	2.71	23.03	3.21	23.41
	cleaning	main body	4.81	18.62	5.78	20.08
	cleaning	main body	3.33	18.31	5.32	19.36
	cleaning	main body	2.49	18.21	3.90	18.79
3	cleaning	rear	4.40	10.90	14.50	18.67
	cleaning	main body	2.50	28.70	2.60	28.93

**adopted from Paddan et al, 1999, Table B1, p. 48.*

This study recommended that measurements for hand-transmitted vibration should include direct measurement of vibration magnitudes, documentation of tool use and duration patterns, and ergonomics in the workplace (Paddan et al., 1999).

Palmer, Coogon, Bendall, Kellingray, Pannett, Griffin, and Haward (1999), conducted a postal survey in Great Britain to determine occupational exposures to vibration. The study determined personal vibration exposures based on a_{hw} (dominant, frequency-weigthed, single-axis) values from published and other sources of information. The study determined the dominant rms single-axis acceleration value for needle scalers was 16.0 m/s^2.

Some tool manufacturers (Trelawny SPT Ltd. (2006), Chicago Pneumatic (2006), and Jet Tools (2006)) list the acceleration levels for their equipment in a specification sheet or on their web sites. The three listed manufacturers indicate that they use the ISO 8662-14 standard (1996) for the measurement of their needle guns. The ISO 8662-14 is the specific guidance used in determining vibration levels with needle guns in laboratory-type controlled conditions. The requirements of the ISO 5349-1 standard (2001) gives more latitude as how to collect and document the vibration levels. Trelawny SPT Ltd. (2006), Chicago Pneumatic (2006), and Jet Tools (2006) website posted acceleration values for needle scalers can range from less than 10 to nearly 25 m/s^2.

Study Objectives

The principal purpose of this study was to assess the vibration level of a typical needle gun used by the U.S. Navy in the free and contact modes. A second objective was to examine the effects of tool supply air pressure on vibration. The null hypotheses for this study were:

- Tool supply air pressure does not affect vibration
- There is not a difference in vibration levels between contact and no contact with a surface

METHODS

Materials and Equipment

The test needle gun for this study was the Taylor Pneumatic Tool Company needle scaler (Model No.: T-7356). The needle scaler was borrowed from new stock of a U.S. Navy ship's tool issue. The Taylor needle scaler is a cylindrical-shaped tool that is 15 inches long, weighs 6 pounds and is shown in Figure 4. The manufacturer of the needle scaler states that the tool operates at 4500 blows per minute (bpm) which can be converted to a fundamental frequency of 75 Hz. The needle scaler manufacture literature indicates that 10 cubic feet per minute (cfm) is required to operate the tool at 90 pounds per square inch (psi) and not to operate the tool above 90 psi. A 50 foot section of rubber hose was connected between the air compressor and the tool. The hose was uncoiled to prevent restrictions on air flow.

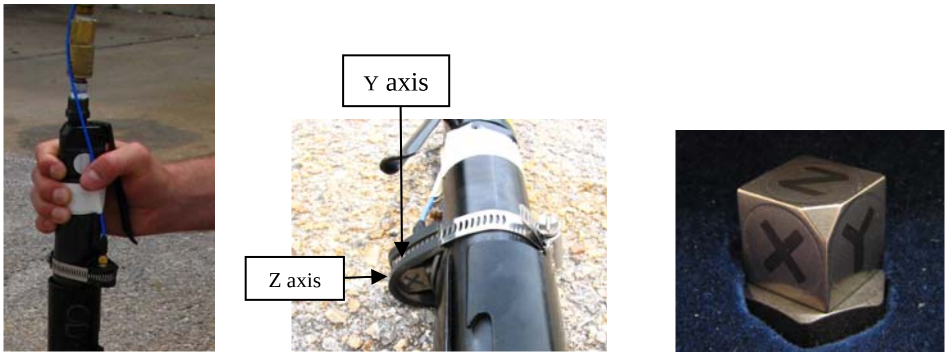
A Mi-T-M Corporation single stage air compressor (Model No.: AC1-PH55-08M) was used to power the needle gun. The specifications for the air compressor indicate that 9.0 cfm of air can be delivered at 100 psi. Part of the reason for selecting 80 and 60 psi was for sustained air flow to the tool.

Figure 4. Taylor Pneumatic Tool Company, Needle Scaler, Model T-7356

Vibration Measurement Instrumentation

The Quest Technologies HAV*Pro* personal human vibration monitor was used for the data collection. The HAV*Pro* vibration kit comes with a tri-axial, integrated circuit - piezoelectric (ICP) accelerometer manufactured by PCB Group, Inc. (Triaxial PCB ICP® Model 356A67).

Due to mounting limitations on the Taylor needle scaler, the tri-axial accelerometer was mounted on the tool such that the actual basicentric "Y" (percussive) axis was the "X" axis on the mounted accelerometer and illustrated in Figures 5a-c. The mounted Z axis is the X axis on the basicentric coordinate system and mounted Y is the basicentric Z axis. See Figure 1 for comparative purposes.



(a) (b) (c)

Figure 6. Illustration of Accelerometer Mounting. (a) Photo of tool grip of hand and mounted accelerometer. (b) Photo of the ICP accelerometer mounted onto the needle scaler. X axis runs parallel to tool handle and would be considered the Y axis on the basicentric coordinate system, (c) illustration of all three axes on the ICP accelerometer.

Two 1/16" rubber gaskets (as a double layer) were installed between the tool and the accelerometer and another 1/16" piece of rubber was wrapped around the hose clamp illustrated in Figures 5a and 5b. This provided the mechanical filter as suggested by the ISO 5349-2 standard. The filters are used to lower measurement errors by reducing the high acceleration in the higher frequencies and "prevents the overloading of the piezoelectric system” (ISO 5349-2, 2001). The specifications for the PCB ICP accelerometer and Taylor needle scaler are provided in Appendix A and B, respectively.

The tool-mounted accelerometer was connected to the Quest Technologies HAV*Pro* instrument by way of a shielded cable. The cable was taped to the tool and to a small length of the hose to reduce a triboelectric effect.

The HAV*Pro* meets requirements of the ISO 8041:1990(E) Human response to vibration – Measuring instrumentation. Since the HAV*Pro* meets the requirements for ISO 8041, the instrument is compatible with ISO Standards 5349-1:2001 and 5349-2:2001.

Protocol

Five test subjects held the needle scaler in three conditions: 1) idle, in hand, 2) activated, in hand, and 3) activated on a cast iron manhole cover. The idle condition was conducted one time for each test subject. Each of the other two conditions was conducted for twenty seconds and each condition was repeated three times. Conditions #2 and #3 were repeated at two different air pressures: 60 and 80 pounds per square inch (psi). The pressures used in this research were in accordance with the manufacturer’s recommendations of less than 90 psi.

A total of 13 measurements were collected for each subject. The HAV*Pro* instrument was setup to average in 1 second intervals for the x, y, z axes and the root sum of squares (a_{hv}). Prior to each measurement, the instrument was allowed to stabilize for approximately twenty seconds. The data was stored onto the HAV*Pro* and then downloaded to a laptop computer which interfaced with the QuestSuite Professional, Version 1.70 software package.

The data from the QuestSuite were then exported into Microsoft Excel and formatted for analysis. Each of the thirteen 20-second samples per individual was converted to a root-mean-square (rms) value by Equation 2. The rms acceleration values for the root sum of squares (*x, y, and z axes*) were then analyzed with the JMP IN 5 statistical software (SAS Institute, Cary, NC) using an analysis of variance (ANOVA) and providing descriptive statistics. Significant differences were considered to exist when the probability of a Type I error was less than 0.05. A multiple comparison procedure, Tukey's Honestly Significant Difference (HSD) test, was used in a further statistical analysis.

RESULTS

The primary purpose of this study was to characterize hand-transmitted vibration of one needle scaler used by U.S. Navy sailors. ISO frequency-weighted, rms (root-mean-square) acceleration levels were measured on the needle scaler with five subjects, two different pressures (60 and 80 psi), and measurements were gathered when the tool was activated and in contact with a surface and not in contact with a surface. An additional twenty second condition was evaluated when the tool was not activated in the subject's hand. The output from the *HAV*Pro instrument provided an averaged rms acceleration level at each second for each of the three axes (x, y, and z) and the root sum of squares (a_{hv}) of the three axes. The order of exposures for each subject is listed below in Table 5. Subjects were measured in the order listed (left to right) and then from top to bottom. The rms acceleration levels for a_{hv} from each 20-second sample and the means and standard deviations are summarized below in Table 6.

Table 5. Order of Exposures

Test #	Subj 1	Subj 2	Subj 4	Subj 5	Subj 3
1	R	R	R	R	R
2	80NC	60C	60NC	80C	60NC
3	80C	60NC	60C	80NC	60C
4	80NC	60C	60NC	80C	60NC
5	80C	60NC	60C	80NC	60C
6	80NC	60C	60NC	80C	60NC
7	80C	60NC	60C	80NC	60C
8	60C	80NC	80C	60NC	80C
9	60NC	80C	80NC	60C	80NC
10	60C	80NC	80C	60C	80C
11	60NC	80C	80NC	60NC	80NC
12	60C	80NC	80C	60NC	80C
13	60NC	80C	80NC	60C	80NC

R = tool resting in hand, not activated
60 or 80 = pressure in psi
C = tool activated and in contact with surface
NC = tool activated in hand, no contact with surface

Table 6. Summary of a_{hv} for All Subjects, Trials, Pressure (60 & 80 PSI), and Contact/No Contact

		60 PSI		80 PSI		Tool Idle
		No Contact	Contact	No Contact	Contact	Not Activated
Subject	Trial	a_{hv} (m/s^2)	a_{hv} (m/s^2)	a_{hv} (m/s^2)	a_{hv} (m/s^2)	a_{hv} (m/s^2)
1	1	13.7	10.7	15.2	13.0	0.143
	2	13.6	11.6	15.5	12.5	
	3	13.7	11.7	15.5	12.6	
2	1	13.9	11.1	15.9	12.9	0.195
	2	13.9	11.8	16.1	13.4	
	3	13.7	11.5	16.0	12.8	
3	1	14.1	11.4	16.9	13.0	0.151
	2	14.3	11.8	16.8	12.9	
	3	14.2	11.9	16.8	13.4	
4	1	13.7	11.7	15.5	13.2	0.261
	2	14.1	11.6	16.3	13.8	
	3	13.9	12.3	16.9	13.2	
5	1	14.1	11.3	17.1	14.1	0.137
	2	14.2	10.8	17.3	12.6	
	3	13.9	11.4	17.1	13.0	
Means		13.9	11.5	16.3	13.1	0.177
Standard Deviations		0.219	0.421	0.697	0.450	0.052

A three-way ANOVA (subjects by pressure by contact) with replicates (not including idle conditions) was conducted on the data. The analysis included the main effects and the interaction of pressure and contact. The subjects were treated as a blocking variable. All the main effects and the interaction were significant at $p<0.001$. Tukey's HSD test was used to determine which pairs were significantly different among the interaction pairs. Each interaction pair was significantly different at $p<0.001$ level. The interaction of pressure and contact shows the amount of increase in acceleration levels from 60 to 80 psi in the contact mode is greater than the increase in acceleration levels when the tool was not in contact with a surface.

DISCUSSION AND CONCLUSIONS

The main purpose of this study was to provide data on vibration associated with the use of a needle gun used by U.S. Navy sailors. The vibration of the Taylor T-7356 needle gun was evaluated at two pressure levels and contact conditions.

Significant differences in vibration were noted with change in pressure and between contact with a surface and no contact. The measured mean acceleration levels for the Taylor needle gun in contact with a surface were 11.5 and 13.1 m/s^2 at 60 and 80 psi, respectively. The mean accelerations without contact were 14.0 and 16.3 m/s^2 at 60 and 80 psi, respectively; with increased vibration over contact of 2.5 and 3.2 m/s^2.

Two British reports (Palmer et al., 1999. and Paddan et al., 1999) identified differences in accelerations in the contact and no contact modes. The first study, Palmer et al. (1999), determined that 16.0 m/s^2 was the dominant, single-axis acceleration representative for needle guns in Great Britain. The root sum of squares value (a_{hv}) would be slightly higher than the dominant single axis value.

The second study, (Paddan et al., 1999) evaluated the acceleration levels of three needle guns used in Great Britain. The Paddan et al. (1999) study mean root-sum of squares (rss) accelerations for tools #1 and #2 were 14.6 and 19.4 m/s^2 in the contact/cleaning mode and 19.7 and 23.4 m/s^2 in the non-contact mode, respectively. Tool #3 appeared to be a gun-type needle scaler and there were two measurements (two different handles) for this particular tool in the cleaning mode. It should be noted that neither of the two British studies indicated the tool supply air pressure. The acceleration levels determined by the British were higher than the values found in this research; and the Paddan et al. (1999) study demonstrated similar differences between accelerations in the contact and no contact modes.

Some tool manufacturers; such as Trelawny SPT Ltd.(2006), Chicago Pneumatic (2006), and Jet Tools (2006), provided acceleration data on their needle scalers. Trelawny SPT Ltd. (S. Jerger, personal communication, July 11, 2006) and Chicago Pneumatic (T. Wastowicz, personal communication, July 13, 2006) indicated they used the ISO 8662 standard for measuring acceleration levels. Jet Tools (2006) just listed the vibration acceleration levels on their web site and did not indicate what method was used to determine the acceleration levels. The ISO 8662-14 standard (1997) for needle guns requires a controlled environment for acceleration measurements. Chicago Pneumatic had several cylindrical needle scalers in their inventory and the accelerations ranged from 3.7 to 16.9 m/s^2 (Chicago Pneumatic, 2006). Trelawny SPT Ltd. had two different cylindrical needle scalers, models 1B and 2B, that had vibration acceleration levels at 8.5 and 9.3 m/s^2, respectively (Trelawny SPT Ltd., 2006). The specifications for Taylor needle scaler used in this research did not provide acceleration data.

There was some lack of uniformity in currently available measurement standards, at least between the two ISO standards, 8662-14 (1996) and 5349 (2001). Tool manufacturers use the ISO 8662-14 (1996) to provide acceleration data for needle guns new tools where the ISO 5349 (2001) method is used for more measuring vibration levels for tools used in the workplace. Both the NIOSH Criteria Document on Hand-Arm Vibration (1989) and the work of Wasserman, D. E., Hudock, Wasserman, J. F., Mullinix, Wurzelbacher, and Siegfried (2002) suggested that newer tools will have lower vibration levels than tools that have been used during normal operations over time and/or poorly maintained.

One outcome that both the Paddan et al. (1999) or Palmer et al. (1999) studies did not evaluate was the effect of tool supply air pressure on vibration. The current research found that increasing pressure increases vibration levels. Adjusting tool supplied air pressure to a minimum level while maintaining tool function can be used as control measure to reduce the acceleration transmitted to the hand. Although, reducing the pressure may increase the amount of time to complete the job with the tool; thereby increasing time of vibration. The current research also demonstrated that the acceleration values were higher in the no-contact mode versus the contact mode.

The mean acceleration values for 60 psi, contact with a surface and 80 psi, contact with a surface were 11.5 and 13.1 m/s^2. Based on the means at the two pressures and with the needle scaler in contact with a surface, the EAV and ELV times for 60 psi would be 23 and 91 minutes, respectively. The EAV and ELV times for 80 psi are 18 and 70 minutes, respectively.

Navy sailors may use the needle scaler, worst case conditions, for four to five hours in a day for a couple of months at a time. However, Navy use of the needle scaler changes with rank. As sailors are promoted, the use of the needle gun either decreases or ceases.

If a sailor were exposed at the 80 psi level of 13.1 m/s^2 for four hours per day, the daily exposure vibration level, $A(8)$, would be 9.3 m/s^2. Based on the group mean total (lifetime) exposure equation (Equation 3), it would take 3 years or 650 working days for this exposure group to present ten percent prevalence of HAVS. It does not likely appear that HAVS would be prevalent in sailor populations because it is not likely that they will use the needle gun for four hours per day for 650 days in their career. However, tool pressure can be used to decrease accelerations to lower exposure levels.

In conclusion, the principal purpose of this study was to provide vibration data on a needle gun used by U.S. Navy sailors. The results of the study revealed the following:

1. Vibration levels were higher in the no contact mode compared to the contact mode,
2. Vibration levels increased as the tool supply air pressure increased and,
3. U.S. Navy sailors are not likely at significant risk for Hand-Arm Vibration Syndrome for lifetime exposures to hand transmitted vibration.

Industrial workers are likely to remain on the same job using a number of different vibrating tools longer than a U.S. Navy sailor. Industrial workers may likely be at higher risk to vibration-induced white finger due to the increased lifetime exposures.

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APPENDIX A: PCB ICP ACCELEROMETER SPECIFICATIONS

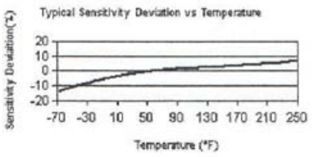
Model Number
356A67

ACCELEROMETER, ICP®, TRIAXIAL

Revision NR
ECN #:

	ENGLISH	SI	
Performance			
Sensitivity (±10 %)	10 mV/g	1.02 mV/(m/s²)	
Measurement Range	±500 g pk	±4900 m/s² pk	
Frequency Range (-5 %) (Y- & Z-axis)	0.5 to 2500 Hz	0.5 to 2500 Hz	[2]
Frequency Range (-5 %) (X-axis)	0.5 to 3000 Hz	0.5 to 3000 Hz	[2]
Resonant Frequency	≥25 kHz	≥25 kHz	
Broadband Resolution (1 to 10000 Hz)	0.0005 g rms	0.005 m/s² rms	[1]
Non-Linearity (400 g, 3920 m/s&#178)	≤1 %	≤1 %	[3]
Non-Linearity (500 g, 4900 m/s&#178)	≤2 %	≤2 %	[3]
Transverse Sensitivity	≤5 %	≤5 %	
Environmental			
Overload Limit (Shock)	±7000 g pk	±68600 m/s² pk	
Temperature Range (Operating)	-65 to +250 °F	-54 to +121 °C	
Temperature Response	See Graph	See Graph	[1]
Base Strain Sensitivity	0.001 g/με	0.01 (m/s²)/με	[1]
Electrical			
Excitation Voltage	20 to 30 VDC	20 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤200 ohm	≤200 ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	
Discharge Time Constant	1.0 to 2.0 sec	1.0 to 2.0 sec	
Settling Time (within 10% of bias)	<5 sec	<5 sec	
Spectral Noise (1 Hz)	150 μg/√Hz	1472 (μm/s²)/√Hz	[1]
Spectral Noise (10 Hz)	25 μg/√Hz	245 (μm/s²)/√Hz	[1]
Spectral Noise (100 Hz)	10 μg/√Hz	98 (μm/s²)/√Hz	[1]
Spectral Noise (1 kHz)	5 μg/√Hz	49 (μm/s²)/√Hz	[1]
Physical			
Sensing Element	Ceramic	Ceramic	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Hermetic	Hermetic	
Size (Height x Length x Width)	0.55 in x 0.80 in x 0.55 in	14.0 mm x 20.3 mm x 14.0 mm	
Weight	0.37 oz	10.5 gm	[1]
Electrical Connector	1/4-28 4-Pin	1/4-28 4-Pin	
Electrical Connection Position	Side	Side	
Mounting Thread	10-32 Female	10-32 Female	
Mounting Torque	10 to 20 in-lb	113 to 225 N-cm	

CE[4]



All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB group, Inc.

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

Notes
[1] Typical.
[2] Upper frequency response is ± 500 Hz from the specified value.
[3] Zero-based, least-squares, straight line method.
[4] See PCB Declaration of Conformance PS023 for details.

Supplied Accessories
080A109 Petro Wax (1)
080A12 Adhesive Mounting Base (1)
081B05 Mounting Stud (10-32 to 10-32) (1)
ACS-1T NIST traceable triaxial amplitude response, 10 Hz to upper 5% frequency. (1)

Entered: DMO	Engineer: DMO	Sales: WDC	Approved: BAM	Spec Number:
Date: 03/03/2003	Date: 03/03/2003	Date: 03/10/2003	Date: 03/10/2003	22169

PCB PIEZOTRONICS
VIBRATION DIVISION

Address: 3425 Walden Avenue
Depew, NY 14043
United States
Phone: 888-684-0013
Fax: 716-685-3886
E-mail: vibration@pcb.com
Web site: www.pcb.com

APPENDIX B: TAYLOR NEEDLE SCALER T-7356 SPECIFICATIONS

Master Distributors

Warming your hearts and homes since 1982.
SALES: 888-917-2244 FAX: 800-791-8595

Taylor Pneumatic Scaler Tools

Taylor premium quality pneumatic automotive, construction and industrial air tools.

Taylor Pneumatic Scaler: T-7356

- Model: T-7356
- Needle Scaler
- Needle Diameter: 3 mm
- Number of Needles: 19
- Bore & Stroke: 1" x 1-1/8"
- Blows per minute: 4,500
- Length 15"
- Weight 6 lbs.
- Air Pressure: 90 PSI Maximum
- Lever throttle
- Precision machined and hardened parts
- All steel construction
- Needles adjust to contours
- The T-7356 has many applications
- Chipping concrete and brick, cleaning castings and paint, and rust removal

Limited Lifetime Warranty:

Most products of Taylor Pneumatic are warranted to be free from defects in material or workmanship for the life of the tool. This warranty applies to the original purchaser only. This warranty does not cover tools that have been abused, misused, modified, not properly lubricated or to normal wear and tear. Taylor Pneumatic will at its option repair or replace the defective product free of charge except for shipping. Taylor Pneumatics sole liability and your exclusive remedy under this warranty is limited to the repair or replacement of the defective product. There are no other warranties expressed or implied and Taylor Pneumatic shall not be liable for incidental, consequential, or special damages, expenses or costs except as described above. Warranty void if tool is disassembled.
(The warranty period on the following tools is 90 days: T-6600 series nailers and staplers, T-7756 Die Grinder, T-7007 and T-7015 paint spray guns and T-7618 caulking gun.)

Returning Repairs:

Return all repairs to:
Taylor Pneumatic Tool Company
505 North Railroad Ave.
Boynton Beach, FL. 33435

Please include:

- What you think may be wrong with the tool
- Do you want an estimate if the tool is not covered under warranty?
- A copy of the original invoice showing the purchase date
- $7.50 to cover return postage

All Pneumatic Tool Warning:

When operating pneumatic tools it is of the utmost importance to think safety first. Disconnect tools from the air supply when changing accessories or when the tool is not in use. Direct exhaust away from yourself and others. Use eye protection. Use hearing protection when tools are being used for extended periods. Use 90 psi maximum pressure at the tool. Putting a few drops of air tool oil in the tool and running for a few seconds at the end of a day will help protect internal parts. Follow all operating instructions and operate tool in accordance with the ANSI B186.1 safe operating code.

Shipping Details **Valuable Sites**