Tasked-Based Assessment of Occupational Vibration and Noise Exposures in Forestry Workers

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INTRODUCTION

Due to the focus on safe work practices designed to reduce the tremendous safety hazards involved in forestry work, health hazards associated with forestry work have historically received little attention. Exposure to occupational hand-arm vibration (HAV) has been associated with a variety of adverse health effects, a number of conditions collectively known as Hand Arm Vibration Syndrome (HAVS), since the early 1900s. Long-term whole-body vibration (WBV) exposure to seated persons has been associated with an increased risk of degenerative lumbar spine injuries, CNS disturbances, and possibly damage to the digestive and genital/urinary systems. Occupational noise exposure has been recognized as a causal factor for permanent, irreversible hearing loss for several hundred years.

Forestry industry workers employed in the US Pacific Northwest (PNW) are exposed to numerous sources of HAV, WBV, and noise. Examples of these sources include chainsaws, yarding equipment, processors, log stackers, log trucks, and earth-moving equipment. The types of forestry work covered in this study include logging road construction, felling, bucking and limbing, log processing, log collection (via yarding and landing or shovel logging), log loading and transport to a sort yard, and intra-sort yard log movement.

The current study has several goals. The first is to describe the occupational exposure of the studied PNW forestry worker population to sources of HAV, WBV, and noise. The second is to assess the exposure risk presented by the use of various tools and performance of certain tasks. The third is to examine the relationship between vibration and noise exposure levels. The fourth and final aim is to measure the levels of HAV received through the controls of heavy equipment, a source of exposure which has previously received little attention.

METHODS

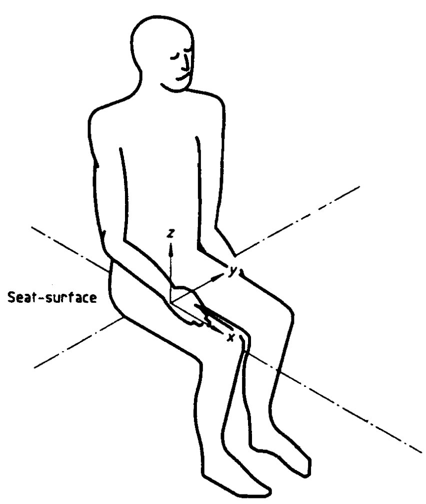
Two large PNW forestry companies participated in this study. Six trades were monitored: fellers, vehicle operators, rigging slingers, chokermen, landing men, and hooktenders. Forty-three workers volunteered to participate in the research. Data were collected on 10 different days over 8 weeks in spring 1999 at 1 felling site, 4 yarding and landing sites, 2 log handling facilities, and multiple road construction sites. Sites and dates were selected based on the potential number of subjects available. Subjects participated voluntarily; incentives were offered to increase participation rates. Full-shift noise exposure measurements were made on up to 5 subjects per day, and multiple vibration measurements were made on each subject during various tasks. Subjects completed brief self-report activity questionnaires as the workday progressed which listed operation-specific tasks and tools likely to be encountered and allowed workers to report the timing and frequency of their activities with approximately 15-minute time resolution. A researcher observed the workers periodically throughout the workday, documenting the timing of their actual activities for post-workshift comparison to their self-reported activities to allow for statistical analysis of their reporting accuracy.

Full-shift noise exposures were measured using Quest Q-300 datalogging dosimeters configured to capture two channels of data simultaneously. Channel 1 was set to the legally-enforceable OSHA Permissible Exposure Limit for Hearing Conservation (an 85 dBA 8-hour Time-Weighted Average using a 5 dB exchange rate), and channel 2 was set to the more protective, but voluntary, 1998 NIOSH Recommended Exposure Limit (an 85 dBA 8-hour Time-Weighted Average using a 3 dB exchange rate). The exchange rate (ER) is the number of decibels required to have or double the allowable exposure time; i.e., using a 5 dB ER, a worker is allowed 8 hours a 85 dBA, 4 hours at 90 dBA, 2 hours at 95 dBA, 1 hour at 100 dBA and so on. A 3 dB ER requires shorter exposures at the same levels: 8 hours at 85 dBA, 4 hours at 88 dBA, 2 hours at 91 dBA, 1 hour at 94 dBA, etc. Dosimeters were placed on workers' belts or in jacket or pants pockets; the microphones were placed on the shoulder of the workers' dominant hand within 4 inches of the ear. For each minute monitored, the dosimeters yielded an L_{OSHA} (5 dB ER), L_{EQ} (3 dB ER), L_{max}, and L_{peak}. The dosimeters also yielded 8-hr TWA levels for both the OSHA and NIOSH metrics. Noise measurement data were downloaded directly into a PC for analysis.

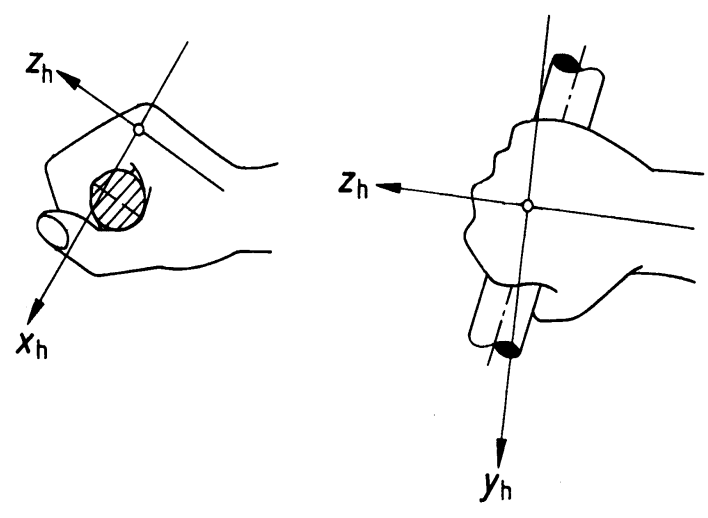
Vibration exposure measurements were made with a Bruel & Kjær 2231 Type 1 Sound Level Meter (SLM) equipped with a B&K 2522 Human Vibration Unit and B&K BZ7105 Human Vibration Module. Biodynamic weighted root-mean square (rms) acceleration WBV measurements were made in 3 mutually perpendicular axes (x, y, and z) according to International Organization for Standardization (ISO) standard 2631/1-1985. Triaxial measurements account for the vector nature of vibration, which involves both a magnitude and a direction. Triaxial basicentric weighted rms acceleration HAV measurements were made according to ISO 5349-1986. The axes on which the HAV and WBV measurements were based are shown in Figure 1.

Figure 1: Vibration Measurement Axes

a)Whole Body:



b)Hand Arm:



HAV measurements were made using three B&K 4374 miniature piezoelectric accelerometers in a B&K UA0891 triaxial hand mount (a T-shaped mount placed between the workers' 2^{nd} and 3^{rd} fingers with the crossbar of the T touching the grip of the measured tool). WBV measurements were made with a B&K 4322 triaxial seat accelerometer, a flat rubber plate with integrated accelerometers laid between the seat pan surface and the workers' buttocks. Each task and type of equipment was measured multiple times. Data obtained at download included summary (triaxial) equivalent acceleration level (A_{EQ}), and L_{max} (rms), L_{min} (rms), L_{peak}, and A_{EQ} for each of the 3 axes. Vibration measurements were compared to several occupational exposure standards, including the American Conference of Government Industrial Hygienists' (ACGIH) Threshold Limit Value (TLV) for HAV, ISO 5349, and document "COM(92) 560 – Final" from the Commission of the European Communities (CEC), a framework directive which establishes Action and Ceiling Limits for WBV. All of these vibration standards are voluntary; there are currently no legally enforceable, quantitative US vibration exposure standards.

The SLM and dosimeters were calibrated pre- and post-monitoring. Vibration measurements were matched to the average of the corresponding dosimeter 1-min average noise levels to allow for calculation of correlation coefficients. Crosstabulation tables were generated to compare worker-reported tasks and tools to those observed by the researcher; the statistics calculated indicate excellent agreement between researcher and worker reporting.

RESULTS

Forty-four noise exposure samples were collected, with one individual monitored twice. Two noise samples were discarded due to instrument failure. One hundred seventy-four vibration exposure measurements were made, of which 164 were successful. Vehicle operators represent 81% of all samples; however, the operators in this study operated 11 different types of heavy equipment. Workers in the 6 trades sampled performed 16 different tasks and used 12 different pieces of equipment. The mean worker age was 47 yrs, the mean experience level was 22 yrs, and the mean equipment age was 8 yrs.

The 42 noise exposures monitored represent 19,235 1-min averages. The mean dosimeter runtime was 7 hr 39 min. The average NIOSH TWA was 90.2 dBA, while the average OSHA TWA was 86.1 dBA. The highest mean NIOSH and OSHA TWAs by operation were felling and road construction, and job title were tree feller and hooktender, respectively. Exceedance fractions for the NIOSH and OSHA TWAs are shown in Table 1. Exceedance percentages were highest in road construction and tree felling operations.

The mean 1-min OSHA noise level was 81.0 dBA, and the mean 1-min NIOSH noise level was 85.3 dBA. Forty-one percent of all L_{OSHA} 1-min readings were above 85 dBA, while 24% exceeded 90 dBA; 49% of all L_{EQ} 1-min readings exceeded 85 dBA, and 29% exceeded 90 dBA. The highest NIOSH and OSHA 1-min noise levels by task were unbelling chokers and felling, limbing, and bucking, while highest levels by tool for both metrics were chainsaw and dozer.

Workers self-reported using HPDs 84% of the total monitored time. Earplugs accounted for 85% of the time HPDs were used, earmuffs 6%, and double protection (earplugs and earmuffs) 9% of the time. The type of HPD reported was noted to change appropriately with increasing noise exposure, i.e. higher levels of protection were used at higher sound levels, indicating that workers protected themselves better at high noise exposure levels.

HAV measurements were made on hand tools and heavy equipment operating controls, and WBV measurements were made on equipment seats. Of the 164 successful vibration readings, 65 were HAV and 99 were WBV; all measurements combined represent 744 total minutes of monitoring. The mean HAV measurement duration was 2 min 15 sec, and the mean WBV duration was 5 min 54 sec. Measurement durations were made to represent task cycle times where possible.

Table 1: Vibration and Noise Exposure Exceedance Fractions

Category	% TWAs >85 dBA		% TWAs > 90 dBA		% HAV Measurements >4 hr limit			% HAV Measurements > 8 hr limit			% WBV Measurements > 8-hr Action Limit	% WBV Measurements > 8-hr Ceiling Limit
	OSHA	NIOSH	OSHA	NIOSH	ACGIH			ACGIH			CEC	CEC
					X	Y	Z	X	Y	Z	Vector Sum	Vector Sum
Operation												
Tree Felling	100	100	67	100	50	14	18	91	64	82		
Log Handling	50	83	33	33	33	0	0	33	0	0	84	76
Sorting and Loading	67	100	0	67	0	0	0	100	0	0	40	33
Shovel Logging	67	100	0	0							25	13
Log Processing	25	25	0	25							80	80
Road Construction	90	100	50	50	0	0	0	10	0	0	81	69
Yarding and Landing	38	77	23	54	44	11	33	56	44	56	22	22
Job Title												
Chokerman	100	100	0	33								
Tree Feller	100	100	67	100	50	14	18	91	64	82		
Hooktender			100	100								
Landing Man	75	100	50	100	44	11	33	56	44	56		
Operator	60	80	23	37	4	0	0	17	0	0	60	53
Rigging Slinger			0	0								
Overall	60	83	29	48	29	7	13	53	33	42	60	53

The 99 WBV events had a mean summary frequency-weighted acceleration component of 3.5 m/s^2. The highest WBV mean A_{EQ} exposure in all 3 axes was from log processing, while the task and job title associated with the highest WBV A_{EQ} exposures in all 3 axes were operating a vehicle and vehicle operator. The equipment generating the highest WBV A_{EQ} exposure in all three measured axes was the Front End Loader. The 65 HAV events had a mean summary frequency-weighted acceleration of 5.5 m/s^2. The highest HAV mean A_{EQ} exposure levels by operation for the x, y, and z axes were associated with tree felling, and the highest mean HAV A_{EQ} exposure level for all 3 axes by job title was for tree fellers. The task with the highest HAV A_{EQ} exposure level was notching stump for the x axis, felling trees for the y axis, and idling a chainsaw for the z axis. Lastly, the tool with highest HAV A_{EQ} mean exposure level was the chainsaw for all three axes.

Vibration exposure exceedance fractions are presented in Table 1. Between 22-84% of all WBV summary frequency-weighted measurements by type of operation exceeded the 8-hr CEC Action Level, and 22-80% exceeded the 8-hr Ceiling Level. The operations with the highest WBV exceedance values were log handling and log processing.

The HAV levels associated with heavy equipment controls were surprisingly high when compared to the traditionally-recognized source of HAV, the chainsaw. Seventeen percent of all measurements taken on the x axis of the controls of the heavy equipment assessed were over the 8 hr TLV; a further 4% were over 4 hr TLV. Overall, 33-53% (depending on the axis) of all HAV A_{EQ}s exceeded the 8 hour HAV TLV, and 7-29% (again depending on the axis) of all HAV A_{EQ}s exceeded the 4 hour HAV TLV.

Spearman correlation coefficients were calculated to assess the relationship between noise and vibration levels. Neither the correlation value for summary weighted HAV vector magnitudes compared to the mean of the corresponding 1-min NIOSH noise levels nor summary WBV levels compared to NIOSH 1-min noise level were significant. Additionally, no significant correlations were found between equipment age and NIOSH noise level or vibration level by axis.

DISCUSSION

No existing studies of WBV exposure levels in forestry workers were identified in a literature search. WBV studies in occupations with exposures similar to those measured here suggest that adverse health effects may be associated with these exposure levels. For example, a questionnaire survey of operators of heavy construction equipment operators found no significant difference between low back pain rates or upper arm and hand symptoms in dozer and shovel operators and a control group [(1)].

The HAV exposure levels from chainsaws measured in this study generally agree with measurements of exposure in Finland, Italy, Canada, Japan, and other countries. In these nations, the introduction of antivibration chainsaws has reduced exposure levels; however, these levels may still be high enough to produce new occurrences of HAVS, and do not eliminate vibration-related health effects.

According to ISO 5349-1986, the average hand arm vibration levels measured in the current study can be expected to cause vascular symptoms within 6 years in 10% of workers, within 11 years in 30% of workers, and within 14 years in 50% of workers. However, tasks involving intensive chainsaw use, including felling, limbing, and bucking trees, will likely result in the appearance of vibration-related health effects in a shorter period of time.

The HAV exposure levels measured on heavy equipment controls are another area of concern. Few studies have been done on equipment control vibration levels. One study of HAV exposure from motorcycle controls in Japanese police officers found HAV levels similar to those measured here, and significantly higher rates of adverse health effects when compared to a control group [(2)]. These findings suggest that the forestry equipment controls in the current study are sources of potentially hazardous levels of vibration. ISO 5349 estimates indicate that the heavy equipment control HAV exposure levels measured will produce vascular symptoms in 10% of workers after 15 years of exposure, and 50% after 25+ years of exposure, with equipment like loaders and stackers producing symptoms faster.

The noise exposures and HPD usage rates measured in this study are consistent with exposures reported elsewhere. NIOSH estimates a 29% excess risk of NIHL in workers exposed for a 40-yr working lifetime to the NIOSH noise exposure levels measured in the current study (90 dBA), and a 15% excess risk at 85 dBA. Available data indicate that chainsaw noise levels have decreased over the past 25 years, a finding consistent with the introduction of quieter, muffled saws.

Reducing noise and vibration levels through engineering controls and design alteration is the most desirable approach to reducing the prevalence of Hand Arm Vibration Syndrome (HAVS), WBV-related health effects, and noise-induced hearing loss (NIHL) among forestry workers. Noise control strategies include acoustic treatment, enclosure of engine compartments and heavy equipment operator workstations, and installation of mufflers and silencers. Transmission of WBV can be reduced with adjustable, air-cushioned seats. Proper vehicle tire inflation reduces shock vibration from rough surface travel, which can contribute significantly to WBV exposures. Proper and timely maintenance of vehicle systems and hand tools can reduce vibration and noise exposure. Substituting older chainsaws with newer antivibration saws or adding vibration-dampening fittings will likely reduce HAV exposure levels, but will not completely reverse the damage caused by non-AV saw experience.

Administrative controls for HAV, WBV, and noise include regulating the operator's exposure time to vibrating or noisy equipment, providing education on the harmful effects and prevention of vibration and noise exposure, and, for HAV and WBV, protecting workers against prolonged exposure to cold temperatures. Medical surveillance is an essential part of any prevention strategy. An effective hearing conservation program (HCP) - which both companies in this study had - will reduce the risk of NIHL. Workers suffering from vibration- or noise-related health problems should be removed from further exposure. Cessation of vibration exposure can reduce, though not eliminate, the symptoms of VWF; NIHL is permanent and irreversible.

AV gloves offer additional HAV protection for the worker, and the use of Hearing Protection Devices (HPDs) can reduce noise exposure when other controls are not feasible.

Although it has been demonstrated that noise dosimetry can be used to accurately model noise and vibration exposure duration by chainsaw operating mode [(3)], no correlation was found in the current study between measured noise level and concurrent vibration exposure level. Vibration and noise levels may not be significantly correlated due to the fact that vibration levels are highly influenced by the condition of the machinery generating the vibration and noise, while the emitted noise levels are more stable. Also, the effects of terrain on heavy equipment cannot be discounted. It appears that noise dosimetry is not useful for estimating vibration exposure magnitudes.

CONCLUSIONS

Noise and vibration exposure represent a major occupational hazard to forestry workers. This project demonstrates that workers employed in logging-related activities in the PNW have substantial overexposures to vibration and noise. Health hazards such as noise and vibration have received limited attention in the forestry industry in the past, due to the inherently dangerous nature of forestry work. However, the recent introduction of safer and more mechanized work practices offers an opportunity to go beyond acute hazards and focus on long-term health effects. Control strategies should be implemented to reduce forestry noise and vibration exposure levels. The findings of this study indicate that the highest HAV exposure sources are also the highest noise sources: chainsaws, felling operations, and yarding and landing operations, and that HAV exposure control efforts should include heavy equipment controls, including joysticks and operating levers. The worst WBV sources were log processing, road construction, front end loaders, and excavators. The task and tool associated with the highest noise exposure levels were unbelling chokers on landings and chainsaws, while the task and tool associated with the highest vibration exposure levels were log processing and front end loaders (WBV), and notching stumps and chainsaws (HAV). No significant correlations were identified between HAV or WBV and the corresponding NIOSH noise exposure levels. Study subjects were significantly likely to use increasing higher levels of hearing protection at higher levels of noise exposure. Excellent agreement was found between worker reporting and simultaneous researcher observation, suggesting that noise and vibration exposures can be modeled in populations that report their activities. Further research is needed on small contract logging operations, which may differ from the larger companies in the current study.

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