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

Forty-two noise exposures and 164 whole-body (WBV) and hand-arm (HAV) vibration exposures were collected from 43 forestry workers in six trades employed by two forestry companies. Data were collected on 10 days over 8 weeks during various felling, logging, and log handling operations. Up to 5 volunteers were monitored for noise and vibration daily using datalogging noise dosimeters, which provided daily time-weighted averages (TWAs) and 1-min averages; and a precision sound level meter equipped to measure human vibration, which provided triaxial HAV and WBV event-weighted averages (A_{EQ}s). Workers completed a short questionnaire throughout the workday detailing the timing and number of tasks performed and equipment used. Substantial overexposures to noise and vibration were seen; for example, 60% of Occupational Safety and Health Administration (OSHA) TWAs and 83% of National Institute for Occupational Safety and Health (NIOSH) noise TWAs exceeded 85 dBA, 33–53% of the axis-specific HAV A_{EQ}s exceeded the 8-hour American Conference of Governmental Industrial Hygienists' HAV threshold limit value, and 34% of all summary weighted WBV A_{EQ}s exceeded the Commission of the European Communities' 8-hour exposure limit. The mean for 99 WBV summary weighted A_{EQ} was 3.53 ± 7.12 m/sec^2, whereas the mean for 65 HAV summary weighted A_{EQ} was 5.45 ± 5.25 m/sec^2. The mean OSHA TWA was 86.1 ± 6.2 dBA, whereas the mean NIOSH TWA was 90.2 ± 5.1 dBA. The task and tool with the highest exposure levels were unbelling chokers on landings and chain saws (noise), log processing and front-end loaders (WBV), and notching stumps and chain saws (HAV). An internal validation substudy indicated excellent agreement between worker-reported and researcher-documented tasks and tools.

Keywords: exposure assessment, forestry, hand–arm vibration, occupational noise, whole-body vibration

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Work in the forestry industry traditionally has involved exposure to a wide variety of safety and health hazards. The multibillion–dollar forestry industry, which includes the most dangerous occupation in the United States—logging—employed approximately 122,000 workers nationwide in 1996.(1) The fatality rate for loggers is 128 deaths per 100,000 workers, compared to the overall U.S. rate for all occupations of 5/100,000.(2) Washington and Oregon, in the U.S. Pacific Northwest (PNW, which also includes Alaska and Idaho) together represent 16.7% of total U.S. logging employment, and account for 73 logging deaths annually, or 9.5% of all annual U.S. logging fatalities.(2) Overall, logging employees comprise only 0.5% of all U.S. employment, but account for almost 2% of all U.S. occupational fatalities.(2)

Due to the focus on safe work practices designed to reduce these alarming statistics, the health hazards associated with forestry work historically have 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),(3) since the early 1900s.(4) Long-term whole-body vibration (WBV) exposure to seated persons has been associated with an increased risk of degenerative lumbar spine injuries, central nervous system disturbances, and possibly damage to the digestive and genital/urinary systems.(5–8) Occupational noise exposure has been recognized as a causal factor for permanent, irreversible hearing loss for several hundred years.

The approximately 20,000 forestry industry workers employed in the PNW, including the 7728 logging employees working in Washington State in 1998,(9) are exposed to numerous sources of HAV, WBV, and noise. Examples of these sources include chain saws, 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, shovel logging, or skidding); log loading and transport to a sort yard; and intra-sort yard log movement. Logging road construction involves cutting trees along the desired path of the road, removing the logs, road grading and bridge and drainage system construction as necessary, and road surfacing (with rock or gravel). Felling is the cutting of a stand of trees by chain saw or mechanized feller/buncher, whereas bucking and limbing involve cutting logs into sections of desired length and removing tree limbs, respectively. "Yarding" is the movement of a "turn" (group) of logs to a nearby collection area, or "landing." On steep terrain this is done via a yarder, a tall steel spar or lattice-work structure rigged with cables fitted with chokers (chains to attach to logs) and strung over a large area to permit logs to be dragged from the felling site to the landing. On flat terrain, logs are sometimes landed by a grappling device-equipped tracked log loader ("shovel") or rubber-tired skidder. Logs requiring further modification are cut at the landing by a mechanized processor. Logs are then loaded onto a log truck by a loader and transported to a sort yard, where they are unloaded and moved by stackers and further sorted by loaders for shipment elsewhere.

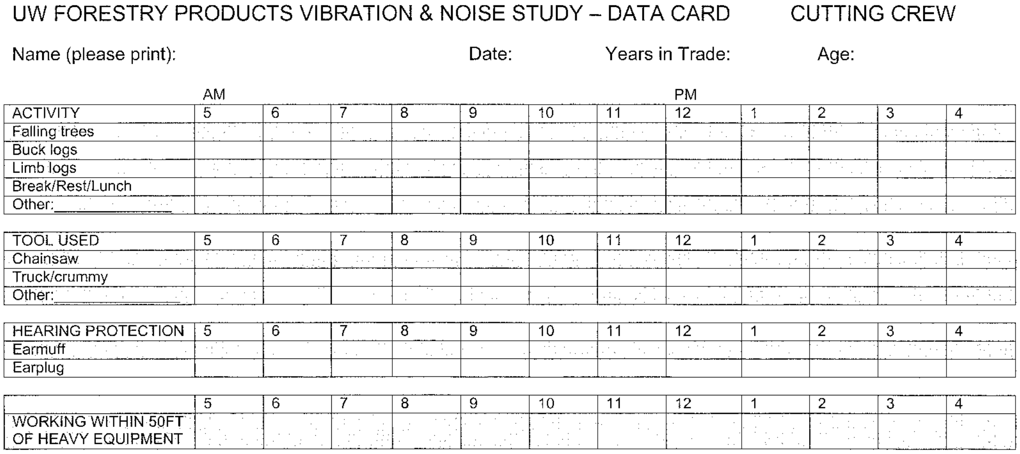
Previous research has documented the prevalence of HAV- and noise-related health problems in forestry workers of other nations. HAV research in Japan has indicated that between 9–27% of forestry workers studied suffered from Raynaud's phenomenon or VWF,(10–12) whereas 30.5–51% of studied Canadian forestry workers have been found to have one or both of these conditions.(13,14) Other countries have reported similar rates.(15,16) A literature search identified no WBV data specific to forestry workers. However, existing studies on trades with WBV exposure sources similar to forestry workers (i.e., construction earth-moving equipment operators and truck drivers) found increases in back pain complaints and radiological spinal abnormalities when compared with control populations.(5,7) Several studies in the 1970s found chainsawyers overexposed to noise by then-current standards,(17,18) though there has been little subsequent research on U.S. logging noise exposures. Hearing loss appears to be common among PNW forestry workers. In Washington State, 6% of accepted state fund hearing loss claims between 1984–1991 were from forestry and logging workers; this equates to an incidence rate of 33.2 accepted claims/10^{-3} worker-years, compared with the state average of 1.26/10^{-3}.(19) There is some evidence of an association between noise-induced hearing loss (NIHL) and vibration exposure(20–22) and WBV and NIHL.(8)

The current study had several goals. The first was to describe the occupational exposure of the studied PNW forestry worker population to sources of HAV, WBV, and noise. The second was to assess the exposure risk presented by the use of various tools and performance of certain tasks. The third was to further examine the relationship between vibration and noise exposure levels previously suggested by Teschke.(23) The fourth and final aim was to measure the levels of HAV received through the controls of heavy equipment, a source of exposure that previously has received little attention.

METHODS

Two large PNW forestry products companies, each owning more than 200,000 acres of timberland in Washington State,(24) participated in this study. Six trades were monitored during this study: fellers, vehicle operators, rigging slingers, chokermen, landing men, and hooktenders. Data were collected on 10 different days over 8 weeks in spring 1999 at one felling site, four yarding and landing sites, two log handling facilities, and multiple road construction sites. Sites and dates were not chosen randomly, but were selected based on the potential number of subjects available. Subjects participated voluntarily; incentives were offered to increase participation rates. Forty-three workers volunteered to participate in the research (22 from Company A and 21 from Company B). All workers at each site were given brief presentations on the study; workers interested in participating then signed an informed consent form. Nearly every worker approached was willing to participate. Full-shift noise exposure measurements were made on up to 5 subjects per day, whereas multiple vibration measurements were made on each subject during various tasks. The number of vibration measurements per subject varied according to the number, complexity, and duration of tasks performed. Subjects completed brief self-report activity questionnaires (Figure 1) as the workday progressed. These operation-specific cards listed tasks and tools likely to be encountered and allowed workers to report the timing and frequency of their activities with approximately 15-min time resolution (subjects were instructed to visually divide each 1-hour block on the activity card into four, 15-min segments). Workers also reported their ages and years of experience in their current trades. Activity cards were distributed with the dosimeters each morning and collected at the conclusion of the work shift. A researcher observed the workers periodically throughout the workday, documenting the timing of their actual activities for postwork-shift comparison to their self-reported activities; this approach allowed for statistical analysis of the agreement between worker-reported and researcher-observed activities (i.e., their reporting accuracy).

Full-shift noise exposures were measured using Quest (Oconomowoc, Wisc.) Q-300 datalogging dosimeters configured to capture two channels of data simultaneously. The first channel was set to the Occupational Safety and Health Administration (OSHA) permissible exposure limit for hearing conservation: 90 dBA criterion level (CL), 80 dBA threshold level (TL), 5 dB exchange rate (ER), 115 dBA ceiling, and slow response. Channel 2 was set to the 1998 National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit: 85 dBA CL, 80 dBA TL, 3 dB ER, and fast response. Dosimeters were placed on workers' belts or in jacket or pants pockets; the microphones were placed on the shoulder of a worker's dominant hand within 4 inches of the ear. The dosimeters yielded the following values for each 1-min interval monitored: L_{OSHA} (5 dB ER), L_{EQ} (3 dB ER), L_{max} (highest level measured with response time and weighting), and L_{peak} (highest instantaneous unweighted level). The dosimeters also yielded 8-hour TWA levels for both the OSHA and NIOSH metrics. Noise measurement data were downloaded directly into a personal computer (PC) for analysis.



UW FORESTRY PRODUCTS VIBRATION & NOISE STUDY – DATA CARD CUTTING CREW

Name (please print): Date: Years in Trade: Age:

	AM							PM				
ACTIVITY	5	6	7	8	9	10	11	12	1	2	3	4
Falling trees												
Buck logs												
Limb logs												
Break/Rest/Lunch												
Other:__________												

TOOL USED	5	6	7	8	9	10	11	12	1	2	3	4
Chainsaw												
Truck/crummy												
Other:__________												

HEARING PROTECTION	5	6	7	8	9	10	11	12	1	2	3	4
Earmuff												
Earplug												

	5	6	7	8	9	10	11	12	1	2	3	4
WORKING WITHIN 50FT OF HEAVY EQUIPMENT												

FIGURE 1. Sample activity card

Probability plots and histograms were used to assess the normality of the TWA and 1-min average noise data. The TWAs were approximately normally distributed; however, the 1-min average readings were truncated as a result of the dosimeter recording characteristics. The 80 dBA TL used in the OSHA and NIOSH exposure metrics results in 1-min intervals with no sound levels exceeding 80 dBA being assigned a value of 0 dBA. Zero-value data points were modified to estimate these limit of detection readings using a technique (described in detail in Ref. 25) that recoded all 0 dB readings as missing, and then replaced missing values with an average of the first previous and subsequent nonmissing value. This data interpolation resulted in approximately normal 1-min noise level distributions.

Vibration exposure measurements were made with a Bruel & Kjær (Norcross, Ga.) 2231 Type 1 sound level meter (SLM) equipped with a B&K 2522 Human Vibration Unit and B&K BZ7105 Human Vibration Module. Biodynamic root-mean square (rms) acceleration WBV measurements were made in three mutually perpendicular axes (x, y, and z) according to International Organization for Standardization (ISO) standard 2631/1–1985, using a 1-sec time constant, units of meters per second squared, a 0.5–80 Hz range, and the appropriate weighting curves. Triaxial measurements account for the vector nature of vibration, which involves both a magnitude and a direction. A more current ISO WBV standard is available, ISO 2631–1 1997; however, the equipment available for field measurements was not compliant with this newer standard, and additional equipment such as a data recorder or spectrum analyzer were not practical for this application. The validity, appropriateness, and variability of measurements obtained using this updated ISO WBV standard also have been questioned.(26,27) Triaxial basicentric rms acceleration HAV measurements were made according to ISO 5349–1986, using a 1-sec time constant, units of meters per second squared, a 5.6–1400 Hz range, and the specified weighting curves. The axes on which the HAV and WBV measurements were based are shown in Figure 2. The SLM used was not capable of recording vibration frequency spectra, and instead yielded averaged axis-specific and summary frequency-weighted acceleration component values for each measurement event.

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' second and third fingers with the crossbar of the T touching the grip of the measured tool). The hand accelerometer mount was placed on the worker's hand, and the accelerometer cables leading to the SLM were rubber-banded to the worker's arm to prevent interference with the worker's movements. After completion of one or more cycles of the task or tool being monitored (with a targeted minimum measurement duration of 1 min), or at the first available break in work operations, the accelerometer mount was removed. 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. Space permitting, the researcher remained in the operator's cab during WBV measurements; otherwise, the SLM was left in the cab and a measurement was made until the SLM was removed by the researcher during the next break in operations. Each task and type of equipment was measured multiple times. HAV and WBV vibration data were downloaded directly into a PC for statistical analysis. Data obtained at download included event runtime, summary equivalent acceleration level (A_{EQ}), and L_{max} (rms), L_{min} (rms), L_{peak}, and A_{EQ} for each of the three axes. Vibration measurements were compared with several occupational exposure standards, including the American Conference of Government Industrial Hygienists' (ACGIH) threshold limit value (TLV®) for HAV, ISO 5349 (on which the HAV TLV is generally based), and document COM(92) 560—Final from the Commission of the European Communities (CEC), a framework directive that establishes action and ceiling limits for WBV measured according to ISO 2631/1,(28) and which was recently revised by the European Parliament and the Council of the European Union (Directive 2002/44/EC, issued June 25, 2002). All of these vibration standards are voluntary; there are currently no legally enforceable, quantitative U.S. vibration exposure standards. The CEC-defined WBV limits were utilized because the acceleration components yielded by the SLM used are not directly comparable with the ISO or ACGIH WBV standards, which specify frequency-specific exposure values. Table I shows the ACGIH HAV TLV, predicted ISO health effects based on HAV exposure level, and the WBV limits established by the CEC.

The SLM and dosimeters were calibrated pre- and postmonitoring; samples were discarded if calibration values exceeded allowable limits. Dosimeter and vibration data were downloaded into separate PC spreadsheet files for 1-min noise levels, noise

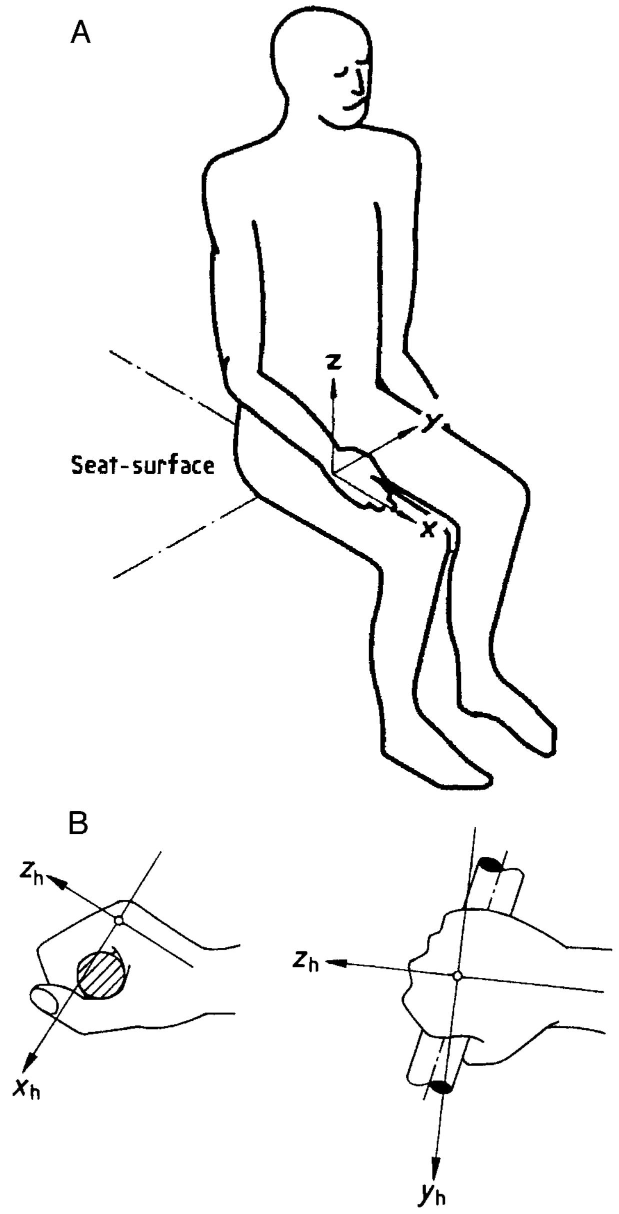


FIGURE 2. Vibration measurement axes: (A) Whole body; ©International Organization for Standardization (ISO). All rights reserved. (B) Hand-arm; from American Conference of Governmental Industrial Hygienists (ACGIH®), *Documentation of TLVs® and BEIs®*. Copyright 2001. Reprinted with permission.

TWAs, and vibration measurements. Task- and tool-use information from corresponding activity cards was added directly to the 1-min noise level and vibration event files. Descriptive noise TWA and vibration A_{EQ} statistics were developed by company, trade, and type of operation, and, for the 1-min sound levels and vibration measurements, by task and tool. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 9.0 (Chicago, Ill.).

Vibration measurements were matched to the average of the corresponding dosimeter 1-min average noise levels to allow for calculation of correlation coefficients. More than 98% of all vibration measurements exceeded the ACGIH-recommended duration of 1-min.

Cross-tabulation tables were generated to compare worker-reported tasks and tools with those observed by the researcher; from this table, a Cohen's kappa statistic of agreement was calculated. Workers were observed for a total of 672 min. The tool-associated Cohen's kappa was 0.89; the task-associated kappa was 0.69. These statistics 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 (4.5% failure rate); the failures resulted from a broken microphone lead and the loss of a microphone windscreen on a windy day, which resulted in an artificially elevated noise exposure. One hundred seventy-four vibration exposure measurements were made, of which 164 were successful (5.7% failure rate). The 10 failures resulted from loss of power (3), accelerometer cable breaks (3), and invalid postmonitoring calibration values (4).

Vehicle operators represent 81% of all samples; however, the operators in this study operated 11 different types of heavy equipment. Nonoperator trades were encountered less frequently at the sampled forestry sites. Workers in the six trades sampled performed 16 different tasks and used 12 different pieces of equipment. The mean worker age was 47.0 ± 10.5 years, the mean worker experience level was 21.6 ± 10.3 years, and the mean equipment age was 7.8 ± 7.1 years. No significant differences were found in subject demographics; equipment age; or for HAV, WBV, or noise exposure levels between the two participating companies. Given the similarities between the two companies, the data from both are presented here in aggregate.

The 42 noise exposures monitored represent 19,235 1-min averages. OSHA and NIOSH TWA noise results are presented by job title and operation type in Table II, and by task and tool in Table III. The mean dosimeter runtime was 7 hours 39 min (SD 1 hour 24 min). The average NIOSH TWA was 90.2 ± 5.1 dBA, wheras the average OSHA TWA was 86.1 ± 6.2 dBA. The highest mean NIOSH and OSHA TWAs by operation were felling and road construction,. The highest mean NIOSH and OSHA TWAs by job title were tree feller and hooktender. Exceedance fractions for the NIOSH and OSHA TWAs are shown in Table IV. Exceedance percentages were highest in road construction and tree felling operations.

The mean 1-min OSHA noise level was 81.0 ± 12.5 dBA, and the mean 1-min NIOSH noise level was 85.3 ± 8.7. Forty-one percent of all L_{OSHA} 1-min readings were above 85 dBA, whereas 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, whereas highest levels by tool for both metrics were chain saw and dozer.

Workers self-reported using hearing protection devices (HPDs) 83.7% of the total monitored time. Earplugs accounted for 84.7% of the time HPDs were used, earmuffs 6%, and double protection (earplugs and earmuffs) 9.4% of the time. The type of HPD reported was noted to change appropriately with increasing noise exposure; that is, higher levels of protection were used at higher sound levels. The increase was found to be statistically significant (p=0.0001) using a mixed factor random effects model that estimated noise exposure level coefficients by type of HPD used. For no HPD reported, the estimated NIOSH noise exposure level was

TABLE I. ACGIH HAV and Modified WBV Allowable Exposures

	Total Daily Exposure Duration, hrs	Value of Dominant RMS Acceleration Component, m/s^2		
ACGIH HAV TLV	4 to less than 8	4		
	2 to less than 4	6		
	1 to less than 2	8		
	Less than 1	12		
		Total Daily Exposure Duration Til Health Effects, yrs		
	Weighted Acceleration, m/s^2	10th percentile	30th percentile	50th percentile
ISO HAV Limit	2	15	>25	>25
	5	6	11	14
	10	3	5	7
	20	1	2	3
	50	<1	<1	1
		Value of Vector Sum RMS Acceleration Component, m/s^2		
CEC WBV Limits	8-hr action limit	0.50		
	8-hr exposure limit	1.15		

80.1 dBA; for earplugs, 85.8 dBA; for earmuffs, 84.1 dBA; and for double protection, 91.5 dBA. Mixed model analysis and marginal factor and linear models produced near-identical estimates. Approximate HPD attenuation was judged to increase in the following order: no protection, earplugs, earmuffs, and double protection.(29) Although the model estimates do not agree completely with the NIOSH recommendations (earplug and earmuff use were reversed from the NIOSH guidelines), the model indicates that workers protected themselves better at high noise exposure levels.

The trades of landing man and chokerman had mean per-shift maximum noise levels exceeding 115 dBA (115.6 ± 4.6 and 116.7 ± 0.3 dBA, respectively), and landing man, tree feller, and chokerman had mean times per-shift over the 115 dBA ceiling of 3 ± 6 sec, 49 sec±1 min 16 sec, and 2 ± 4 sec, respectively. The other trades measured had mean maximum levels below the OSHA 115 dBA ceiling. Peak data are not reported here due to the wind gusts present at some sites; these environmental conditions can produce artifactual peak data, despite the use of microphone windscreens. Mean and maximum 1-min noise levels are less affected by wind, as the slow meter response tends to smooth out transient sound levels.

After preliminary data analysis, four outlier vibration data points were removed (two HAV and two WBV). These data were collected on a single day of monitoring, and all four points were more than five SD from the mean of measurements made that day, and more than four SD from the mean of all measurements. The two HAV outliers, with summary A_{EQ} values of 95.2 and 96.4 m/sec^2, were taken consecutively and involved a landing man operating a chain saw during a yarding and landing operation. The two WBV outliers, also taken consecutively, and with summary A_{EQ} values of 101.0 and 79.2 m/sec^2, involved a hooktender operating a dozer (tailhold) on the same yarding and landing operation. Immediately after these samples were taken, the SLM indicated insufficient battery power; after the batteries were replaced, all readings were within a reasonable range.

HAV measurements were made on hand tools and heavy equipment operating controls. 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 (±2 min 20 sec), and the mean WBV duration was 5 min 54 sec (±6 min 36 sec). Measurement durations were made to represent task cycle times where possible.

HAV and WBV exposure levels are presented by job title and operation type in Table II, and by task and tool in Table III. The 99 WBV events had a mean summary frequency-weighted acceleration component of 3.5 ± 7.1 m/sec^2. The highest WBV mean A_{EQ} exposure for the x, y, and z exposure axes was from log processing, whereas the task and job title associated with the highest x, y, and z axis WBV A_{EQ} exposures 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 ± 5.3 m/sec^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 three 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 chain saw for the z-axis. Lastly, the tool with highest HAV A_{EQ} mean exposure level was the chain saw for all three axes.

Vibration exposure exceedance fractions are presented in Table IV. Between 22–84% of all WBV summary frequency-weighted measurements by type of operation exceeded the 8-hour CEC action limit, and 0–80% exceeded the 8-hour exposure limit. 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 with the traditionally recognized source of HAV, the chain saw. The saws measured in this study had mean A_{EQ} acceleration components of 6.0 m/sec^2 for the x-axis, 4.2 m/sec^2 for the y-axis, and 5.4 m/sec^2 for the z-axis. In comparison, the mean A_{EQ} exposure level associated with loader controls in the x-axis was 5.9 m/sec^2, whereas the front-end loader had a mean x-axis A_{EQ} exposure level of 1.8 m/sec^2, and the stacker had average x-, y-, and z-axis A_{EQ} exposure levels of 3.1, 1.9, and 1.2 m/sec^2, respectively. The mean A_{EQ} exposure level for all heavy equipment controls was 1.2, 1.1, and 0.7 m/sec^2 for the x-, y-, and z-axes, respectively. Seventeen percent of all measurements taken on the x-axis of the controls of the heavy equipment assessed were over the 8-hour TLV; a further 4% were over the 4-hour TLV. Overall, 53% of all x-axis HAV A_{EQ}s exceeded the 8-hour HAV TLV, whereas 33% of the y-axis and 42% of the z-axis A_{EQ}s were over this limit. Furthermore, 29% of all x-axis, 7% of all y-axis, and 13% of all z-axis HAV A_{EQ}s exceeded the 4-hour HAV TLV.

Spearman correlation coefficients were calculated to assess the relationship between noise and vibration levels (Table V).

TABLE II. Descriptive Statistics for TWA Noise and Vibration Events by Operation and Job Title

		Mean Noise Level (dBa) (*SD*)			HAV A_{EQ} Vibration Level (m/s^2) (*SD*)					WBV A_{EQ} Vibration Level (m/s^2) (*SD*)			
Category	No. Meas.	NIOSH	OSHA	No. Meas.	Sum.	X axis	Y axis	Z axis	No. Meas.	Sum.	X axis	Y axis	Z axis
Operation Type													
Tree Felling	3	98.43	94.97	23	10.36	6.65	4.87	5.74					
		6.92	*7.11*		*3.78*	*2.75*	*1.91*	*3.01*					
Log Handling	8	88.70	85.55	7	2.90	3.11	1.86	1.21	24	1.69	0.58	0.67	1.05
		4.47	*4.92*		*2.99*	*3.69*	*1.80*	*1.14*		*2.0*	*0.62*	*0.90*	*1.28*
Sorting and Loading	3	89.27	84.07	4	2.49	5.88	1.72	0.49	14	3.38	1.31	1.56	1.48
		3.44	*4.46*		*2.82*		*1.43*	*0.25*		*6.23*	*2.38*	*3.08*	*3.01*
Shovel Logging	3	88.27	85.40						9	0.34	0.13	0.15	0.18
		2.41	*3.48*							*0.33*	*0.12*	*0.15*	*0.20*
Log Processing	4	85.45	81.15						5	9.17	4.37	3.71	4.17
		3.99	*6.04*							*9.05*	*4.99*	*3.65*	*3.38*
Road Construction	10	91.92	89.45	23	1.29	0.70	0.74	0.52	28	6.15	2.48	2.41	3.18
		3.67	*4.05*		*1.79*	*1.51*	*1.03*	*0.65*		*9.62*	*4.35*	*4.08*	*4.8*
Yarding and Landing	13	89.63	83.91	9	7.48	4.61	2.99	4.80	18	2.29	1.11	0.70	1.33
		5.01	*6.59*		*6.39*	*3.75*	*2.77*	*4.64*		*7.88*	*3.9*	*2.34*	*4.62*
Job Title													
Chokerman	3	88.10	80.70										
		2.4	*1.73*										
Tree Feller	3	98.43	94.97	23	10.36	6.65	4.87	5.74					
		6.92	*7.11*		*3.78*	*2.75*	*1.91*	*3.01*					
Hooktender	1	97.40	92.60										
Landing man	4	93.65	88.73	9	7.48	4.61	2.99	4.8					
		2.31	*3.94*		*6.39*	*3.75*	*2.77*	*4.64*					
Operator	32	89.12	85.68	34	1.77	1.22	1.05	0.66	99	3.53	1.46	1.4	1.83
		4.14	*5.33*		*2.24*	*2.17*	*1.29*	*0.78*		*7.12*	*3.27*	*2.9*	*3.64*
Rigging Slinger	1	81.00	71.50										
Overall	44	86.11	90.15	65	5.45	3.91	2.60	2.96	99	3.53	1.46	1.40	1.83
		6.22	*5.08*		*5.25*	*3.63*	*2.32*	*3.45*		*7.12*	*3.27*	*2.90*	*3.64*

The correlation value for summary weighted HAV vector magnitudes compared with the mean of the corresponding 1-min NIOSH noise levels was 0.249, and the correlation value for summary weighted WBV vector magnitudes was −0.173. Neither correlation was significant at the $P=0.05$ level. Correlation coefficients for individual task and tool HAV and WBV measurements and NIOSH noise level were also calculated; only one tool, the excavator, had a significant correlation with the corresponding noise levels (0.900 correlation, significant at the $P=0.05$ level). Axis-specific correlations between HAV and noise were very low, ranging from 0.217–0.306; only the y-axis correlation was significant ($P=0.017$). For axis-specific WBV levels versus noise, the correlations ranged from −0.156 to −0.208; with no significant axis-specific correlations. No significant correlations were found between axis-specific HAV levels and noise examined by task, and only one significant correlation (stacker, x-axis, $R=0.93$, $P=0.003$) was seen when examined by tool. No significant correlations were found between axis-specific WBV levels and noise examined by task, and only one significant correlation (excavator, z-axis, $R=0.90$, $P=0.037$) was seen when examined by tool. 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 search of the scientific literature. 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 study of WBV and health effects in agricultural machinery drivers found low back pain in 43% of 69 male tea-leaf plucking machinery operators,(30) though the study noted the difficulty of ascribing low-back pain to equipment operation only. Exposure measurements made on tea-leaf plucking machinery, which had a vector sum exposure of 1.628 m/sec^2, are lower than eight of the nine pieces of forestry equipment measured in the current study—in some cases by more than an order of magnitude. A questionnaire survey of 355 operators of heavy construction equipment operators found no significant difference between low-back pain rates in dozer and shovel operators and a control group of office workers.(31) This same study found no rate differences between upper arm and hand symptoms, including Raynaud's phenomenon, between the operators and controls.

The HAV exposure levels from chain saws measured in this study generally agree with ISO 5349-compliant measurements of exposure the existing literature. Several studies in Finland, Italy, and Canada have documented axis-specific chain saw HAV levels between 1.8–12.8 m/sec^2(32–35) A study(36) of 222 Italian forestry workers documented antivibration (AV) chain saw exposure levels of 3.73–6.35 m/sec^2, with dominant single-axis exposures on non-AV chain saws of 10.5–15.2 m/sec^2. Approximately 23% of workers studied suffered from VWF. The authors conclude that the relatively low prevalence of VWF among these highly exposed workers suggests that ISO 5349 overpredicts the risk of VWF

TABLE III. Descriptive Statistics for Vibration Event and One-Minute Noise Exposures by Task and Tool

	NIOSH Noise (dBA)		Hand-Arm, Weighted (m/s^2)					Whole-Body, Weighted (m/s^2)				
	Count (min)		Summary A_{EQ} Level		A_{EQ} (x)	A_{EQ} (y)	A_{EQ} (z)	Summary A_{EQ} Level		A_{EQ} (x)	A_{EQ} (y)	A_{EQ} (z)
		Mean *SD*	Count	Mean *SD*	Mean *SD*	Mean *SD*	Mean *SD*	Count	Mean *SD*	Mean *SD*	Mean *SD*	Mean *SD*
Task												
Break/Rest/Lunch	380	79.71										
		8.02										
Bucking Tree			8	7.37	5.11	3.09	4.22					
				3.66	*2.83*	*1.41*	*2.02*					
Chop Firewood	346	77.72										
		6.87										
Felling Tree			8	10.51	6.33	5.64	5.84					
				4.28	*2.26*	*2.16*	*3.44*					
Idling Chainsaw			9	11.01	6.55	4.32	6.95					
				5.96	*4.37*	*2.13*	*4.96*					
Limbing Log			5	7.51	5.39	3.19	3.94					
				4.09	*3.01*	*1.96*	*2.17*					
Multiple Tasks	3733	88.61										
		10.11										
Notch Stumps	114	83.44	1	10.30	8.12	4.16	4.72					
		11.16										
Operating Vehicle	6069	84.12	34	1.77	1.22	1.05	0.66	99	3.53	1.46	1.40	1.83
		6.22		*2.24*	*2.17*	*1.29*	*0.78*		*7.12*	*3.27*	*2.90*	*3.64*
Prepare/Supervise Rigging Changes	471	84.58										
		11.22										
Pull/Set Rigging	759	78.09										
		6.86										
Unbell Chokers at Landing	454	91.54										
		6.06										
Vehicle Maintanance	225	79.24										
		7.08										
Tool/Equipment												
Bulldozer	2032	88.02	5	1.35	0.33	1.06	0.69	8	3.18	0.69	1.96	1.05
		10.27		*2.08*	*0.13*	*1.78*	*1.10*		*6.36*	*0.95*	*4.26*	*1.63*
Chainsaw	2127	90.73	31	9.36	5.98	4.16	5.40					
		11.32		*4.68*	*3.15*	*2.08*	*3.52*					
Excavator	1149	85.85	4	1.95	1.42	0.82	0.63	6	6.30	3.14	2.17	3.00
		6.84		*2.61*	*2.55*	*0.90*	*0.63*		*5.59*	*2.75*	*1.94*	*3.08*
Front End Loader	562	82.15	5	2.53	1.76	1.47	0.95	5	14.38	6.53	5.81	6.80
		8.35		*2.16*	*2.75*	*0.72*	*0.50*		*17.70*	*8.59*	*7.02*	*7.99*
Grader	1151	84.25	4	0.32	0.11	0.09	0.24	5	6.33	2.00	1.70	4.97
		7.29		*0.33*	*0.12*	*0.12*	*0.32*		*6.58*	*2.05*	*1.75*	*5.50*
Multiple Tools	60	81.41										
		10.13										
No Tool Reported	2228	80.33										
		7.98										
Processor	1460	83.62						7	6.68	3.15	2.71	3.04
		5.83							*8.53*	*4.57*	*3.43*	*3.37*
Shovel	3295	85.61	4	2.49	5.88	1.72	0.49	23	2.32	.90	1.07	1.03
		7.57		*2.82*		*1.43*	*0.25*		*5.19*	*1.99*	*2.55*	*2.49*
Stacker	2168	84.01	7	2.90	3.11	1.86	1.21	12	2.60	0.84	1.10	1.60
		7.57		*2.99*	*3.69*	*1.80*	*1.14*		*2.59*	*0.81*	*1.17*	*1.69*
Truck	1073	83.59	5	0.47	0.28	0.29	0.17	17	0.80	0.33	0.25	0.51
		7.50		*0.17*	*0.22*	*0.10*	*0.06*		*0.40*	*0.20*	*0.13*	*0.28*
Yarder	1629	85.44						16	2.52	1.24	0.76	1.47
		6.04							*8.36*	*4.13*	*2.49*	*4.90*
Overall	19325	85.31	65	5.45	3.91	2.60	2.96	99	3.53	1.46	1.40	1.83
		8.67		*5.25*	*3.63*	*2.32*	*3.45*		*7.12*	*3.27*	*2.90*	*3.64*

from HAV exposure; this finding is supported by other research.(37) A later study, again on Italian sawyers, found VWF cases in sawyers with occupational exposure to AV chain saws only,(38) suggesting that, despite the possibility of overprotective standards, medical surveillance of HAV-exposed workers is still necessary. This study found vector HAV exposures of 6.4–8.6 m/sec^2 in AV chain saws, and 16.7–23.0 m/sec^2 in non-AV saws. Clearly, AV chain saws can reduce exposure levels; however, the HAV levels measured on AV saws in these studies are still high compared with the ISO and ACGIH exposure recommendations. New onset of

TABLE IV. Vibration and Noise Exposure Exceedance Fractions

	% TWAs > 85 dBA		% TWAs > 90 dBA		% HAV Measurements > 4-Hour Limit			% HAV Measurements > 8-Hour Limit			% WBV Measurements > 8-Hour Action Limit	% WBV Measurements > 8-Hour Exposure Limit
					ACGIH			ACGIH			CEC	CEC
Category	OSHA	NIOSH	OSHA	NIOSH	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	36
Sorting and Loading	67	100	0	67	0	0	0	100	0	0	40	27
Shovel Logging	67	100	0	0							25	0
Log Processing	25	25	0	25							80	80
Road Construction	90	100	50	50	0	0	0	10	0	0	81	54
Yarding and Landing	38	77	23	54	44	11	33	56	44	56	22	11
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	34
Rigging Slinger			0	0								
Overall	60	83	29	48	4	6	8	13	9	17	60	34

TABLE V. Symmetric Correlation Measures—Summary Weighted Vibration A_{EQ} vs. NIOSH Sound Level

Observed Activity	No. Cases	Spearman Correlation Value	Asymptotic Standard Error
HAV—Activity			
Bucking Logs	7	−0.324	0.409
Felling Trees	9	0.293	0.262
Idling	9	−0.322	0.295
Limbing Logs	5	−0.1	0.622
Operate Vehicle	30	−0.051	0.203
WBV—Activity			
Operate Vehicle	79	−0.173	0.12
HAV—Tool			
Bulldozer	7	−0.179	0.482
Chainsaw	31	−0.02	0.153
Excavator	4	0.8	0.3
Front End Loader	3	−0.5	0.612
Grader	4	0.8	0.3
Stacker	7	0.536	0.356
Truck	5	−0.7	0.351
WBV—Tool			
Bulldozer	9	−0.4	0.33
Cable Yarder	13	−0.429	0.299
Excavator	5	0.9[A]	0.164
Front End Loader	3	−1	0.000
Grader	5	0.1	0.432
Grapple Yarder	2	−1	0.000
Processer	6	−0.2	0.533
Shovel	20	−0.118	0.267
Stacker	10	−0.036	0.276
Truck	6	0.371	0.495
Overall HAV	62	0.215	0.124
Overall WBV	79	−0.173	0.12

[A] Significant at P=0.05.

VWF symptoms was noted in British Columbia sawyers with experience on AV saws only, suggesting that these saws may not prevent new occurrences of VWF;(14) furthermore, no drop in the prevalence of Raynaud's phenomenon in fellers in this study was seen, indicating that AV saws 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. These prevalence estimates are supported by research findings on PNW forestry workers.(34) However, tasks involving intensive chain saw use, including felling, limbing, and bucking trees, will likely result in the appearance of vibration-related health effects in a shorter period of time. These estimates are based on only 4-hour vibration exposure per workday; actual exposure durations can exceed 4 hours, which could result in even higher incidence rates.

The HAV exposure levels measured on heavy equipment controls with mean axis-specific A_{EQ} levels from 0.7–1.2 m/sec^2 are another area of concern. Few studies have been done on equipment control vibration levels. One study of HAV exposure from motorcycle controls in 119 Japanese police officers found x-axis ISO-5349 HAV levels from 2.2–4.9 m/sec^2, and significantly higher rates of adverse health effects when compared with a control group of hospital workers.(39) This study also found that prevalence of finger and shoulder symptoms increased with higher cumulative vibration doses. These findings suggest that the forestry equipment controls in the current study are sources of potentially hazardous levels of vibration. ISO 5349 estimates indicates that the heavy equipment control HAV exposure levels measured will produce vascular symptoms in the 10th percentile worker after 15 years of exposure, and the 50th percentile 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.(40) NIOSH estimates a 29% excess risk of NIHL in workers exposed for a 40-year working lifetime to the NIOSH noise exposure levels measured in the current study (90.2 ± 5.1 dBA), and a 15% excess risk at 85 dBA.(29) A 1974 SLM survey on Montana loggers documented chain saw noise levels (using the then-proposed OSHA noise control standard settings) between 91–116 dBA.(17) The range of chain saw OSHA noise exposure levels in the current study was 70.2–113.8 dBA. These data suggest that chain saws have become quieter since the 1970s, an observation consistent with the introduction of quieter, muffled exhaust chain saws. The sawyers in the 1974 study spent 39–65% of their time, on average, above 100 dBA; in the current study, only 20% of time was spent above 100 dBA using the OSHA hearing conservation standard. This further supports the notion that chain saw noise levels decreased in the interval between the two studies. A 1977 study on PNW loggers found average OSHA noise control TWA noise exposure levels (90 dBA CL and TL, 5 dB ER) of 98.6 dBA for chain saws, 89.2 dBA for yarders; 90.0 dBA in loaders; and 102.2 dBA for tractors), with 100% of all chain saw and tractor measurements, and more than 25% of yarder and loader measurements, exceeding 90 dBA.(18) These levels are similar to those measured in the current study. However, the 1977 study used the OSHA noise control standard, which is less protective than the OSHA hearing conservation standard issued in 1983. Due to the higher TL used in the noise control standard (90 dBA versus the 80 dBA hearing conservation TL), measurements made using the hearing conservation standard are often higher than those with the noise control standard. The similarities in exposure levels between these two studies suggest that noise exposures from forestry equipment in fact decreased between 1977 and 1998. The large differences seen in the current study between TWAs using the NIOSH-recommended 3 dB ER and the OSHA-mandated 5 dB ER have been documented elsewhere, with NIOSH levels 1.5(41)−2.7(42) times higher than OSHA levels. Differences in exceedance percentages are similar, with larger differences in variable-noise trades like those found in construction(25,43) and the forestry workers examined here, than in occupations with more steady-state exposures.(44)

The success of the task- and tool-based exposure assessment methodology used in this project and others(25,43) indicates that exposure modeling is feasible for unmeasured workers who have reported their exposure sources and durations. A recent national study in the United Kingdom used self-reporting to estimate occupational exposures to HAV(45) and WBV(46) Agricultural workers, a group that included forestry workers, were found to be among the most highly exposed groups for both HAV and WBV in the United Kingdom. A validation study of exposure self-reporting(47) found that reporting of exposure sources was highly accurate, but that exposure durations were commonly overreported. This suggests that the current exposure-response standards, largely based on self-reported assessments, may not be adequately protective (i.e., overestimated exposure durations for given health effects result in overestimates of allowable exposure times). However, other studies have found that ISO 5349 may overestimate the risk of HAV at realistic exposure levels.(48) The existing data certainly indicate that further work is needed to develop more accurate exposure-response models for both HAV and WBV. Some authors have already suggested HAV exposure standards to protect specific worker populations.(49)

Reducing noise and vibration levels through engineering controls and design alteration is the most desirable approach to reducing the prevalence of HAVS, WBV-related health effects, and 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.(50) Proper and timely maintenance of vehicle systems and hand tools can reduce vibration and noise exposure. In several countries, including Japan and Finland, HAV exposure levels, and subsequently VWF prevalence, dropped substantially following the introduction of AV chain saws.(16,51) Substituting older saws with newer AV saws or adding vibration-dampening fittings will not completely reverse the damage caused by non-AV saw experience,(37) and the effectiveness of vibration-dampening fittings has been questioned.(34)

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.(52) Medical surveillance is an essential part of any prevention strategy. An effective hearing conservation program—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;(53,54) NIHL is permanent and irreversible.

AV gloves offer additional HAV protection for the worker, and the use of HPDs can reduce noise exposure when other controls are not feasible. The spectrum of engineering, administrative, and personal protective equipment-based vibration-reduction measures described here has proven effective for Japanese forestry workers.(55)

A relationship between vibration and noise exposure durations has been suggested by Teschke for exposure modeling purposes.(23) Although Teschke demonstrated that dosimetry can be used to accurately model noise and vibration exposure duration by chain saw operating mode, no correlation at any level of detail 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, whereas the emitted noise levels are more stable, a phenomenon that has been discussed elsewhere.(34) The effects of terrain on heavy equipment cannot be discounted, as terrain type has a tremendous impact on vibration levels, and very little effect on noise levels. The correlations measured between HAV and NIOSH noise levels produced during chain saw operation—which ranged from −0.324 for bucking logs to 0.293 for felling trees, with no significant relationships found—indicate that the relationship between noise and vibration is highly variable and influenced by other variables. Therefore, the utility of noise dosimetry in vibration exposure modeling is limited to measuring the duration of vibration exposure, as shown by Teschke; it would appear that noise dosimetry is not useful for estimating vibration exposure magnitudes.

This study has several weaknesses. The small population studied, combined with the nonrandom site selection process, may have yielded atypical exposure measurements. The high degree of agreement between worker reporting and researcher observation might not be representative of situations in which workers report without simultaneous observation. The lack of a correlation between measured vibration and noise levels could be a spurious finding resulting from the relatively small number of samples collected. Data were collected during only one season; this sampling strategy does not account for any seasonal differences in work practices. Lastly, the subjects in this study worked at two large companies; however, as a whole this industry is characterized by a large number of small contractors (more than one-third of logging workers are self-employed).(2)

CONCLUSIONS

Noise and vibration exposure represent major occupational hazards to forestry workers. This project demonstrated that workers employed in logging-related activities in the PNW have substantial overexposures to vibration (according to ACGIH, ISO, and CEC guidelines) and noise (according to NIOSH and OSHA exposure metrics). These high exposure levels are reflected in the high rates of NIHL claims among Washington State loggers.(19) 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: chain saws, 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 chain saws, whereas the task and tool associated with the highest vibration exposure levels were log processing and front-end loaders (WBV), and notching stumps and chain saws (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 unmonitored populations that report their activities. Further research is required on small, contract logging operations, which may differ substantially from the larger companies assessed in the current study.

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