AIHAJ 62:615–621 (2001)

Ms. #245

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Noise Exposure among Construction Electricians

Data-logging noise dosimetry was used to assess the exposure levels of electricians working for a major electrical subcontractor in Washington State at five sites using four types of construction methods. Subjects documented activities and work environment information throughout their work shift, resulting in an activity/exposure record for each of the 174 full-shift samples collected over the 4-month duration of the study. Over 24% of the TWA samples exceeded 85 dBA; 5.2% exceeded the federal Occupational Safety and Health Administration permissible exposure limit of 90 dBA. The National Institute for Occupational Safety and Health exposure metric, which specifies a 3-dB ER, was also utilized; using this metric, 67.8% of the samples exceeded 85 dBA and 27% exceeded 90 dBA. Subjects were directly observed for a subset of 4469 min during which more detailed activity and environmental information was recorded. Linear and logistic regression models using this subset were used to identify the determinants of average exposure, and exposure exceedences, respectively. These models demonstrated the importance of multiple variable modeling in interpreting exposure assessments, and the feasibility and utility of modeling exposure exceedences using logistic regression. The results further showed that presumably quiet trades such as electrician are at risk of exposure to potentially harmful noise exposures, and that other workers' activities and the general environment contribute substantially to that risk. These results indicate that noise control strategies will have to address the construction work environment as an integrated system.

Keywords: construction industry, electricians, exposure assessment, exposure determinants, logistic regression, noise induced hearing loss

Despite the clear association between noise exposure and hearing loss, and an understanding of the mechanisms of hearing damage, effective means for the prevention of occupational noise-induced hearing loss (NIHL) are elusive, and noise-induced damage remains endemic in many industries.(1) Construction workers are at particularly high risk.(2–6) Although the available trade-specific hearing loss data are limited, one study suggests that electricians have only slightly less severe loss than other trades, with a mean deficit of 40 dB at 4 kHz.(4)

Work in construction is characterized by the intense use of heavy equipment, the ubiquity of power tools, and a continually changing environment, resulting in a large potential for elevated noise exposures, presenting serious challenges to the development of effective engineering controls. Portable power tools operate at extremely high noise levels, frequently well over 100 dBA,(7) and noise levels associated with heavy machinery typically range from 90 to 120 dB.(3,8) Despite recognition of the high levels of noise generated by construction-related tools and equipment, there have been relatively few comprehensive noise exposure assessments in the construction industry. A study in 1992 examined, among other exposures, the noise dosimetry of 29 construction workers from various trades and the levels associated with certain power tools and heavy equipment. Overall, 8-hour time-weighted averages (TWAs) ranged from 74 to 104 dBA with an arithmetic mean of 90.25 dBA.(9) Carpenters' exposures ranged from 81 to 100 dBA, laborers' from 80 to 101 dBA, and operating engineers' from 75 to 97 dBA; no specialty trades were included. A study among various construction sectors in Ontario reported average TWAs in the range of 93–107 dBA, with most trades' TWAs exceeding 90 dBA.(10) No electricians were included in this study.

The authors recently completed a noise exposure assessment through a large general contractor in Washington State.(11) The study covered four trades (carpenters, laborers, operating engineers, and iron workers) and five building construction sites with a total of 338 TWA samples. The mean exposure level for all trades was 82.8 dBA with a range of 61.6 to 99.3 dBA; nearly 40% of the samples exceeded an 85 dBA TWA and 13% exceeded the Occupational Safety and Health Administration (OSHA) permissible exposure level of 90 dBA. All four trades had very similar average exposure levels, despite wide variation in specific task or tool-associated exposure levels and a significant difference between exposure levels on the study sites. These findings support the idea that the environment in which the subject works is an important predictor of exposure levels.

The current study extends these findings by addressing a specialty trade, electricians. Electricians predominantly use unpowered hand tools and therefore should have noise exposure profiles more heavily influenced by the activities of people around them and the environment in which they work. To address these external factors, several pieces of information concerning the subject's work environment were included on the list of potential determinants of exposure to address the importance of these exposure sources to electricians.

Studies exploring determinants of exposure have primarily used linear regression models.(12) The models are used to predict the average exposure associated with a combination of potentially explanatory variables. Because risk is generally associated with elevated long-term average levels, these models make sense for determining the risk associated with particular work conditions. However, if risk is nonlinear, or is elevated only when exposure exceeds some threshold level, then the average exposure level may not be sufficiently predictive. Furthermore, if a study is aimed at determining which conditions give rise to those temporary high levels or identifying factors that predict exceedence of an exposure limit, then a method other than linear regression is needed. Logistic regression can be used to identify the association between categorical or continuous variables and a single binary outcome, such as the exceedence of a threshold. Logistic regression takes the form of:

$$\text{logit } P(\Upsilon_i = 1 \mid X_{ji}) = \alpha + \sum \beta_j X_{ji}$$

that is, the logit of the probability of Υ taking on the value of 1 (i.e., that the exposure exceeds the defined limit), given that X_j, the exposure determinants, have certain values can be modeled as a simple function as in linear regression. An equivalent expression:

$$P(\Upsilon_i = 1 \mid X_{ji}) = \frac{e^{\alpha+\beta X}}{1 + e^{\alpha+\beta X}}$$

provides the predicted probability of a limit excursion given any combination of the determinants in the model. In this study the use of logistic regression to evaluate the determinants of exposure exceedences is demonstrated.

METHODS

The project described here was conducted over a 4-month period in 1998 with the cooperation of a large electrical subcontractor. Relevant methods are described here; additional details of the project are available(13) and may be viewed on the authors' web site (http://depts.washington.edu/cnstsafe/cnst_research.htm). A total of five construction sites were selected from those on which the contractor had electricians working at the time. The largest job was construction of a new sports stadium involving both cast-in-place and concrete tilt-up methods, with as many as 50 electricians employed for extended periods of time. Two sites were concrete tilt-up commercial/industrial buildings and one was a cast-in-place structure. One tenant improvement project of sufficient size was available for monitoring. Volunteers were solicited from among the electricians on site at the beginning of the workday. Each subject signed an informed consent letter prior to participation. Subjects were encouraged to participate on more than one occasion.

During the monitored work shift, study participants were asked to complete an activity card that identified the start and end time associated with all activities performed during the day. The format of the card was the same as that used previously.(11) However, additional information was requested concerning other noise sources in the environment. In addition to tasks performed and tools used, the card included questions about the number of other workers working nearby; which trades were present and which tools others were using; work location (inside, outside, or in a partially enclosed area); use of hearing protection devices (HPDs); and the workers' subjective assessment of noise level (quiet, moderate, loud). The list of tasks and tools likely to be encountered were developed with input from the electrical contractor.

In addition to asking subjects to record activities, workers were observed on a subset of monitoring days. The observer recorded activities and tools in the same manner as the subject, but also provided a more detailed level of information. The subject-reported activity data were compared with the observed activities using a kappa statistic as a measure of agreement. As in the previous study, worker-reported task (κ=0.86) agreed very well with observed information. The presence of other trades was also reported very well (κ=0.81). Reported hearing protection use and work location were reported with reasonable agreement (κ=0.70), whereas tool use and number of nearby workers were reported with somewhat less accuracy (κ=0.55 and 0.33, respectively).

Noise monitoring was conducted with data-logging noise dosimeters (Quest, Q-300, Oconomowoc, WI), calibrated prior to each sampling day and checked to be within 0.5 dB postsampling. Three noise metrics were used simultaneously to assess the noise levels present during each minute of sampling time. The metrics included the OSHA hearing conservation metric (L_{OSHA}) with an 80 dB threshold level (TL) and 5 dB ER, a National Institute for Occupational Safety and Health (NIOSH) metric (L_{EQ}) with no TL and 3 dB ER and a modified ISO metric which included an 80 dB TL and 3 dB ER. All three metrics used A frequency weighting filter, slow response and a 115 and 140 dB maximum and peak level, respectively.

After sampling, dosimetry data were downloaded and converted to spreadsheet files. Activity card data were then entered on the spreadsheet before final conversion to a statistical analysis program. If the sound level did not exceed the threshold (80 dBA) during a minute period, the dosimeter logged a value of 0 dB. These zero values were corrected by interpolating the average of the next earlier and next later recorded nonzero values. The resulting 1-min noise levels were approximately normally distributed.

Descriptive analyses are presented for the TWAs and 1-min levels for the whole dataset. Additional analyses that describe 1-min noise levels associated with potential determinants of exposure use the subset of data for which direct observations were made. The

TABLE I. Summary of the Study Sites and Samples Collected

Parameter	A	B	C	D	E	Total
Construction method	Multiple Concrete (Stadium)	Cast-in-Place Concrete	Tilt-Up Concrete	Tenant Improvement	Tilt-Up Concrete	
Mean (SD) worker age in years	38 (10)	36 (8)	32 (8)	26 (7)	31 (8)	34 (9)
No. TWAs	50	50	20	20	34	174
No. monitored mins	24,978	24,540	10,069	8,113	16,642	84,342
No. workers	19	12	10	7	11	59
Minutes of observed work	433	1250	941	0	1845	4469
No. TWAs per worker	2.63	4.17	2.00	2.86	3.09	2.95

information on this subset is more detailed and more accurate than that available for the whole, self-reported dataset.

Exposure determinants were assessed using multiple regression. Each variable was simplified by reducing the number of levels into a small set of descriptive factors. Site was reduced to three levels (no observation data were available for the tenant improvement site) and the two concrete tilt-up sites were combined. Tasks were combined to a simple set consisting of Trenching (commonly associated with heavy equipment, outdoors), Prefab/Wall Conduit (including mechanical operations commonly involving power tools), Wiring (installation of wire and components typically using only hand tools), and Material Handling (typically without the use of tools). Tools were similarly grouped into Hand, Power, None, and (because of its special characteristics) Hand Hammer. Tools used by other trades were grouped into Hand, Electric Powered, Gas Powered, Powder Actuated, and Heavy Equipment. In each case a separate category was identified for break time in which no tools were used or activities occurring. The age of the subject was dichotomized at age 25, to approximate those working as apprentices and journeymen with more years on the job.

Linear regressions were developed for both L_{OSHA} and L_{EQ} including each of the potential determinants; no models were run for the modified ISO metric because of its similarity to the NIOSH metric. Logistic regressions were also developed with the dependent variable defined as the 1-min L_{OSHA} or L_{EQ} higher than 90 dBA, or for a peak exposure over 140 dB. Some additional collapsing of variable levels (e.g, no tools or tasks were combined with break) was done to reduce the multicolinearity observed.

RESULTS

A description of the data collected on each of the five sites is presented in Table I. A total of 174 TWA samples were collected from 59 electricians. The average duration of monitoring was 502 (±40) min per TWA. Approximately 50 TWAs were obtained from the Stadium (A), Cast-in-Place (B) and Concrete Tilt-Up (C and E) projects. Fewer samples were obtained on the Tenant Improvement site (D), and none of the work time at this site was observed.

The results of the 174 TWA samples are presented in Table II. Use of the 3-dB ER made a substantial difference in the overall mean TWA of 87 and 81 dBA for the 3- and 5-dB ERs, respectively. On the other hand, the threshold made very little difference; 87.7 and 87.3 dBA for the 0 and 80 dBA thresholds, respectively. These measurement parameters had similar effects on the exceedence percentages; 24 and 5% of the L_{OSHA} values exceeded 85 and 90 dBA, respectively, whereas 68 and 27% of the L_{EQ} (NIOSH) values exceeded these same levels.

No large differences were observed in average noise exposure levels or exceedence percentages between sites, except for somewhat lower levels at Tenant Improvement, which was about 2–5 dB lower on average. Only 10% of the L_{OSHA} and 40% of the L_{EQ} (NIOSH) values exceeded 85 dBA. Interestingly, it appears from this analysis that younger workers (<25 years old) had slightly higher average exposure levels.

One-minute exposure levels (L_{OSHA}) for the total of 4469 min of observed sampling time, stratified by potential determinants, are presented in Table III. The overall average level was 76.3 dBA (note that this is lower than the average TWA, because TWAs for noise are not simple averages, but are computed from the observed dose). The Concrete Tilt-Up jobs had substantially lower averages than the Stadium or Cast-in-Place projects. Trenching, which commonly involved work outside near heavy equipment (typically backhoes) was very loud—almost 90 dBA on average. Electric power tool use represented the highest exposure class of tools, about 89 dBA, whereas hand tool use and no tool use were almost the same, 76 dBA. Work in partially enclosed areas, for instance in an unfinished building with incomplete walls, was much louder (88 dBA) than work outdoors (82 dBA) or indoors (75 dBA). A clear trend was observed depending on the number of workers in the subjects' vicinity; 80, 77, and 70 dBA, for work with ≥5, 1–4, and 0 other workers, respectively. Work around laborers, insulators, and masons provided the highest noise levels, whereas work around plumbers and other electricians involved the lowest levels. Interestingly, work around carpenters was similarly low, perhaps reflecting the type of work done by carpenters when in association with electricians.

Only a small percentage of the subjects wore HPDs—a total of about 14% of the time overall. Interestingly, they were worn when the noise exposure levels on average, were lower than other times. Thus, it is clear that HPD use was dependent on the individual, and many workers chose not to wear HPDs even when exposed at higher levels. As with the TWAs, the younger workers had slightly higher 1-min exposures, on average.

It is important to note that each of these reported levels is the average 1-min level during the period of time that each activity/condition was observed, regardless of what else was going on. For instance, the level measured outdoors does not reflect the fact that while outdoors, the subject was more likely to be digging a trench with heavy equipment while several laborers worked in close proximity. To try to account for these various concurrent conditions, linear regression models were run (Table IV) using the L_{OSHA} and L_{EQ} (NIOSH) levels as the dependent variables. Some unexpected results were obtained. For instance, working on Prefabrication of Conduit installation appears to be 15 dBA (L_{OSHA}) lower than levels on break. However, the model coefficients must be interpreted with the whole model in mind. Although a subject was conducting Conduit installation, he was likely inside using electric tools, and near several workers using electric power tools. Under

TABLE II. TWA (dBA) Noise Exposures and Exceedence Percentages Using Three Exposure Metrics

Variable Category	n	TWA (Mean—SD)			Exceedence Percentage					
		OSHA	NIOSH	ISO	OSHA		NIOSH		ISO	
					>85	>90	>85	>90	>85	>90
All samples	174	80.9 (6.2)	87.7 (5.5)	87.3 (5.8)	24.1	5.2	67.8	27.0	63.8	25.9
Construction Method										
Cast-in Place Concrete	50	82.7 (4.5)	88.7 (4.4)	88.4 (4.5)	32.0	4.0	82.0	34.0	80.0	34.0
Tilt-Up Concrete	54	80.9 (6.5)	87.7 (5.8)	87.4 (6.0)	22.2	5.6	66.7	25.9	61.1	25.9
Stadium	50	80.4 (6.0)	87.4 (5.5)	87.0 (5.7)	24.0	4.0	66.0	24.0	62.0	20.0
Tenant Improvement	20	77.4 (8.3)	85.9 (7.1)	85.3 (7.5)	10.0	10.0	40.0	20.0	35.0	20.0
Age										
<25 yrs	38	83.1 (7.2)	89.8 (6.5)	89.5 (6.7)	39.5	13.2	78.9	36.8	78.9	36.8
≥25 yrs	136	80.2 (5.8)	87.1 (5.1)	86.7 (5.3)	19.9	2.9	64.7	24.3	59.6	22.8

Note: The three metrics include the OSHA hearing conservation metric, the NIOSH recommended metric, and a modification of the International Organization for Standardization (ISO) metric. Details of these metrics are provided in the Methods section.

these conditions, the model-predicted L_{OSHA} exposure level would be 45.4 (background) + 7.4 (inside) + 27.3 (using electric tools) + 5.3 (Other worker using electric tools) = 85.4 dBA. The comparable model-predicted L_{EQ} would be 89.7 dBA. After controlling for activities and conditions, the effect of age of the subject is reversed. In contrast to the univariate result (Table III), the older workers appear to have slightly higher exposure levels, when researchers controlled for type of work being done.

Coefficients and odds ratios for the logistic models predicting the association of various work activities and conditions with 1-min exceedences of 90 dBA, and with the occurrence of a peak greater than 140 dBA, are given in Table V. Generally, high odds ratios are observed across all three models for the same work characteristics—e.g., the Cast-in-Place project had higher odds of excursions for each of the three metrics. Working near heavy equipment during trenching had highly elevated odds of high exposures, as did use of electric power tools. Working in partially enclosed areas was associated with extremely high odds of exceeding 90 dBA, which reflects the fact that the average 1-min level was almost equally as high (L_{OSHA}=88.1 dBA). Although use of a hammer suggested elevated odds of exceeding 90 dBA, it was not associated with peaks above 140 dBA.

As with linear regression, the odds ratios reported are in comparison with the baseline for that variable and are adjusted for all other components of the model. To calculate probability of an exceedence for work in categories combined across variables, the equation provided in the introduction may be used. For instance, the model-predicted probability of a 1-min L_{OSHA} exceeding 90 dB for an individual inside, installing conduit, using electric tools, and surrounded by five or more other workers using electric tools would be

$$\left\langle P(L_{OSHA} > 90\text{ dBA}) \middle| \begin{array}{l} \text{work inside} \\ \text{install conduit} \\ \text{electric tools} \\ \text{electric tools by others} \\ 5 + \text{workers} \end{array} \right\rangle$$

$$= \frac{e^{-4.21+1.31-2.49+2.60+1.00+1.43}}{1 + e^{-4.21+1.31-2.49+2.60+1.00+1.43}} = 0.41$$

Probabilities of exceedence can be similarly calculated for any other set of determinants or for the other logistic regression models given.

DISCUSSION

Noise exposure and the resulting NIHL continue to represent a major problem in the construction industry. Contrary to prior expectations, this project demonstrated that even electricians, a relatively quiet trade that uses primarily hand tools, commonly have excessively high noise exposures on large building construction sites. Average TWA noise exposures were about 81 dBA using the 5-dB ER and 87 dBA using a 3-dB ER. The L_{OSHA} averages were associated with TWAs that exceeded 85 dBA, the hearing conservation action level, about a quarter of the time, whereas about 1 in 20 exposures was over 90 dBA. These exceedences were substantially greater when the 3-dB ER was used.

A previous study of laborers, carpenters, ironworkers, and operating engineers using similar methods produced comparable results.(11) The average L_{OSHA} levels for 338 TWAs was 83 dBA, with very little variation among the four trades. Forty percent of the L_{OSHA} TWAs exceeded 85 dBA, and about 13% exceeded 90 dBA. The average TWAs observed in electricians were only 2 or 3 dBA lower than for these trades and, although lower, exceedences in electricians were still substantial. Given that electricians are much less likely to produce high noise levels through their own work tasks and tools, the high levels observed in this study suggest that the construction work environment may be very noisy regardless of any one worker's particular activity. The data confirmed that the presence of other trades in the environment, the number of other workers in the vicinity, and the tools used by other workers contributed significantly to the subject's noise exposure.

OSHA remains one of the few agencies in the world that bases its standard on the 5-dB exchange, or doubling rate, which is used in dose accumulation calculations. Most scientific organizations and governmental agencies, including the American Conference of Governmental Industrial Hygienists and NIOSH, have adopted the 3-dB ER.(14) The 3-dB value is based on the equal energy hypothesis and is more closely related to the potential risk posed to the ear by sound energy distributed over time.(1) In steady-state environments, there is no difference between the doses calculated using the two rates, but in a highly fluctuating noise environment, of which the construction environment is a prime example, the difference is pronounced. Continued use of the 5-dB ERs to calculate allowable doses puts construction workers at higher risk than workers exposed to similar average steady-state noise levels.

The use of multiple regression models to identify and characterize the determinants of exposure is an important area for occupational exposure assessment. Univariate associations between

TABLE III. One-Minute Average Noise Levels (L_{OSHA}) by Observed Determinants

Variable Group	Minutes	Mean	St. Dev.	% with Peaks $>$ 140 dBA
Overall	4469	76.3	12.1	6.5
Site group				
Stadium	433	82.1	9.9	1.8
Cast-in-Place Concrete	1250	80.9	11.5	9.5
Tilt-Up	2786	73.3	11.7	5.9
Activity				
Trenching	194	89.7	7.6	27.8
Pre-Fab/Conduit	2629	74.9	11.6	5.8
Wiring	1253	78.1	11.7	2.7
Mat'l Handling	27	78.8	12.6	25.9
Break	366	72.2	12.7	2
Tools				
None	1137	75.6	12.4	8.4
Electric Power Tools	176	88.6	9.1	12.5
Hammer	59	83.3	8.3	6.8
Misc. Hand Tools	2708	76.3	11.0	4.6
Tools used by other trades				
Hand Tools	1902	75.1	11.3	3.4
Electric Power Tools	512	78.9	10.8	3.1
Heavy Equipment	626	82.1	10.7	14.1
Gas Power Tools	320	84.0	9.9	2.5
Powder Actuated	2	81.5	15.0	50.0
None	719	71.7	12.2	9.6
Environment				
Indoor	3319	74.7	11.5	5.6
Outdoor	454	82.3	10.8	12.6
Partial Enclosure	330	88.1	8.3	1.5
No. other workers				
0	349	70.1	12.8	7.7
1 to 4	3247	77.0	11.4	6.1
≥5	486	80.1	12.5	4.5
Trades				
Masons	400	80.8	11.3	10.3
Carpenters	1588	74.6	10.3	3.6
Electricians	2317	74.8	11.6	5.2
HVAC	401	72.0	9.8	1.0
Insulators	230	83.8	11.4	0
Laborers	195	87.6	11.2	1.0
Other	144	81.1	9.5	0
Plumbers	852	74.2	11.7	3.4
Sheetrockers	355	76.1	11.1	2.3
Hearing protection				
None	3455	77.5	12.1	6.3
Foam Plugs	627	72.4	9.40	4.5
Age group				
<25 years	851	77.7	14.2	7.4
>25 years	3618	75.9	11.5	6.3

TABLE IV. Linear Regression Models Describing Mean 1-min L_{OSHA} and L_{EQ} Exposure Levels

Variable	L_{OSHA} β (SE)	L_{EQ} β (SE)
Intercept	45.4 (2.5)^B	67.4 (1.5)^B
Site (ref: Tilt-Up)		
Cast in Place	6.7 (0.4)^B	4.6 (0.3)^B
Stadium	2.3 (0.8)^A	1.4 (0.5)^B
Age (ref: <25 years)		
>25 years	2.6 (0.5)^B	1.0 (0.3)^B
Location (ref: outside)		
Partial enclosure	17.0 (1.1)^B	11.4 (0.7)^B
Inside	7.4 (0.8)^B	4.5 (0.5)^B
No. workers in vicinity (ref: 5+)		
0	−3.6 (0.85)^B	−2.3 (0.5)^B
1–4	−1.2 (0.5)^A	−1.0 (0.3)^B
Task (ref: Prefab/Conduit)		
Trenching	25.3 (1.3)^B	17.0 (0.8)^B
Break	15.3 (2.4)^B	4.9 (1.4)^B
Material handling	5.3 (2.1)^A	4.9 (1.3)^B
Wiring	2.3 (0.5)^B	1.0 (0.3)^B
Tools (ref: Break)		
Electric	27.3 (2.4)^B	14.6 (1.5)^B
Hammer	23.0 (2.6)^B	11.2 (1.7)^B
Hand	15.9 (2.3)^B	6.5 (1.5)^B
None	15.2 (2.3)^B	5.8 (1.5)^B
Tools used by others (ref: None)		
Powder-Actuated	11.4 (7.1)	9.8 (4.5)^A
Gas Powered	7.3 (0.8)^B	3.9 (0.5)^B
Electric	5.3 (0.7)^B	3.2 (0.4)^B
Heavy Equipment	4.3 (0.7)^B	2.3 (0.5)^B
Hand Tools	2.0 (0.5)^B	1.4 (0.3)^B
Model r^2	0.318	0.342

$^A p<0.05$
$^B p<0.01$

work or environmental characteristics and exposure levels can easily be confounded by the complex concurrence of activities and conditions that occur in most work processes. Regression models offer a methodology for sorting out the relative contributions of various factors occurring in real working conditions. For instance, the apparent elevation in noise levels associated with younger workers (Table III) disappeared, or was reversed, when addressed in the linear regression models (Table IV) taking into account what the subjects were doing at the time.

Most studies of exposure determinants have used linear models to predict the average exposure level. Only one study using logistic regression was identified in a recent thorough literature review.(12) In this agricultural study, the odds of reporting exposure on an industry-wide questionnaire survey were evaluated with respect to the type of farm, using only individual binary explanatory variables.(15) It appears that multiple variable logistic models have not previously been applied to evaluating measured exposure excursions.

Because industrial hygienists are frequently interested in predicting excursions of exposure above some specified level, the use of logistic regression models fits well with the goals of exposure assessment. Thresholds may be important for predicting acute health effects, for identifying exposure conditions that may exceed advisory or regulatory limits, or for identifying priorities for exposure control intervention. The use of logistic regression for modeling such excursions has been successfully demonstrated here.

The output of a logistic regression model provides the ratio of the odds of an event (e.g., an excursion of the specified limit) occurring under the condition specified (the determinant; e.g., an activity, tool, etc.) to the odds of the event occurring in the absence of that condition (the reference level of that variable). An odds ratio of five, for instance, suggests that there is a fivefold increase in the probability that the excursion occurs under some condition, as compared with when that condition is not present. These calculated odds ratios are predicted while controlling for all other variables in the model.

As demonstrated, the model output also can be used to predict the probability of an excursion occurring under any combination of the determinants in the model. This calculation may be very helpful in predicting under which circumstances excursions are

TABLE V. Logistic Regression Models Describing Odds Ratios for 1-min L_{OSHA} and L_{EQ} Exposure Levels Exceeding 90 dBA and a Peak Level Exceeding 140 dBA

	$L_{OSHA} > 90$		$L_{EQ} > 90$		Peak > 140	
Variable	OR	β (SE)	OR	β (SE)	OR	β (SE)
Intercept		−4.21 (0.40)[B]		−3.46 (0.31)[B]		−3.83 (0.66)[B]
Site (ref: Concrete Tilt-Up)						
Cast-in-Place Concrete	6.1	1.80 (0.16)[B]	3.9	1.35 (0.13)[B]	4.1	1.40 (0.16)[B]
Stadium	1.2	0.22 (0.34)	1.5	0.40 (0.24)	1.1	0.07 (0.52)
Location (ref: outside)						
Partial enclosure	58.6	4.07 (0.41)[B]	27.3	3.31 (0.32)[B]	1.1	0.07 (0.90)
Inside	1.2	1.31 (0.34)[B]	3.1	1.12 (0.26)[B]	3.7	1.31 (0.63)[A]
Task (ref: Break/None)						
Wiring/Hand Tools	0.1	−2.43 (0.61)[B]	0.1	−1.90 (0.49)[B]	0.1	−2.05 (0.57)[B]
Install Conduit/Power Tools	0.1	−2.49 (0.58)[B]	0.1	−2.15 (0.47)[B]	0.3	−1.17 (0.53)[A]
Trenching/Work Near Machines	16.2	2.78 (0.63)[B]	10.2	2.32 (0.52)[B]	6.0	1.78 (0.81)[A]
Tools (ref: Break/None)						
Hand	1.1	0.08 (0.16)	1.1	0.07 (0.13)	0.6	−0.52 (0.17)[A]
Electric	13.5	2.60 (0.24)[B]	10.1	2.32 (0.21)[B]	1.1	0.06 (0.29)
Hammer	3.2	1.16 (0.39)[A]	3.6	1.27 (0.32)[B]	0.8	−0.17 (0.54)
Tools Used by Others (ref: None/Break)						
Gas Powered	3.3	0.88 (0.32)[A]	1.2	0.15 (0.25)	0.2	−1.40 (0.42)[B]
Electric	3.6	1.00 (0.29)[B]	1.5	0.42 (0.21)[A]	0.4	−0.99 (0.31)[A]
Hand Tools	1.9	0.41 (0.26)	1.0	−0.04 (0.18)	0.4	−0.82 (0.22)[B]
Heavy Equipment	1.4	0.01 (0.32)	0.9	−0.12 (0.23)	1.4	0.31 (0.28)
No. Workers in Vicinity (ref: Break)						
0	1.9	0.64 (0.67)	2.9	1.07 (0.53)[A]	3.6	1.27 (0.59)[A]
1–4	2.7	0.99 (0.65)	4.4	1.48 (0.51)[A]	3.7	1.30 (0.57)[A]
5+	4.2	1.43 (0.61)[A]	6.1	1.81 (0.49)[B]	3.5	1.25 (0.51)[A]

[A] $p<0.05$

[B] $p<0.001$

most likely to occur, and therefore where interventions would be most effective in preventing high exposures.

The use of real-time data-logging dosimeters allowed for the simultaneous collection of both TWA exposure levels (for comparison with standard exposure limits) and short-term task-associated exposure levels. By combining the data-logged record of 1-min levels with time-activity card information, task-based exposure levels could be determined. In addition, the contribution of work characteristics that change constantly over the workday could be modeled. Several challenges are presented by this approach. Obtaining accurate accounting of a large number of potential activities is very difficult. The data collection instrument used allowed the electrician to record the start and stop time (with a resolution of about 10–15 min) for 10 predetermined tasks, 4 tools, up to 4 other trades present, and classifications of the number of other workers present, and location (in addition to the perceived noise level and use of HPDs). Although documenting this information represents a relatively significant burden for the individual subject, it is also a fairly crude assessment of the potential determinants of exposure. Additional detail, and increased accuracy of reporting, was provided only by direct observation of the worker during monitoring.

Even with direct observation of work activities during exposure monitoring, the development of explanatory models for exposure determinants required collapsing variables into a reasonable number of levels. the number of levels was reduced for the models using a priori judgements concerning appropriate grouping. Although this approach provides simpler interpretations, alternative grouping strategies may provide more accurate results with models that better fit the data. Even so, problems of multicolinearity forced the collapse of variables to a higher degree than desired in order to fit the logistic models. The result of this additional level of grouping is slightly less detailed model interpretations.

Noise exposure, and the subsequent NIHL, remain significant challenges in the construction industry. The authors observed HPDs being worn by electricians only 14% of the time, and this was not during the higher noise exposure periods. Although HPDs should be used as a last resort to protect workers, their use has commonly been the first line of defense against noise exposure in the construction industry. Unfortunately, HPDs may always be necessary in certain construction situations that are not amenable to noise control strategies; however, if the construction environment is considered to be an integrated system, reductions in certain key noise sources may reduce general environmental levels to a point at which a majority of workers are no longer exposed to injurious noise levels.

It has been shown that exposure is not limited to those trades or activities that are traditionally associated with high noise, such as iron worker and operating engineer. Even relatively quiet trades such as electrician can be highly exposed—partly due to their own activities, but to an even greater degree due to the general construction environment, and activities of co-workers. Modeling the contributions of various sources to noise levels, and excursions of exposure limits, provides some guidance for intervention strategies to prevent NIHL. Isolation of noisy operations and concentrated efforts to reduce sound levels produced by heavy equipment and electric powered hand-tools will help reduce this risk, but to be successful these efforts must address the construction environment as a whole.

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