ORIGINAL ARTICLE

Noise exposure and hearing loss prevention programmes after 20 years of regulations in the United States

W E Daniell, S S Swan, M M McDaniel, J E Camp, M A Cohen, J G Stebbins

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See end of article for authors' affiliations

Correspondence to: Dr W E Daniell, Department of Environmental and Occupational Health Sciences, University of Washington, Box 357234, Seattle, WA 98155, USA; bdaniell@u.washington.edu

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Objectives: To evaluate noise exposures and hearing loss prevention efforts in industries with relatively high rates of workers' compensation claims for hearing loss.

Methods: Washington State workers' compensation records were used to identify up to 10 companies in each of eight industries. Each company (n = 76) was evaluated by a management interview, employee personal noise dosimetry (n = 983), and employee interviews (n = 1557).

Results: Full-shift average exposures were ⩾85 dBA for 50% of monitored employees, using Occupational Safety and Health Administration (OSHA) parameters with a 5 dB exchange rate (L_{ave}), but 74% were ⩾85 dBA using a 3 dB exchange rate (L_{eq}). Only 14% had L_{ave} ⩾90 dBA, but 42% had L_{eq} ⩾90 dBA. Most companies conducted noise measurements, but most kept no records, and consideration of noise controls was low in all industries. Hearing loss prevention programmes were commonly incomplete. Management interview scores (higher score = more complete programme) showed significant associations with percentage of employees having L_{ave} ⩾85 dBA and presence of a union (multiple linear regression; $R^2 = 0.24$). Overall, 62% of interviewed employees reported always using hearing protection when exposed. Protector use showed significant associations with percentage of employees specifically required to use protection, management score, and average employee time spent ⩾95 dBA ($R^2 = 0.65$).

Conclusions: The findings raise serious concerns about the adequacy of prevention, regulation, and enforcement strategies in the United States. The percentage of workers with excessive exposure was 1.5–3 times higher using a 3 dB exchange rate instead of the OSHA specified 5 dB exchange rate. Most companies gave limited or no attention to noise controls and relied primarily on hearing protection to prevent hearing loss; yet 38% of employees did not use protectors routinely. Protector use was highest when hearing loss prevention programmes were most complete, indicating that under-use of protection was, in some substantial part, attributable to incomplete or inadequate company efforts.

Occupational hearing loss (OHL) provides an excellent model for studying the preventability of chronic occupational illnesses. The causative mechanism is relatively well understood, exposure-response relationships are well characterised, the exposure and primary health effect are easily measurable, and regulations based on these attributes have been in effect in the United States for more than 20 years.[1] However, in spite of its potential preventability, noise induced hearing loss remains a prevalent occupational health problem. In Washington State, for example, the annual number of workers' compensation claims for OHL increased more than tenfold in a decade, with annual costs exceeding $50 million in recent years.[2] Much of this increase occurred among individuals older than the usual retirement age, suggesting the increase was at least partially a reporting phenomenon and not related to contemporary work circumstances. However, substantial increases also occurred among younger individuals who presumably had more recent or ongoing noise exposures, suggesting that current workplace practices may place contemporary workers at risk for hearing loss.

The US Occupational Safety and Health Administration (OSHA) has, since the early 1980s, required employers to maintain an effective hearing conservation programme when an employee's full-shift time weighted average noise exposure can reach or exceed 85 dBA (decibels).[3 4] A programme must include noise monitoring, training, hearing protection, and audiometric monitoring. If employee full-shift average exposures reach 90 dBA, the employer must utilise noise controls, if feasible. In Washington State, the regulations apply to construction and agriculture, as well as fixed industry.

Reducing or eliminating a hazard is generally the preferred strategy for mitigating the health risk associated with that hazard; however, personal hearing protection remains a cornerstone of contemporary efforts to prevent OHL in the United States. The US National Institute of Occupational Safety and Health (NIOSH) conducted extensive surveys of workplace hazards, including noise, in the 1970s and 1980s; however, there is only limited broad based information about noise exposures since that time.[5] In general, noise levels have declined and hearing protector usage has increased in recent times,[6 7] but hearing protectors are under-used in noisy industries.[8 9] The present study evaluated the current extent of occupational noise exposure and hearing loss prevention efforts in a broad sample of companies in one region of the United States, in order to characterise the risk for OHL 20 years after implementation of the US hearing conservation regulations.

METHODS

This cross-sectional study evaluated noise exposures and hearing loss prevention activities at worksites in each of eight industries with relatively high industry specific rates of OHL claims. The study instruments and procedures were refined in

Abbreviations: DLI, Department of Labor and Industries; FTE, full-time equivalent; NIOSH, National Institute of Occupational Safety and Health; OHL, occupational hearing loss; OSHA, Occupational Safety and Health Administration a preceding pilot study in foundries.[10] All study instruments and procedures were reviewed and approved in advance by the University of Washington institutional review board.

Industry sample

The industry and company samples were drawn from the population of employers whose industrial insurance is provided (State Fund) or regulated (self insured) by the Washington Department of Labor and Industries (DLI), which encompasses nearly all non-federal employers and workers in the state. The DLI provided records in year 2000 for OHL claims filed during 1992–98, plus annual reported employment hours in all DLI industry categories. These categories were combined into 106 industry groups.[2 11 12] Employment hours were divided by 2000 to estimate full-time equivalent (FTE) workers and calculate incidence rates of OHL claims.

Industry specific statistics for OHL claims were used to select nine industries that broadly represented the distribution of those statistics, based on claims filed in 1992–98.[13] The 106 industry groups were characterised primarily by their prevention index (PI), calculated for each industry as the average of ranks for two variables, the annual number and annual incidence rate of OHL claims.[14] An industry with a higher number and higher incidence rate of OHL claims has a lower PI. Other selection criteria were: ⩾20 companies in the industry, each with ⩾10 but <500 FTE employees; and a business address in the extended Puget Sound region. Companies with ⩾500 FTE employees were counted if they had more than one location and average employment per location was <500 employees. The nine selected industries are listed in table 1.

Company sample

The DLI provided contact information and employment hours for all companies with employment in any one of the nine industries, whether or not employment was linked to an OHL claim. Companies were potentially eligible if they met the size and geographic criteria. The goal in each industry was to enrol 10 companies. Recruitment efforts gave priority to companies that reported ⩾20 and <250 FTE employees. If a company had more than one location and each location independently managed production and safety and health efforts, then each location was potentially eligible to participate as a ''separate'' company; however, priority was given to companies with a unique corporate structure.

Candidate companies were contacted first by mail and then by telephone. Recruitment efforts continued in each industry until the goal (n = 10 companies) was achieved or the eligible pool was exhausted. Participation was voluntary. No incentives were provided except a report of findings and recommendations for the company. Overall, about 50% of companies contacted by phone agreed to participate. Participation was lowest in lumber milling and road construction, about 30–40%, and was highest in machine shops, sheet metal manufacturing, and wood products manufacturing, up to about 60%. Ten companies were recruited in each of six industries, and nine in another (heavy gauge metal manufacturing). Only one paper mill was recruited; no findings for that industry are reported. Only seven lumber mills were recruited, including three that were part of one corporation but functioned independently. Three pairs of fruit/vegetable processing companies and one pair of road construction companies were each part of one corporation but functioned independently.

Employee sample

The employee sample at each company was selected to be as representative as possible of employees involved in noisy tasks or working in noisy areas, as established during a preliminary walk-through visit. Participation was voluntary, and no incentives were provided. In general, the employee sample was obtained by first enrolling volunteer or company designated employees in targeted noisy jobs and then approaching employees individually, until the enrolment goal was achieved in specific jobs. The refusal rate by employees approached individually was less than 5–10% (estimated). The median number of employees participating in noise monitoring at each company was 12 (total n = 983). The median number of employees who completed an interview, including nearly all who completed noise monitoring, was 19 (total n = 1557).

Data collection

Between September 2000 and August 2002, 76 companies were evaluated in eight industries (plus one pulp and paper company). Data collection at each company usually involved one work shift on one day but sometimes needed a second shift or a second or third day at larger sites. Data collection included: full-shift personal noise dosimetry, one management interview with the person most responsible for hearing loss prevention activities, employee interviews, and observations of hearing protector use.

Personal noise monitoring utilised a Quest 300 or Quest 400 type 2 data logging noise dosimeter worn for an entire shift. Dosimeters were calibrated before and after each monitoring period. The dosimeters recorded two channels of data, one using OSHA parameters (90 dBA criterion, 5 dB exchange rate, 80 dBA threshold, slow response),[3 4] and one using parameters recommended by NIOSH (85 dBA criterion,

Table 1 Selected industries with high numbers and incidence rates of occupational hearing loss claims, 1992–98

Industry*	Number of workers† (annual mean)	Number of claims (annual mean)	Claims incidence (per 1000 FTE)†	Prevention index‡
Pulp and paper production	8100	159.9	19.7	5.0
Lumber milling	16373	289.7	17.7	5.0
Road construction	5102	132.4	26.0	5.5
Heavy gauge metal manufacturing	3708	31.1	8.4	23.5
Machine shops	9382	51.9	5.5	25.0
Sheet metal manufacturing	9780	47.0	4.8	27.5
Fruit/vegetable processing	19616	53.4	2.7	35.0
Wood product manufacturing	6367	19.6	3.1	42.5
Printing	8423	20.1	2.4	46.0
All industries	1833132	3209	1.75	(1–106)

*Industries listed in order of prevention index.
†Full-time equivalent (FTE) employees.
‡Average of $rank_{number}$ and $rank_{incidence}$

Table 2 Major findings of work site evaluations, by industry

		Printing n = 10	Wood prod mfg n = 10	Fruit/veg processing n = 10	Sheet metal mfg n = 10	Machine shops n = 10	Heavy gauge metal mfg n = 9	Road construction n = 10	Lumber milling n = 7	Total n = 76	p value*
Noise exposure											
Sample duration (h)		8.0 (1.3)	8.2 (0.9)	8.3 (0.6)	8.6 (0.8)	8.3 (0.8)	8.5 (1.0)	8.4 (1.0)	8.9 (0.7)	8.4 (0.9)	0.68
L_{eq} (dBA)		84.3 (3.5)	88.3 (2.0)	89.0 (2.7)	87.3 (2.3)	86.2 (2.8)	91.5 (2.1)	88.8 (3.1)	95.8 (1.6)	88.6 (4.0)	<0.001
L_{ave} (dBA)		80.3 (4.8)	83.9 (3.0)	86.4 (3.0)	82.5 (2.8)	81.2 (4.1)	86.7 (2.5)	84.2 (3.7)	93.7 (1.8)	84.5 (4.9)	<0.001
L_{ave} >85 dBA (%)		29.9 (33.1)	47.8 (24.8)	61.5 (26.7)	37.4 (21.6)	29.3 (24.2)	68.7 (22.8)	45.4 (28.6)	94.5 (6.2)	49.9 (30.9)	<0.001
L_{ave} >90 dBA (%)		8.3 (16.3)	15.1 (9.5)	27.6 (25.2)	6.2 (12.0)	9.7 (14.2)	23.9 (19.2)	13.6 (15.0)	81.2 (12.8)	20.8 (25.6)	<0.001
L_{max} (dBA)		108.2 (2.5)	114.5 (2.2)	110.9 (3.2)	113.5 (3.0)	113.5 (2.9)	117.8 (2.1)	115.2 (2.6)	119.1 (2.2)	113.9 (4.1)	<0.001
Time >85 dBA (min)		127.8 (98.0)	195.9 (88.3)	249.1 (95.1)	152.7 (58.3)	122.7 (64.3)	218.4 (56.6)	176.8 (92.9)	421.5 (60.5)	199.5 (112)	<0.001
Time >90 dBA (min)		56.5 (76.9)	81.6 (46.9)	131.4 (91.3)	61.5 (36.7)	53.8 (39.1)	107.9 (35.5)	92.1 (75.6)	356.7 (68.8)	108.4 (103)	<0.001
Time >95 dBA (min)		18.7 (30.4)	19.1 (11.3)	38.0 (30.9)	17.6 (15.4)	18.5 (21.4)	40.1 (18.3)	44.6 (67.3)	221.4 (81.8)	45.7 (68.8)	<0.001
Management interview score†		(n = 8)				(n = 9)				(n = 73)	
Noise	⩽12	5.9 (2.0)	5.3 (2.1)	5.7 (2.3)	6.1 (1.4)	5.4 (2.6)	4.6 (1.8)	6.1 (2.7)	6.1 (3.2)	5.6 (2.3)	0.82
Training	⩽11	3.7 (3.5)	4.3 (3.2)	5.3 (3.2)	6.4 (2.4)	3.0 (3.2)	7.3 (2.6)	4.7 (3.5)	7.9 (1.2)	5.3 (3.2)	0.01
Hearing protectors	⩽7	3.0 (1.1)	3.3 (1.6)	4.9 (2.0)	4.3 (0.8)	3.8 (1.6)	4.2 (1.3)	4.4 (1.1)	5.1 (1.6)	4.1 (1.5)	0.04
Audiometry	⩽10	4.4 (3.9)	5.1 (3.1)	6.4 (2.5)	6.8 (3.2)	5.2 (3.3)	7.7 (3.0)	4.8 (3.6)	8.6 (0.8)	6.0 (3.2)	0.08
Overall	⩽40	17.0 (9.4)	18.0 (7.9)	22.3 (7.7)	23.6 (5.3)	17.4 (8.7)	23.8 (7.6)	20.0 (9.8)	27.7 (5.1)	21.1 (8.2)	0.09
Employee interview score†		(n = 8)				(n = 9)				(n = 73)	
Noise	⩽6	1.4 (0.5)	0.8 (0.4)	0.9 (0.4)	1.4 (0.5)	1.2 (0.6)	1.2 (0.8)	1.3 (0.7)	1.8 (1.2)	1.2 (0.7)	0.08
Training	⩽8	2.0 (1.1)	1.7 (0.9)	2.6 (1.5)	3.2 (1.2)	2.3 (1.6)	3.3 (1.2)	2.3 (1.3)	3.6 (1.2)	2.6 (1.4)	0.008
Hearing protectors	⩽8	5.0 (1.1)	5.0 (1.3)	5.6 (1.7)	5.4 (0.9)	5.2 (1.3)	6.0 (0.7)	5.1 (1.1)	7.0 (0.5)	5.5 (1.2)	0.02
Audiometry	⩽3	1.7 (1.4)	1.7 (1.1)	2.0 (1.0)	1.9 (0.9)	1.5 (1.3)	2.5 (0.8)	1.4 (1.0)	2.9 (0.1)	1.9 (1.1)	0.02
Overall	⩽25	10.1 (3.7)	9.2 (3.3)	11.1 (4.3)	12.0 (2.9)	10.2 (4.1)	12.9 (2.9)	10.0 (3.5)	15.3 (2.8)	11.2 (3.8)	0.02
Employees reported always using hearing protectors when exposed (%)		44.9 (26.6)	57.7 (28.3)	71.0 (34.0)	56.8 (23.6)	41.6 (24.5)	85.1 (9.8)	45.1 (25.7)	92.6 (6.9)	60.3 (29.1)	<0.001

Table shows mean (and standard deviation) using data aggregated by company.
*Significance determined by one way ANOVA.

3 dB exchange, no threshold, slow response).[1] Data were processed with QuestSuite software.[15] The output included: full-shift time weighted average sound pressure level using OSHA (L_{ave}) and NIOSH (L_{eq}) parameters; highest sampled sound pressure level, measured by slow response (L_{max}); and total time in noise exceeding specific levels.

The management and employee interviews included sections with questions about noise monitoring and noise controls, training and hearing protector fitting, hearing protector availability and use, audiometric testing, and background information. The employee interview was translated into Spanish. Summary scores were derived for both interviews, calculated as the unweighted sum of favourable responses on representative non-duplicated questions (total possible scores: management, 40; employee, 25).

Employees' use of hearing protection was assessed by two interview questions: "At this workplace, how often do you work around noise that is so loud you have to raise your voice for someone to hear you from an arm's length (or 2–3 feet) away?" and "Whenever you work around noise that loud, how often do you wear hearing protection?". The questions used five response options, later combined into three categories: "always or almost always"; "less than half", "about half", and "more than half" the time (combined as sometimes); and "never or almost never".

Reliability of reported exposure and hearing protector use

Observations of hearing protector use were conducted in five industries (road construction, lumber milling, machine shops, sheet metal manufacturing, and fruit/vegetable processing). An investigator traversed the site up to four times during the day and unobtrusively observed participating employees, who wore number badges. One or more observations were completed for 876 subjects (88%). When feasible, a handheld type 2 sound level meter was used to measure noise levels. The observer noted whether the subject was exposed to noise $\geqslant$85 dBA and, if so, was wearing a hearing protector and was wearing it properly.

A brief post-shift interview was additionally conducted in these five industries, using only the questions about perceived noise exposure and protector use, with specific reference to the study day. Only 514 subjects (51%) could be interviewed, amid the rush to leave work; priority was given to subjects wearing a dosimeter (80%).

Data analysis

The primary unit of analysis was the company. In general, data collected from individual employees were aggregated at the level of the company for data analysis—that is, the percentage of subjects or the mean value. Variable description used the mean and standard deviation (SD) or, when the distribution was not normal, the median and interquartile interval. Bivariate associations were evaluated with Pearson correlation coefficients (r_p); and between-group associations, with χ^2 tests or one way analysis of variance (ANOVA). Multiple linear regression with stepwise forward entry (p to enter and p to remove >0.10) was used to assess associations of the primary dependent variables (management interview score and percent of employees who reported always using hearing protection) with company specific noise variables (mean L_{ave} and L_{eq}; percentage of employees with L_{ave} and L_{eq} $\geqslant$85 or $\geqslant$90; mean minutes in noise $\geqslant$85, $\geqslant$90, or $\geqslant$95 dBA; mean L_{max}); management interview score (in hearing protection model); other categorised company descriptors (work force size, years of ownership, reported policy requiring protector use, history of OSHA inspection or noise citation, presence of union); and specific industry. Reliability assessment used categorical variables and was characterised by the percent of categorical concordance and intra-class correlation coefficient (r_{icc}). Analyses of hearing protector observations were restricted to the subset of observed subjects who had $\geqslant$3 observations, including $\geqslant$1 observation during exposure $\geqslant$85 dBA (n = 381; 43%).

RESULTS

Study sample

In most industries, at least 80% of the companies had been owned by the present owner for >10 years; the exceptions were printing and sheet metal manufacturing companies, in which only 60% had been owned this long. Smaller workplaces, with $\leqslant$50 production employees, were most common in machine shops and heavy gauge metal manufacturing companies (40% and 44%, respectively; others, 0–30%). A union was present at 57% or more of companies in the sheet metal, lumber milling, and road construction industries, but no more than 33% of companies in other industries. Overall, 78% of companies had been inspected by Washington State OSHA at some point, but only 9% ever received a citation related to noise exposure or hearing conservation.

Most interviewed employees (>79%) were men, except in fruit/vegetable processing, where 50% were men. The age distribution was divided evenly between <35 years (34%), 36–45 years (34%), and >45 years (32%). Overall, 71% had been employed at their present company for $\geqslant$2 years, and 17% for <1 year. Most employees had completed high school (85%), and 45% had additional education or vocational training. The percentage who completed high school was low in fruit/vegetable processing, 44%. The primary spoken language was other than English for 22–35% of interviewed employees in the wood products manufacturing, printing, and fruit/vegetable processing industries, and 4–13% in other industries.

Noise exposure

The mean sample duration did not differ significantly between industries and overall was 8.4 hours (SD 0.9; table 2); 98% were $\geqslant$6 hours. The full-shift, time weighted average noise exposures, L_{ave} and L_{eq}, and not eight-hour equivalent values are reported here.

Excessive noise exposure was common in all industries. All companies except one machine shop and two printing companies (96%) had $\geqslant$1 monitored employee with L_{ave} $\geqslant$85 dBA, and 79% had $\geqslant$3 employees exposed this high. Employers in the US must maintain a hearing conservation programme for employees with such exposures. In addition, 62% of companies had $\geqslant$1 employee with L_{ave} $\geqslant$90 dBA, the level at which noise controls are required, if feasible. Full-shift exposures were highest in lumber milling, where 95% of monitored employees had L_{ave} $\geqslant$85 dBA; >60% of monitored employees in heavy gauge metal manufacturing and fruit/vegetable processing had exposures this high, and $\geqslant$30% in all other industries (table 2 and fig 1).

Excessive exposure was more common and higher using the L_{eq}, which differs from the OSHA L_{ave} primarily by using a 3 dB rather than 5 dB exchange or doubling rate (fig 1). Overall, 74% of monitored employees had L_{eq} $\geqslant$85 dBA, whereas 50% had L_{ave} $\geqslant$85 dBA; and 42% had L_{eq} $\geqslant$90 dBA, whereas only 14% had L_{ave} $\geqslant$90 dBA.

Employee noise exposures were generally intermittent during their work shift. Most lumber mill workers were exposed to noise levels $\geqslant$85 dBA throughout the work shift (table 2). However, in other industries, considering only workers whose full-shift L_{eq} was $\geqslant$85 dBA, the median time spent in noise levels $\geqslant$85 dBA was 4.7 hours (interquartile interval 3.8–6.5).

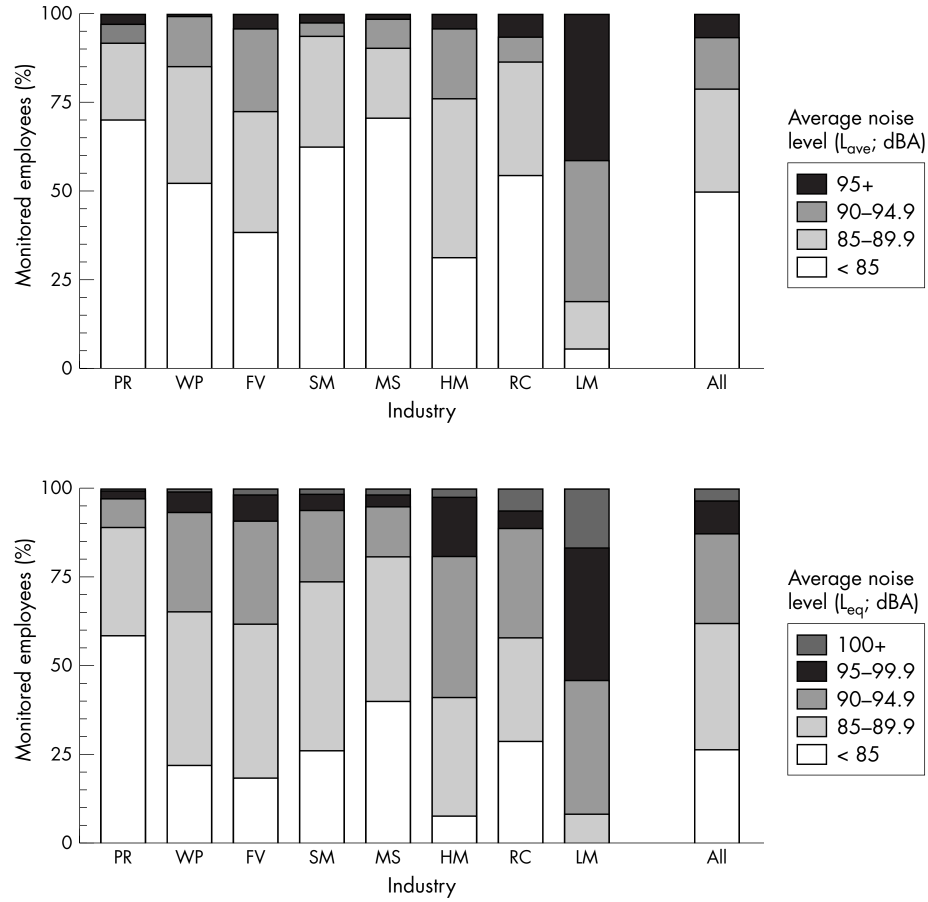

Figure 1 Full-shift personal noise exposure (L_{ave} and L_{eq}), by industry. L_{ave} or L_{eq}, full-shift time weighted average sound pressure level using OSHA (5 dB exchange) or NIOSH (3 dB exchange) parameters, respectively. PR, printing; WP, wood products mfg; FV, fruit/vegetable mfg; SM, sheet metal mfg; MS, machine shops; HM, heavy gauge metal mfg; RC, road construction; LM, lumber milling.

Interviews

Analyses of interview data excluded three companies where no monitored employees had full-shift exposures ⩾85 dBA, because if sampling was representative, those companies were not required to have a hearing conservation programme. However, each company provided hearing protection and was included in analyses of protector use.

The overall management interview score showed a marginally significant difference across the eight industries, primarily reflecting differences in training and hearing protector responses, and less pronounced differences in noise monitoring and audiometry responses (tables 2 and 3). Although most companies had conducted noise measurements, most of them kept no records, and consideration of controls was low in all industries. Most companies conducted annual audiometry, in fact more than reported conducting annual training. Management overall scores varied widely within industries. Every industry included at least one company in the lowest quartile (overall score 4–16) and at least one in the highest quartile (28–35).

Multiple linear regression was used to evaluate whether management interview score was associated with noise levels or other characteristics at individual companies. Management score showed the strongest associations with the percent of employees with L_{ave} ⩾85 dBA (partial correlation, $r_{a.b} = 0.38$; $p = 0.001$) and the presence of a union ($r_{a.b} = 0.32$; $p = 0.007$). Companies with relatively larger workforce, >200 employees, tended to have higher scores ($r_{a.b} = 0.23$; $p = 0.06$), and road construction companies tended to have lower scores ($r_{a.b} = -0.23$; $p = 0.06$). None of the other examined variables contributed further to the model (see Methods). The combined association was modest (model adjusted $R^2 = 0.24$, $p < 0.001$).

In general, employee interview responses were consistent with the management interviews (table 2). There was a strong correlation between the company average employee overall score and the management overall score, at the level of individual companies ($r_p = 0.75$, $p < 0.001$), and when company values were averaged by industry ($r_p = 0.93$, $p < 0.001$). One exception involved training. Among employees who worked at least one year at the 46 companies with annual training programmes, only 60% (SD 27%) said they recalled any training. The percentage did not differ significantly with length of employment, management interview score, or whether or not the employee underwent audiometric testing. In contrast to the management reports, the percentage of employees who reported having annual audiometry differed significantly between industries.

Reported use of hearing protection

Overall, 62% of interviewed employees (mean; SD 29%) said they always (or almost always) used hearing protection while exposed to loud noise, and another 25% (SD 21%) said they sometimes used protection. Reported use of protection differed significantly between industries (table 2). Usage was highest in the three industries (lumber milling, heavy gauge metal manufacturing, and fruit/vegetable processing) where excessive noise exposure was most prevalent. In the other industries, on average, only about 40–60% of employees reported always using protection when exposed. The reported

Table 3 Responses to selected questions on management interview, by industry

	Printing (n = 8)*	Wood prod mfg (n = 10)	Fruit/veg processing (n = 10)	Sheet metal mfg (n = 10)	Machine shops (n = 9)*	Heavy gauge metal mfg (n = 9)	Road construction (n = 10)	Lumber milling (n = 7)	Total (n = 73)*	p value†
One person is designated to be responsible	3 (38%)	7 (70%)	10 (100%)	10 (100%)	6 (67%)	9 (90%)	9 (90%)	5 (71%)	59 (81%)	0.002
Noise monitoring and controls										
Ever measured noise levels	5 (63%)	7 (70%)	8 (80%)	10 (100%)	9 (100%)	9 (100%)	10 (100%)	7 (100%)	65 (89%)	0.38
Kept records of measurements	2 (25%)	2 (20%)	3 (30%)	3 (30%)	3 (33%)	4 (44%)	5 (50%)	3 (43%)	25 (34%)	0.87
Has noise map	1 (13%)	0 (0%)	1 (10%)	2 (20%)	0 (0%)	1 (11%)	n/a	2 (29%)	7 (11%)	0.45
Posts noise warning signs	6 (75%)	7 (70%)	8 (80%)	7 (70%)	7 (78%)	6 (67%)	2 (20%)	5 (71%)	48 (66%)	0.14
Ever made changes to reduce noise	4 (50%)	4 (40%)	3 (30%)	4 (40%)	7 (78%)	3 (33%)	8 (80%)	4 (57%)	37 (51%)	0.17
Ever measured noise after changes	1 (13%)	0 (0%)	1 (10%)	0 (0%)	0 (0%)	0 (0%)	3 (30%)	2 (29%)	7 (10%)	0.07
Plans changes to reduce noise	4 (50%)	4 (40%)	5 (50%)	3 (30%)	4 (44%)	1 (11%)	3 (30%)	4 (57%)	28 (38%)	0.52
Training and hearing protector fitting										
Training provided annually	4 (50%)	6 (60%)	6 (60%)	9 (90%)	3 (33%)	7 (78%)	4 (40%)	7 (100%)	46 (63%)	0.02
Training includes required content	1 (13%)	1 (10%)	3 (30%)	5 (50%)	2 (22%)	5 (56%)	3 (30%)	5 (71%)	25 (34%)	0.08
Trained person shows how to insert protector	4 (50%)	5 (50%)	6 (60%)	5 (50%)	3 (33%)	9 (100%)	7 (70%)	6 (86%)	45 (62%)	0.03
Trained person checks placement of protector	2 (25%)	2 (20%)	2 (20%)	1 (10%)	0 (0%)	5 (56%)	5 (50%)	1 (14%)	18 (25%)	0.05
Hearing protector availability and use										
Provide protectors	8 (100%)	10 (100%)	10 (100%)	10 (100%)	9 (100%)	9 (100%)	10 (100%)	7 (100%)	73 (100%)	ns
Provide two types of protectors	5 (63%)	6 (60%)	7 (70%)	9 (90%)	9 (90%)	8 (89%)	10 (100%)	7 (100%)	61 (84%)	0.02
Have policy requiring protector use	0 (0%)	2 (20%)	6 (60%)	2 (20%)	2 (22%)	4 (44%)	4 (40%)	5 (71%)	25 (34%)	0.02
Audiometry										
Conduct testing annually	5 (63%)	8 (80%)	8 (80%)	8 (80%)	5 (56%)	8 (89%)	5 (50%)	7 (100%)	54 (74%)	0.16
Provides noise level information to tester	1 (13%)	1 (10%)	0 (0%)	3 (30%)	3 (33%)	3 (33%)	0 (0%)	0 (0%)	11 (15%)	0.05
When an employee has an STS:‡										
Provide written notification	3 (38%)	6 (60%)	6 (60%)	6 (60%)	3 (33%)	8 (89%)	6 (60%)	7 (100%)	45 (62%)	0.04
Provide retraining	1 (13%)	2 (20%)	4 (40%)	4 (40%)	3 (33%)	5 (56%)	2 (20%)	6 (86%)	27 (37%)	0.06

*Table does not include three companies where all monitored employees had full-shift noise exposure <85 dBA.
†Significance determined by χ^2 test; ns: not significant (not calculable because all values 100%).
‡STS = OSHA standard threshold shift: ⩾10 dB mean worsening at 2–3–4 kHz, from baseline to current audiogram.

use of protection differed widely between companies within each industry; variance was lowest in the two loudest industries, lumber milling and heavy gauge metal manufacturing.

Only 25 (34%) management representatives said their company had a formal policy or enforcement practices requiring use of hearing protection, either in the entire production area or in specific noisy areas (table 3). According to employees, however, protector use policies were more common than this. At 23 (32%) companies, >90% of employees said there was a policy requiring them to wear protection. At another 25 (34%) companies, 51–90% of employees said a company policy applied to them; and at 19 (26%) companies, 25–50% of employees said this.

Using multiple linear regression, the percentage of employees who reported always used hearing protection during exposure showed independent associations with a number of variables: percentage of employees who said there was a company requirement to use protection ($r_{a.b} = 0.50$, $p < 0.001$); management interview score ($r_{a.b} = 0.37$, $p = 0.001$); mean number of minutes employees were exposed ⩾95 dBA ($r_{a.b} = 0.30$, $p = 0.01$); and employment in heavy gauge metal manufacturing ($r_{a.b} = 0.30$, $p = 0.01$). None of the other examined variables contributed further to the model. The combined association was high (adjusted $R^2 = 0.65$, $p < 0.001$).

Reliability of reported exposure and hearing protector use

Exposure data from full-shift personal dosimetry and post-shift interviews were available for 335 subjects. Reported exposures were fully concordant with the measured percentage of time for 30% of employees, using the five response option categories, and agreed within one category for another 49%. This represented moderate agreement: intra-class correlation ($r_{icc} = 0.52$; $p < 0.001$).

Post-shift interviews were available for 213 employees with at least three observations. Reported use of protection on that day was fully concordant with observations for 86%, using the three combined categories (used because of imprecision with the limited number of observations): never, sometimes, and always. Another 12% were discordant by one category, and only 2% were fully discordant. Overall agreement was high, $r_{icc} = 0.78$ ($p < 0.001$).

DISCUSSION

The findings of this study—20 years after OSHA implemented hearing conservation regulations—raise serious concerns about the adequacy of contemporary OHL prevention, regulation, and enforcement strategies in the United States. In this broad sample of companies from eight industries with variously high rates of OHL claims, nearly all of the companies had employee exposures that required a hearing conservation programme, and more than half had exposures that required the employer to consider possible noise controls. The percentage of workers with full-shift exposures over 85 or 90 dBA would have been 1.5–3 times higher if noise measurements had used a 3 dB exchange rate rather than the OSHA 5 dB exchange rate. Although most companies had measured noise levels, few had kept any records on which to base current or future actions, and the possibility of new noise controls generally received low priority. Furthermore, most companies had potentially important shortcomings in their hearing conservation programmes, and each industry included companies where policies and practices were substantially incomplete. Finally, personal hearing protection was commonly under-used.

Overall, only 62% of interviewed employees said they always (or almost always) used hearing protection when they were exposed to loud noise. This is comparable to what other investigators have found,[7–9 16] and systematic observations in this study indicated that reported use is a reasonably accurate measure. The percentage of employees who always used protection when exposed differed widely between industries and between companies within the same industry. The frequency of protector use was significantly higher at companies where noise exposures were higher and more common. It is not surprising that workers would be more likely to wear protection in higher noise, if only to reduce ear discomfort from the noise, but perhaps also because hearing conservation programmes tended to be more complete (that is, management interview scores were higher) when noise exposure was more common. Ironically, workers with the greatest risk for OHL may be those employed at companies where a moderate or low percentage of workers are overexposed to noise but use of protection is low, rather than at companies where noise is most prevalent and protector use is higher.

Independent of noise levels, the use of protection was significantly higher at companies with more complete hearing conservation programmes, particularly those where protector use policies were actively promoted or enforced, and use of protection was lower at companies with less complete programmes. Employee awareness of hearing loss prevention efforts in general (that is, employee interview scores) also tended to be higher at companies with more complete programmes. Lusk and co-workers have identified a variety of cognitive-perceptual and situational factors that influence reported use of hearing protection.[17–19] However, innovative efforts to redesign training around that knowledge have had limited impact on protector use.[20–24] The findings of the present study emphasise that employee under-use of protection is, in some substantial part, attributable to incomplete or inadequate company efforts. Interventions to improve use of hearing protection may need to focus on the company as well as workers.

Federal OSHA (but not Washington State OSHA) enforcement policy ''allows employers to rely on personal protective equipment and a hearing conservation programme rather than engineering and/or administrative controls...[unless] employee exposure levels border on 100 dBA''.[25] Given this tolerance for levels of noise that, without hearing protection, are potentially harmful, the primary reliance on hearing conservation programmes and personal protection can only be effective at preventing OHL if efforts are continually and optimally maintained. The present study did not evaluate the true preventive effectiveness of current workplace efforts; this can only be judged by long term monitoring of worker hearing ability. However, the extent of protector under-use in this study suggests a substantial fraction of workers in noisy workplaces are at risk for OHL.

It is reassuring that the studied outcomes were highest at companies with the highest commitment to hearing loss prevention, indicating that hearing conservation programmes are probably worth the effort; however, the potential benefit appears proportional to the level of company effort. Unfortunately, programmes were commonly incomplete at companies in all of the studied industries, with the relative exception of lumber milling. Most of the study companies had been inspected by State OSHA at some point in time, but only 9% received a citation related to noise or hearing conservation, and neither a past inspection nor citation was associated with current programme completeness or use of hearing protection. These findings suggest the regulatory priority given to personal protection and hearing conservation programmes needs to be re-evaluated. There is a need either for increased regulatory enforcement or consultation to make this strategy effective or for greater emphasis on reducing levels of noise.

Main messages

- Using an exchange rate of 5 decibels instead of 3 decibels to measure full-shift average noise exposure substantially underestimated the extent of worker overexposure.
- At least in one region of the United States, small and medium sized companies commonly gave limited or no attention to noise controls to reduce worker noise exposure.
- After 20 years of OSHA regulations, hearing conservation programmes were commonly incomplete and hearing protection was often under-used at small and medium sized companies.
- Use of hearing protection was highest when company hearing loss prevention efforts were most complete and when noise exposure was relatively high or continuous.

Policy implications

- The regulatory priority given by OSHA to personal protection and hearing conservation programmes, and relative inattention to noise controls, needs to be re-evaluated.
- Worker under-use of hearing protection is, in some substantial part, attributable to incomplete or inadequate company efforts. Interventions to improve use of hearing protection may need to focus on the company as well as workers.
- Workers with the greatest risk for hearing loss may be those employed at companies where a moderate or low percentage of workers are overexposed, than at companies where noise is more prevalent.

There are a number of limitations to the present study. The company and employee samples could reflect a volunteer bias. However, we believe any such bias is predominantly non-differential relative to the studied exposures and outcomes, and is more likely to diminish rather than inflate or distort study findings relative to the true occurrence in the underlying population. Efforts were made to obtain a population based sample of companies, but only about half of the approached companies participated in the study, and some companies belonged to the same corporation. Recruitment was lowest in the three industries (including pulp and paper production) with highest incidence of hearing loss claims, suggesting participation may have been influenced by claims experience. However, it seems unlikely that otherwise "good" companies with complete hearing conservation programmes would be less willing to participate than companies with incomplete programmes, or that any such bias would differ substantially between industries. Similarly, to minimise interference with production activities and ensure optimal company cooperation, employee recruitment relied primarily on volunteer and company designated employees. However, employee selection was designed to be representative of employees in noise exposed jobs, and the rate of participation by approached employees was high. As with companies, we consider it more likely that employees with good practices would be willing to participate than those whose practices were lacking. The exclusion of workers who did not speak English or Spanish could result in underestimation of the OHL risk for some minority workers if there were differences in either the jobs to which they are usually assigned, their ability to comprehend company training or policies, or the prevalence of pre-existing hearing problems. However, more complete representation of this small minority would be unlikely to substantially alter the study findings. Finally, it is reassuring that the rates of company and worker participation were comparable to those in a recent Danish study that used a comparable strategy to recruit 91 workplaces in 10 industries with very high incidence rates of suspected OHL.[16] The findings of that study were also comparable in that 50% of 830 monitored workers had full-shift average noise exposures >85 dBA, and 20% had exposures >90 dBA. Overall, about half of workers reported using hearing protection, ranging from 37% of workers in the lowest use industry (furniture production) to 85% in the highest use industry (basic metal manufacturing).

The present study sample primarily consisted of small and medium sized companies and may have limited or no generalisability to larger companies. On the other hand, the needs of smaller and medium companies are generally under-addressed by OSHA, given the number of such companies. In Washington State, employer businesses with <250 employees account for >99% of establishments and 72% of non-federal employees.[26] The findings of the present study may have limited applicability to companies in other parts of the USA, and even less applicability in other countries where different regulations apply, although this is probably more true for specific findings than for the more general findings and conclusions.

The present study examined programme completeness and use of hearing protection, which is not equivalent to programme effectiveness. It is not possible to say how much incompleteness is needed before a programme is ineffective, or vice versa; however, the strong association between programme completeness and use of protection indicates the former is at least meaningful on a relative scale. Finally, the study relied primarily on reported outcome measures. The consistency between company and employee responses, as well as the high level of agreement between reported and observed use of protection, provides some reassurance that these measures are meaningful.

The potential implications of this study are broader than just noise exposure and hearing loss. There are fewer gaps in knowledge about OHL than for virtually all other occupational illnesses, and the primary barriers to prevention lie in implementation of that knowledge. If workers cannot be effectively protected against the development of OHL, then one must question how well workers are protected against other, more complex or less well understood hazards.

Authors' affiliations

W E Daniell, S S Swan, J E Camp, M A Cohen, Department of Environmental and Occupational Health Sciences, University of Washington, Seattle, WA, USA
M M McDaniel, Pacific Hearing Conservation, Seattle, WA, USA
J G Stebbins, Policy and Technical Services, Department of Labor and Industries, Olympia, WA, USA

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REFERENCES

1 **US National Institute for Occupational Safety and Health (NIOSH)**. *Criteria for a recommended standard: occupational noise exposure. Revised criteria, 1998*, DHHS/NIOSH Pub No 98-126. Cincinnati, OH: Department of Health and Human Services, 1998.
2 **Daniell WE**, Fulton-Kehoe D, Cohen M, *et al*. Increased reporting of occupational hearing loss: workers' compensation in Washington State, 1984–1998. *Am J Ind Med* 2002;**42**:502–10.
3 **US Occupational Safety and Health Administration (OSHA)**. Occupational noise exposure. Standard 1910.95. In: Regulations; Standards, *Code of Federal Regulations (CFR)* **29**. Washington, DC: OSHA. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table = STANDARDS&p_id = 9735 (accessed 29 July 2005).
4 **Washington State Department of Labor**, Industries (DLI). Hearing loss prevention (noise) rule. Chapter 296-817. In *Washington Administrative Code (WAC)* Olympia, WA, DLI. http://www.lni.wa.gov/wisha/rules/noise/default.htm.
5 **Boiano JM**, Hull RD. Development of a National Occupational Exposure Survey and Database associated with NIOSH hazard surveillance initiatives. *Appl Occup Environ Hyg* 2001;**16**:128–34.
6 **Middendorf PJ**. Surveillance of occupational noise exposures using OSHA's Integrated Management Information System. *Am J Ind Med* 2004;**46**:492–504.
7 **Reilly MJ**, Rosenman KD, Kalinowski DJ. Occupational noise-induced hearing loss surveillance in Michigan. *J Occup Environ Med* 1998;**40**:667–74.
8 **Lusk SL**, Kerr MJ, Kauffman SA. Use of hearing protection and perceptions of noise exposure and hearing loss among construction workers. *Am Ind Hyg Assoc J* 1998;**59**:466–70.
9 **Lusk SL**, Ronis DL, Baer LM. Gender differences in blue collar workers' use of hearing protection. *Women & Health* 1997;**25**:69–89.
10 **Daniell WE**, Swan SS, McDaniel MM, *et al*. Noise exposure and hearing conservation practices in an industry with high incidence of workers' compensation claims for hearing loss. *Am J Ind Med* 2002;**42**:309–17.
11 **Washington State Department of Labor**, Industries (DLI). *Classification Code Manual: Schedule Groupings*. Olympia, WA: DLI, 1 January, 1997.
12 **DLI**. *Code Manual: Class and Subclass History*. Olympia, WA: DLI, 1 July, 1996.
13 **Daniell WE**, Swan SS, Camp J, *et al*. *Occupational hearing loss in Washington State*, Final report to NIOSH for grant R01 OH 03894-03. Seattle, WA: University of Washington, 2005.
14 **Silverstein B**, Viikari-Juntura E, Kalat J. Use of a prevention index to identify industries at high risk for work-related musculoskeletal disorders of the neck, back, and upper extremity in Washington state, 1990–1998. *Am J Ind Med* 2002;**41**:149–69.
15 **Quest Technologies, Inc**. *Quest-Suite Professional* [software]. Oconomowoc, WI: Quest.
16 **Kock S**, Andersen T, Kolstad HA, *et al*. Surveillance of noise exposure in the Danish workplace: a baseline survey. *Occup Environ Med* 2004;**61**:838–43.
17 **Pender NJ**, Murdaugh CL, Parsons MA. The health promotion model. In: *Health promotion in nursing practice*, 4th edition. Upper Saddle River, NJ: Prentice Hall, 2002:59–79.
18 **Lusk SL**, Ronis DL, Kerr MJ. Predictors of hearing protection use among workers: implications for training programs. *Hum Factors* 1995;**37**:635–40.
19 **Lusk SL**, Ronis DL, Hogan MM. Test of the health promotion model as a causal model of construction workers' use of hearing protection. *Res Nurs Health* 1997;**20**:183–94.
20 **Lusk SL**, Kerr MJ, Ronis DL, *et al*. Applying the health promotion model to development of a worksite intervention. *Am J Health Promot* 1999;**13**:219–27.
21 **Lusk SL**, Hong OS, Ronis DL, *et al*. Effectiveness of an intervention to increase construction workers' use of hearing protection. *Hum Factors* 1999;**41**:487–94.
22 **Eakin BL**, Brady JS, Lusk SL. Creating a tailored, multimedia, computer-based intervention. *Comput Nurs* 2001;**19**:152–60.
23 **Lusk SL**, Ronis DL, Kazanis AS, *et al*. Effectiveness of a tailored intervention to increase factory workers' use of hearing protection. *Nurs Res* 2003;**52**:289–95.
24 **Lusk SL**, Eakin BL, Kazanis AS, *et al*. Effects of booster interventions on factory workers' use of hearing protection. *Nurs Res* 2004;**53**:53–7.
25 **OSHA**. Violations of the noise standard. Section 7, Chapter III, subsection C.3.b. In: OSHA field inspection reference manual, CPL 2.103. Wash, DC: OSHA. www.osha.gov/Firm_osha_data/100007.html (accessed 29 July 2005).
26 **US Census Bureau**. *County business patterns 2003 Washington*, Pub No CBP/03-49. Washington, DC: Census Bureau, 2005, 3, 33.