ORIGINAL ARTICLE

Noise exposure and serious injury to active sawmill workers in British Columbia

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ABSTRACT

Background Occupational noise might increase the risk of workplace injury through a variety of mechanisms, including interference with communication and increased stress.

Objectives The purpose of this study was to assess the effect of chronic noise exposure on serious workplace injury, and how the timing of exposure influenced risk.

Methods The authors examined a cohort of 26 000 workers, who worked between 1950 and 1989. Cases were those hospitalised for a work-related injury (ICD-9 codes 800—999, and E codes E800—E999), from April 1989 to December 1998. Cumulative exposure levels were estimated for subjects based on a quantitative retrospective exposure assessment. An internal comparison of cumulative noise exposure and subchronic durations of noise exposure and injury was conducted using Poisson regression. There were 163 cases for the cumulative and 161 cases for the subchronic analysis.

Results Cumulative noise exposure were associated with a decreased risk for injuries, with the risk generally decreasing as cumulative noise levels increased, while most durations of subchronic exposure were associated with an increased risk for injury. An inverse U-shaped trend was observed with the time period of 90 days to 1 year demonstrating the most elevated RR compared with 0—1 days of exposure.

Conclusions Workers highly exposed to noise, or exposed for long periods of time, might develop effective methods of communicating the risk and preventing injuries when exposed to noise.

What this paper adds

- Occupational noise increases the risk of workplace accidents and injuries.
- The mechanism by which noise leads to injury is unclear.
- The results of this study suggest that among sawmill workers, the mechanism that workplace noise leads to injury is not through noise-induced hearing loss.

INTRODUCTION

Workplace-noise exposure is one of the most prevalent workplace exposures[1] with a large number of workers being exposed to levels above the 8 h exposure limit of 85 dB(A) in Canada. In a study of British Columbia (BC) lumber mills, Davies *et al*[2] found that workers were exposed to average noise levels of 92 dB(A), and in Alberta sawmills, 27% of workers were found to be exposed to noise at 95 dB(A) or higher.[3]

Noise-induced hearing loss is the most common health outcome associated with exposure to noise. However, there is evidence to suggest that there are also 'non-auditory' health problems caused by exposure to noise, including psychiatric symptoms,[4] myocardial infarction and other cardiovascular effects,[5 6] and injuries.[7] Occupational noise apparently increases the risk of both fatal and non-fatal workplace injuries.[4 8] Melamed *et al*[4] found that noise levels greater than 80 dB(A) contributed significantly to occupational injuries in both men (OR=1.38) and women (OR=2.15), and Choi *et al*[9] found that wearing hearing protection occasionally (OR=1.98) significantly increased the risk for accidents. In a study of shipyard workers, Moll van Charante and Mulder[7] found that together, hearing loss and noise accounted for 43% of the injuries; and in a recent study, Girard *et al*[10] found that working in noisy environments (≥90 dBA) significantly increased the risk for workplace accidents.

Wilkins and Action[11] discussed the possible mechanisms that link noise and injuries. Loud noise itself or the use of hearing protection may impede concentration or interfere with possible warning signals. Noise-induced hearing loss can hamper the perception of sounds, reducing the ability to distinguish between certain sounds and increasing the chance of misunderstanding alerts and messages. When working in noise levels of 85 db(A) and over, aural warning signals were often found to be too weak[1]; normal conversation, and messages shouted from a distance in environments at this noise level, cannot be understood.[12] Furthermore, noise can trigger a stress response in workers, or fatigue the worker, making them less sensitive to warning signals.[13] The use of hearing protection was adopted in BC in 1978, and although this was intended to protect workers against hearing loss, hearing protection may contribute to problems with communication, which increases the risk of injury.

Thus, each of noise exposure, personal protective devices, hearing loss and noise-associated psychological factors such as fatigue and stress may play a role in noise-related injuries, and there are likely interactions among these factors.

The purpose of this study was to examine the association of noise exposure on workplace injury rates in a cohort of sawmill workers in British Columbia. Specifically, the objectives were to:

1. Assess the effect of cumulative noise exposure on serious workplace injuries. It was

hypothesised that increasing cumulative noise exposure would lead to increased workplace accidents and injuries (via the increased noise-induced hearing-loss mechanism)

2. Examine the effect of subchronic noise exposure on serious workplace injuries. It was hypothesised that high levels of short-term noise 'proximal' exposure would lead to an increase in serious workplace injuries (via breakdown in communication, concentration or warning signals)

MATERIALS AND METHODS

Study population

Records for this study were obtained from a larger study of sawmills in British Columbia (BC) that was originally used to examine the effects of a wide range of exposures including chlorophenates, noise, wood dust and job strain, and health outcomes (cancer, CVD and injuries).[14–16] The original cohort consisted of approximately 26 000 male workers employed for at least 1 year in one of 14 BC sawmills between 1950 and 1985. The cohort now includes workers through 1998 and has added female workers.[14 15]

Starting in April 1989, in British Columbia, certain International Classification of Disease (ICD9) external codes or 'E codes' began to use a fifth digit to indicate whether the injury was work-related.[16] The health regions in Canada follow a standardised and comparable coding scheme; coding errors from this system are minimal and equally distributed. More information on coding can be found in Alamgir *et al.*[17]

The cohort created for the current study was defined as being all those who met the original cohort definition of working for at least 1 year in one of the study sawmills, but was then restricted to those who worked at least 1 day between April 1989, when E-codes for work relatedness were first coded, and December 1998. Further information on the creation of this cohort can be found in Alamgir *et al*[16] and is summarised in figure 1.

Follow-up began on the 366th day of employment or 1 April 1989, whichever came later. The end of the follow-up date was defined as the date of (a) death, (b) hospitalisation for work-related injury, (c) the end of employment at a study sawmill or (d) 31 December 1998, whichever occurred earlier. There were 6512 cohort members who met this definition, and these were linked to their hospital discharge record using probabilistic linkage through the British Columbia Linked Health Database. The British Columbia Linked Health Database integrates health-service records, population health data and census statistics, making it possible to link administrative records anonymously at an individual level.[18] From these 6512 cohort members, 5876 (90.2%) of the workers were successfully linked to the BCLHDB,[16] resulting in 40 806 hospital discharge records.

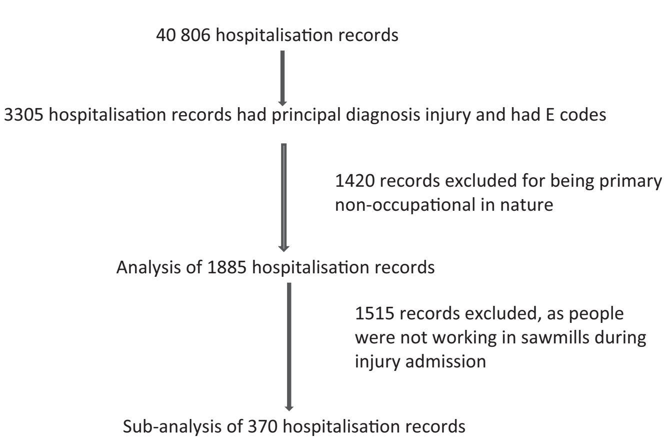

Figure 1 Study populations for analysis of work-related hospitalisations, taken from Alamgir *et al.*[16]

Inclusion criteria for cases

Cases were subjects who had an overnight hospitalisation (ie, injuries serious enough to be beyond the scope of occupational health or local health clinics regardless of whether these services were available or not) for a work-related injury (fatalities were excluded). Work-relatedness was identified where the hospital discharge record either (1) had an E-code (E codes E800–E999 and ICD-9 codes 800–999) indicating work-relatedness or (2) indicated the Workers' Compensation Board under the field 'responsibility for payment.'[16] Under this definition, 3317 admissions had ICD-9 codes between 800 and 999, and 3305 were E-coded.

Exclusion criteria for cases

A total of 2935 admissions were excluded, either for not being primarily work related or because the worker was not working in one of the study sawmills at the time of admission. This left 370 admissions for the active sawmill workers. Of these 370, it was determined that 173 were hospitalisations for work-related injuries. Multiple hospitalisations for a single case were also excluded. Ultimately, 163 cases remained for the cumulative noise exposure analysis and 161 for the subchronic noise-exposure analysis.

Exposure assessment

Work-history data were collected directly from study sawmill records for each cohort participant and included start and end dates, job title and department for every sawmill job, leave periods and termination date,[14 15] and linked in a many-to-one relationship to a cohort members demographic data and exposure data. Information on the work process can be found elsewhere.[19] Noise exposure data were collected from (a) 1901 full-shift personal noise dosimetry data previously collected by one of the authors (HD), (b) compliance measurements from the local regulatory agency, and (c) compliance measurements made by professional noise consultants. Information on the determinants of exposure to noise was also collected by questionnaire and worksite visits. A fixed-effect multiple linear regression model built using a subset of data that included only full-shift noise dosimetry from cohort mills was then used to estimate exposure for job, mill and time combinations. These were merged with work-history files; noise levels were assigned to 81 job titles using a job-exposure matrix.[2] Temporal effects from 1970 to 1980 were investigated in a separate regression analysis on a reduced set of independent variables, while 1980 onwards was included in the determinants model.[2] These data have recently been validated by their ability to predict hearing loss in the same cohort.[20] These estimates did not take the use of hearing protection into account, but previously collected data indicated that the use of hearing protection was nearly universal among workers highly exposed to noise.

Subjects' cumulative exposure to noise was then calucated (dB (A)-years), and the lowest exposure category was used as the reference group in each analysis.

Statistical analyses

The National Institute of Occupational Safety and Health life table analysis system[21] was used to enumerate person-days at risk, stratified by categories of gender, race, age, calendar year,

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exposure and time since first exposure. The life table analysis system was also used to calculate the cumulative incidence. Person-days were calculated from the date on which a person was first exposed to the end of the study follow-up period.[22] Race was initially categorised as (a) Caucasian, (b) Sikh and (c) Chinese and other Asian. Five-year age categories (25–55) were used, and calendar years were separated into three categories based on the distribution of this variable: 1989; 1990–1994; 1995–1998. Age and calendar year correspond to the time of the accident.

Cumulative exposure

Cumulative exposure was assessed by taking the sum of the average noise level (on a logarithmic scale) in each job and multiplying it by the length of time a worker was in that job using the following equation[2]:

$$\text{Cumulative exposure} = 10\log\left[\sum_{j=1}^{k} T_j\left(10^{\frac{Leq_j}{10}}\right)\right]$$

Exposure categories for the cumulative analysis were defined as 0–116, 121–125, 126–130, 131–135, and 136+ dB(A)-years. Cut-off points for cumulative exposure were not predetermined and were created after examining the distribution of this variable for the entire cohort.

Subchronic duration of exposure

The amount of time a worker was exposed to noise levels above 85 dB(A), 90 dB(A) or 95 dB(A) during their current job, based on average shift noise exposure, was measured to investigate if there was an association between length of time of noise exposure, intensity of noise exposure and injury. Exposure during previous jobs was not considered, as this was used to examine the impact of exposure more proximal to the injury event. For example, considering worker A who held job X for 6 years at 82 dB(A) and then held Job Y at 96 dB(A) for 6 months and was then injured, he/she would contribute 6 years of follow-up to <85 dB(A) with no injury and 6 months to >95 dB(A) with injury. This permits the investigation of intensity and temporal aspects simultaneously. Time periods of exposure were defined as 0–1 day, 2–90 days, 91 days to 1 year, 1–2 years, 2–5 years and 5+ years. Cut-off points for duration of exposure were created after examining the distribution of this variable. Subchronic measurements were based on average shift exposure.

Poisson regression was used for internal comparisons. The PROC GENMOD procedure in SAS V.9.1 was used. Unadjusted and adjusted rate ratios for hospitalisation associated with work-related injury, and two-sided Wald 95% CIs were calculated. The variables gender, race, age and calendar year were entered into the model as potential confounders, and variables were included in the multivariate model based on a p value of <0.25 at the univariate level using a backwards stepwise approach. Noise exposure was also modelled as a continuous variable to test for a linear trend. The lowest exposure level was used as the reference category. Hospitalisation associated with work-related injury was the outcome of interest.

RESULTS

Descriptive statistics

This cohort consisted of 5876 sawmill workers. Ninety-eight per cent of these workers were male, 86% were Caucasian, 13% were Sikh, and 1.5% were of Chinese or other Asian descent (combined in the analysis owing to small numbers, table 1). Cumulative noise exposure ranged from 87.7 to 161.5 dB(A)-years with an average of 128.9 dB(A)-years for the entire cohort, and from 94.1 to 156.4 dB(A)-years with an average of 128.1 dB(A)-years for the cases (table 2). The mean age at the end of follow-up was 45.2 years for the cohort and 46.7 years for the cases. The mean age of injury for the cases was 42.4 years. The minimum time since first exposure was 1 year with a maximum of 50 years; the average time since first exposure was 18.5 years (table 2). The mean duration of employment in a study sawmill was 16 years with a range of 1–49 years (table 2). The top three injury categories by nature were dislocation, sprains and strains (21.3%), open wounds (21.3%) and fracture of upper limbs (15.2%). The top three injury categories by nature were machinery-related (29.3%), fall (16.5%) and struck against (14.6%).[16 22]

Table 1 Cohort characteristics

	Cohort		Cases	
	Frequency	Percentage	Frequency	Percentage
Sex				
Male	5745	97.8	161	98.77
Female	131	2.2	2	1.23
Race				
Caucasian	5031	85.6	147	90.18
Sikh	753	12.8	14	8.59
Chinese/other Asian	92	1.6	2	1.23

Cumulative noise exposure and serious injuries

Bivariate Poisson regression models were used to examine the independent association of gender, race, age, calendar year, noise exposure and time since first exposure on workplace injuries (table 3).

Time since first exposure greater than 15 years was associated with a reduced risk, but this was non-significant in all categories, and there was no apparent trend. Higher cumulative noise exposure levels were found to have a decreased association with injury with a generally decreasing trend with increasing exposure. Subjects of non-Caucasian race were found to be less likely to sustain injury (RR=0.53, 95% CI 0.32 to 0.89); and there was a decreasing trend in injury with increasing calendar year. No association between age and injury was found.

A multivariable Poisson regression model was used to perform internal comparisons of cumulative noise exposure and serious workplace injuries (table 3). Time since first exposure was excluded from the model owing to its high correlation with age. The lowest exposure group in each analysis was used as the reference category. When adjusted for gender, race, age and calendar year, cumulative noise exposure continued to show a decreased association with injuries at all cumulative exposure levels with the same decreasing trend in risk for injury with increasing exposure, though the linear trend was not significant (p=0.27). In the multivariate model, being of non-Caucasian race (RR=0.59, 95% CI 0.35 to 0.99) continued to remain

Table 2 Exposure characteristics

	Minimum	Maximum	Mean	Median	SD
Time since first exposure (years)	1.0	50.1	18.5	19.0	11.2
Duration of employment (years)	1.0	49.3	16.4	15.6	10.5
Noise exposure (cohort) (dB(A)-years)	87.6	161.5	128.9	129.4	8.0
Noise exposure (cases) (dB(A)-years)	94.1	156.4	128.1	128.0	8.4

Table 3 Association of gender, race, age, calendar year, noise exposure and time since first exposure on serious injury

Explanatory variables	Cases	Univariate RR (95% CI)	Multivariable RR (95% CI)
Cumulative noise exposure (dB(A)-years)			
0–120	28	1.00	1.00
121–125	38	0.91 (0.56 to 1.55)	0.91 (0.56 to 1.56)
126–130	38	0.59 (0.36 to 0.97)	0.59 (0.36 to 0.97)
131–135	31	0.48 (0.29 to 0.81)	0.50 (0.29 to 0.85)
136+	28	0.60 (0.35 to 1.00)	0.58 (0.33 to 1.00)
Race			
Caucasian	147	1.00	1.00
Other	16	0.53 (0.32 to 0.89)	0.59 (0.35 to 0.99)
Calendar year			
1989	25	1.00	1.00
1990–1994	101	0.72 (0.46 to 1.15)	0.74 (0.48 to 1.17)
1995–1998	37	0.47 (0.28 to 0.78)	0.48 (0.29 to 0.80)
Time since first exposure (years)			
0–4	33	1.00	
5–9	23	0.83 (0.47 to 1.43)	
10–14	30	1.01 (0.64 to 1.77)	
15–19	27	0.59 (0.36 to 0.98)	
20–24	29	0.68 (0.41 to 1.13)	
25–29	8	0.30 (0.14 to 0.64)	
30+	13	0.56 (0.29 to 1.06)	

significant from the univariate analysis, and increasing calendar year demonstrated a decreasing risk for injuries.

Subchronic duration of noise exposure and serious injuries

The effect of duration of 'proximal' noise exposure on serious injury was also explored in this study by measuring the length of time exposed in a work environment with noise levels above 85, 90 and 95 dB(A) in order to determine the time periods of exposure most relevant to the risk of injury (table 4). Results were adjusted for age, race and calendar year. At all levels of exposure, there appeared to be an inverse U shape trend in risk for injury with the risk peaking at the time period of 91 days to 1 year; the risk at this time period at noise levels above 85, 90 and 95 dB(A) was found to be 2.01 (95% CI 1.06 to 3.78), 1.34 (95% CI 0.82 to 2.17) and 1.77 (95% CI 1.01 to 3.10) respectively. There did not appear to be a relationship between increasing noise levels and risk of injury in this analysis.

DISCUSSION

This study measured the association of noise exposure (both cumulative and subchronic durations above a threshold) with serious (hospitalised) occupational injuries. It was hypothesised that increased cumulative noise exposure would lead to an increase in noise-induced hearing loss and occupational injuries. Our results do not support this hypothesis and, in fact, there was a negative association of cumulative noise exposure and injury.

Greater cumulative noise exposure is likely a marker for working longer in the sawmill industry. Cumulative exposure (level × duration) was used on the basis that those with higher cumulative durations to noise are more likely to have hearing loss. A person working longer in the industry surrounded by high levels of noise may, over time, develop better methods of recognising and communicating potential risks of injury. This hypothesis is supported by our finding that workers with a time since first exposure of 25 years or more are at less risk for workplace injuries in the univariate analysis. Another explanation is that hearing protection at higher levels of noise may, in fact, be protective. Rabinowitz *et al*[23] found that there was no higher rate of hearing loss at higher noise exposure levels; they suggested that hearing protection may reduce hearing loss in those with a higher noise exposure while in workers with lower noise exposure, hearing protection may cause too much attenuation resulting in the inability to communicate properly. This may explain why our analysis found a higher injury risk with lower cumulative noise exposure.

It was also hypothesised that short-term high levels of noise exposure would lead to an increase in serious workplace injuries. Very-short-term noise exposure was not significantly associated with injuries; however, workers exposed for 91 days to 1 year were at an increased risk of injury. This study indicates that not all workers have the same level of risk of injury when exposed to the same noise level. The results suggest that the risk of injury owing to noise exposure increases until a worker has been exposed between 91 days and 1 year, and that the risk then decreases as the duration of exposure increases. This was further supported by the results of the cumulative analysis, which found higher exposure categories to be protective against injury. We hypothesise that this pattern is occurring because workers, when entering a new job, are likely to be vigilant with respect to warning signals and their environment, but that this vigilance decreases as the worker becomes accustomed to their environment.

When considering subchronic duration of exposure above threshold levels, we saw consistently elevated risk of injury across all exposure levels and time periods. We did not see an increasing risk with increasing noise exposure thresholds; in fact risks were lower at a 90 dB(A) threshold than at a 85 dB(A) threshold, but increased again at 95 dB(A). This could be interpreted to suggest that a noise of 85 dB(A) is sufficiently loud to cause the observed effect, and increasing the noise level beyond 85 dB(A) does not substantially increase the risk. This would be consistent with the findings of Moll van Charante and Mulder[7] who found that noise >82 dB(A) contributed significantly to the risk of injuries in male shipyard workers. Melamed *et al*[24] found

Table 4 Subchronic noise exposure above 85, 90 and 95 dB(A)†

	85 dB(A)		90 dB(A)		95 dB(A)	
Explanatory variables	Cases	RR (95% CI)	Cases	RR (95% CI)	Cases	RR (95% CI)
Duration of exposure						
0–1 days	13	1.00	80	1.00	118	1.00
2–90 days	15	1.58 (0.74 to 3.38)	11	1.17 (0.62 to 2.25)	7	1.66 (0.74 to 3.4)
91–1 year	38	2.01 (1.06 to 3.78)	24	1.34 (0.82 to 2.17)	14	1.77 (1.01 to 3.10)
1–2 years	30	1.82 (0.94 to 3.56)	20	1.36 (0.80 to 2.29)	9	1.57 (0.76 to 3.03)
2–5 years	48	1.75 (0.90 to 3.12)	26	0.74 (0.47 to 1.22)*	13	0.87 (0.49 to 1.68)*
5+ years	17	1.27 (0.58 to 2.55)				

*Duration of exposure: 2+ years.
†Adjusted for age, race and calendar year.

that workers in industrial plants were at a significantly increased risk of injury when exposed to noise above 80 dB(A). In their studies of steelworkers, Barreto *et al*[25 26] found an increased risk of all workplace fatalities, as well as workplace motor-vehicle fatalities, with an increase in intensity of occupational noise exposure above 80 dB(A). In a case–control study of sawmill injuries, Punnet[27] found that higher noise levels were significantly related to injuries in the univariate analyses. These studies suggest that exposure to at least 80 dB(A) may be necessary for noise to become part of the causal mechanism leading to injury, whether the injury occurs through a more acute mechanism or cumulatively through hearing loss.

This study has been able to build on the methodologies of previous studies. Personal noise monitoring data were collected quantitatively through full-shift measurements rather than relying on solely on qualitative self reported exposure. Cases for this study were drawn from a large cohort with a long follow-up period. Previous studies have not assessed the duration or time periods of noise exposure necessary before an injury results. Furthermore, this study was able to estimate levels of noise exposure in the time directly preceding an injury, which previous studies have not yet measured.

However, there are several limitations to this study. The largest limitation was that all workers who worked less than 1 year in the study sawmills were excluded from the cohort, as defined for the original cohort purpose. Therefore, this study does not include all new and inexperienced workers who may have been injured during their first year on the job and then subsequently left employment, perhaps due to injury associated with noise exposure. Having 1 year or less of experience has been shown to be significantly associated with injury in sawmills.[27] Thus, by including these workers, we might have seen a stronger association of noise and injury.

Owing to the nature in which cases could be identified, this study was not able to include cases with more minor accidents who were not hospitalised for their injuries. It is likely that many workers in this cohort were injured, but not severely enough to be sent to the hospital. Studies that have used industry records of injuries suffered while at work have found an association between noise exposure and injury (eg, Moll van Charante and Mulder[7]). A further limitation of this is that the number of cases was low. This study also did not take into account whether a worker was formerly injured, as workers with a previous injury are at a higher risk for future injury.[28 29]

The cumulative exposure analysis could not be adjusted for job task. We can assume that jobs which utilise more powerful machinery are more hazardous. It is likely that there was a correlation between noise level and hazardous job task; however, we did not see any increase in injury with increasing noise levels, and we do not believe this affected our results. Previous studies on this topic, such as those noted in the Introduction, have also been unable to adjust for hazardous work tasks, and this is an ongoing limitation. Future studies should adjust for hazardous work tasks.

Neither hearing loss nor hearing protection was measured in this study. Cumulative exposure may not be a reliable proxy for potential noise-induced hearing loss; this has not been proven in the literature, and hearing loss was not measured directly in this study. This measure does not reflect noise exposure around the time prior to the injury. It may be that hearing-loss data are necessary to assess the effect of cumulative noise exposure on hearing. Furthermore, being unable to assess for hearing loss or hearing protection makes it difficult to fully assess the pathway of cumulative noise leading to hearing loss and injuries.

No noise measurements were available prior to 1970, determinant data were not available, and therefore exposures for this period had to be estimated, based on 1970s exposure levels.[2]

Many of these limitations noted above can be common in observational studies, and we do not consider them to be 'fatal flaws' to this study.

Conclusions and future directions

This study found that being exposed to noise levels above 85 dB (A) between 91 days and 1 year was associated with a higher risk of injury. Being exposed to higher cumulative noise exposure levels was associated with a lower risk of injury which may likely be due to more experience on the job. Future studies should include individuals working for various lengths of time in the analysis, as well as both hospitalised and non-hospitalised injuries. Events occurring directly prior to the injury should also be documented and analysed, in order to target specific strategies to prevent injuries occurring from noise exposure. When workers are exposed to these levels of noise, other mechanisms, such as visual methods of communicating risk, can be put in place so that workers do not need to rely on their ability to perceive sound to keep them safe from potential hazards. The use of hearing protection works to prevent noise-induced hearing loss but may not prevent injuries due to noise exposure. The only true method of preventing noise-related injuries is to reduce noise from the source. There should be a greater emphasis on engineering noise controls because hearing protection only contributes to the problem.

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