Hearing Loss in British Columbia Sawmill Workers

An Epidemiologic Analysis of Audiometry Data from Industry Hearing Conservation Programs, 1979 – 1996

Report to:

Hearing Conservation Section,
Workers' Compensation Board of British Columbia,
PO Box 5350 Station Terminal,
Vancouver BC

By:

Hugh Davies[1], Steve Marion[2], Kay Teschke[1,2]

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1 School of Occupational and Environmental Hygiene,
University of British Columbia,
2206 East Mall,
Vancouver, BC, V6T 1Z3

2 Department of Health Care and Epidemiology,
University of British Columbia,
5804 Fairview Avenue,
Vancouver, BC, V6T 1Z3

Summary

The purpose of this study was to investigate the relative risk of hearing loss among sawmill workers in British Columbia since the initiation of hearing conservation programs in the late 1970s. Data from two Workers' Compensation Board data bases, audiometry and noise exposure, were analyzed using epidemiologic methods to estimate the relative risks of "OSHA" standard threshold shifts associated with cumulative noise exposure and use of hearing protection devices, and to determine if the relative risks changed with time

The study utilized survival-analysis techniques to estimate the risk of threshold shifts while simultaneously controlling for multiple potential confounders. Age, a strong confounder because of its relationship to both hearing loss and cumulative noise exposure, was controlled for, but its effects were not estimated. The effects of pre-existing hearing loss at initial hearing test, and non-occupational noise exposure, were estimated.

The results indicated that there was an increased risk of hearing loss among sawmill workers, and that the relative risk increased with increasing cumulative noise exposure, reaching 6.6 in the most highly exposed group (an increase of 560%). The use of hearing protection was shown to have a protective effect, reducing the risk of hearing loss by approximately 30%. While calendar year itself was not predictive of threshold shift, the year in which a person had their first hearing test was: those entering hearing conservation programs after 1988 had a 30% reduced risk of threshold shift.

To improve the utility of WCB data for future research, recommendations were made to improve data collection and quality control. In addition, it would be useful to obtain more audiometry data from employees in noisy industries who themselves are not exposed, to provide an unexposed comparison group for epidemiologic analyses such as this.

Contents

Introduction

Objectives

The Hearing Conservation Section of the Workers' Compensation Board of British Columbia (WCB) asked the authors to analyze sawmill industry audiometry data managed by the WCB. Within the context of evaluating the impact of hearing conservation programs, the objectives were to ascertain:

1. the relative risk of developing hearing loss in noise-exposed BC sawmill workers as compared to a group not occupationally exposed to noise; and
2. to what degree noise induced hearing loss had been reduced in sawmill workers over the period 1980 – 1996

A secondary objective was to develop an analysis methodology that could be applied by the WCB to other audiometry data from other industry sectors.

Outline of Work Program and Methods

Data Sources

Data for the study was provided by the WCB in 3 databases:

- *Audiometric database:* An extract of the full WCB audiometric database. It contained 316,476 observations relating to 66,130 subjects, obtained during the period 1979 to 1996. From the inception of the database, the rate of deposition of hearing tests from sawmills was steady at approximately 15,000 – 20,000 per annum. Appendix A lists the database structure.
- *WCB noise exposure database*: An extract of the WCB noise exposure database of field measurements for the industry subclass 10501. This file contains noise exposure measurements made by WCB regulatory officers, and measurements made by the sawmills as part of their noise control programs, and voluntarily submitted to the WCB.
- *NIOSH audiometry databases:* The WCB provided extracts from 4 audiometric databases commissioned by NIOSH and selected by the "ANSI S12.13 Working Group on Hearing Conservation Program Evaluation" as standards for evaluating program effectiveness.

Background

To date, hearing conservation programs have been evaluated using several methods: the investigation of variability in audiometry results ("audiometric database analysis", ANSI, 1991, Royster and Royster, 1990); the investigation of hearing-related outcomes such as hearing threshold levels (Ridgely, 1991, Bertrand and Zeidan, 1999) and standardized threshold shifts (Wolgemuth et al, 1995). The ANSI S12.13 draft standard has been criticized for its restrictive subject eligibility criteria, poor reliability and generalizability, limitations in handling the effects of pre-existing hearing loss and sensitivity to audiometric test method (Adera et al, 1993a, 1995, Simpson, Stewart and Kaltenbach, 1993, Simpson, Amos and Rintelman, 1993). Alternative methods of evaluation continue to be sought.

Although established epidemiological techniques have been previously recommended (Erdreich and Erdreich, 1984, Adera, et al, 1995), few studies that utilized such techniques have been published. Only Adera and his colleagues (1993a, 1993b) have approached the problem in this way. They estimated age-adjusted risk ratios for standard threshold shift using an external control data set (ANSI, 1991) and Mantel-Haenszel stratified analysis.

We felt that in order to make the best use of the longitudinal nature of audiometry data, however, a more appropriate technique would be to use survival analysis. Further, statistical modeling would allow us to simultaneously adjust for the multiple potential confounders of the relationship between noise exposure and hearing loss.

Analytical approach

Survival analysis is particularly suited to this data, as the outcome - hearing loss - is a common disease, and routine audiometry gives us a reasonable estimate of the time of onset. Survival analysis makes very efficient use of the information provided by those who do *not* suffer hearing loss during the follow up period, as well as those who do.

At periodic hearing tests (there may be several before the hearing loss "event" occurs) the audiometric technician records an individual's status for various risk factor for hearing loss, including: noise exposure, use of hearing protection, non-occupational exposure to noise, and health-related risk factors. All of these can change with time, and survival analysis is also well suited to handling this complexity.

Modeling, using Cox's proportional hazard model (a type of survival analysis) allows not only adjustment for multiple confounders, but also permits estimates of their effects. In addition, it provides very precise control of the effects of age, which is a particularly strong confounder of the relationship between hearing loss and duration of exposure to noise.

Because individuals enter hearing conservation programs at different times, and remain in them for different periods, (but usually for several years) determining the effect of calendar year on risk of hearing loss is particularly complex. Cox modeling allows the estimation of these year-effects without multiple stratifications that might reduce the overall power of the analyses.

Methods

Subject Selection

Subjects were excluded from analyses if:

- the job they held was likely not a permanent sawmill job (e.g. construction contractors)
- they had only one hearing test (prevents estimation of a shift in hearing threshold)
- their data had coding or logic errors (except missing values) at any of their hearing tests.

After these exclusions, the number of subjects available for analyses was 42,282. Of these, only 22,376 subjects had all variables completed for every hearing test. All hearing tests following a test at which hearing loss (defined below) was identified were excluded, as they would provide no relevant explanatory information.

Preparatory Work (Noise Exposure Assessment)

The exposure database provided to UBC by the WCB contained 5,743 personal dosimetry measurements from 185 sawmill sites around BC.

To allocate exposure levels to occupations, each observation in the exposure database was first assigned a UBC standardized job title (job titles in the WCB exposure database were text only and not standardized)[1]. The mean exposure level was calculated (using the WCB data) for each standardized job title. Standard job titles were then cross-referenced to WCB occupation codes used in the audiometry file, allowing each observation (hearing test) to be assigned the mean noise level associated with the job title held at that time. Some job titles (e.g. "Production line worker") were assigned mean values of a group of representative jobs.

Occupation codes that were not sawmill jobs were referred back to the Hearing Conservation Section. Exposure data on the majority of the remaining occupation codes was obtained, and again mean exposure levels were estimated and allocated.

A full list of occupation codes, job titles, the distribution of job titles among hearing tests and mean exposure levels is provided in Appendix B.

Preparatory Work (Audiometric Data)

The audiometric database was systematically checked for data errors (Appendix C). Wherever possible errors were corrected, else all observations for the affected individual were excluded.

Each eligible subject had n (where $n \geq 2$) hearing tests, resulting in n-1 periods between hearing tests. It was assumed that the personal information provided at a hearing test (job title, exposure and medical history) represented the conditions during the entire duration of the previous period.

[1] This step had been performed earlier as part of another study conducted at UBC using the WCB exposure database.

Some data items (such as hearing level at initial audiogram) remain unchanged with time – they are said to be "fixed". Other data items are free to change with time (such as cumulative exposure) and were therefore re-calculated at each hearing test. These are said to be "time-varying".

The variables used in the statistical analyses are summarized in Table 1. A detailed description of the variables follows.

Table 1: Analysis Variables and Codes

Variable	Values	Codes	Fixed or Time-Varying
Health outcome: OSHA STS in better ear.	0|1[2]	0 = no STS 1 = STS during last period	Time-varying
Use of hearing protection	0|1	0 = not a regular hearing protection devices wearer 1= regular HPS wearer	Time - varying
Cumulative noise exposure	0 - 5	0 = reference 1 = 80.1 - 85.0 dB 2 = 85.1 - 90.0 dB 3 = 90.1 - 95.0 dB 4 = 95.1 - 100.0 dB 5 = > 100.0 dB	Time - varying
Year of hearing test	1979 - 1996		Time - varying
Year of initial hearing test	1979 - 1996		Fixed
□			
Pre-existing hearing loss at initial audiogram	0 - 4	0 = ≤ 15 dB 1 = 16 - 30 dB 2 = 31 - 45 dB 3 = 46 - 60 dB 4 = ≥ 61 dB	Fixed
Ever had ear surgery?	0|1	0 = yes 1 = no	Time - varying
Ever had a serious head injury?	0|1	0 = yes 1 = no	Time - varying
Ever had dizziness or balance problems?	0|1	0 = yes 1 = no	Time - varying
Ever had a severe ear infection?	0|1	0 = yes 1 = no	Time - varying
Ever had a relative with hearing loss before age 50?	0|1	0 = yes 1 = no	Time - varying
Ever exposed to loud noises in the armed forces?	0|1	0 = yes 1 = no	Time - varying
Ever exposed to loud noises off the job?	0|1	0 = yes 1 = no	Time - varying
Ever exposed to loud noises at a previous job?	0|1	0 = yes 1 = no	Time - varying
Ever shot trap/skeet/target (not hand guns)?	0|1	0 = yes 1 = no	Time - varying
Ever hunted?	0|1	0 = yes 1 = no	Time - varying
Ever shot handguns	0|1	0 = yes 1 = no	Time - varying

Health Outcome

The health outcome specified by WCB for the analysis was the OSHA standard threshold shift (STS), calculated as a cumulative average threshold shift of 10 dB or greater at 2000, 3000 and 4000 Hz in the better ear (i.e. the ear with the lower hearing threshold at time of audiogram). This is given by the equation:

$$Y = [\{\text{Hearing level at 2KHz} + \text{Hearing level at 3KHz} + \text{Hearing level at 4KHz}\}/3]_{\text{(periodic audiogram)}}$$

[2] | = "or"

- [{Hearing level at 2KHz + Hearing level at 3KHz + Hearing level at 4KHz }/3]$_{\text{(baseline audiogram)}}$

If Y ≥ 10 dB, the subject was considered to have an STS event.

Cumulative Noise Exposure

Each hearing test was assigned a noise exposure level corresponding to the current occupation reported by the subject. Cumulative noise exposure was estimated in decibels as the sum of the products of noise intensity and duration for all occupations reported up to and including the current hearing test (see "composite noise immision levels", Robinson and Shipton, 1977):

For i^{th} audiogram:

Cumulative-exposure$_i$ (dB re: 20 microPascal-years) =
10 $\log_{10}$ ($\Sigma_{1 \text{ to } i}$ (sound intensity$_i$ (microPascals) x duration of employment$_i$ (years)))

Thus a 3 dB increase in cumulative exposure represents a doubling of either the duration or the intensity of exposure. The elapsed time between hearing tests was used in estimating exposure duration. Self-reported "years at occupation" was not used, as it was only less than elapsed time in approximately 10% of observations, and was prone to reporting error. Exposure prior to the initial audiogram could not be used in our analyses, because we had no record of these exposures. Prior exposures were accounted for with the variable “Pre-Existing Hearing Loss at initial audiogram”.

Hearing Protection Use

At each hearing test the subject reported if they “regularly wear ear protectors”. The proportion of follow up time that hearing protection was worn was calculated for each hearing test. This was dichotomized for analysis into those who continuously wore hearing protection devices during the follow up period and those who did not.

Calendar Year

Gives the year the hearing test was performed. Potentially reflects changes in the environment (or individual) that occur with time.

This variable might estimate otherwise unmeasured effects of hearing conservation programs, beyond the effects of hearing protection use and cumulative noise exposure.

Year of Initial Hearing Test

This gives the year of the subject's first hearing test. This variable allows the model to adjust for a "cohort" effect, i.e., an effect associated with being in the group who began their hearing conservation program experience in a given year.

Pre-Existing Hearing Loss at First Hearing Test

Because of uncertainty regarding exposure levels and status of confounders prior to a subject's initial hearing test, we treated every subject's initial hearing test as a "baseline". All noise exposure prior to first audiogram was ignored and initial hearing loss was assumed to reflect the effect of any prior noise exposure. The level of hearing loss at a subject’s initial hearing test was determined as the average threshold of both ears at 2, 3, 4 kHz.

The level of existing hearing loss is also known to influence the rate of change of hearing threshold. This variable allowed us to control for this.

Intrinsic Risk Factors

These covariates report whether the subject ever had:

1. ear surgery
2. dizziness or balance problems
3. a serious head injury

4. a relative with hearing loss before age 50
5. a severe ear infection

These variables have dichotomous values (yes/no). The WCB hearing test protocol leaves a subject's response blank on the data entry form if there had been no change in status from the previous hearing test. Therefore we attempted to "fill in" all missing values for the medical risk factor variables with the last non-missing value reported, where available. As self-reporting was at all times voluntary, a great number of missing values nevertheless remained.

Extrinsic risk factors

All of these variables are dichotomous (yes/no). They were “filled in” as required (see intrinsic risk factors). These covariates report whether subject:

1. was ever exposed to loud noises at previous job
2. was ever exposed to loud noises off the job
3. was ever exposed to loud noises in the armed forces
4. ever hunted
5. ever shot trap/skeet/target (but not handguns)
6. ever shot handguns

Statistical Analyses

Statistical analyses were completed using STATA 5 (STATA Corp, Texas). Specific statistical tests used are referenced in the text. Means and standard deviations are given where the underlying distributions appeared normal, otherwise medians and interquartile ranges are provided.

Comparisons to External Populations

Cumulative incidence of STS in the sawmill worker cohort was compared with cumulative incidence in an external control group. For this purpose, we selected an extract of one of the NIOSH audiometry data sets (ANSI0002). The extract was prepared for the WCB by a member of the ANSI working group (Royster, 1999) and contained only records for white males exposed to noise levels below 85 dB(A) in synthetic fiber manufacturing. These subjects were reported not to wear hearing protection.

Relative risks were estimated using age-stratified contingency tables, and summary relative risks were estimated using Mantel Haenszel adjustment, following the method of Adera et al (1993b).

Comparisons within the Sawmill Population

Survival Time Definition

Survival analyses allow us to model time-to-event (in this case time-to-STS) using a variety of possible time parameters. We elected to use age (in years) as the underlying "time variable". Thus the univariate (Kaplan Meier) survival analysis results are given as "median age at STS".

This has the effect of "controlling" for age, a strong risk factor for hearing loss, in a very precise way (Checkoway et al., 1989). A drawback of this approach is that the effect of age on STS incidence cannot be simultaneously estimated. Preliminary analyses of the sawmill worker data showed the expected strong association between age and hearing loss.

To overcome a potential bias caused by non-commensurate intervals between hearing tests among those who went on to have an STS event and those who did not, follow-up periods were restructured into 2 year "time periods". These time periods were then assigned the covariate values of the actual underlying period between audiograms.

To prevent the possibility of individuals biasing their responses to personal risk questions based on knowledge of the status of their hearing, the data from each hearing test was applied "prospectively" to the following period. This also had the indirect effect of "lagging" exposures by up to two years (i.e. STS events and matched controls are associated with cumulative exposures received up to a point up to 2 years earlier, but not after that point). This lagging is appropriate if noise does not cause an immediate STS, but has its effect after an induction period of at least 2 years.

Univariate Analyses

Kaplan Meier tests were used to examine the relationships between individual co-variates and STS. Only those with $p \leq 0.20$ were retained and offered in initial multivariate modeling.

Multivariate Model Building

Covariates for exposure and initial hearing loss were offered in every model. Age was adjusted for in every model as it was entered as the "survival time" variable. All co-variates with $p \leq 0.20$ in univariate tests were then added, and non-significant co-variates ($p > 0.05$) were removed one at a time. Each covariate's contribution to the model was gauged by the statistical significance of the covariate, the log-likelihood ratio, and the percentage change in the remaining co-variates (Hosmer and Lemeshow, 1999). Once the final model was built, all co-variates not previously offered in the model were offered to see if they were significant in a multivariate setting.

Results

Subject Demographics

Gender and Age

All 42,282 subjects were male, and ages at hearing tests ranged from 16 to 79 years.

The median age at *initial* hearing test was 31, with an inter-quartile range of 24 – 43, and a range of 16 to 75. The mean age at first hearing test changed with time. In earlier calendar years, there was a larger proportion of older individuals receiving their first hearing test. The mean age at first hearing test dropped from 36.9 to 29.2 between 1979 and 1996 (Figure 1).

Median age at *end of follow up* (at last hearing test, or when STS detected) was 40 (inter-quartile-range 31 – 51, range 16 – 79).

Personal Risk Factors for Hearing Loss

Table 2 shows median levels of pre-existing binaural hearing loss by decade of age. As expected, there is a substantial increase in hearing threshold with age, with an approximate doubling of median hearing loss with each decade. Age and pre-existing hearing loss were strongly correlated (Pearson $r = 0.6$). Median binaural pre-existing hearing loss at initial hearing test was 9.2 dB. Median pre-existing hearing loss decreased with increasing calendar year (Figure 1).

Table 2: Pre-existing hearing loss by age

Age group	n	Median binaural hearing loss (dB)	Inter-quartile Range
≤ 30	10,020	3.3	1.7 - 7.5
31 - 40	11,657	5.8	2.5 - 11.7
41 - 50	9,522	11.7	5.0 - 21.7
51 - 60	8,076	25.8	14.2 - 39.2
> 60	3,007	38.3	25 - 51.7
All	42,282	9.2	3.3 - 22.5

Table 3 shows the proportion of subjects self-reporting personal risk factors, and the proportion of missing values. Despite our attempt to correct missing values by "filling forward" from the last non-missing value reported for a covariate, there remained a substantial amount of missing data.

Figure 1: Mean age and median pre-existing hearing loss at first hearing test, by calendar year.

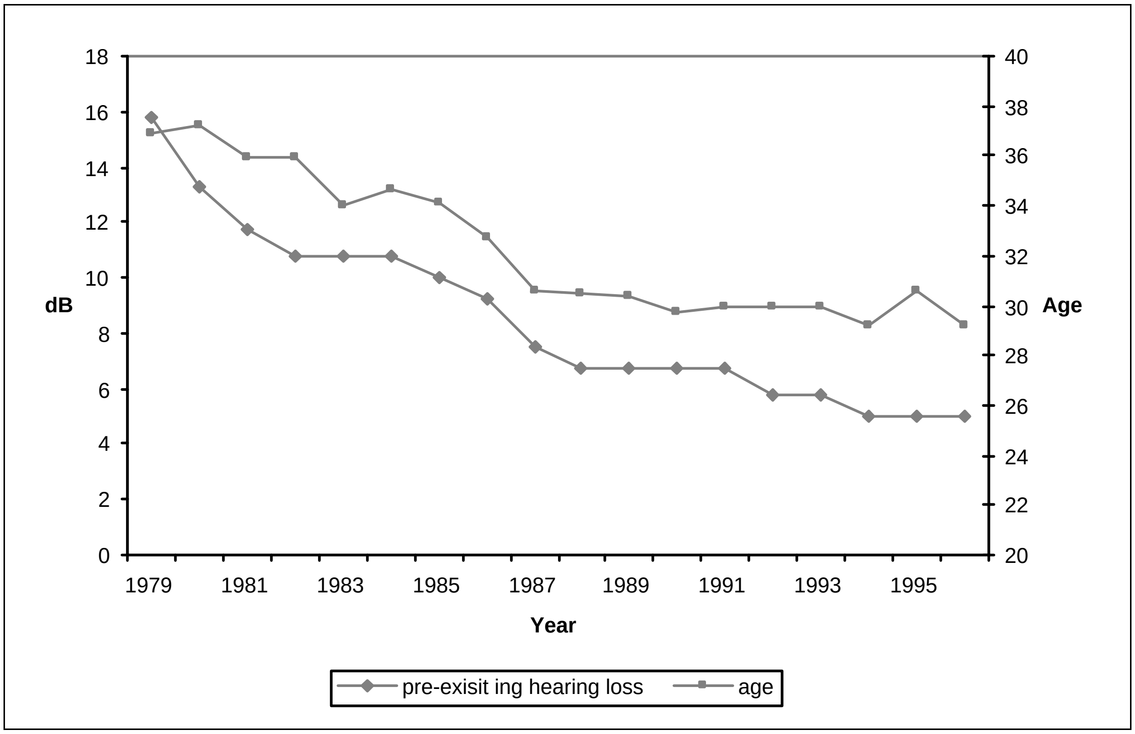


Table 3: Proportion of subjects self-reporting risk factors for hearing loss

Risk Factor	% responding positively on at least one hearing test, of those responding	% subjects never responding
Medical History		
Ear infection	11.5	36.9
Relative with HL before 50	7.5	37.6
Serious headinjury	6.3	37.4
Dizziness or balance	5.6	37.2
Ear surgery	3.2	37.3
Exposed to noise:		
At previous job	63.7	35.5
At home	49.2	37.3
In armed forces	11.3	38.0
Firearm use:		
Ever hunted	52.6	37.1
Ever shot trap/skeet/target	29.2	38.7
Ever shot handguns	22.0	38.7

Ear surgery and problems with balance or dizziness were the least frequently reported medical problems at 3.2% and 5.6% respectively. A severe ear infection was the most common medical condition, reported by 11.5% of those responding.

Only 11.3% of subjects reported exposure to noise in the military, while 49.2% and 63.7% reported exposure to noise off the job and exposure in a previous job, respectively. Over half the respondents had hunted at some time, and between 20 and 30% had shot trap, skeet or targets, or shot handguns.

At their initial hearing test, 57.9% of subjects reported having been exposed to noise at a previous job. Even among those aged 20 years or less, 37.5% reported a previous noisy job; this increased to 69.7 % in those aged 60 years and older at their first hearing test.

Table 4 shows levels of pre-existing hearing loss at initial hearing test associated with self-reported risk factors for hearing loss. Those reporting noise exposure during military service had an almost 3-fold increase in the level of pre-existing hearing loss. Those reporting exposure to noise in a previous job showed a more mild elevation.

Those reporting exposure to noise off the job had a significant decrease of over 40% in pre-existing hearing loss. Increases were seen in those reporting prior ear surgery, dizziness or balance problems and severe ear infections, the largest increase being for those having had surgery. Firearm use in hunting prior to initial hearing test resulted in a very small increase in HL. Given the very large number of observations, it is advisable to regard the clinical significance of these results with more weight than the statistical significance.

Table 4: Self- Reported Personal Risk Factors (at Initial Test) and Pre-existing Hearing Loss (dB)

Risk Factor	Yes		No	
	n	Pre-existing HL (dB)	n	Pre-existing HL (dB)
Exposed to noise:				
Military	2636	21.7*	21433	7.5
Previous job	14430	10.0*	9937	7.5
Off the Job	11645	6.7†	12705	11.7
Ever had:				
Ear Surgery	649	16.7*	23663	8.3
Dizziness/balance problem	1167	12.5*	23188	8.3
Severe ear infection	2088	10.0*	22238	8.3
Head Injury	1369	8.3	22929	8.3
Familial hearing loss	1675	8.3	22552	8.3
Ever:				
Hunted	12593	9.2*	11844	8.3
Shot trap/skeet/target	6632	7.5†	17096	9.2
Shot handguns	5007	8.3†	18718	9.2

*Statistically significant (Mann-Whitney) at $p < 0.05$, increase in pre-existing hearing loss
†Statistically significant (Mann-Whitney) at $p < 0.05$, decrease in pre-existing hearing loss

Non-response to Health and Exposure Questions

35.4% (13,999) had missing values for all non-occupational exposure and medical history questions at all hearing tests. Compared to other subjects, these "non-responders" were older at first hearing test (mean age 35.5 vs. 32.5 years; t-test, $p < 0.05$) This group also had slightly higher pre-existing hearing loss (16.3 dB vs. 14.6 dB, t-test, $p < 0.05$), and reported slightly less hearing protection usage (80% vs 83%, $p<0.05$). There was a very small difference in average noise exposure in the non-responding group; they were exposed to an average noise level of 91.1 compared to 91.2 dB (t-test, $p < 0.05$).

Hearing Protector Use

Use of hearing protection was self-reported by subjects at each hearing test. The proportion of those using hearing protection (those responding positively to the question "do you regularly use ear protectors") increased from 71.6% in 1979 to 91.1% in 1996. Use of hearing protection devices was greatest in the highest noise exposed groups (Figure 2) but has been increasing at all exposure levels. Use of hearing protection was also associated with subject age, with younger subjects more likely to be regular users (Figure 3).

Figure 2: Proportion Self-Reported Hearing Protection Use by Calendar Year and Average Noise Exposure Level

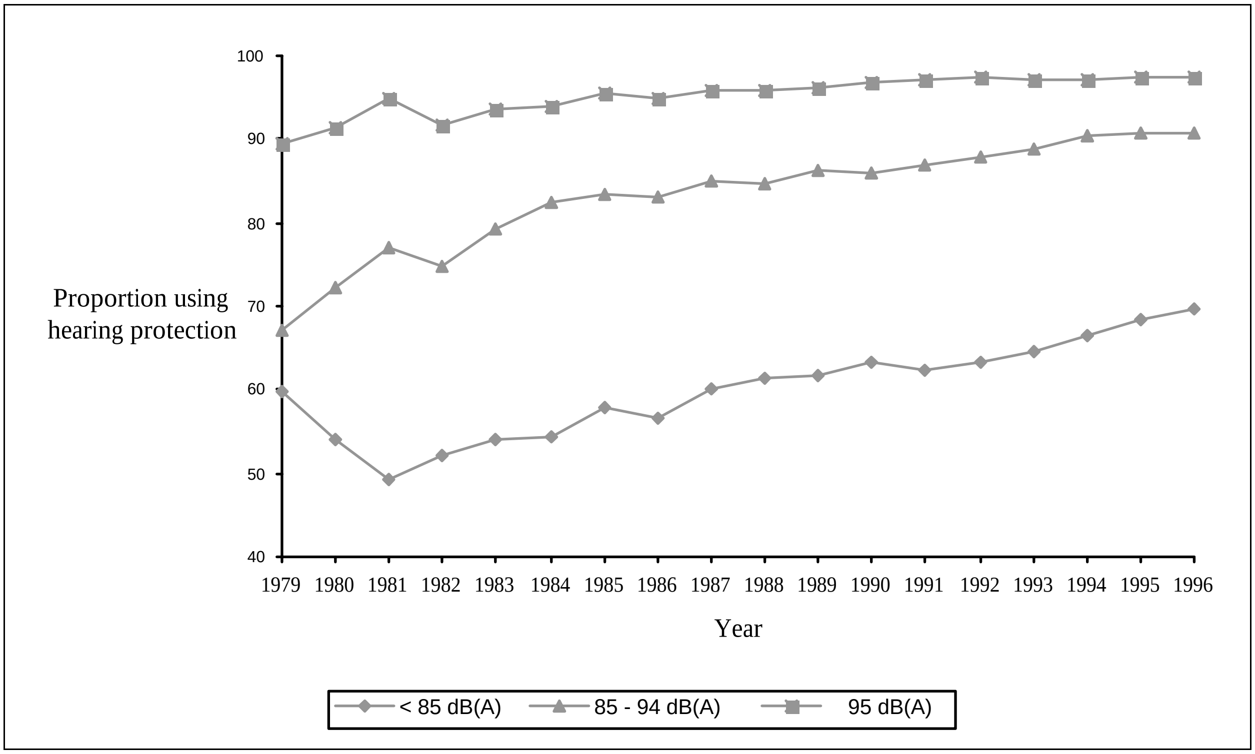
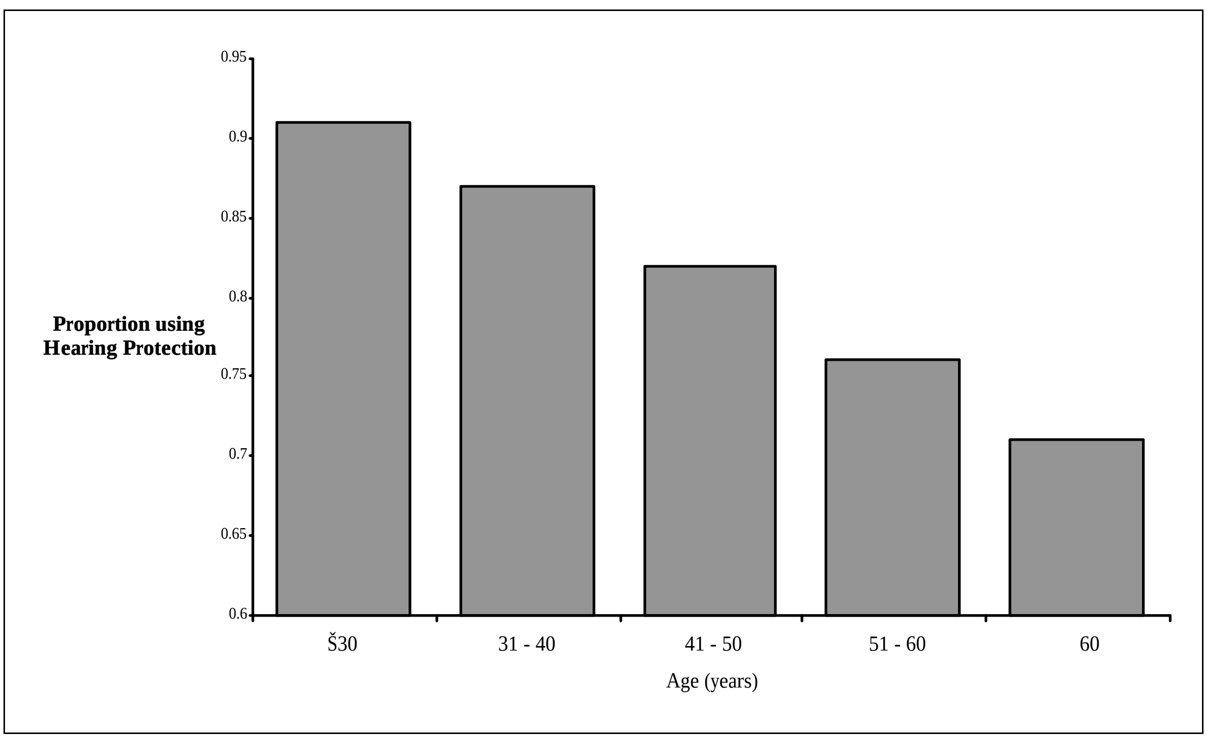


Figure 3: Proportion Of Subjects Using Hearing Protection Devices By Age



Frequency of Hearing Tests and Length of Follow-up

The median period between hearing tests for an individual was 1.1 years, with 75% of periods less than 1.6 years and 90% of periods less than 2.4 years. The range of periods was 28 days to 18 years. The median period length was not significantly different between those who suffered STS and those who did not, nor between various average exposure groups (data not shown).

The median number of hearing tests per person in the database was 9, with a range of 2 to 19 (after excluding subjects with single audiograms).

The mean follow up time (from initial to final hearing test) was 7.1 years. This is consistent with the findings of a large cohort study of BC sawmill workers which found that among those employed for at least one year between 1950 and 1985, 60% of workers were employed for 9 years or less (Ostry, 1998).

The mean length of follow up time was associated with average exposure level. Those having a lower average exposure level tended to be followed up for a shorter period of time (Table 5). The final group (≥ 101.7 dB) is comprised entirely of one job-group (those who have worked exclusively as chipper operators). Their relatively short follow up time may be biased by early migration from this job to "quieter" jobs.

Table 5: Mean follow up time by average noise exposure category

Average noise exposure dB(A)	Number of hearing tests	Mean follow up time (years)
≤ 85.0	3171	5.5
85.1 – 90.0	9567	7.2
90.1 – 95.0	22345	8.0
95.1 – 100.0	6792	8.4
100.1 – 101.6	206	9.2
≥101.7	201	4.8
All	42282	7.1

Frequency of Standard Threshold Shift (STS)

A total of 5,919 Standard Threshold Shifts (STS) were identified. An individual was only permitted a single STS, at which time follow up for the individual ceased (i.e. subsequent hearing tests were ignored).

Noise Exposure

A full list of occupation codes, job-titles and mean exposure levels is given in Appendix B.

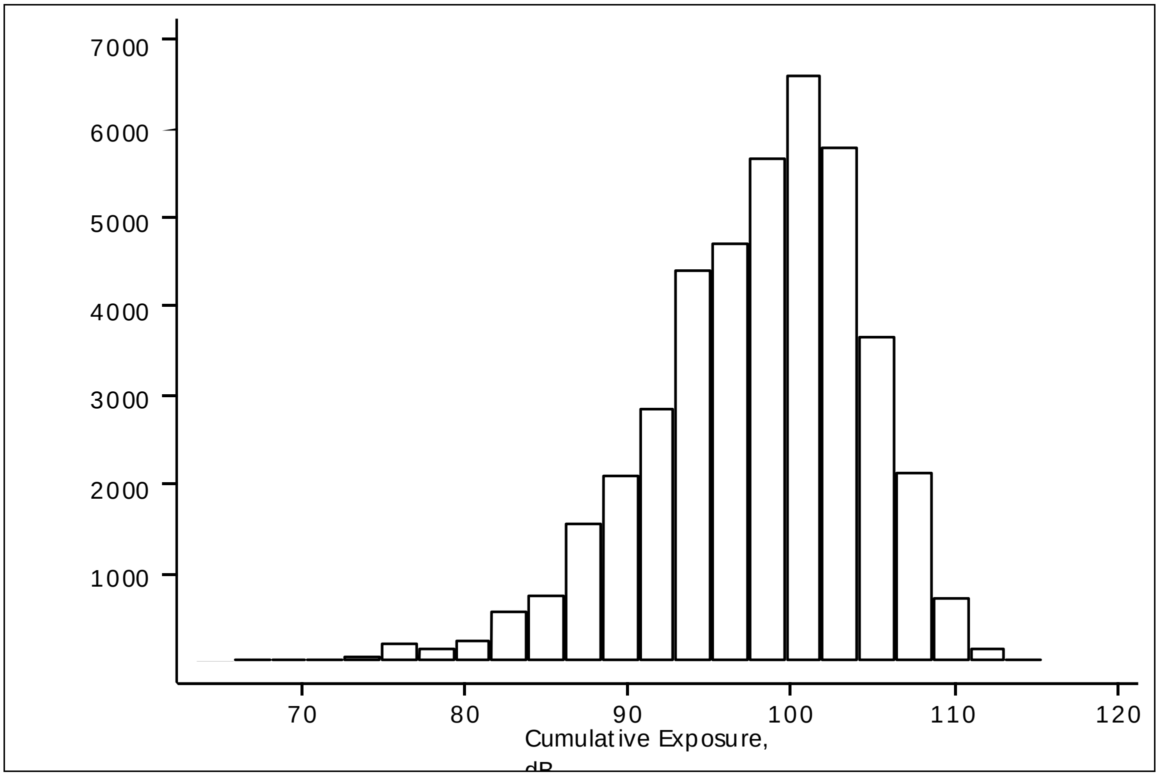
Cumulative exposure levels were estimated for each subject at each of their hearing tests, thus cumulative exposure levels increased throughout the follow-up period.

The distribution of cumulative exposure levels is shown in Figure 4. The mean cumulative exposure level for all subjects at end of follow up was 98.1 dB(A) with a standard deviation of 6.1.

Cumulative exposure measurements incorporate both an intensity and a time factor, and are in decibels (10 x log10 (noise intensity at jobi in Pascals x duration of employment in jobi in years)). This unit conforms to the equal energy hypothesis, thus a doubling of either sound intensity or duration of exposure will increase the cumulative exposure level by 3 dB.

A small group of subjects comprised a “non-exposed” group, identified by the audiometric technician with an occupation code of “9999999”, for their entire work history. Only 0.8% of subjects fit this category (n=329). The median follow up time for this group was only 1.3 years, with 82.3% having 2 or fewer periodic hearing tests.

Figure 4: Frequency Distribution of Cumulative Exposure (dB)



Univariate Analyses

Table 6 shows the results of univariate Kaplan Meier analyses of all potential co-variates. All variables were tested as categorical (rather than continuous) variables. The likelihood ratio test tests the statistical significance of the difference of the univariate models and the null model. The median age at STS is the age at which half of the individuals in the category had suffered an STS. Only those variables with a P-value of ≤ 0.2 were retained for further analysis in the multivariate model.

Table 6: Univariate Analyses of Median Age of onset of STS

Variable	Category	Likelihood Ratio Test (p-value)	Median age at STS	Retained for multi-variate Analysis
Cumulative noise exposure (dB)	ref	<0.001	. □	√
	80 - 85		65.7	
	85 - 90		58.4	
	90 - 95		59.3	
	95 - 100		53.7	
	>100		49.9	

[3] unable to estimate (insufficient cases)

Table 6: Univariate Analyses of Median Age of onset of STS (continued)

Variable	Category	Likelihood Ratio Test (p-value)	Median age at STS	Retained for multi-variate Analysis
Pre-existing HL(dB)	≤ 16	<0.001	54.1	√
	17 - 31		52.3	
	32 - 46		54.7	
	47 - 61		61.2	
	≥62		.	
Year of first hearing test	1984	<0.001	54.7	√
	1988		58.9	
	1992		63.5	
	1996		.	
Hearing protection devices use	No	<0.001	53.6	√
	Yes		56.0	
Target shooting	No	0.004	55.0	√
	Yes		53.3	
Calendar year of hearing test	1984	<0.001	63.2	√
	1988		55.8	
	1992		52.1	
	1996		51.8	
Handgun use	No	0.018	55.1	√
	Yes		53.1	
Severe ear infection	No	0.169	54.8	√
	Yes		53.9	
Noise in military	No	<0.001	54.2	√
	Yes		57.5	

Table 6: Univariate Analyses of Median Age of onset of STS (continued)

Variable	Category	Likelihood Ratio Test (p-value)	Median age at STS	Retained for multi-variate Analysis
Hunting	No	0.794	54.7	
	Yes		54.3	
Head injury	No	0.438	54.7	
	Yes		54.6	
Ear surgery	No	0.923	54.7	
	Yes		54.8	
Familial hearing loss	No	0.619	54.7	
	Yes		55.8	
Dizziness or balance impairment	No	0.298	54.7	
	Yes		55.4	
Non-occupational noise	No	0.463	54.3	
	Yes		54.5	
Noise in previous job	No	0.933	54.9	
	Yes		54.7	

Multivariate Modeling

Table 7 shows the output of the final multivariate model. Because some of the co-variates had large numbers of missing values, the number of subjects examined in the model was 22,376 (from a total of 42,282) including 2,839 STS "events" (from a total of 5,919). Nevertheless the model had ample power to model the covariates of interest. Overall the model was very highly statistically significant (p <0.0001).

All variables are categorical. If not dichotomous, they were grouped by logical breakpoints. Relative risks greater than one indicate an elevated risk of developing an STS, i.e. a relative risk of 2 means that the risk of developing STS is doubled (100% increase in risk). Relative risks below one suggest that the factor has a "protective" effect, i.e. a relative risk of 0.5 means the risk of developing STS is one half of the baseline risk.

The multivariate model estimates the effect (relative risk) associated with each factor while simultaneously adjusting for all other factors. Thus each risk factor can be examined independent of the others - the same as saying "while holding all other factors constant, the relative risk, for example, associated with target shooting is 1.1".

Table 7: Multivariate model, showing relative risks of STS

Variable	Relative Risk	95% confidence Interval
Cumulative noise exposure (dB)		
ref	1	
80 - 85	2.1	1.3 - 3.6
85 - 90	3.0	2.3 - 4.0
90 - 95	3.3	2.8 - 4.0
95 - 100	4.6	3.8 - 5.4
> 100	6.6	5.6 - 7.9
Pre-existing hearing loss (dB)		
≤15	1	
15 - 30	1.2	1.1 - 1.3
30 - 45	1.1	1.0 - 1.3
45 - 60	0.6	0.5 - 0.7
≥ 60	0.3	0.2 - 0.4
Year of first hearing test		
≤ 1988	1	
> 1988	0.7	0.5 - 0.9
Always wore hearing protection device	0.7	0.7 - 0.8
Ever shot trap/skeet/target (no handguns)	1.1	1.0 - 1.2

The model indicates that the risk of STS increases with increasing cumulative exposure, from a RR of 2.1 for those exposed between 80 and 85 dB, to a RR of 6.6 in the group exposed to greater than 100 dB. Recall that cumulative exposure combines noise intensity with duration of exposure in accordance to the equal energy hypothesis. Therefore 100 dB (intensity) for one year duration in this scale is equal to 97 dB(intensity) for 2 years; both equal 100 dB (cumulative).

The relative risks of the noise-exposed groups are given with reference to a control group exposed below 80 dB. This group primarily consists of all subjects at their initial hearing test.

Increasing pre-existing hearing loss (at initial hearing test) is associated with a slightly increased risk in STS among those with an initial shift of 15 to 30 dB (a result of their prior noise exposure) but a reduced risk in those who started with an initial loss of more than 45 dB (a result of the smaller threshold shift possible among those who have already experienced substantial hearing loss). The risk of STS drops sharply to 0.6 for those with 45 - 60 dB loss and to only 0.3 for those with pre-existing HL above 60 dB.

The continuous use of hearing protection resulted in a reduced risk for STS (RR = 0.7).

The effect of time on the risk of STS was examined in two ways. Both year of test and year of first test were entered into the model. Calendar year of test had little impact on the risk of STS and was removed. Year of first hearing test showed a reduced risk in later years, with those who had their first hearing test after 1988 having a relative risk of 0.7.

Finally, having ever shot trap, skeet or target (but excluding handgun) gave a slightly elevated risk of STS (RR = 1.2).

Incidence Rate Analysis; External Control Group.

In a secondary analysis, the incidence of STS in the sawmill worker cohort was compared with an external control group provided by the NIOSH database, and adjusted for age (Table 8). Because of the relatively small number of controls, all subjects over 40 years were collapsed into a single category.

The relative risk of STS increases from 0.5 in the youngest group (less than 30 years) to 10.5 in the 40 and over group. Combining these data gave an overall RR for the sawmill group of 2.6.

Comparing the change in risk between earlier and later periods in the WCB dataset we found that the overall age-adjusted relative risk dropped from 2.7 to 2.1 in the latter period. This appears to be mainly due to reduction in risk in the oldest of the three age groups where the relative risk was reduced from 10.9 to 7.9.

Table 8: Incidence Rate Analysis, External Comparison Group

Age	Sawmill Workers N (STS Cases)	Comparison Group N (STS Cases)	Relative Risk	95% Confidence Interval
All Years				
≤29	4128 (418)	47 (9)	0.5	0.3 - 1.0
30-39	5212 (940)	81 (5)	3.1	1.3 - 7.3
≥40	6696 (2189)	62 (2)	10.5	2. 7 - 40.9
Age-adjusted			2.6	1.6 - 4.1
1982 and earlier				
≤29	1941 (225)	47 (9)	0.6	0.3 - 1.1
30-39	2902 (562)	81 (5)	3.3	1.4 - 7.8
≥40	4512 (1526)	62 (2)	10.8	2.8 - 42.4
Age-adjusted			2.7	1.7 - 4.4
1990 and later				
≤29	347 (37)	47 (9)	0.6	0.3 - 1.1
30-39	313 (54)	81 (5)	3.0	1.2 - 7.2
≥40	222 (53)	62 (2)	7.9	2.0 - 31.3
Age-adjusted			2.1	1.3 - 3.4

Discussion

Relative Risk of Hearing Loss in the Sawmill Cohort

The analysis indicated that there was an increased risk of hearing loss in sawmill workers.

After adjusting for age, level of hearing loss at first hearing test, year of first test, trap shooting and hearing protection use, there remained an elevated relative risk associated with cumulative exposure to noise. The relative risk showed an increasing trend with increasing levels of cumulative exposure, ranging from 2.1 for low (80 - 85 dB) to 6.6 for high (> 100 dB) cumulative noise levels.

These relative risks for noise exposure were estimated with reference to an internal comparison group who were exposed to less than 80 dB (cumulative). This control group was constructed from those truly exposed to less than 80 dB, but also included each subject at their first periodic hearing test following baseline (or at 2 years, which ever was smaller).

The model is interpreted thus: a sawmill worker, when all other factors are held constant, exposed to one year at (say) 102 dB (or the equal energy equivalent, e.g. 2 years at 99 dB, 4 years at 96 dB, 16 at 90 dB etc) has approximately 6.6 times the risk of STS of a worker exposed to <80 dB.

An internal comparison group gives the benefit of a characteristically similar comparison group. However, it does not permit the estimation of the "absolute risk", the excess risk above background (i.e. STS due to presbycusis), because by definition there are no (or very few) truly non-occupationally exposed subjects in the hearing conservation program. Because of this, it is likely that the absolute risk would be higher than that found in the internal analysis.

We also conducted an external, age adjusted, cumulative incidence analysis using a NIOSH control data set. We found that the overall RR for STS was approximately 2.6 in sawmill workers, but that it ranged from 0.5 in the youngest to 10.9 in the oldest age groups. It is likely that the fairly broad age groups incompletely controlled for age, but the trend in RR demonstrated is consistent with that within the sawmill group.

The Effect of Hearing Protection Use

The continuous use of hearing protection devices during the follow-up period reduced the risk of STS by approximately 30% (RR = 0 .7). Given that there is inevitably misclassification of true hearing protection device use it seems likely that their use would be over-reported rather than under-reported. This would lead to an under-estimate of their true protective effect.

Changes in the Relative Risk for Hearing Loss with Time

We were able to measure only one aspect of hearing conservation programs directly, that being hearing protection device usage (noise control was also partially reflected in cumulative noise exposure). It was hoped that the influence of other hearing conservation program elements (noise control, education, audiometry, etc) and of the program as a whole, would be reflected in a reduction in STS incidence with time.

Reduced risks were associated with those having more recent *initial* hearing tests. This suggests that those entering a hearing conservation program later in the study period were less likely (after adjusting for all other factors) to suffer STS than those who entered a hearing conservation program in an earlier period.

Other data showed that in recent years, the average age of those entering hearing conservation programs was lower. The reduction in risk could in part be explained if hearing conservation programs were more effective for those entering them at a younger age, and/or with less industrial experience. The corollary is that hearing conservation programs may be less effective for older, experienced workers with perhaps more established work and hygiene habits.

The external cumulative incidence analysis using the NIOSH/ANSI comparison file also showed a moderate decrease in risk between the sawmill groups from before 1984 and after 1992. This analysis was limited however as that both sawmill time-groups had to be compared to the same group from the ANSI file, and therefore did not adequately control for possible changes in incidence with time in the comparison group.

Estimating Overall Impact of Hearing Conservation Programs

Because the relative risks are multiplicative, we can estimate the combined effects of hearing protection devices and year of entry into hearing conservation program. The combined protective effects of recent entry into a hearing conservation program and continual use of hearing protection devices is 0.7 X 0.7 = 0.49, or a 51% reduction in the risk of STS.

Thus the RR for a worker in the lowest cumulative exposure category, hearing protection use and a recent entry into a hearing conservation program is approximately one (2.1 X 0.49 = 1.0). This assumes a pre-existing hearing loss ≤ 15 dB. However the risk of STS for workers with higher cumulative exposure levels and similar conditions would be greater than 1, and increases to 3.2 in the highest exposure group.

Other Hearing Conservation Program Issues

Thirty-seven percent of those under 20 years reported on their initial audiograms noise exposure at a previous job. While it is possible that they had had earlier baseline tests done elsewhere, it is a potential concern that a large percentage of young workers are exposed to noise before entering an hearing conservation program. It may be helpful to examine the full audiometric database to gauge the full impact of this.

The analyses show a clear increase in the use of hearing protection devices over the 18 years of follow up. Not surprisingly, the proportion of noised-exposed workers using hearing protection was dependent on the level of noise exposure, although in an ideal situation all participants in a hearing conservation program should report regular use. Prior to 1996 however, the regulation only required hearing protection devices use at exposures above an 8-hour Leq of 90 dB(A), while audiometry was required for those with an 8-hour Leq of 85 dB(A) or greater.

Risk Estimates for Non Occupational-Noise Factors

The audiometry data demonstrated a strong negative association between pre-existing hearing loss and STS. This is consistent with evidence that accrual of hearing loss is non-linear (Arslan and Ozran, 1998), with most noise-induced hearing loss occurring in the first 5 - 10 years. The effect was only evident for those with > 45 dB of hearing loss.

History of certain medical conditions (ear surgery, dizziness and severe ear infection) at initial hearing test were associated with pre-existing hearing loss, but in the final multivariate model no medical history factor significantly contributed.

Target shooting (excluding handgun) and handgun use both resulted in an increase in relative risk of STS in univariate analysis, but only target shooting stayed in the final multivariate model, with a 10% increase in risk of STS.

Limitations of the Study

The ability of the analysis to examine the relationship between non-occupational factors and hearing loss was weakened by the selection of STS in the better ear (several of these risk factors could potentially produce unilateral hearing loss).

There is little doubt that the majority of production and maintenance jobs in a sawmill are highly exposed to noise. However the exposure levels reflected by individuals in hearing conservation programs are a biased representation of overall exposure at sawmill because only those exposed to 85dB(A) Leq or above are required to participate in a hearing conservation program. This potentially restricts the range of exposure levels that can be investigated.

Our method of exposure assessment has a number of limitations. Misclassification of job-title might have occurred both when assigning noise-exposure measurements to job-title but also while cross-referencing WCB occupation codes to the UBC standardized job titles. The noise measurements that were available only recorded noise intensity, and not other noise parameters that might modify the effect of noise on STS, for example impulsivity of noise and length of shift, that would influence recovery time.

A further misclassification of noise exposure was due to an ignorance of the determinants of exposure for each mill/job/time-period combination to which we assigned exposure levels. For example we knew some jobs at certain points in time were likely to be done with the protection of a soundproof control booth. However the mean exposure level we estimated for a job title included both protected and unprotected workers. Thus assigning this value to all subjects in the same job title would have over-estimated exposure for those who work in booths and underestimated for those who didn't. We didn't know the actual sampling strategy employed to collect data (e.g. random sampling vs. "worst-case" sampling) and this could potentially lead to bias toward overestimating exposures

Despite these limitations, confidence in the exposure assignment was increased by having an occupational hygienist familiar with sawmills (HD) review the estimated exposures to check that the ranking of job exposures was reasonable. Further, the assigned exposure levels permitted us to discriminate among hearing protection device usage level quite clearly suggesting that the assigned exposure levels were defining discrete exposure groups (Figure 2).

Noise exposure before initial audiogram was only partially known because subjects only reported current occupation and years at that occupation. Large proportions of subjects reported either exposure "off the job" or at a previous job (49.2% and 63.7%, respectively). It is unlikely that noise exposure is homogeneous among all those reporting some exposure, leading to misclassification of these variables. We adjusted for this by entering initial hearing loss in the model, and ignoring all prior noise exposure.

All of the potential misclassificiation reported here is likely to be "non-differential" (equally probable to occur among any subgroup) and would usually be expected to reduce any apparent effect.

Limitations of the Data

Audiometry databases often lack data on those considered "non-exposed", because only at-risk workers are required to participate. This is a widespread problem, and true of the WCB database. While it was originally hoped that a control group could be formed from those individuals labeled unexposed (occupation code = 9999999) they were in fact too small a group, with too limited follow up time and relatively few audiograms. The bulk of the hearing tests for this group were from a short number of years in an earlier period. In addition the validity of the audiometry technician's assessments of exposure could not be tested because no actual occupation code was recorded.

Other studies of this type have utilized audiometry databases compiled for the purpose of developing and validating measures of the effectiveness of hearing conservation programs (NIOSH, 1987). One of databases was used in this study for a secondary analysis, but there were a number of limitations associated with its use. Their status as a "control group" was based in part on the ANSI committee's judgement that the participants were part of a good hearing conservation program and therefore "effectively" unexposed. Further, the limited amount of data available was all from a single time period, one that was different from the sawmill data. It also lacked data on a number of potential confounders, and on measurement methods.

Thirty-five percent of data was missing for the exposure history questions. Upon examination, these "non-responders" were found to be slightly older, to have slightly increased pre-existing hearing loss at their initial hearing test, but they were not exposed to a substantially different average noise level. Individuals with any missing data were not included in the multivariate model. There is a potential for selection bias if the non-response rate was different between those who go on to have an STS and those who do not.

Regarding non-occupational exposures, very large numbers reported positively to shooting-hobbies; therefore we might assume very wide-range of noise exposure in each group and subsequent misclassification. No detailed information was available with respect to magnitude or timing of exposure, nor duration etc. This would have led to substantial variability in the actual exposure received by those who respond "yes" to any of these questions, and a bias in the relative risk toward the null.

It might be possible to improve the outcome measure. A reported test of the reliability of the measure identified that only 51% of those with an audiogram after an initial STS were shown to have a STS on the follow-up audiogram. Several other measures of hearing loss have been reported with higher levels of reliability (NIOSH, 1998). Misclassification of the hearing loss outcome in our analyses would also be expected to decrease relative risk estimates towards the null.

Application of Analytical Technique by WCB in Other Industry Sectors

We do not recommend at this time that this analysis methodology be applied to other industry sectors without the guidance of a competent statistician.

We identified a number of steps in the data preparation and analysis that required a sophisticated understanding of the mathematics underlying the statistical procedure. These required decisions that cannot, at this point, be generalized into a simple protocol.

Possible Areas for Further Investigation

Several items were identified as areas worthy of further study:

- Repeat analyses on other industry groups to determine if protocol is generalizable.
- Examine relationship of exposure and hearing loss using other definitions of threshold shift (such as "Repeated 15 dB shift at any frequency").
- Examine the effect of hearing conservation programs on noise exposure by investigating noise levels directly; combine UBC and WCB data to look for changes in noise exposure with time.
- Improve exposure assessment by reducing misclassification due to grouping by job, and by modifying exposure levels based on predicted adoption of noise control techniques such as sound-proof booths
- Identify more appropriate external control groups (such as WCB OHO's or Sataloff (1999) group).
- Link audiometry file to UBC sawmill cohort file to improve individual work histories

Conclusions and Recommendations

Sawmill workers participating in hearing conservation programs in British Columbia are at an increased risk of hearing loss as measured by the OSHA STS (better ear). This risk increases with increasing cumulative exposure levels in a typical dose-response fashion to a relative risk of 6.6 in the highest exposed group.

Hearing protection devices are associated with a 30% reduction in risk of STS. Entering a hearing conservation program at a later period in time (after 1988) was associated with a further 30% reduction.

These relative risks suggest that a sawmill worker in 1996, continually wearing hearing protection, still had an elevated risk of a STS.

With respect only to the utilization of audiometry data for research purposes, it is recommended that:

- Data collection protocols be changed to encourage full completion of medical and exposure histories, and the coding be updated to reflect differences between "no status change" and "refused to answer".
- Improve quality control practices to reduce the number of data errors and missing values in the audiometry file.
- Increase testing of non-exposed workers in all sites (as recommended by NIOSH, 1998) to provide better internal control data.

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Appendix A: Audiometry Database Fields

Table A.1 WCB Audiometry Database File Structure

Field	Retained for Analysis	Description
ID	√	Unique personal identifier
AGE	√	Age of subject
DOB		Date of birth
SIN		Social insurance number
SUBCLASS		Industry subclass identifier
FIRM_NO		Company identifier
LOC_NO		Location identifier (within FIRM_NO)
OCCUP	√	WCB occupation code
OCCYRS		Years at occupation
HP_USER	√	Hearing protection user?
TESTDATE	√	Date of test (YYMM)
TESTTYPE		Baseline or periodic hearing test
TESTCAT		Classification of test outcome
TESTYEAR		Year of test
AGEGROUP		Age category
HRS_AWAY		Hours away from noise before test
HRS_IN		Hours in noise before test
HPWRNREG		Type of hearing protector regularly worn
HPBEFTST		Type of hearing protection before test
LE1000HZ	√	Hearing threshold, left, 1000Hz
LE2000HZ	√	Hearing threshold, left, 2000Hz
LE3000HZ	√	Hearing threshold, left, 3000Hz
LE4000HZ	√	Hearing threshold, left, 4000Hz
LE500HZ	√	Hearing threshold, left, 500Hz
LE6000HZ	√	Hearing threshold, left, 6000Hz
LE8000HZ		Hearing threshold, left ear, 8000 Hz
RE1000HZ	√	Hearing threshold, right, 1000Hz
RE2000HZ	√	Hearing threshold, right, 2000Hz
RE3000HZ	√	Hearing threshold, right, 3000Hz
RE4000HZ	√	Hearing threshold, right, 4000Hz

RE500HZ	√	Hearing threshold, right, 500Hz
RE6000HZ	√	Hearing threshold, right, 6000Hz
Field	Retained for Analysis	Description
RE8000HZ		Hearing threshold, right ear, 8000 Hz
MEDHXA		ENT visit in last 5 years
MEDHXB	√	Ever had severe ear infection
MEDHXB2		Ear infection left or right
MEDHXE	√	Ever had ear surgery
MEDHXE2		Ear surgery left or right
MEDHXF	√	Ever had dizziness or balance problem
MEDHXG	√	Ever had a serious head injury
MEDHXG2		Head injury left or right
MEDHXH		Ever Blast exposure
MEDHXH2		Blast exposure left or right
MEDHXI		Ever had hearing aid
MEDHXI2		Hearing aid left or right
MEDHXJ	√	Ever had a relative with hearing loss before age 50
NOISEHXA	√	Ever been exposed to loud noise at prior job
NOISEHXB	√	Ever been exposed to noise off job
NOISEHXC	√	Ever been exposed to noise in armed forces
FIREARMA	√	Ever hunted
FIREARMB	√	Ever shot trap/skeet/target (not handguns)
FIREARMC	√	Ever shot handguns
FIREARMD		Hearing protection worn while shooting
FIREARME		Shoulder shot from
FIREARMF		Number of years shooting

Appendix B: Noise Exposure Levels in Sawmill-Related Occupations

The following list gives WCB occupation code and standardized WCB job title (used in audiometry file), as well as the matched UBC standardized job title which had earlier been used to code WCB sawmill exposure data that has no standardized job coding in the raw Noise Exposure file.

Where a UBC standardized job title exists, the number of dosimetry measurements used in the estimation of the 8-hr Leq is given. Where the UBC standardized job is blank, the noise level was estimated from non-sawmill exposure data provided at a later date by the WCB. In all cases the number of hearing tests to which the estimate was applied is given.

The table is in order of occupation code.

Table B.1 Noise Exposure Assessment

WCB Occupation Code	WCB Standardized Job Title	UBC Standardized Job title	Number of dosimetry measurements used in estimate	Noise Exposure Level (dB(A)) 8-hr L_{eq}	Number of observations in audiogram Database
1113129	OFFICE/CLERICAL WORKER	CLERK	8	80.8	546
1116621	SAFETY/HYGIENE/INSPECTION OFFICER	MANAGER/SUPERINTENDENT		88.2	37
1133699	TEACHER/INSTRUCTOR	CLERK		80.8	3
2142510	ENGINEER (PROF;ENVIRONMENTAL)	CLERK		80.8	149
2145640	INSPECTOR/QUAL CTRL/ENV MONITOR/FIELD OP			92.3	1004
2161510	TECHNICAL SPECIALIST/INSTRUMENT TECH	ELECTRICIAN		88	67
2163466	DRAFTSPERSON/LAYEROUT	CLERK		80.8	94
3135276	FIRST AID ATTENDANT	FIRST AID	2	67.5	754
4143149	COMPUTER OPERATOR	CLERK		80.8	28
4153731	SHIPPER/RECEIVER		5	81.3	1173
4155138	TALLYPERSON/CHECKER	TALLYMAN	14	81.8	2309
4155790	PARTSMAN/STOCK CLERK/TOOL CRIB			79	180
4157677	WEIGH SCALE OPERATOR	YARD WORKER		81.6	41
5133855	SALESPERSON/SERVICE PERSON	YARD WORKER		81.6	210
5193204	DELIVERY DRIVER			86.5	13
6111255	FIRE INSPECTOR	MANAGER/SUPERINTENDENT		88.2	8
6115913	WATCHMAN/SECURITY	WATCHMAN	10	88	1552
6191349	CLEANUP/JANITOR/UTILITY/MAINTENANCE	CLEANUP	113	93.3	14730
7112319	GARDENER/GROUNDSKEEPER/LANDSCAPER			81.6	13
7511255	AVALANCHE CREW/TRAIL CREW/FOREST TECH	FOREST CONSERVATION OFFIC		83	344
7511316	FIRE WARDEN/FIRE CHIEF	MANAGER/SUPERINTENDENT		88.2	22
7513267	FALLER/BUCKER/POWERSAW OP/CHAINSAW OP	BUCKER	14	95.9	1021
7513450	CAT SWAMPER			90	48
7513478	BUNCHER/FELLER/DELIMBER/LOG PROCESSOR	BUCKER	14	95.9	172
7517062	BOOM WORKER	BOOMMAN	28	84.3	2315
7517126	SKIDDER OPERATOR		2	99.5	297
7517137	CHASER			91.2	196

WCB Occupation Code | WCB Standardized Job Title | UBC Standardized Job title | Number of dosimetry measurements used in estimate | Noise Exposure Level (dB(A)) | Number of observations in audiogram Database

			estimate	8-hr L_{eq}	Database
7517202	FLUME TENDER/SLIP WORKER	SLIPMAN	12	89.4	18
7517255	FORESTER/CONSERVATION OFFICER			83	1235
7517425	LANDING WORKER/LOG DECK WORKER	LOG DECKMAN	33	89	383
8153327	SCREEN TENDER	CHIPE SCREEN TENDER	3	93	4
8159521	MOULD HANDLER			96.5	3
8171143	GRINDER/RUBBER	GRINDERMAN	21	85.7	145
8173478	PRESS OPERATOR		1	89	186
8228458	PRODUCTION LINE WORKER	AVG[…]		93.1	287
8231059	SHAKE/SHINGLE WORKER		2	90.8	116
8231088	SAWYER	HEAD SAWYER	168	87.8	10676
8231142	CHIP & SAW OPERATOR	CHIPNSAW	65	84.1	3049
8231216	DRAGSAW OPERATOR	CUTOFF SAW	178	81.9	79
8231317	GANG OPERATOR	GANG SAW	4	96.3	1296
8231745	SLASHER		24	91.4	362
8231806	SHAKE/SHINGLE SAWYER		4	95.25	104
8231856	TRIMMER	TRMMER OPERATOR	523	96.8	11114
8233472	CLIPPER/JOINTER OPERATOR			94.7	585
8233473	GRADELINE/LATHE OPERATOR		3	93.3	317
8233474	STRIP SAW/RECOVERY			90.8	381
8233893	MILL/PLYWOOD WORKER	AVG[…]		92.3	5689
8235413	KILN OPERATOR	KILN OPERATOR	9	87.9	1065
8236455	GRADER/HANDLER/SORTER/SCALER	GRADER	265	95.2	13957
8238038	BARKER OPERATOR/DEBARKER	BARKER OPERATOR	244	82.9	5811
8238051	SAWMILL HAND	LABOURER		93.8	33874
8238134	GREENCHAIN OP/OFFBEARER/PLANER CH PULLER	OFFBEARER	229	87.8	18463
8238166	CONVEYOR WORKER		14	92.5	63
8238240	EDGER OPERATOR	EDGER OPERATOR	592	93.8	7065
8238241	EDGER/GANG TAILER	TAILSAWYER	336	98.9	2425
8238359	HOG ATTENDANT	HOG OPERATOR	27	90.4	417
8238595	PLANER OPERATOR	PLANER FEEDER	81	99.2	6789
8238655	RESAW OPERATOR	RESAWYER	293	97.3	3941
8238756	DROP EDGE SORTER	DROPSORT OPERATOR	312	97.8	6097
8238762	SPOTTER	SPOTTER	137	98.1	179
8239202	DECK WORKER(SAWMILLS)	LOG DECKMAN	33	88.9	1571
8239332	CHIPPER OP/BEATER/GRINDER	CHIPPER OPERATOR	194	101.7	6106
8256830	TESTER			94.6	107
8311708	TOOL & DIE MAKER	MACHINIST		80.7	17
8313477	MACHINE SHOP WORKER			86.3	19
8313479	MACHINIST	MACHINIST	9	80.7	1331
WCB Occupation Code	WCB Standardized Job Title	UBC Standardized Job title	Number of dosimetry measurements used in estimate	Noise Exposure Level (dB(A) 8-hr L_{eq}	Number of observations in audiogram Database
8313718	MACHINE TOOL SETTER	MILLWRIGHT		90.9	2
8331048	BLACKSMITH/FORGER	MILLWRIGHT		90.9	37
8331497	CHAINMAKER			94	246
8333725	SHEET METAL WORKER/TINSMITH	SHEET METAL WORKER	3	91.3	3

8333726	ASSEMBLER			92.3	9
8335917	WELDER	WELDER	20	87.4	3951
8339708	SAWMAKER/SAWSMITH	SAWFILER		90.5	34
8339925	WIRE ROPE WORKER	WIRE-TIE	7	86.3	13
8393707	FILER/FITTER	SAWFILER (EXCL FITTER)	41	90.5	7760
8513497	AUTO BODY SHOP WORKER			84.5	1
8523492	MECHANIC (AUTO, BOAT, GAS, CHAINSAW)	MECHANIC	8	82.8	667
8549046	BENCH HAND	BENCHMAN	20	90.6	859
8549931	WOODWORKER	CARPENTER		87.3	141
8573894	TIREPERSON			93	19
8579478	MACHINE OPERATOR	AVG[…]		93.9	1146
8584492	HEAVY DUTY MECHANIC	MECHANIC	8	82.8	4769
8584505	MILLWRIGHT	MILLWRIGHT	59	90.9	20048
8589556	WIPER/OILER/GREASER	OILER	10	88.8	2645
8592397	JOINER			95	11
8595017	SPRAY BOOTH OPERATOR	GRADER		95.2	470
8595575	PAINTER (BRUSH)			90.3	143
8715423	LABOURER	LABOURER	4	93.8	2380
8719393	JACKHAMMER OPERATOR			105	4
8733243	ELECTRICIAN (INCL. HELPER;APPRENTICE)	ELECTRICIAN	26	88	6810
8780768	STEAMFITTER	PIPEFITER	2	90.5	28
8781121	CARPENTER	CARPENTER	9	87.3	1806
8791591	SPRINKLER FITTER/PIPEFITTER	PIPEFITTER	2	90.5	1122
9130811	YARDMASTER	YARD WORKER		81.6	3
9131444	ENGINEER(LOCOMOTIVE)	TRAIN DRIVER	4	85.9	9
9131514	ENGINE WORKER	MECHANIC		82.8	42
9139119	UNLOADER	FORKLIFT		90.1	58
9151054	CAPTAIN (MARINE)	BOAT OPERATOR	67	90.8	163
9151201	MARINE DECK WORKER(DECK OFFICER,SEAMAN)	BOAT OPERATOR	67	90.8	55
9159053	DOZER/BOOM BOAT OPERATOR	BOAT OPERATOR	67	90.7	1384
9159201	BARGER/SCOW TENDER	SCOWMAN	9	81.8	269
9175860	TRUCK DRIVER	TRUCK DRIVER	4	85.8	2012
9193676	PAINTER		1	87	29
9238051	CAR BLOCKER			88	395
9238187	CANT HOOK WORKER	EDGER/GANG TAILER		98.9	270
9311361	HOIST/WINCH OPERATOR	HOIST OPERATOR	24	95.2	2036

WCB Occupation Code	WCB Standardized Job Title	UBC Standardized Job title	Number of dosimetry measurements used in estimate	Noise Exposure Level (dB(A) 8-hr L_{eq}	Number of observations in audiogram Database
9311362	CRANE CHASER/SLINGER		5	82.6	112
9313214	WHARF WORKER/LONGSHORE WORKER	YARD WORKER		81.6	111
9313227	DUMPER		1	94	15
9313801	SWAMPER		8	90.2	470
9313908	WAREHOUSE WORKER		2	75	318
9315119	TANK FARM OP/CAR LOADER (INCL. RAIL)		6	81.2	399
9315124	FRONT END LOADER/FORKLIFT OPERATOR	FORKLIFT	141	90.1	23819
9315126	EQUIP OP/HEAVY(DOZER,CAT,BACKHOE,CRANE)	CAT OPERATOR	65	90.6	3739

	OP/HEAVY(DOZER,CAT,BACKHOE,CRANE)				
9315457	AUTOSTACKER OP (SM;PM)	STACKER OPERATOR	147	92	5153
9317101	BAGGER/WRAPPER/TIEUP/BUNDLER/STRAP/BALER	PACKAGE PRESS	21	85.8	4539
9317422	LABELLER/PACKER			82.5	684
9318457	LUMBER PILER	OFFBEARER	229	87.8	10269
9319119	LOADER (BY HAND)			81.5	2051
9393707	SAW FILER	SAWFILER	41	90.5	1230
9539247	FIREPERSON/STATION.ENGINEER(POWER PLANT)	POWER HOUSE MAINTENANCE	15	82.7	1778
9910390	CHARGEHAND/SUPERVISOR/FOREMAN	FOREMAN	59	90.3	14221
9910518	MANAGER/SUPERINTENDENT/WARDEN	MANAGER/SUPERINTENDENT	19	88.2	1293
9918949	YARD WORKER			81.6	291
9999999	NO NOISE			75	7838

Appendix C: Sources of data error on audiometric database

Only those variables listed in Appendix A as retained for analysis were checked. Among the issues that were identified were:

- "TESTTYPE" - baseline measurements: of 68027 aggregated trajectories, 18,943 had no baseline.
- "OCCUP" - Non-sawmill jobs attributed to sawmill industry
- "OCCUP": code "9999999" (non-exposed) couldn't be verified because no job title given.
- Unidentified codes in medical, noise exposure and firearm history variables
- Some birth dates had non-integer values in month, and some months = 13 or 18
- Multiple occurrences where "OCCYRS" > age (or implausible for given age)
- Multiple occurrences where individuals had inconsistent DOB