

Contributions of Non-occupational Activities to Total Noise Exposure of Construction Workers

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This paper describes how exposures received during routine and episodic non-occupational activities contribute to total noise exposure in a group of occupationally exposed workers. Two-hundred and sixty-six construction apprentices enrolled in a longitudinal hearing loss study and completed questionnaires at 1 yr of follow-up to determine their episodic activities (e.g. concert attendance, power tool use, firearms exposure). Noise exposure levels for these episodic exposures were determined from the published literature. Routine activities were assessed using activity cards filled out over 530 subject-days, along with noise dosimetry measurements made over 124 subject-days of measurement. Equivalent L_{eq} exposure levels were then calculated for specific activities. These activity-specific L_{eq} values were combined into estimated individual annual L_{eq} exposure levels for the 6760 nominal annual non-occupational hours in a year ($L_{Aeq6760h}$), which were then transformed into equivalent levels for a 2000 h exposure period ($L_{A2000hn}$) for comparison with occupational noise exposure risk criteria. The mean non-occupational $L_{Aeq6760h}$ exposure values for the cohort ranged from 56 to 87 dBA (equivalent $L_{A2000hn}$ 62–93 dBA). At the mid range of the routine and episodic activity exposure level distribution, the mean $L_{Aeq6760h}$ was 73 dBA ($L_{A2000hn}$ 78 dBA). Nineteen percent of the $L_{A2000hn}$ non-occupational exposures exceeded 85 dBA, the generally recommended occupational limit for a 2000 h workyear, at the mid-range of exposure levels. Due to a lack of available data, firearms use could not be incorporated into the total noise exposure estimates. However, firearms users reported more exposure to other noisy non-occupational activities and had statistically significantly higher estimated exposure levels even without including their firearms exposure than did non-shooters. When compared with the high levels of occupational noise found in construction, non-occupational noise exposures generally present little additional exposure for most workers. However, they may contribute significantly to overall exposure in the subset of workers who frequently participate in selected noisy activities.

Keywords: exposure assessment; hearing loss risk; non-occupational noise

INTRODUCTION

The relationship between exposure to high levels of occupational noise and hearing loss has been known for hundreds of years. Since the 1950s, models have been developed which relate the intensity and duration of occupational noise to the severity of the resulting noise-induced hearing loss (NIHL) (Glorig *et al.*, 1961; Kryter *et al.*, 1966; Passchier-Vermeer, 1973). These models provided the basis for the development of occupational noise exposure standards,

which have in some situations reduced the incidence of NIHL (Bruhl and Ivarsson, 1994; Gillis and Harrison, 1998).

However, in many nations, including the USA, the occurrence of NIHL has not dropped dramatically and has even been reported to have increased, despite the presence of pertinent standards (Reilly *et al.*, 1998; Daniell *et al.*, 2002). Agencies which regulate occupational noise exposure almost universally specify a permissible 8 h equivalent average (L_{A8hn}) exposure of 85 dBA (assuming 2000 h of work annually). These occupational standards assume that recovery from noise effects will occur during time

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away from work and also typically allow for some acceptable risk of NIHL.

Because occupational exposures are now more regulated than they have been historically, some have argued that any substantial hearing loss in workers may be due to unregulated non-occupational exposures (Johnson, 1991; Axelsson, 1996). Even children too young to have experienced occupational noise exposure can develop NIHL (Niskar *et al.*, 2001), presumably from non-occupational and environmental noise sources. Despite workplace noise regulations and national campaigns to reduce non-occupational noise exposure (Hohmann *et al.*, 1999), noise exposure remains a significant threat to public health (Passchier-Vermeer and Passchier, 2000).

Little research has been done to realistically estimate the magnitude of non-occupational noise exposure levels and, as a result, there is a paucity of reliable and comprehensive estimates of the risk of NIHL associated with such exposure. Most studies have investigated either the magnitude of non-occupational noise levels, exposure durations or participation rates in noisy non-occupational activities in a population. Other studies have assessed the link between NIHL and certain non-occupational activities, such as recreational firearms use, but did not thoroughly characterize the levels or durations associated with the activities themselves (Johnson and Riffle, 1982; Phaneuf and Hetu, 1990; Kryter, 1991; Dalton *et al.*, 2001).

The current study used exposure measurements and the reported frequency of selected non-occupational activities gathered as part of a longitudinal study of noise exposure and hearing loss in apprentice construction workers, along with previously published noise exposure levels associated with episodic activities to estimate annualized non-occupational noise exposures in that population. These estimates were then compared with typical occupational exposures.

MATERIALS AND METHODS

A cohort of apprentice construction workers from a variety of trades in the Puget Sound area of Washington State was assembled from 1999 to 2000 to participate in a 5 year longitudinal study of noise exposure and hearing loss. All participants in the incoming classes of 10 apprenticeship programs were asked to participate in the study. A total of 394 subjects were enrolled and 266 (68%) of them were seen at a first follow-up visit ~1 yr later. Loss to follow-up in the first year was primarily due to individuals leaving the construction industry. Subjects received information regarding the study and signed an informed consent form prior to participation. All study procedures were approved by the University of Washington institutional review board. Each subject

completed a baseline and one to three annual computer-based follow-up questionnaires delivered by trained interviewers. These questionnaires included questions about participation in specific noisy non-occupational activities.

The present study is based on the first follow-up questionnaire in the longitudinal study, supplemented by daily activity logs and personal dosimetry completed by a subset of the study population. The questionnaire included questions about exposures to noise during 'routine' daily activities (home, travel, shopping, etc.) and 'episodic' activities (using power tools, attending sporting events, etc.). Episodic exposures were assessed separately from routine activities because the daily activity logs and personal dosimetry did not provide enough data to characterize all of the relatively infrequent episodic activities. Routine activity exposures were estimated using daily activity logs and noise levels measured by dosimetry during this study. Episodic activity exposures were estimated using the questionnaire responses concerning the frequency with which these activities were undertaken and noise levels associated with these activities reported in the published literature. Estimates for total non-occupational noise exposure used low, medium and high estimates of the exposure levels associated with each routine and episodic activity. Figure 1 outlines the sources of data used in this study and also indicates the combinations of data used to estimate non-occupational noise exposure levels.

Two noise exposure metrics were used to summarize this exposure information. The exposures were extrapolated to the nominal 6760 h of non-occupational time in a year ($365 \text{ days/yr} \times 24 \text{ h/day}$, less 40 h/week of worktime for 50 weeks/yr, or 2000 h) and the annual exposures were then integrated to determine a 2000 h equivalent exposure (i.e. the noise level that would have occurred if the sound energy associated with the total 6760 h exposure had instead occurred over a 2000 h interval). The 2000 h equivalent exposure levels allow direct comparison with risk estimates for occupational exposures. This approach has been employed elsewhere (Medical Research Council Institute of Hearing Research, 1986).

Routine activity estimates

The time spent doing routine activities (Routine Frequency in Fig. 1) was assessed using activity logs distributed to the cohort by mail. The activity logs provided a continuous timeline designed to cover both workshifts and intervening non-work periods. The logs contained a pre-selected list of occupational and non-occupational activities and equipment. The six pre-selected non-occupational activities were: bar, restaurant, shopping, theater; home; listen to music or watch TV; travel in a car or bus; yardwork;

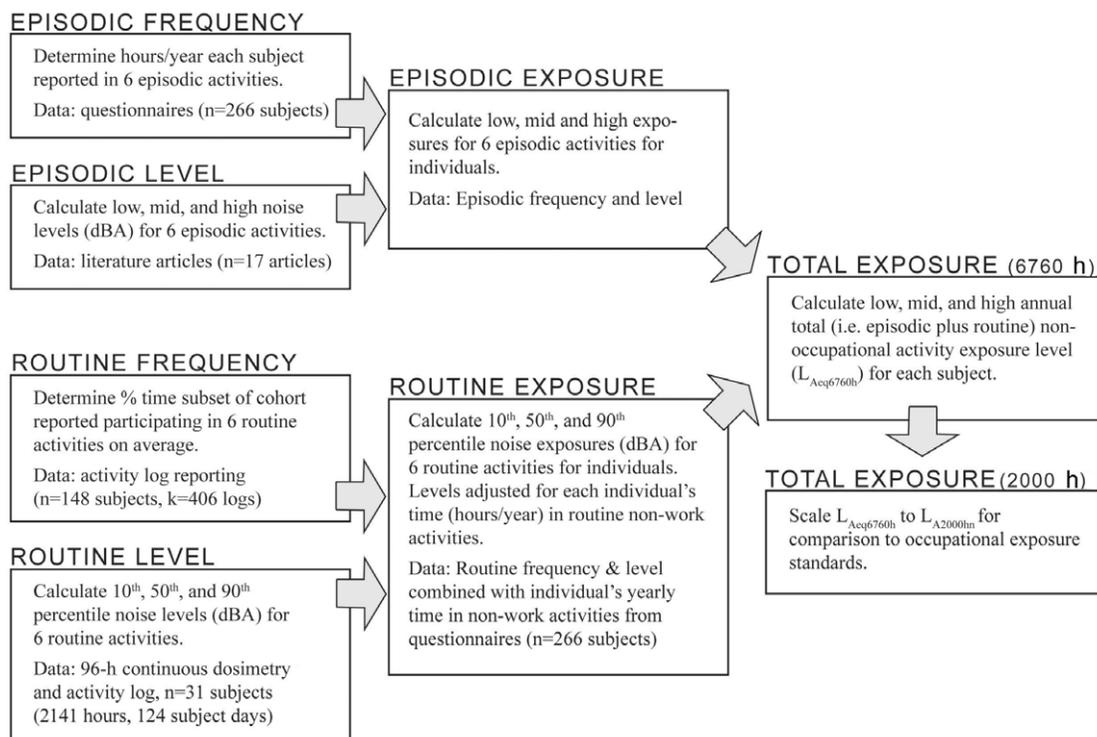


Fig. 1. Overview of data sources and combination of data.

other. The average fraction of non-occupational time spent in each of these activities was calculated over the full 530 subject-days of activity log reporting. The activity-specific fractions of time at the cohort level were then assigned to each individual in the cohort to estimate the time individuals spent in each activity. The design of these activity logs has been previously validated for occupational noise exposure assessment (Neitzel *et al.*, 1999; Seixas *et al.*, 2001; Reeb-Whitaker *et al.*, 2004).

Noise exposure level data for routine non-occupational activities (Routine Level in Fig. 1) were collected using Quest Q-300 data logging noise dosimeters with a measurement range of 40–110 dBA, criterion level of 85 dBA, slow response, no threshold and a 3 dB exchange rate. Dosimeters were issued to 31 volunteer subjects, who wore the dosimeters for four consecutive days (including two non-work days) and simultaneously completed free-field activity logs. Activity information from these logs was collapsed into the six major routine activities listed previously. The activity data and the corresponding 1 min L_{eq} sound levels were merged and then were aggregated within each subject to determine their total time spent in each activity and their activity-specific L_{eq} exposure levels. The activity-specific L_{eq} values were combined for all subjects reporting the activity to calculate the mean L_{eq} and 10th, 50th, and 90th percentile L_{eq} values for each

activity (Routine Exposure in Fig. 1). These dosimetry measurement methods and results are described in more detail elsewhere (Neitzel *et al.*, 2004).

Episodic activity estimates

The frequency and duration of exposure to infrequent, or episodic, non-occupational activities (Episodic Frequency in Fig. 1) was measured using the first annual study questionnaire, completed by all study subjects. Subjects reported the total number of hours spent in the following four activities over the previous 12 months: riding motorcycles; riding snowmobiles or jetskis; piloting an aircraft; using power tools. These responses were standardized to a 1 yr reporting interval because the duration that the questionnaire covered was not always exactly 12 months. Frequencies of participation for firearm use, heavy machinery operation and loud recreational activities (attending concerts, dances, races, or commercial sporting events) were rated categorically as daily, weekly, monthly or less than monthly. These responses were converted to total time per year as follows: daily, 4 exposure h/day for 200 days/yr (800 h/yr); weekly, 4 exposure h/week for 50 weeks/yr (200 h/yr); monthly, 4 exposure h/month for 12 months/yr (48 h/year); less than monthly, 4 exposure h/year. These values were selected to approximate the nominal value of the categories used on the ques-

tionnaire (i.e. daily would not mean every day, but instead an average of four out of every seven days).

The noise levels associated with six of the seven evaluated episodic activities (Episodic Level in Fig. 1) were obtained by a thorough review of the published scientific literature which quantified exposure levels associated with the specific activities addressed in this analysis. The data, summarized in Table 1, were limited to average A-weighted levels and did not include the more frequently reported maximum weighted sound pressure levels (L_{max}) for these activities. The literature noise values were summarized for each episodic activity as 'low' and 'high' (each of which was derived as the arithmetic average of the lowest and highest noise levels reported in each study) and 'mid' (the mid-point between the low and high levels).

Firearms use

Some authors consider recreational firearms use to be the most damaging non-occupational noise exposure (Johnson and Riffle, 1982; Kryter, 1991). However, because there are no validated models for integrating impulse noise from firearms into average L_{eq} levels, the peak sound pressure levels of firearms available in the literature could not be included in the final estimated annual exposure levels. Firearms use frequencies are included here for informational purposes, but firearms noise levels and participation duration data were not used in the estimation of annual exposure levels. Only 22% of individuals in this study reported using firearms, so the risk estimates presented here can be considered representative for the majority of subjects assessed. For those subjects with substantial exposure to firearms, and

Table 1. Episodic non-occupational activity noise levels from literature and reported episodic activity occurrence for 266 subjects

Episodic activity	Group	No. of subjects	Participation duration (h/yr) from questionnaire					L_{eq} levels (dBA) from literature ^a		
			Percent of all subjects	Mean	10th percentile	50th percentile	90th percentile	Low	Mid	High
Light aircraft ^d	All subjects	2	0.8	0	0	0	0	88	91	94
	Shooters	0	0	0	0	0	0			
	Non-shooters	2	1	0.1	0	0	0			
Loud recreation ^b	All subjects	155	59	16	0	3	47	81	94	106
	Shooters	35	60	15	0	4	48			
	Non-shooters	120	57	15	0	4	48			
Machinery ^c	All subjects	46	17	17	0	0	44	87	97	106
	Shooters	21	36	21	0	0	48			
	Non-shooters	26	12	16	0	0	4			
Motorcycles ^f	All subjects	57	22	15	0	0	7	93	100	107
	Shooters	26	45	23	0	0	48			
	Non-shooters	31	15	14	0	0	17			
Power tools ^g	All subjects	146	55	56	0	3	145	75	94	113
	Shooters	42	72	81	0	23	242			
	Non-shooters	105	50	49	0	0.5	57			
Snowmobiles, jetskis ^h	All subjects	44	17	8	0	0	10	83	95	107
	Shooters	14	24	16	0	0	52			
	Non-shooters	30	14	4	0	0	13			
Firearms ⁱ	All subjects	58	22	10	0	0	7		c	
	Shooters	58	100	52	4	4	200			

^aLow values are the arithmetic mean of the lowest activity values listed in each reported study, high values are the arithmetic mean of the highest activity values listed in each reported study and mid values are the arithmetic average of the low and high values.

^bLoud recreation consists of rock concerts (Axelsson, 1996; Cohen *et al.*, 1970; Yassi *et al.*, 1993), races (Roberts, 1999) and commercial sporting events (Axelsson, 1996).

^cFirearms levels reported in the literature represent peak (instantaneous) levels rather than equivalent continuous (L_{eq}) levels and cannot be included in this model.

^dTobias (1969), Cohen *et al.* (1970), Smith *et al.* (1975).

^eJones and Oser (1968), United States Office of Noise Abatement and Control (1978), Holt *et al.* (1993).

^fCohen *et al.* (1970), United States Office of Noise Abatement and Control (1978), Ross (1989), McCombe *et al.* (1994).

^gCohen *et al.* (1970), United States Office of Noise Abatement and Control (1978), McClymont and Simpson (1989).

^hBess and Poyner (1974), United States Office of Noise Abatement and Control (1978), Anttonen *et al.* (1994).

ⁱJohnson and Riffle (1982), Kryter (1991).

particularly for approximately one-third of firearms users evaluated who reported never using hearing protection while shooting, the risk levels estimated here are low. To explore whether the total noise exposures of those who reported using firearms differed from non-firearms users in ways other than firearms use, shooters and non-shooters were separated for some analyses in the current study.

Estimation of non-occupational noise exposures

Activity-specific L_{eq} noise levels were estimated for each individual by combining the annual number of hours each individual spent in the six evaluated episodic activities (based on questionnaire responses and excluding firearms use) with the noise levels (low, mid and high level data) obtained from the literature for these six episodic activities. These levels (Episodic Exposure in Fig. 1) were then combined with the routine activity estimates derived from the annual number of hours each individual was estimated to have spent in the six routine activities (based on the cohort-average fraction of time in each of these activities) and with the 10th, 50th and 90th percentile noise levels for these six routine activities.

The activity-specific L_{eq} values were compiled for each individual into an overall annual non-occupational exposure level ($L_{Aeq6760h_i}$) integrated over a 6760 h period using the following equation:

$$L_{Aeq6760h_i} = 10 \log_{10} \frac{1}{T_n} \sum t_{ij} 10^{L_{eqj}/10} \quad (1)$$

where T_n is the reference annual non-occupational time (6760 h), t_{ij} is the time spent at activity j (h) by individual i and L_{eqj} is the equivalent sound pressure level of non-occupational activity j (dBA). Alternative estimates were made for each subject based on all possible combinations of no, low, mid or high episodic and routine noise exposure levels.

The subject-specific average annual 6760 h non-occupational L_{eq} levels [Total Exposure (6760 h) in Fig. 1] were integrated over a shorter exposure duration of 2000 h (for direct comparison with risk estimates for occupational exposure) using the following equation:

$$L_{Aeq2000h_i} = L_{Aeq6760h_i} + 10 \log_{10} \left(\frac{T_n}{T_o} \right) \quad (2)$$

where $L_{Aeq6760h_i}$ is the standardized annual equivalent non-occupational sound pressure level for individual i , T_n is the reference non-occupational exposure duration (6760 h) and T_o is the reference occupational exposure duration (2000 h). The 2000 h equivalent exposure level [Total Exposure (2000 h) in Fig. 1] was always 5.3 dBA higher than the 6760 h average level. Using the various combinations of low, mid and high exposure estimates for each subject, the overall sample averages and subject exceedance percentages (i.e. the percentage of subjects whose

annual exposure exceeded 70, 75, 80, 85 and 90 dBA) were calculated. Analyses were further stratified by firearms use, with levels estimated for non-shooters and for shooters without including their firearms exposure.

RESULTS

A total of 266 apprentice construction workers from 10 trades (bricklayers, brick restoration workers, carpenters, cement masons, electricians, insulation workers, iron workers, operating engineers, sheet-metal workers and tile setters) completed the first follow-up questionnaire in the 5-yr longitudinal noise and hearing loss study. The mean age of all subjects was 28.6 ± 6.2 yr and the mean length of the period covered by the follow-up questionnaire was 56 ± 17 weeks.

A total of 9724 hours of activity log information was collected over 406 total subject-days. These data were reported by a total of 148 out of 266 (56%) subjects who received the logs. An additional 2141 h of simultaneous activity log reporting and dosimetry noise levels were collected over 124 subject-days. These dosimetry measurements were made on 31 apprentice construction workers from six trades drawn from the same population from which the study subjects were recruited.

Routine activities

The annual participation and noise exposure levels for the six routine activities are listed in Table 2. The largest amount of non-occupational time reported by activity log (nearly 50%) was spent in quiet activities at home, while the smallest amount of time was spent doing yardwork. Mean dosimetry-derived L_{eqA} sound pressure levels ranged from 67 (home) to 79 dBA (yardwork). The overall 10th, 50th and 90th percentile levels were 40, 58 and 76 dBA, respectively. L_{eq} levels <40 dBA were assigned a value of 39.9 dBA by the dosimeters, resulting in a slightly biased estimated mean L_{eq} . However, this bias does not affect percentiles and would have a negligible effect on estimates of risk in the current study.

Episodic activities

Table 1 shows the extent of reported involvement in the seven noisy episodic activities covered in the questionnaires and the range of literature-derived exposure values associated with these activities (with the exception of peak noise levels associated with firearms, which could not be incorporated into this study). These data were also stratified according to subjects' reported use or non-use of firearms. Of the 59 subjects (22%) who reported firearms use, 62% reported less than monthly use. Over half of all subjects reported regular non-occupational use of power tools and attending loud recreational activities

Table 2. Routine non-occupational activity noise levels from dosimetry and cohort-reported routine activity occurrence

Routine activity	Time reported via activity log			Activity-specific levels (L_{eqA} , in dBA) from dosimetry and activity log				
	Total h reported	Percent total	Hours/yr ^a	Total L_{eqA} hours measured	Mean level ^b	10th percentile	50th percentile	90th percentile
Bar, restaurant, shopping, theater	318	3	223	20	71	43	70	77
Home	4739	49	3292	952	67	40	52	70
Listen to music	988	10	690	701	73	40	60	76
Travel in a car/bus	1754	18	1217	121	78	41	70	84
Yardwork	268	3	189	16	79	46	70	78
Other	1656	17	1149	332	76	40	62	80
Total	9724	100	6760	2141	74	40	58	76

^aAssumes 2000 h of worktime and 6760 h of non-worktime per year.

^bBiased because $L_{eq} < 40$ dBA were recorded as 39.9 dBA.

like concerts, dances, races and commercial sporting events. Fewer subjects reported participating in the other non-occupational activities. A higher percentage of shooters reported loud machinery use, motorcycle use, power tool use and snowmobile use than did non-shooters, and the amounts of time spent at these noisy activities were higher for shooters than for non-shooters, in some cases (e.g. power tool use and snowmobile use) substantially higher.

Integrated annual non-occupational noise exposure level estimates

The estimated non-occupational exposure levels over 6760 h of non-occupational activity and the same levels represented as 2000 h equivalent values are given in Table 3 for all combinations of low, mid and high episodic and routine activity levels. The mean $L_{Aeq6760h}$ level at the low, mid and high ranges of routine and episodic activity levels was 56, 73 and 87 dBA, respectively.

Integration of the same 6760 h exposure dose over a 2000 h exposure period yielded exposure estimates 5.3 dBA greater than the corresponding 6760 h estimate. The mean $L_{A2000hn}$ level at the low, mid and high ranges of routine and episodic activity levels was 62, 78 and 93 dBA, respectively.

In general, noise exposure associated with routine activities had more influence on the estimates of mean annual exposure level than did episodic activities. The difference in estimated annual noise levels was 37 dBA when comparing the low and high noise levels associated with routine activities (and assuming no episodic activities occurred), whereas the difference was only 24 dBA when comparing the low and high noise levels associated with episodic activities (and assuming no routine activities occurred) (Table 3). The only circumstance in which mean $L_{A2000hn}$ equivalent non-occupational exposure levels were estimated to exceed 85 dBA was when high episodic noise levels or high routine noise levels were used to derive the estimate.

Differences in annual non-occupational noise exposure level by reported firearms use

Table 4 presents the $L_{A2000hn}$ exposure estimates for non-shooters and for shooters without inclusion of firearms exposure, while considering the different noise levels that may be associated with routine and episodic activities. The corresponding annual $L_{Aeq6760h}$ levels can be calculated by subtracting 5.3 dBA from the $L_{A2000hn}$ levels shown in Table 4. It is interesting that, even excluding the effects of firearms exposure, shooters had higher non-occupational exposure levels than non-shooters because of their higher level of involvement in other noisy activities. For instance, there was a 13 and 14 dBA difference between non-shooters and shooters without their firearms exposure for episodic activities alone at the low or mid levels of exposure, respectively. At the high range routine and episodic activity levels, the difference in $L_{A2000hn}$ levels between shooters and non-shooters is smaller (4 dBA) but still present. The $L_{A2000hn}$ exposure levels for shooters are significantly higher for all possible combinations of low, mid and high routine and episodic activity exposure ($P < 0.001$, Mann-Whitney U -test).

Subject exceedance percentages

The estimated percent of subjects in the cohort with $L_{A2000hn}$ equivalent annual exposures exceeding thresholds in 5 dB steps from 70 to 90 dBA are shown in Table 5, for low, mid and high range routine and episodic exposure levels. Using the mid range of routine and episodic activity exposure levels, 19% of subjects had estimated equivalent 2000 h non-occupational exposure levels that exceeded 85 dBA, and 6% exceeded 90 dBA. Considering all possible combinations of low, mid or high routine and episodic exposure levels, the percent of subjects exceeding 85 dBA ranged from 1% (low range routine and episodic activity level estimates) to 72% (high range routine and episodic activity level estimates).

The estimated percent of subjects in the cohort with L_{A2000h} equivalent annual exposures exceeding the five threshold levels were also stratified by firearms use (Table 5). At the mid range episodic and routine activity noise levels, 16% of non-shooting subjects had 2000 h equivalent non-occupational exposure levels >85 dBA, compared to 29% of shooters excluding firearms exposure. Shooters had statistically significantly higher (χ^2 test, $P < 0.001$) levels than non-shooters in three of the five exceedance percentage steps for the low routine, low episodic activity noise combinations, three of the five steps for the mid routine, mid episodic activity noise combinations and two of the five high routine, high episodic activity noise combinations.

Table 3. Estimated mean annual 6760 h average non-occupational noise level and 2000 h^a equivalent level using low, mid or high noise levels for routine and episodic activities

Routine activity noise level	Annual noise level (dBA) ^a			
	Episodic activity noise level			
	None	Low	Mid	High
6760 h average level, $L_{Aeq6760h}$				
None		48	60	72
Low (10th percentile)	41	56	68	80
Mid (50th percentile)	64	67	73	84
High (90th percentile)	78	79	80	87
2000 h equivalent level, L_{A2000h} ^b				
None		54	65	77
Low (10th percentile)	46	62	73	85
Mid (50th percentile)	70	72	78	89
High (90th percentile)	84	84	86	93

^aBiased because $L_{eq} < 40$ dBA were recorded as 39.9 dBA.

^bEquivalent 6760 h dose received over a 2000 h exposure period.

Table 4. Estimated mean annual 2000 h^a equivalent non-occupational noise level using low, mid or high noise levels for routine and episodic activities for shooters, excluding firearms exposure, and non-shooters

Routine activity noise level	Group	L_{A2000h} noise level (dBA) ^{b,c}			
		Episodic activity noise level			
		None	Low	Mid	High
No routine activities included	Shooters without firearms		64	76	89
	Non-shooters		51	62	74
Low (10th percentile)	Shooters without firearms	46	67	79	93
	Non-shooters	46	60	71	83
Mid (50th percentile)	Shooters without firearms	70	73	81	94
	Non-shooters	70	72	77	88
High (90th percentile)	Shooters without firearms	84	84	86	96
	Non-shooters	84	84	85	92

^aEquivalent 6760 h dose received over a 2000 h exposure period; the 6760 h average level is 5.3 dBA less than 2000 h equivalent level.

^bBiased because $L_{eq} < 40$ dBA were recorded as 39.9 dBA.

^cDifferences between shooters and non-shooters statistically significant (χ^2 test, $P < 0.001$) for all combinations of low, mid and high routine and episodic noise levels.

In general, high subject exceedance percentages at the upper threshold levels (85 and 90 dBA) were seen only at the high range episodic and routine activity levels for the 2000 h equivalent annual non-occupational exposures. A much higher percentage of shooters were exposed above the higher thresholds, even without including their firearms exposure. This difference was statistically significant for many of the potential exposure combinations.

DISCUSSION

Estimation of the contribution of non-occupational noise exposure to NIHL is very important for both public health and medical/legal reasons. However, quantification of non-occupational noise exposures is extremely difficult, requiring data on sound pressure levels and the duration and frequency of participation for individuals or a population. Furthermore, exposure levels associated with non-occupational activities are highly dependent on the details of that activity and the context within which it occurs. As a result, any estimate of non-occupational noise exposure is necessarily crude and requires some bounding of the range of potential risks.

In the present analysis, several sources of data were utilized to estimate non-occupational noise exposure. The exposure estimates were based primarily on the reported experience of a group of 266 construction apprentices who provided information about the frequency with which they engaged in a number of non-occupational activities with known potential for high noise exposure. Although this sample is not necessarily representative of all construction workers or all apprentices with respect to their non-occupational activities and exposures, there is no reason to believe that their experience is particularly different from other young construction workers and is likely

Table 5. Estimated annual 2000 h equivalent non-occupational exposure (L_{A2000h})^a risk of overexposure at estimated episodic and routine activity exposure levels for all subjects, shooters, excluding firearms exposure and non-shooters

Group by activity noise level			Subject percent				
Group	Routine activity	Episodic activity	% > 70 dBA	% > 75 dBA	% > 80 dBA	% > 85 dBA	% > 90 dBA
All subjects	Low (10th percentile)	Low	24	13	4	1	0
Shooters without firearms			45	22 ^b	3 ^b	2 ^b	0
Non-shooters			18	10	4	1	0
All subjects	Mid (50th percentile)	Mid	83	59	34	19	6
Shooters without firearms			93 ^b	81 ^b	62	29	5 ^b
Non-shooters			80	53	26	16	6
All subjects	High (90th percentile)	High	100	100	100	72	60
Shooters without firearms			100	100	100	88 ^b	81 ^b
Non-shooters			100	100	100	67	54

^aEquivalent 6760 h dose received over a 2000 h exposure period.

^bDifference between shooters and non-shooters statistically significant (Mann–Whitney *U*-test, $P < 0.001$).

to be similar to many other North American blue collar groups.

Subjects participated in some of the non-occupational activities assessed in this study too infrequently for reliable estimation, so some noise level information used in this study was derived from published studies on these activities, providing a range of possible exposure values for each activity. The published range of levels was assumed to be representative of the activities, although it is possible that the levels are positively biased by their authors' interest in documenting the high range of possible risks.

Few studies have incorporated measures of noise exposure during routine daily activities such as listening to television, shopping or traveling by car or public transportation. To assess the contribution of noise exposure in these activities, subjects were asked to report the time spent in broad categories of routine activities on daily activity logs, and another group of construction apprentices wore datalogging dosimeters while simultaneously reporting their activities. The dosimeters used in this study were limited in their capacity to measure very low noise levels encountered frequently during the day. It was also not possible to estimate reliably the fraction of time individual subjects spent in each of the routine activities over the course of a year from the limited amount of self-report activity data collected. Instead, the cohort-average fraction of time for each activity was applied to each individual, resulting in a somewhat homogeneous distribution of activities at the individual level. Although the subjects and days on which activities were recorded and noise levels measured may not be fully representative of the average study subject, there is no reason to believe that the values obtained are atypical for young blue collar

workers. The use of a relatively crude timescale and categories covering multiple activities resulted in L_{eqA} exposure estimates that include a range of activities and have associated exposure levels which are often lower than those cited in the literature for specific activities. For example, the 90th percentile L_{eqA} noise level for the activity category bar, restaurant, shopping, theater (77 dBA) is lower than would be expected from a discrete measurement made in a theater during a movie. However, the level used here includes other activities with lower levels than would be obtained from a theater-only measurement. Similarly, the 90th percentile level associated with listening to music (76 dBA) is lower than the levels often cited in the literature, but the measurements from which this level was derived represent a number of subjects who probably listened to different kinds of music at varying distances and in various acoustic and social environments. The resulting level is lower than other maximum, or even typical, levels cited in the literature. Nevertheless, these data provide reasonable estimates of the distribution of routine daily exposures encountered by most members of the study population.

The use of firearms provided a particularly challenging aspect of this assessment. No validated models for calculating a simple integrated L_{eq} level for firearms exposure were available, so firearms noise exposure could not be included in the estimates presented here. However, even excluding firearms exposure, recreational shooters had a higher total noise exposure levels than did non-shooters. This suggests that some people who use firearms are at higher risk of NIHL than those who do not as a result of all of their non-occupational activities, and not just shooting.

By characterizing the range of possible activity frequencies and noise levels for both routine daily activities and occasional episodic activities, estimates were created for a range of non-occupational noise exposure scenarios. The most representative estimate (mid range for both routine and episodic activities) suggests an equivalent 2000 h exposure level of 78 dBA for the non-occupational activities of the construction apprentices studied. The actual exposure level estimated over the ~6760 h of non-work time in a year would be 73 dBA. Among this population of construction apprentices, at the mid range exposure levels, 16% of non-shooting subjects and 29% of shooters (without including their firearms exposure) have 2000 h equivalent non-occupational exposures which exceed 85 dBA, the level at which most occupational health agencies assume that there is an increased risk of NIHL. NIOSH estimates that there is an excess risk of 8% for a 25 dB average hearing loss at 1, 2, 3 and 4 kHz at an occupational $L_{A2000\text{h}}$ of 85 dBA and 25% excess risk at a level of 90 dBA (National Institute for Occupational Safety and Health, 1998). These risk estimates should also apply for non-occupational $L_{A2000\text{h}}$ exposure levels.

If the occupational exposure levels of construction workers are typically in the range 85–90 dBA L_{eq} , as has been reported elsewhere (Legris and Poulin, 1998; Neitzel *et al.*, 1999; Seixas and Ren, 2001; Kerr *et al.*, 2002), the highest non-occupational levels seen here could produce additional risk of NIHL in occupationally exposed individuals. Occupational (L_{eqO}) and non-occupational (L_{eqN}) annual exposure levels (both integrated over 2000 h intervals) can be logarithmically summed to obtain a total annual L_{eq} exposure level (L_{eqT}) for individual i using the equation

$$L_{\text{eqT}_i} = 10 \log_{10} \left[10^{\frac{(L_{\text{eqO}_i})}{10}} + 10^{\frac{(L_{\text{eqN}_i})}{10}} \right].$$

Using this equation, a construction worker with an occupational exposure level of 90 dBA who does not use firearms and is exposed to mid level episodic and routine non-occupational activity noise levels (2000 h equivalent annual non-occupational exposure level 77 dBA, from Table 4) would have a cumulative annual exposure level of 90 dBA, indicating that the non-occupational exposure would contribute essentially nothing to the cumulative exposure level. However, a worker with the same occupational exposure, and who does not use firearms, but who has high episodic and routine non-occupational activity noise levels (annual non-occupational exposure level 92 dBA, Table 4) would have a total annual exposure level of 94 dBA, with the non-occupational exposure contributing substantially to the total exposure level. If that same worker were to use firearms, the total exposure level would rise even further, especially if hearing protection was not used while shooting.

However, the additional exposure due to firearms use cannot be quantified using the current model.

Only 11% of subjects reported using headphones while listening to music, an exposure that cannot be accurately measured using dosimetry. Most subjects reported never using hearing protection devices (HPDs) during any episodic or routine non-occupational activities, with the exception of firearms use, in which almost 45% of subjects reported always using HPDs when firing. Lack of detailed HPD fit and attenuation data makes it impossible to estimate individual HPD attenuation factors. For both headphones and HPDs, however, the minimal reported use by subjects in this cohort allows reasonable modeling of noise exposure levels for the majority of the cohort.

Numerous authors have suggested that certain non-occupational noise exposures could conceivably cause NIHL, including public transportation (Cohen *et al.*, 1970), woodworking (Dalton and Cruickshanks, 2001), home power tools (McClymont and Simpson, 1989), firearms (Johnson, 1991; Axelsson, 1996; Stewart *et al.*, 2001) and listening to music (Yassi *et al.*, 1993; Hohmann *et al.*, 1999). However, few studies have attempted to assess the cumulative contribution of these non-occupational exposures and compare them to the typically high occupational noise exposures received by construction workers or to current occupational noise exposure risk estimates.

Johnson and Farina (1977) reported that certain non-occupational exposures (i.e. parties, nightclubs, bowling and automotive work) can constitute the majority of an individual's total noise exposure. However, their research involved only one subject for a 31 day period, with reporting of only those activities that the subject considered noisy. The equivalent average level over the 31 day period was 76 dBA, which is close to the 73 dBA L_{Aeq6760h} estimate in the current study for mid range episodic and routine exposure levels (Table 3). The authors offered no estimates of risk, other than to say that the levels measured were lower than an occupationally exposed worker would receive.

Schori and McGatha (1978) combined 7 day dosimetry measurements with self-report activity logs and audiometric assessment for 50 individuals from five exposure groups, and also reported that certain non-occupational activities (i.e. working with a power tool, attending a rock concert and riding in an automobile) provided the majority of the total noise exposure for some subjects. The mean 24 h equivalent exposure level (L_{eq24}) measured in the study was 75 dBA, which, like the Johnson and Farina study average level, agrees very well with the mid range episodic and routine exposure level L_{Aeq6760h} estimate in the current study. As with the Johnson and Farina study, the authors noted that the measured exposure levels were far below the level that an individual with intense occupational noise exposure would achieve.

Schori and McGatha did not attempt to assess the frequency with which subjects were likely to be exposed to episodic activities and, as a result, were not able to provide risk estimates associated with various activity patterns.

Berger and Kieper (1994) collected 165 L_{eq24} levels from 20 subjects, four of which had occupational noise exposure. Three of the highest daily exposure levels came from the occupationally noise exposed subjects, whose L_{eq24} exposure levels were, on average, 7 dBA higher than the subjects with no occupational exposure. As with the Johnson and Farina and Schori and McGatha studies, the mean L_{eq24} level of 78 dBA measured by Berger and Kieper is close to the mid range episodic and routine exposure level $L_{Aeq6760h}$ estimate in the current study.

Jokitulppo *et al.* (1997) administered a questionnaire regarding non-occupational activity frequency, perceived activity loudness and perceived hearing damage to Finnish teenagers. Non-occupational activity noise exposure levels were drawn from the literature and assigned to individual's reported activities based on their self-reported activity loudness level. The average number of hours per week spent in various non-occupational activities and percentage time spent at each of the self-reported loudness levels was calculated and from these data an estimated weekly noise exposure level was estimated. Fifty-one percent of 405 subjects had weekly exposure levels in excess of 85 dBA. These results are similar to those of a study by Hohmann *et al.* (1999), which found that 59% of 347 young people with a weekly L_{eq} exceeding 85 dBA (and therefore with a presumed $L_{A2000hn} > 85$ dBA). The findings of the current study are somewhat lower at the mid exposure levels, with 19% of subjects' $L_{A2000hn}$ values exceeding 85 dBA, but with up to 72% exceeding 85 dBA at the high range of exposure levels. Activities with the highest associated noise exposures included playing in a band, motor sports, attending concerts and shooting. The activities examined in the Jokitulppo study were primarily episodic in nature and no common, everyday activities other than watching TV and listening to music were evaluated.

The UK Medical Research Council Institute of Hearing Research (1986) conducted an assessment of the risk of NIHL associated with non-occupational noise exposure from several sources. The authors reviewed noise exposures (expressed in terms of annual L_{eq}) from discotheques, live concerts and personal cassette players to the exposed UK population and compared these exposures to a typical occupational exposure to estimate the risk associated with the non-occupational activities. The authors concluded that high occupational exposures (>90 dBA) present the majority of risk to hearing, but that non-occupational exposures can represent a significant portion of

overall noise exposure for workers with lower occupational exposures.

CONCLUSIONS

Assuming that the mid range episodic activity exposure levels (91–100 dBA, depending on activity) and the 50th percentile routine activity exposure levels (52–70 dBA, depending on activity) are representative for most individuals, 19% of 2000 h equivalent annual L_{eq} exposures would exceed the 85 dBA NIOSH recommended limit (REL) for occupational exposure from their non-occupational exposure alone. This suggests that about one in every five construction apprentices could have non-occupational exposures that place them at risk for hearing loss, even before considering their occupational noise exposures. Firearms users were more likely to have non-occupational exposures this high, even without considering their firearms use, because they were more likely than non-shooters to engage in noisy non-occupational activities. The difference in exposure levels for firearms users and non-shooters was statistically significant. Conversely, nearly 80% of the cohort examined would be at low risk of hearing loss resulting from non-occupational exposure. Occupational exposure limits are based on damage risk criteria that assume that non-occupational time is spent at very low noise levels which allow the ear to recover. The data presented here show that this is not always the case.

Hearing loss prevention efforts should focus on high exposures, regardless of where they occur. For most people in construction or other high risk occupations, the focus should remain on the workplace. However, the current data suggest that additional focus should also be placed on those individuals with exposure to relatively high noise in other parts of their lives.

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