ORIGINAL ARTICLE

Accuracy of task recall for epidemiological exposure assessment to construction noise

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Aims: To validate the accuracy of construction worker recall of task and environment based information; and to evaluate the effect of task recall on estimates of noise exposure.

Methods: A cohort of 25 construction workers recorded tasks daily and had dosimetry measurements weekly for six weeks. Worker recall of tasks reported on the daily activity cards was validated with research observations and compared directly to task recall at a six month interview.

Results: The mean L_{EQ} noise exposure level (dBA) from dosimeter measurements was 89.9 (n = 61) and 83.3 (n = 47) for carpenters and electricians, respectively. The percentage time at tasks reported during the interview was compared to that calculated from daily activity cards; only 2/22 tasks were different at the nominal 5% significance level. The accuracy, based on bias and precision, of percentage time reported for tasks from the interview was 53–100% (median 91%). For carpenters, the difference in noise estimates derived from activity cards (mean 91.9 dBA) was not different from those derived from the questionnaire (mean 91.7 dBA). This trend held for electricians as well. For all subjects, noise estimates derived from the activity card and the questionnaire were strongly correlated with dosimetry measurements. The average difference between the noise estimate derived from the questionnaire and dosimetry measurements was 2.0 dBA, and was independent of the actual exposure level.

Conclusions: Six months after tasks were performed, construction workers were able to accurately recall the percentage time they spent at various tasks. Estimates of noise exposure based on long term recall (questionnaire) were no different from estimates derived from daily activity cards and were strongly correlated with dosimetry measurements, overestimating the level on average by 2.0 dBA.

It is well documented that construction workers are exposed to harmful levels of noise. Noise measurements (eight hour time weighted average (TWA)) for construction workers range from 74 to 108 decibels (dBA).[1–5] The number of construction workers exposed to daily noise levels above 85 dBA was estimated in the early 1980s at 421 000–513 000 workers.[6 7] More recent estimates of the number of construction workers exposed to noise are lacking. A 1998 risk assessment on occupational noise conducted by the National Institutes of Occupational Safety and Health (NIOSH) indicated that a 40 year lifetime exposure to 85 or 90 decibels (dBA) is associated with an excess risk of developing occupational hearing loss of 8% and 25%, respectively.[7] In addition to hearing loss, chronic exposure to noise may affect the cardiovascular system,[8 9] compromise balance,[10] interfere with communication,[11] and contribute to social and psychological problems.[12]

Preventing hearing loss in construction is particularly challenging because the workers are highly mobile, and generally do not retain steady employment with any given contractor. It is difficult therefore to ensure that individuals receive formalised education on hearing loss or are enrolled in an effective hearing conservation programme. Less regulatory protection is afforded to the construction industry than in general industry, and routine audiometric testing that might inspire a worker to use hearing protection is typically not available to transient workers like those found in construction.

Exposure assessment for epidemiology of construction risks is similarly challenging because of the dynamic nature of the work. Attributing exposure by task may reveal more useful exposure information than the traditional approach using job title or exposure group alone. Such a task based approach can also be used to identify activities that result in over-exposure and to evaluate control measures.[13]

For these reasons, recent studies of health issues in the construction industry have adopted a task based exposure assessment strategy. Efforts to characterise highway construction have been undertaken using task based sampling methods for workers involved in the central artery/tunnel construction project in Boston, Massachusetts.[14 15] In the evaluation of exposure to metal fumes, Susi *et al* described a task based exposure assessment model (T-BEAM) that was applied to boilermakers, pipe fitters, and ironworkers.[16] In the residential construction sector, Methner *et al* conducted a "range finding" study in which they assessed chemical exposure during 19 different tasks performed by 12 different trades.[17] Other studies have documented task based noise measurements for carpenters, labourers, ironworkers, and operating engineers.[5 18 19] The task based exposure assessment strategy used in these studies included information not only on the task being performed, but also on additional exposure determinants such as the work environment, duration of work, tools used, adjacent workers, and other pertinent factors associated with the exposure.

Task based exposure assessment can be very useful in epidemiological studies; however, such an approach requires that subjects can accurately recall their work tasks. Education can be a determinant in valid recall regarding the start date of a job,[20] and the validity of self report data has been found to decline with the precision required by the data.[21] Education, social class, and age (for normal working age individuals) do not have an effect on a subject's ability to recall very basic information.[20 22] While published studies have addressed lifelong recall of work histories, few have assessed the accuracy of recall of detailed work characteristics such as the time spent in specific exposure related work tasks.

The goal of the study presented here was to validate the accuracy of construction worker recall of task and

Main messages

- Task based exposure assessment methods require accurate recall by study subjects. Construction apprentices were able to recall the percentage time they spent at various tasks with accuracy sufficient for exposure assessment.
- Estimates of noise exposure, based on subject recall, were strongly correlated with dosimetry measurements taken during the recall period.

Policy implications

- That construction apprentices could accurately recall their tasks in this study is relevant to future task based epidemiological studies in the construction industry.

environment based information. In addition to validating reporting accuracy, the effect of task recall on estimates of noise exposure was evaluated.

METHODS

The study was conducted at four different commercial building sites in the Seattle, Washington area and consisted of a six week (July–August 2000) field based assessment with a follow up interview conducted six months later. The field assessment included daily recording of tasks performed by each subject, and weekly measurement of noise exposure and observation of work tasks by research personnel. A total of 25 apprentices on the four sites were informed about the study and agreed to participate. The subjects included 11 carpenters, nine electricians, two sheet metal workers, and one each of operating engineers, sprinkler fitters, and labourers. Because there were so few subjects in the latter four trades, these trades were grouped together as ''other'' trades.

Two sites (A and D) included four and nine subjects, respectively. These sites were in the structural phase, which includes foundation slab pour, steel/column erection, and floor/roof concrete pours. Site B had six subjects and was in the site preparation phase, which includes grading, tower crane erection, and structural erection. Site C had six subjects who were engaged in finishing operations.

All subjects wore noise dosimeters (Quest model Q-300, Oconomowoc, WI) and were observed from approximately 7 30 am to 3 30 pm one day per week. Dosimeters were clipped to the tool belt and the microphone was placed either on their hard hat or on their collar, within 10 cm of their ear and on the same side of the body as their dominant hand. Noise in this study was measured in A-weighted decibels, using the OSHA metric (5 decibel (dB) exchange rate) and the NIOSH metric (3 dB exchange rate). The exchange rate is the number of dB required to halve or double the duration of acceptable exposure. Only the results based on the NIOSH metric are presented here because this metric best describes risk of noise induced hearing loss.[7]

Seventeen subjects were randomly selected to complete one activity card per day for six weeks; the remaining eight subjects were asked *not* to complete activity cards. Those who did not complete activity cards served as a control group for evaluating the effect completing the card might have had on recall. The trade specific activity cards were developed during a previous study.[18] The front of each card listed tasks and tools common to a specific trade. For the carpenter, electrician, and sheet metal trades, the total number of different tasks listed on the activity card ranged from 8 to 11 and the number of tools ranged from 9 to 11. The operating engineer card had a total of 14 tasks and two tools, while the labourer card listed 12 tasks and seven tools. The category ''other'' allowed subjects to write in additional tasks or tools that may not have been listed. Adjacent to the task/tool list was a time line running from 5 am to 5 pm. Each subject was instructed to indicate the time of day a given task was performed or tool was used, with a 15 minute time resolution. The back of the card contained another time line running from 5 am to 5 pm, and subjects were asked to indicate time spent wearing hearing protection, type of work area (outside/inside/partial enclosure), and number of workers nearby (3 or fewer/4 or more). Subjects were encouraged to carry the activity card with them throughout the day to maximise their reporting accuracy.

Subjects were observed and had dosimetry measurements once per week on a randomly selected day. Research observations were conducted on each subject multiple times per shift for a period of 10–15 minutes. With the ratio of researchers to subjects that we had per site, it was a goal to watch each subject at least once per hour. Subjects were not observed during breaks or lunch. Research staff recorded observations on a tally sheet containing the same categories as the trade specific activity cards. Tasks were mutually exclusive, and if more than one task was observed during an observation period, the dominant task was reported. Tools, however, were not mutually exclusive, and a list of all tools used was recorded. For analysis, the unit of time used to compare dosimetry, activity card information, and researcher observation was one minute intervals. This was dictated by the fact that the dosimeters gave one reading per minute.

Approximately six months after the intensive task card and observation period, 23 subjects completed the work history questionnaire. Two subjects did not complete the interview: one subject could not be located and the other subject was located but did not complete the questionnaire. The interview was conducted over the telephone, with copies of the questionnaire mailed to the subject's home in advance. The questionnaire was trade specific and contained the same list of tasks and environmental details present on the activity cards. For example, carpenters were given a list of 10 tasks common to that trade and asked to estimate the time they spent at any given task during July and August 2000. The total time spent on all possible tasks was always equal to 100% time.

The variability in noise exposure between all workers and by trade was calculated from the variance components of an analysis of variance (ANOVA) and the methods outlined in Boleij.[23] The ratio of the 97.5th and 2.5th centiles of the between-worker distribution was calculated to describe the range of exposures experienced between workers from day to day.

The agreement of subject self report and researcher observation of task, environment, and number of nearby workers was tested with the kappa statistic. The kappa is a measure of agreement scaled from 0 to 1, with 0 being the agreement that might occur by chance, and 1 being perfect agreement. Qualitative descriptions for the values between 0 and 1 have been proposed as: slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), and almost perfect (0.81–1.00).[24] χ^2 analysis was used to compare self reported use of hearing protection with researcher observation. If data were missing from either the activity card or the research observation sheet, the missing data were included but coded as ''missing''.

The mean percentage time at a task was calculated from the activity cards and compared to the percentage time reported on the questionnaire using paired *t* tests. In addition, the bias (mean (X_q–X_{ac})), and precision (SD of X_q–X_{ac}), where X_q and X_{ac} are the time reported at a specific task on the questionnaire (q) or the activity card (ac) were calculated.[25] These measures were combined to provide a summary measure of accuracy = $(100-\sqrt{\text{bias}^2+\text{precision}^2})$.[25] Confidence intervals (95%) were provided for the bias estimates.

Noise estimates were calculated using the percentage time at task reported on both the activity card and the questionnaire. Mean differences in the estimates derived from the activity card, the questionnaire, and dosimetry were compared using paired analysis and summary confidence intervals. Simple linear regression models were constructed to investigate the relation between the dosimetry measurements and either the activity card based estimates or the questionnaire based estimates.

The taskbased estimates of noise exposure, were made using:

$$L_{EQ,i} = q^* \log_{10}\left[\sum_{t=1}^{T} p_{i,t}\left(\frac{\sum_{m=1}^{M}(10^{\frac{Lm}{q}})}{M}\right)_t\right]$$

Where:

$L_{EQ,i}$ = noise estimate for subject i, on a given day

q = exchange rate (3 dBA)/log (2) = 10

T = total number of tasks performed by a given worker

$p_{i,t}$ = percentage time reported at a given task (t) by each worker (i)

L_m = noise level logged at one minute interval by dosimeter

M = total number of minutes all subjects spent at a given task, t

Noise estimates were made using $p_{i,t}$ estimated from the individual's activity card or recall questionnaire, and compared using paired *t* tests.

RESULTS

Table 1 describes the number of subjects that participated in various components of the study. Of the 25 subjects that were observed, 17 subjects were asked to complete daily self report activity cards and all complied, yielding a total of 389 daily activity cards. Twenty three subjects completed the work history questionnaire. Three subjects were female; the average age of all subjects was 30 (8) years. At the onset of the study, subjects had completed an average of 6 (16) months apprentice work in their given trade.

A total of 130 subject/days of noise measurements were completed, with an average work shift noise level ranging from 78.5 (2.1) dBA for sprinkler fitters to 90.6 (1.5) dBA for operating engineers (see table 2). Carpenters had an average level of 89.9 (4.1) dBA and electricians averaged 83.3 (3.8) dBA. Overall, 60% of the samples exceeded 85 dBA, the NIOSH recommended exposure limit (REL). Operating engineers, carpenters, and sheet metal workers had the greatest percentage of samples that exceeded the permissible exposure limit.

Table 3 shows the variability between and within workers for dosimetry measurements. For all subjects combined the within and between worker variances were comparable. For carpenters, the variability in dosimetry measurements between workers was very low with a $_B\sigma^2$ of 0.3 indicating that they had similar noise exposure day-to-day. In contrast, electricians had somewhat higher day-to-day variability in dosimetry measurements between workers with a $_B\sigma^2$ of 3.2, suggesting that electricians vary more in their individual exposures. Not surprisingly, the ''other trades'' encompasses several different trades, and the variability in noise estimates between workers was the highest at 5.3. The range of exposures, $_BR_{95}$, is very small for carpenters (1.0) and much larger for electricians (12.5).

Daily activity cards were completed for an average of 88% time of the six week field assessment. During the field assessment, subjects were observed for six days each, for approximately 11% of their work day. Table 4 shows the agreement (kappa) between daily activity cards and research observations. For tasks reported, the agreement for all subjects with research observation was substantial (0.67 (0.1)). Carpenters and electricians had similar task reporting concordance (0.64 (0.1)) and the concordance for the ''other'' trades was moderate (0.51 (0.1)). Information regarding the environment was reported with a higher concordance than task for all subjects (0.70 (0.1)). Carpenters and electricians both had concordance values that are considered substantial (0.71 and 0.67, respectively), while the ''other'' trade was moderate (0.51). The reporting of number of nearby workers was considered fair for all subjects combined (0.24 (0.1)). Carpenters reported the number of workers with poor concordance (0.13 (0.1)); workers from the ''other'' trades did better (0.49 (0.3)).

The variability of tasks was characterised by determining the average number of tasks reported per day. The number of tasks reported per day ranged from 1 to 4 for all subjects and the mean number of tasks reported per day was 2.5 for all subjects, with little variability by trade.

Twenty three of 25 subjects completed the work history questionnaire six months after the initial assessment. The questionnaire was specific to activities that took place during the reporting and observation period of July and August 2000. In addition to describing their work history subjects were asked about things that may affect their recall. There were a total of 28 work weeks between 1 July and the week the questionnaire was administered; subjects reported that they worked an average of 23.6 (4.8) weeks during this period. Electricians reported working the greatest number of weeks (27) while the carpenters reported working the fewest weeks (21). Construction workers often change job sites and the average number of different sites worked at since the assessment was 1.8 (1.2).

Tables 5 and 6 compare the average percent time reported on the daily activity cards with that reported on the questionnaire. Overall, the accuracy for reporting task

Table 1 Subject participation

Trade	No. of subjects observed	Observation/ dosimetry days	No. of subjects completing daily activity cards	Activity card days	No. of subjects completing interview
All subjects	25	130	17	389	23
Carpenter	11	60	8	196	10
Electrician	9	47	5	118	8
Other trades*	5	23	4	75	5

*Other trades includes labourer (1), sheet metal worker (2), sprinkler fitter (1), and operating engineer (1).

Table 2 Mean decibel measured (L_{EQ}) during shifts

	No. of subjects	DBA, mean (SD)	% of samples >85 dBA	Sample time, minutes, mean (SD)
All subjects	130	86.5 (5.2)	60	460 (48)
Carpenter	61	89.9 (4.1)	87	464 (49)
Electrician	47	83.3 (3.8)	32	462 (48)
Other trades*	22	84.1 (5.2)	2	448 (46)
Labourer	4	84.2 (1.8)	25	440 (18)
Sheet metal worker	8	85.0 (4.8)	63	435 (30)
Operating engineer	4	90.6 (1.5)	100	523 (14)
Sprinkler fitter	6	78.5 (2.1)	0	421 (41)

*Other trades includes labourer, sheet metal worker, operating engineer, and sprinkler fitter.

(table 5) was better than the accuracy for reporting the tools, number of workers, or the work environment (table 6).

In general, subjects recalled task time percentages on the questionnaire no differently than what they had reported on daily activity cards. Time spent at two of the 22 tasks was reported significantly differently. The task break/rest/cleanup (all subjects) was overestimated on the questionnaire and building gang forms (carpenters) was underestimated on the questionnaire compared to the activity cards. The percentage time spent at both of these tasks was reported with significant difference at a nominal 5% level. The median accuracy of percentage time at tasks from the questionnaire was 91%. Three tasks common to all trades included ‘‘break/rest/cleanup’’, ‘‘manual material handle’’, and ‘‘work vehicle operation’’; the reporting accuracy for these tasks ranged from 87% to 93% for all workers. By trade, the task reporting accuracy ranged from 78% to 96% for carpenters, and 53% to 100% for both electricians and sheet metal workers.

In addition to time spent at tasks, subjects were asked to report on tools, number of nearby workers, and work environment. The retrospective recall in these areas was no different than what had been recalled daily using the activity cards. Time spent using certain tools was slightly over-reported on the questionnaire; five of nine tool categories were positively biased. Approximately four of nine tools were reported with an accuracy of 90% or better. The accuracy of reporting the number of workers was no greater than 76% and the accuracy for reporting the environment was no better than 62%.

For all subjects, the reported use of hearing protection devices on the activity cards was 12.3% of the time; this percentage of time was significantly greater than the 8.5% time observed by research staff (Pearson χ^2, $p<0.05$, data not shown). The questionnaire did not ask for a percentage time using HPDs but rather ‘‘Do you always, sometimes, or occasionally wear HPDs when in a high noise area?’’. A ‘‘high noise area’’ was defined as having to raise one’s voice to be heard by a co-worker within three feet of the subject. Three subjects reported never being in a ‘‘high noise area’’. Of 20 subjects that had been in a high noise area the use of HPDs as reported on the questionnaire was as follows: 25% always, 60% sometimes, and 15% occasionally wore hearing protection.

A comparison of noise estimates obtained from dosimetry, activity cards, and the questionnaire is shown in table 7. For all subjects as well as the carpenter trade alone, there were differences between the noise estimate derived using dosimetry compared with both the activity card and questionnaire method, at the nominal 5% significance level. However, noise estimates derived from the activity cards were strongly correlated with dosimetry measurements ($R^2 = 0.62$, fig 1). Similarly, questionnaire based noise estimates were also strongly correlated with dosimetry measurements ($R^2 = 0.59$, fig 2). Estimates from the activity cards and the questionnaire were on average 1.5 dBA and 2.0 dBA, respectively, greater than the dosimetry estimate. There was no difference between the noise estimate derived from the activity cards as compared to the questionnaire (table 7) and these estimates were highly correlated ($R^2 = 0.91$, fig 3).

DISCUSSION

A task based exposure assessment strategy is appropriate for construction workers because of their dynamic work environment. However, when used in an epidemiology study, task based assessment relies on the ability of construction workers to accurately recall their tasks. This study was conducted to determine the accuracy of both daily self reports and six month recall by construction workers of tasks performed, tools used, work environment, number of nearby workers, and hearing protection usage. Validation of worker recall is key to exposure assessment in a prospective epidemiological study, such as that currently underway at the University of Washington in construction apprentices. The present study has shown that daily self reports by apprentice workers are substantially concordant with research observations for information such as task and environment, but only fairly concordant for reporting the number of nearby workers. The self reports were of sufficient quality for task and work environment that they could be used as a benchmark for validation of longer term recall. Six months after tasks were performed the accuracy for recalling time spent at given tasks ranged from 53% to 100%. Average estimates of noise

Table 3 Variance components of dosimetry measurements

Category	No. of subjects	No. of samples	k	${}_B\sigma^2$	${}_W\sigma^2$	${}_BR_{95}$
All subjects	25	130	5.2	4.2	3.2	16.4
Carpenter	11	61	5.5	0.3	4.1	1.0
Electrician	9	47	5.2	3.2	2.2	12.5
Other trades*	5	22	4.4	5.3	1.8	20.8

k = average number of samples per worker.
${}_B\sigma^2$ = variance between workers.
${}_W\sigma^2$ = variance within workers.
${}_BR_{95}$ = ratio of 97.5th and 2.5th centile of the between worker distribution (range of exposures).
*Other trades included labourer, sheet metal worker, sprinkler fitter, and operating engineer.

Table 4 Correlation of daily activity cards and research observations

Category (no. of subjects)	No. of minutes	Kappa statistic (SE) [% agreement]		
		Task	Environment	No. of workers
All subjects (17)	4775	0.67 (0.01) [69]	0.70 (0.01) [83]	0.24 (0.01) [58]
Carpenters (8)	2873	0.64 (0.01) [72]	0.71 (0.02) [88]	0.13 (0.01) [49]
Electricians (5)	1231	0.64 (0.01) [70]	0.67 (0.02) [78]	0.41 (0.02) [69]
Other trades* (4)	671	0.51 (0.01) [53]	0.51 (0.03) [71]	0.49 (0.03) [72]

*Other trades included labourer, sheet metal worker, sprinkler fitter, and operating engineer.

exposure based on long term recall were no different from estimates derived from short term recall. While the activity card and questionnaire based noise estimates were respectively, on average 1.5 and 2.0 dBA greater than dosimetry measurements, this difference was relatively consistent across the range of measurements with a high degree of correlation observed.

The ideal gold standard for validating long term recall would be to compare that recall to continuous researcher observations. In this study, a given subject was observed for approximately 11% per day for six of the 30 study days and this was not enough direct observation to validate the work history questionnaire. The daily activity cards, however, had been completed for approximately 88% time of the six week study. Because the daily activity cards were highly concordant with research observations and because they served as a complete record they were used to validate the work history questionnaire.

The results reported in this study regarding daily recall, long term recall, and exposure estimates are similar to the trends reported by Kalliokoski, in a study of chemical exposures in two rotogravure plants.[26] In the present study, percentage time at task for two of 22 tasks were reported significantly differently ($p<0.05$) on the daily activity cards compared to the six month questionnaire. In Kalliokoski's study, end of shift questionnaires completed by workers were validated with researcher observation and time estimates for two of 34 tasks were significantly different (*t* test, $p<0.05$). In addition, Kalliokoski's workers completed a questionnaire two months after the study in which they again estimated their average time distribution. Eight of the 34 tasks had statistically different average time fractions ($p<0.05$) reported at the two month recall compared to the daily recall.[26] Kalliokoski reported that end-of-shift chemical exposure estimates were no different than estimates based on a two month retrospective questionnaire.[26] Similarly, the noise estimates reported here were highly correlated with dosimetry measurements.

It is reasonable to think that completing daily activity cards could enhance subject recall. Thorough evaluation of this

Table 5 Reported percentage time at tasks

Tasks by trade	No. of subjects	Mean % time (SD)		Bias	95% CI of the bias	(%) accuracy
		Activity card	Questionnaire			
All subjects						
Break/rest/clean up	16	8.3 (3.6)	12.7 (5.9)	−4.4*	−1.2 to −7.6	93
Manual material handling	15	4.9 (7.3)	10.1 (12.1)	−5.2	−11.1 to 0.7	87
Work vehicle operation	15	0.5 (1.0)	4.2 (8.1)	−3.6	−7.6 to 0.4	91
Carpenter						
Build gang form	8	49 (30)	30 (27)	18.8*	10.0 to 27.5	78
Layout	8	3.2 (6.2)	8.9 (9.3)	−5.7	−11.6 to 0.3	91
Other carpenter task	8	15.0 (19.3)	10.3 (9.1)	4.7	−10.8 to 20.1	81
Place concrete	8	7.1 (20.1)	10.3 (29.3)	−3.3	−10.9 to 4.4	90
Shop work	8	1.8 (4.8)	3.1 (8.3)	−1.3	−4.2 to 1.7	96
Wood framing	8	5.2 (7.5)	13.7 (18.4)	−8.5	−20.0 to 2.9	84
Electrician						
Install cable tray	4	1.9 (2.2)	0 (0)	2.0	−1.7 to 5.5	97
Install slab conduit	4	9.1 (18.1)	22.8 (37.4)	−13.7	−85.3 to 57.9	53
Install trench conduit	4	9.8 (18.0)	13.2 (20.0)	−3.4	−10.0 to 3.1	95
Install wall conduit	4	18.6 (29.8)	20.7 (28.0)	−2.1	−14.2 to 10.1	92
Other electrician task	4	6.0 (11.2)	1.5 (2.9)	4.4	−15.2 to 24.1	87
Panel wire/fixture installation	4	6.5 (5.1)	0 (0)	6.5	−1.7 to 14.6	92
Pull wire	4	36.1 (39.5)	14.2 (10.5)	21.9	−36.0 to 79.8	58
Sheet metal work	4	0.2 (0.4)	0 (0)	0.2	−0.4 to 0.8	100
Sheet metal						
Fabricate metal products	2	2.3 (3.7)	30.0 (42.4)	−27.4	−375.6 to 320.8	53
Install metal products	2	73.7 (11.7)	70.3 (15.9)	3.7	−34.0 to 41.3	94
Other sheet metal task	2	0.4 (0.5)	0 (0)	0.4	−4.5 to 5.2	100
Labourer						
Flagging	1	93	64	29		–
Operating engineer						
Backhoe operation	1	93	89	5		–

*Significantly different from zero at the 0.05 level, 95% confidence intervals do not include zero.

Table 6 Reported percentage time using tools and at environment parameters

All subjects	No. of subjects	Mean % time (SD) Activity card	Questionnaire	Bias	95% CI of the bias	(%) accuracy
Tools						
Chopsaw	8	0.4 (0.6)	2.1 (4.3)	−1.7	−5.4 to 2.0	95
Hammer/mallet/ sledge/nailgun	16	32.0 (37.6)	26.7 (35.6)	4.9	−5.5 to 15.3	78
Hand power saw	16	17.7 (21.5)	16.3 (22.6)	1.4	−6.9 to 9.6	83
Other hand power tool	16	0.4 (0.8)	3.7 (9.6)	−3.3	−8.0 to 1.5	90
Other tool	8	30.3 (32.6)	11.7 (29.0)	18.7	−3.4 to 40.8	77
Powder actuated tool	12	0.1 (0.5)	0 (0	0.1	−0.2 to 0.4	99
Rotohammer	16	9.5 (14.5)	15.3 (21.7)	−5.7	−12.4 to 1.0	85
Screwgun/drillmotor	16	20.8 (25.6)	22.7 (29.0)	−1.9	−17.2 to 13.4	69
Stationary power tool	16	0.5 (1.3)	1.1 (2.7)	−0.6	−2.1 to 1.0	97
No. of workers						
3 or less	16	50.3 (31.3)	45.9 (28.5)	4.4	−8.4 to 17.2	76
4 or more	16	41.7 (30.4)	54.1 (28.5)	−12.3	−25.6 to 0.9	72
Environment						
Inside	16	11.3 (24.6)	18.3 (29.1)	−7.0	−25.5 to 11.4	23
Partial enclosure	16	34.1 (40.1)	33.4 (33.0)	0.7	−19.4 to 20.7	62
Outside	16	51.0 (44.0)	48.3 (44.3)	2.7	−5.8 to 11.3	49

effect would require comparison of workers who did, and did not fill out activity cards in relation to complete research observations. Although complete research observation was not feasible in this study, indirect evaluation of recall bias was evaluated by comparing exposure (noise dosimetry measurements) and tasks reported on the questionnaire (questionnaire based noise estimates) between subjects who did and did not fill out daily activity cards. No significant differences were observed between these two groups for carpenters or electricians in terms of either their measured exposure levels or their questionnaire recalled tasks. This provides some evidence that the recall accuracy was not substantially affected by completing the activity cards.

The daily reporting of tasks by both electricians and carpenters was substantially concordant with research observation. In a task based assessment of noise exposures of carpenters, electricians, ironworkers, and operating engineers, Neitzel *et al* compared worker self report of tasks with research observation, similar to the study described here.[18] This comparable study reported a task associated correlation of kappa = 0.87 for all workers, a somewhat higher correlation than reported here. Operating engineers have perhaps the smallest number of potential tasks compared to the other trades studied; they are typically assigned to one type of machinery for much of the day. Having a large percentage of subjects from the operating engineer trade could explain the higher correlation reported by Neitzel and colleagues.[18] Van der Beek *et al* also validated self report of tasks in a study of musculoskeletal disorders in professional drivers and nurses.[27] The subjects completed a diary over the course of one working day, with simultaneous researcher observation. Drivers recalled three of eight tasks with moderate or better agreement (kappa $\geqslant$0.41) and nurses recalled just one of eight tasks with moderate or better agreement. The remaining tasks were recalled with fair or slight agreement (kappa $\leqslant$0.41).

In the current study, there was slightly more concordance for the reporting of work environment (kappa = 0.70) than for task (kappa = 0.67). Forty seven per cent of subjects consistently worked in and reported just one type of environment throughout the study period (that is, continuously driving a backhoe *outside* or doing electrical finish work *inside*) and this probably simplified their ability to recall the work environment.

Table 7 Comparison of noise estimates

Trade	No. of subjects	Mean estimated exposure, L_{EQ} dBA (SD)		Bias	95% CI of the bias	(%) accuracy
		Dosimetry	**Activity card**			
All subjects	17	87.2 (3.9)	88.7 (3.5)	−1.5*	−2.7 to −0.3	97
Carpenter	8	89.9 (2.0)	91.9 (1.4)	−2.0*	−3.5 to −0.4	97
Electrician	5	84.0 (2.6)	85.0 (0.5)	−1.0	−4.0 to 2.0	97
Other†	4	85.6 (4.9)	86.9 (2.3)	−1.3	−6.9 to 4.3	96
		Dosimetry	**Questionnaire**			
All subjects	23	86.3 (4.5)	87.9 (4.3)	−1.7*	−2.9 to −0.4	97
Carpenter	10	89.9 (1.8)	91.9 (2.0)	−2.0*	−3.8 to −0.3	97
Electrician	8	83.1 (3.4)	85.1 (0.8)	−2.0	−4.9 to 1.0	96
Other†	5	84.2 (5.3)	84.6 (4.6)	−0.4	−4.4 to 3.5	96
		Activity card	**Questionnaire**			
All subjects	16	88.9 (3.5)	88.8 (3.6)	0.1	−0.6 to 0.5	99
Carpenter	8	91.9 (1.5)	91.7 (2.3)	0.2	−0.9 to 1.3	99
Electrician	4	84.9 (0.5)	85.4 (0.6)	−0.5	−1.7 to 0.8	99
Other†	4	86.9 (2.3)	86.5 (2.4)	0.4*	0.1 to 0.8	99

*Significantly different from zero at the 0.05 level, 95% confidence intervals do not include zero.
†Other trades included labourer, sheet metal worker, sprinkler fitter, and operating engineer.

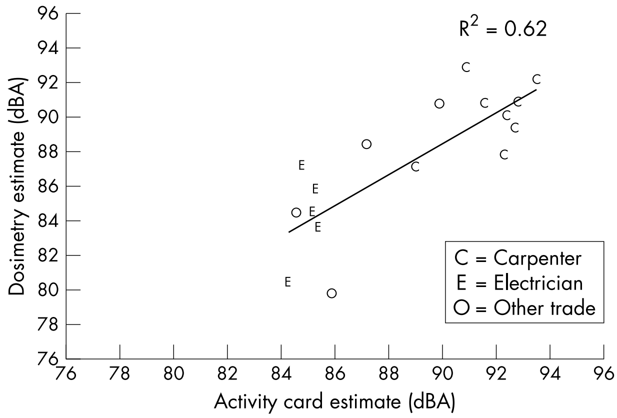

Figure 1 Correlation of activity card noise estimates and dosimetry measurements.

Detailed information such as the number of workers nearby did not correlate as well with research observations (kappa = 0.24). Because the subjects in this study were all apprentices, they were paired with one journeyman throughout the workday. The categories for choosing number of nearby workers were "3 or fewer" and "4 or more". It was observed that the number of nearby workers typically fluctuated from three to five, which may have contributed to the relatively low agreement.

Very little information exists regarding construction workers' use of HPDs. On the activity cards, the percentage time that workers reported using hearing protection was 12.3%, while research observations documented HPD use just 8.5% of the time. Hearing protection (typically earplugs) was readily accessible to all workers at the construction sites visited in this study. The activity cards asked the workers to document their use of hearing protection on a daily basis, regardless of whether or not they were in a "high noise area". Lusk *et al* documented the self reported use of HPDs by operating engineers, plumber/pipefitters, and carpenters when in a high noise area as 49%, 32%, and 18% time, respectively.[28] The percentage of workers who consistently (95% or more of the time) used HPDs ranged from 3% in carpenters to 25% in operating engineers.[28] The risk of noise induced hearing loss will not be reduced unless HPDs are consistently worn nearly 100% of overexposed time.[29 30] This study continues to suggest that HPDs are not worn frequently enough to afford adequate protection. Intervention strategies specific to construction workers for increasing the use of HPDs have been suggested.[31] Reducing NIHL will undoubtedly require several strategies, including effective hearing conservation programmes and increased use of noise control technologies, as well as HPD use.

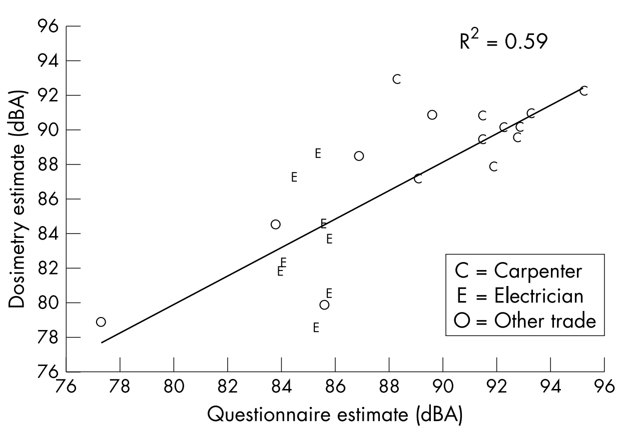

Figure 2 Correlation of questionnaire noise estimates and dosimetry measurements.

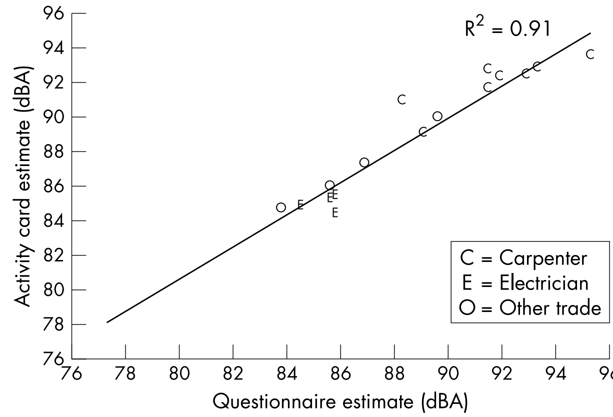

Figure 3 Correlation of questionnaire and activity card noise estimate.

Estimates of noise exposure were derived from three different methods in this study. None of the methods was a complete assessment or "gold standard" measurement covering the entire six week study and each has advantages and disadvantages. The advantage of the dosimetry measurements is that they were direct measurements of noise and they took all environmental factors into account when calculating an individual's noise exposure. A disadvantage to dosimetry is that it was not possible to measure each subject every day. A given subject had dosimetry one day per week, or just 20% of the study period.

The advantage of having workers complete daily activity cards is that a complete, first hand record of activities can be obtained. Because the activity cards contain individual level information, the noise exposure estimate can distinguish between subjects with different activity patterns. The disadvantage of activity cards is that the reporting accuracy may be unknown. We conducted research observations to validate the activity cards; this was a highly labour intensive effort. Because the activity card information did correlate with research observations, the cards are a suitable benchmark for interpreting long term recall on the questionnaire. With research personnel regularly present on the worksites, dialogue on task definitions was ongoing and helped to ensure reporting accuracy of both researcher and worker.

The main advantage of the questionnaire is its efficiency in documenting a subject's activities for the six week study period. The use of a long term questionnaire for assessing exposure is a common tool used in epidemiological studies, but it can be difficult to validate. As the noise estimates derived from the questionnaire were no different from those derived from the activity cards, it can be concluded that the questionnaire alone was sufficient for estimating exposure. However, calculation of exposure from the questionnaire relied on both dosimetry and task specific noise levels (that is, activity cards) and could not have been calculated without either.

It is important to remember that the subjects in this study were from large commercial construction sites and therefore do not fully represent the entire construction industry. The subjects reported an average of 2.5 tasks per day (range 1–4 tasks). The number of tasks performed per day may fluctuate between workers on large commercial, small residential, or road construction sites. The construction workforce is very fluid; however, we targeted workers who expected to remain at their current location for at least six weeks. The fact that the subjects reported working at an average of only 1.8 sites throughout the six month recall period may in part reflect this targeted selection. Other construction workers may work at a greater number of different sites in a six month period, and the number of sites worked at could affect memory recall. This study had just a six month recall period. Longer recall periods could result in lower reporting accuracy.

Conclusion

The construction environment is a dynamic one, and exposure to various agents, including noise, may best be described using a task based exposure assessment strategy. This study shows that apprentice construction workers employed at large commercial construction sites can self report their tasks and work environment in substantial agreement with research observations. This finding is relevant to the many task based exposure assessment studies that are presently being conducted in the construction industry.

Construction workers can recall tasks with accuracy sufficient to support a reasonable assignment for exposure assessment in an epidemiological study. The percentage time at task reported six months after the initial study was, in general, no different from that reported on the daily activity cards for the same time period. Similarly, the resulting noise estimates derived from both the interview and the activity cards were not different from each other and were strongly correlated with dosimetry measurements.

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