Retrospective Noise Estimates for British Nuclear Workers Using an Alternative Approach

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Exposure estimates were required to support an epidemiological study of occupational noise and cardiovascular disease. The study cohort consisted of male industrial workers employed at two nuclear facilities in England between 1945 and 1999 (n = 2412). Historical noise exposure data were available from 6850 sound pressure measurements collected since 1965. Additional information was obtained from interviews with retired and long-term company personnel.

Partly due to the lack of information provided by job title, coupled with the fact that noise behaves differently compared with chemical agents, an unusual approach was used to estimate noise exposure. Rather than grouping homogeneous exposure groups by job title or task, the assessors first used historical sampling data to estimate average area noise levels in each workplace where a survey had been performed. Noise contours were then estimated in the work area and, finally, individual estimates of exposure were further refined based on job title. Estimates were extrapolated to areas where noise surveys were not performed and adjustments were made for potential bias.

Overall, noise exposure estimates ranged from 60 to 97 dBA, with a median of 86 dBA. For use in subsequent exposure–response analysis, cohort work histories were used to calculate exposure indices of cumulative, average intensity and exposure duration above 85 dBA. Validation exercises are discussed.

Keywords: job exposure matrix; noise; retrospective exposure assessment

INTRODUCTION

It is well documented that exposure to excessive noise in the workplace has been shown to increase hearing loss beyond that expected from ageing alone. Hearing loss was recognized over 300 yr ago amongst boilermakers, whose noise sources would have included metal and steam (Hunter, 1978).

In more recent decades, attention has turned towards studying the non-auditory effects. Noise exposure has demonstrated associations with physiological activations such as increased heart rate, blood pressure and peripheral vasoconstriction and thus increased peripheral vascular resistance (Sokolov, 1963), and both raised heart rate and blood pressure may increase the risk of mortality due to coronary heart disease (Turpin and Siddle, 1983). There is also evidence for sleep disturbance, psychiatric disorder and annoyance by noise (Stansfeld et al., 1996).

Although some investigations suggest that chronic noise exposure may constitute a risk factor for cardiovascular disease (Melamed et al., 1997), the relationship remains inconclusive, with most investigations concentrating on non-occupational populations. A well-publicized investigation in Los Angeles in the 1970s showed a higher mortality rate of heart disease amongst residents in a high noise area near Los Angeles Airport compared with lower noise areas (Frerichs et al., 1980). Meecham and Shaw (1979) also investigated the effect of jet noise on mortality rates of myocardial infarction (MI) and found a substantial increase under jet paths. In a study of traffic noise and cardiovascular risk and incidence of ischaemic heart disease, Babisch et al. (1993) suggested a marginal increase in risk for disease incidence for men, as prevalence was slightly higher in the noise group. Further, in a case–control
study of the relationship between subjective work noise exposure and the risk of MI, Ising et al. (1997) concluded that noise exposure was the second greatest risk factor after smoking.

On the other hand, studies have failed to find links between noise and measures of increased risk, such as systolic and diastolic blood pressure and clinical diagnosis of cardiovascular diseases (Kent et al., 1998; Marchand et al., 2000; Chen et al., 2001; Chen et al., 2001). Other methods employ the use of models or algorithms to take account of exposure variants such as changes in workplace controls over time, imprecision/normality of sampling data, changes in sample collection and analysis, dermal and ingestion uptake, concentration of the agent in process materials and/or duration of exposure (Piacitelli et al., 2000; Romundstad et al., 2000; Hughes et al., 2001). For studies with living cases and controls, direct interviews or questionnaires can provide a lifetime occupational history for each individual, complete with task and further detailed information (Weston et al., 2000; Blair et al., 2001).

Because job title alone provides little information on the activity being performed (potentially introducing misclassification), task information has been used to supplement or replace job title (De Roos et al., 2001) and taken further to develop a task exposure matrix (Viet et al., 2000; Benke et al., 2001). Additional methods have used biological samples to indicate exposure, e.g. the analysis of post-mortem lung tissue (McDonald et al., 2001).

Although many of the above methods have been employed for years, it is worth noting that innovative approaches continue to be developed (Gurumurthy, 2001). Also, it is clear that a wide variety of methods continue to be documented in recent literature and a trend towards any one particular method is not immediately apparent.

Retrospective assessments of noise

Compared with chemical agents, relatively few attempts have been made to estimate retrospectively noise for epidemiological study populations. To determine the parameters associated with hearing loss in a cohort of industrial workers exposed to noise, Celik et al. (1998) characterized exposure in a hydroelectric plant by dividing the 130 exposed workers simply by exposure durations of ≤10 yr, 11–20 yr and >20 yr. It was not clear whether the analysis adjusted for age as a confounder. Similarly, De Almeida et al. (2000) used duration as a surrogate for exposure in a retrospective study of 222 patients with occupational sensorineural hearing loss. In a separate study of noise and cardiovascular disease that is ongoing, Davis et al. (2002) is retrospectively assessing noise exposure of 28 000 lumber mill workers. The researchers plan to use noise sampling data (including dosimetry) combined with exposure determinant data (job title, use of controls, hearing protectors, etc.) to build what the researchers call a predictive fixed-effects model. The outcome has not been published as the study is underway.

The need for an alternative method

Like many epidemiological studies, cohort information for our study was limited to job title, date and location only. In fact, job title provided a weak indi-
cation of actual task performed because 46% of the cohort had the same title (process worker). When one single job title includes a wide array of tasks, exposure misclassification is inevitable and is an important reason why we could not opt for an exposure assessment defined by job title alone.

Noise as a unique hazard

Another reason for considering an alternative assessment approach was because, being a physical agent, the characteristics of noise differ fundamentally from chemical agents. Firstly, noise is ubiquitous and all workers are exposed to some degree, both at home and at work. In other words, it is not possible to rank exposure as ‘ever’ or ‘never’. This fact was noted by Sass-Kortsak et al. (1999) in a study of the combined effects of noise and styrene. In that study, styrene was assessed by the conventional approach of reviewing air sample data, followed by categorization by job title and adjustment for respirator use. However, the researchers opted to use self-reported questionnaires to estimate noise, noting that noise was present in all industrial settings.

A second difference is that noise is transmitted quickly compared with chemical agents. There is no real time delay, either in dispersion, exposure or decay. Reverberation is so rapid that, for most noise measurements, it usually forms part of the measurement of the noise source itself, depending on the measurement technique used.

A further difference is that, in a comparison of steady-state point source generation in ideal conditions, the dilution of chemical agents is based on the volume of the sphere, whereas noise, being a pressure wave, disperses based on the surface of the sphere. Therefore, noise decreases with distance \( r \) from a source, proportional to the inverse of \( r^2 \) (inverse square law), while chemical agents decrease by the inverse of \( r^3 \).

Finally, and perhaps most importantly, noise is virtually unaffected by workplace air currents, either mechanical or natural, unlike chemical agents, where exposure levels upwind or downwind of a source can vary by orders of magnitude. In general, when compared with chemical agents, the equal exposure contour for noise is far larger and more robust, being independent of the vagaries of air movement, temperature, etc.

An alternative approach

Although task information was not available from personnel records, task and other details were often recorded on noise survey reports dating back to the 1960s. The authors noticed that when information from the noise reports were combined with job titles for a particular area, a picture emerged of the operation being performed, the source of noise, approximate number of workers exposed, etc.

Because job title alone was a weak marker of exposure, along with the fact that noise behaves differently from chemical agents (e.g. travels faster, dissipates rapidly, and is less affected by ventilation air currents), it was decided that a customized approach could be used to estimate exposures. Rather than collating, averaging or modelling sample results followed by categorization into homogeneous (or similar) exposure groups based on job title, it was decided that each workplace could be evaluated individually, based initially on workplace noise sampling data. The purpose of the following paper is to present and discuss the method used to derive the noise exposure estimates used for this study.

MATERIALS AND METHODS

Available information

The study population worked in 393 different buildings at two separate sites in England. Company personnel files provided individual details of job title, employment duration and work building/location. Additional personnel records were available from routine medical examinations and radiation dosimetry files. These three sources were merged to provide the best possible work history for each man.

The basic starting point in developing the noise exposure matrix was information derived from more than 6850 workplace sound pressure measurements performed since 1965 by company health physicists and occupational hygienists. Over 1200 separate noise survey reports were reviewed and relevant information was summarized and extracted into a database. In addition to location, sample date, process details and results, the survey reports often included numbers of exposed personnel, estimates of likely dose, suggestions for noise controls and other useful information. The company noise surveys consisted of sound pressure readings often depicted onto floor diagrams, showing the position of machines, process flow details and the location of samples collected.

Location identifiers for each sound pressure measurement were individually recorded, e.g. ‘adjacent to work station’. The noise surveys had been performed in a variety of settings, including general work areas, control rooms and isolated parts of buildings, e.g. fan rooms.

Although the majority of noise measurements consisted of direct reading sound pressure levels, ~15% of the samples were short duration integrated readings (1 min \( L_{eq} \)) and ~5% were personal dosimetry measurements. No reliable information was available on the specific noise measurement equipment used or calibration procedures. However, the researchers were confident the sampling equipment would have used a 3 dB doubling rate because that was the historical basis for guidance and equipment available in the UK.
Additional information was obtained from interviews with retired and long-term company personnel, who were asked to provide details of tasks performed in buildings where noise surveys had not been performed, changes in building use over time and the use of hearing protectors.

Method of matrix development

A panel of three occupational hygienists, each with more than 10 yr of professional experience, was given the responsibility to provide noise estimates. Initially the hygienists met to agree a basic set of criteria to minimize inconsistency. Working individually, the hygienists first used noise survey details to determine the likely type of working environment, e.g. office, control room, boiler room, test facility. Then, by taking account of cohort job titles listed for each area (where noise surveys had been performed), the hygienists used the process details and floor diagrams to consider the likely proximity of those jobs relative to the primary noise source(s). From this consideration, each job title was assigned to one of the following worker categories:

- machine operative, e.g. process workers, machinists, operators;
- peripheral worker, e.g. cleaners, electricians, managers;
- office worker, e.g. control room operatives, clerks.

Then, for each area where a survey had been conducted, the hygienists used the noise survey results and process information to estimate an average area noise level (AANL). Specifically, the AANL was defined as the noise exposure that would likely be experienced by a worker immediately adjacent to the primary noise source(s), e.g. machine operator, and without regard for hearing protection. Quantitatively, the AANL was an annual average exposure estimate based on 8 h average sound pressures in A weighted decibels (dB) and based on a 3 dB doubling rate (referred to hereafter as dBA).

In order to estimate integrated exposures, it was necessary in most instances to adjust the AANL to account for likely distance from the noise source, time when the worker was away from the workplace, machine ‘down time’ and the consideration that sampling was likely to have been performed during ‘worst case’ conditions. Theoretically, these corrections would best be performed using objective process and work information or noise dosimetry results, but in the absence of these data, it was thought that the professional judgement provided by hygienists was the next best option. Each hygienist had field experience that included the collection of direct reading sound level measurements and dosimetry simultaneously, and it was this experience that was considered most desirable for this method.

Before performing assessments, the three hygienists met to agree a guideline for adjusting the AANL. Firstly, they agreed to use the AANL and to process details and floor diagrams to develop a mental estimate of noise exposure contours in each workplace where surveys had been performed. Then, for each of the three work categories described above, the AANL would be reduced to create an estimate of 8 h average exposure. As a guide, they agreed that the category machine operative would be reduced by 1–4 dBA. Similarly, peripheral workers were reduced by 3–9 dBA and office workers were not reduced at all. Again, these noise adjustments were agreed by the hygienists in advance of performing the assessments and were based on their combined professional experience. It was decided that deviation from these guidelines were allowed when information suggested that the specified reductions were not appropriate. Where full-shift noise dosimetry measurements were available and noise survey job titles matched those in the cohort, no adjustments were made.

In making modifications to the AANL, the hygienists were instructed to consider the intensity of the noise itself. For example, in an elevated noise area, the exposure of a machine operator might equal the area AANL minus an adjustment of 2 dBA, taking into account down time and the fact that the machine operator is not likely to be exposed for a full 8 h (breaks, lunch, decontamination and other tasks). On the other hand, an adjustment of 2 dBA might be excessive for the same job in relatively quiet areas or jobs with little down time or continuous processes.

As a final consideration, hygienists were instructed to modify the AANL based on their estimate of whether the job involved passively absorbing or actively contributing to noise levels in the area. For example, the excess contribution a pipefitter will make to his own noise exposure will depend on the ambient noise level. In an office environment, the personal contribution of a pipefitter would far outweigh the background level. In this instance, it would be incorrect to use the unadjusted AANL as an estimate of his personal exposure. However, in a noisy area, the pipefitter’s personal contribution might be insignificant and not vary from the AANL. Conversely, an office worker would make little contribution to the AANL, whether working in a noisy workshop or a control room.

For purposes of efficiency, assessments were first performed by two occupational hygienists independently and then compared. Where estimates differed by ≤5 dBA, the mid-point was used for the exposure matrix. If they differed by ≥6 dBA, a third hygienist provided an independent assessment and the median of the three assessments was used. If any two estimates differed by >10 dBA, the three hygienists met to discuss their choices and reach agreement.
For many areas, only one noise survey was available and in the absence of additional information related to process or equipment changes, these measures were used to represent exposure over the entire study period. When noise surveys were repeated in the same location but in different years, it was assumed that noise levels measured from the earliest survey continued up to the date of the subsequent survey, and so on.

At this point, a preliminary matrix was created for all buildings where noise samples had been collected.

Estimations when data not known

For locations where noise surveys had not been performed, procedures were developed to extrapolate noise exposure estimates from other locations. For the two sites separately, the median for each job title was determined for all years (not a median for each year individually). Rather than simply calculating a median of all estimates with a particular job title, a “weighted” median was calculated to account for the number of workers likely to be in a particular location. In other words, if noise surveys had been performed in two locations, one with 100 pipelayers and another with one pipelayer only, the estimates from the two locations would not contribute equally to an extrapolated estimate for pipelayers working at a third location.

A set of rules was then established to determine the appropriate action, depending on the particular situation (Table A1).

Adjustment for bias

The first workplace noise samples were collected in 1965. Over the years, there did not appear to be any systematic strategy for noise sampling. Rather, it appeared that surveys were performed in areas where noise was perceived as loud or where there were complaints of annoyance. Therefore, where noise surveys had not been conducted, it is likely that noise levels were below a level perceived as hazardous or a nuisance. To account for this bias, an upper limit (cap) to the AANL of 80 dBA was adopted for locations where noise surveys had not been performed. The decision to cap at 80 dBA was based on a judgement by the authors (after communications with site employees) that work areas with continuous noise exposures >80 dBA would have been investigated at some point and recorded in a noise survey. No capping adjustments were made for exposures prior to 1965 (before noise sampling).

Adjustment for hearing protectors

Even if it were known when and where hearing protectors were worn, it is likely that the actual attenuation of noise would vary significantly, depending on whether the protectors were worn properly or removed occasionally (even for brief periods). Because few records of hearing protector use were available, questions were posed to long-term employees whose jobs required them to visit many parts of the site and who were likely to remember where, and what types of hearing protectors were worn (Table A2). The information was collated, summarized and used to modify noise estimates. As a result, no adjustments were made for any work occurring before 1960. From 1960 to 1975, adjustments varied between the two sites. Modest noise reductions were made for work in all areas between 1975 and 1990. From 1990 onwards, all estimates >90 dBA were reduced to 90, because it was felt that hearing protectors would have been worn throughout the company. The magnitude of these reductions was difficult to judge because even where hearing protectors are worn, attenuation will vary significantly, depending on the type of protector worn, the duration the protectors were actually worn, whether protectors were worn properly, etc.

Calculation of exposure indices

Once the exposure matrix was developed and adjustments incorporated, all of the noise estimates were converted from decibels to Pascals (sound pressure) and cohort work histories were used to calculate a cumulative measure for each man, i.e.

\[
\text{exposure}_{(\text{cum})} = \sum (x_y)
\]

for all jobs, where \(x\) is the estimated exposure for a particular job/location and \(y\) is duration at that job/location. Additional exposure indices were calculated for use in subsequent exposure–response analyses, including lifetime average intensity, number of years >85 dBA and the highest recorded estimate. For final presentation purposes, Pascals were reconverted to decibels.

RESULTS

The cohort consisted of 2412 men whose length of employment varied considerably. The median was 8.5 yr, but 25% were employed for <2 yr while 21% worked for ≥20 yr. The men had 580 unique job titles with 10 titles accounting for 75.6% of the total. By far the most common job title was process worker (46%), which was differentiated into multiple grades, e.g. PW1, PW2. Aggregating the job histories for the study cohort resulted in 51 074 combinations of worker, job title, location and year.

Noise surveys were not conducted at all locations where workers in the cohort were employed. In fact, survey information was available in 156 of the 393 buildings where the cohort had worked (40%). However, the surveyed buildings provided a reasonable degree of coverage considering where the majority of the cohort worked. As seen in Table 1, of the 51 074
combinations, 36 042 (71%) were from buildings where noise surveys had been conducted.

For all job title/location combinations, the median noise dose estimate was 86 dBA, ranging from 60 to 97 dBA. Site exposure estimates varied slightly with a median of 87.0 dBA for site A and 84.5 dBA for site B.

Trends in noise estimates with time were reviewed for a variety of locations and the most common job titles and although it might be expected that noise exposure levels and their corresponding dose estimates would decrease over time, there was little repeat survey information to confirm such an assumption. Simply graphing the median exposure matrix estimates over time provides little insight, because (due to the nature of the method used) the median depends principally on demographic distribution of the workers, rather than job title. In other words, if calculated noise medians found an increase in a particular year, this might easily be the result of a higher proportion of workers, by chance, working in the noisier areas. One could not conclude that noise had actually increased, either to the individual workers or at individual locations.

To further examine exposure trends, the median noise estimates for subjects within the same location were analysed for a random selection of locations. Although the majority of locations show that noise estimates in recent years are lower than earlier years, few of the downward trends are significant. As an example, Figs 1 and 2 depict the mean noise estimates in one randomly chosen building at site A and one building at site B. Similar variations and trends were seen when graphing noise estimates by specific job title. For example, Fig. 3 plots noise estimates for joiners and Fig. 4 plots fitters.

Adjustments to account for hearing protector use reduced dose estimates in the noisiest areas but, because most estimates were below 90 dBA, these adjustments did not have a large impact on mean noise levels overall.

The matrix results were merged with personnel data to create a cumulative noise metric for each worker. A distribution of these cumulative measures is illustrated in Fig. 5. For the overall cohort, the median was 108 dB yr, ranging from 60 to 123 dB yr. Similarly, the normally distributed average intensity measures are shown in Fig. 6, with an overall average of 86 dBA, ranging from 60 to 96 dBA.

Analysis of inter- and intra-assessor agreement was not easily possible because of the nature of the assessment method we used. Because of the large number of individual assessments made (combin-

Table 1. Degree of coverage provided by noise surveys

<table>
<thead>
<tr>
<th></th>
<th>Site A</th>
<th>Site B</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings where cohort worked</td>
<td>206</td>
<td>187</td>
<td>393</td>
</tr>
<tr>
<td>Buildings where cohort worked and where a noise survey was performed</td>
<td>79 (38% of above)</td>
<td>68 (36% of above)</td>
<td>147 (37% of above)</td>
</tr>
<tr>
<td>Combinations of job title, location and year within the study cohort</td>
<td>30 258</td>
<td>20 816</td>
<td>51 074</td>
</tr>
<tr>
<td>Combinations of job title, location and year where noise surveys performed</td>
<td>19 872 (66% of above)</td>
<td>16 170 (78% of above)</td>
<td>36 042 (71% of above)</td>
</tr>
</tbody>
</table>
Retrospective noise estimates for nuclear workers

Ations of location/job title/year), the noise estimates were handwritten by the assessors directly onto building matrices and only the (calculated) mean level was entered into a database. However, it was possible to determine assessor agreement indirectly by counting the number of assessments performed by the third hygienist. From this, it is evident that noise estimates produced by the two primary assessors were within 5 dBA for 85% of combinations of location/job title. Additionally, the range of noise estimates produced by all three assessors varied by >10 dBA for less than 5% of the location/job title combinations.

**DISCUSSION**

A review of this method

Most job exposure matrices (JEMs) contain one axis depicting a homogeneous worker exposure group, e.g. job title, and another axis for time worked, e.g. year, with internal cells filled with unique exposure estimates. However, because this study estimated noise levels at individual locations, the resulting matrix consists of three axes and over 5500 noise estimates for combinations of job title, location and year.

From the literature it appears that very few other studies have used a comparable approach to the one used here. In a study of beryllium disease and sensitization, Viet et al. (2000) used a design that was similar. In that study, occupational hygienists assigned exposure factors to all job titles and locations relative to a machinist in one specific building where extensive sampling data had been collected since 1960. Our study differs in that exposure adjustments were
are available, (c) the records contain in-depth process
ments had been collected over time, (b) the records
matrix required that (a) significant noise measure-
Limitations
was simple to use in practice.

it is
the use of guidelines to decrease or increase expo-
specific to each location (the AANL), followed by
first requiring hygienists to record a noise level
ment to account for the likely job or task being
likely noise exposure contours in the vicinity of noise
hygienists first assessed the workplace, estimating
noise is generated, i.e. the intensity of noise gener-
ation will vary significantly, which is dissimilar to
chemical agents where evaporation or emission rates

With advancements in this area of research, the use
of models might eventually create scientifically
derived methods that are 100% objective, valid and
robust. However, where information or other
resources are not available, the authors are confident
that expert-derived exposure estimates are acceptable
for the purpose for which they are created. Some
confirmation of this is provided from a recent study
into the validity of using experts (Fritschi et al.,
2003), where the authors compared the ratings of
expert assessments with actual airborne measure-
ments and concluded that experienced raters could
successfully characterize jobs where important
exposures occurred.

It might be argued that our method is common to
other retrospective assessments (where sample
results are available) because the thought process of
most experts would first involve an estimate of likely
exposure in the workplace, followed by an adjust-
ment to account for the likely job or task being
performed, controls used, etc. Whether or not this is
true, the current study formalized this approach by
first requiring hygienists to record a noise level
specific to each location (the AANL), followed by
the use of guidelines to decrease or increase expos-
ures based on job title and other considerations. It is
worth noting that the hygienists claimed the method
was simple to use in practice.

Limitations

The method chosen for developing this exposure
matrix required that (a) significant noise measure-
ments had been collected over time, (b) the records
are available, (c) the records contain in-depth process
details and (d) the surveys cover a broad portion of
the study cohort. For many study populations, meas-
urements meeting these criteria do not exist or may
require significant resources to collate and review. In
such circumstances, using this method would be
inappropriate.

It would have been useful to consider the effect of
changes in the instrumentation that was used to
collect the original noise samples, to account for vari-
ations in precision and accuracy with historical
sampling equipment. However, the company had not
kept records of the noise instrumentation used to
collect measurements at either site, so no adjustments
to account for this were made to our matrix estimates.
Additionally, job history data listed men as working
in a single building only and although it is likely that
many men would have worked in multiple buildings
within the same year (e.g. maintenance, security,
cleaners, groundkeepers), these details were not
available, so the resultant error could not be avoided.

Sample selection bias will almost certainly be
present because noise surveys were likely to be
conducted in areas where noise was elevated.
Because noise and other surveys are often undertaken
with a strategy to detect ‘worst case’ exposures, this
limitation is common to most JEMs that incorporate
workplace measurements and is not a weakness
unique to this study. However, considering that all
jobs produce a degree of noise and it was not known
to what extent other activities in the workplace
contributed to exposure, misclassification for us
might be more pronounced. Because our method
required significant extrapolation from areas where
noise surveys were conducted to those without, it
might be interesting to perform a validation exercise
on a sub-cohort who worked only where noise was
actually measured. However, selecting a cohort who
worked exclusively in areas where noise measure-
ments were collected resulted in a group of <30 men,
and it was felt that analysis on such a small number
would be pointless.

The use of decibels as a unit of noise exposure in
this study was arbitrary and alternative categoriza-
tions were possible, e.g. Pascals, semi-quantitative
metrics, qualitative ranges, etc. In supporting epidemi-
ological investigations, actual metrics of chemical or
physical agents are often used as a mechanism to rank
exposures for comparison with one another. However
tempting, the noise estimates from this study were
not designed to provide answers to other interesting
questions, e.g.

- What accurate noise dose was received by each
worker?
- Does a 3 or 5dB doubling rate more accurately
predict hearing loss?
- What was the threshold of hearing loss in the
study population?
Validation of exposure estimates

Ideally, the validity of any measure, including an exposure matrix, should be tested before use. Because these noise estimates were derived primarily from adjustments to direct reading sound pressure levels, a possible validation exercise would determine how well the assessors used these numbers to predict 8 h time-weighted average exposures. Dosimetry could be performed in a variety of settings to compare with estimates from the matrix. Unfortunately, where dosimetry had been performed at this company, simultaneous sound pressure measurements had not been collected. And due to reasons within the company, the researchers were not allowed to conduct dosimetry surveys to support this study, although it is likely that such tests will be possible in the future.

In the absence of dosimetry measurements, it was felt that an occupational hygienist who has performed noise sampling at the company and is employed full-time at one of the sites might provide reasonably accurate estimates of present day noise exposures. The hygienist was asked to provide estimates of 8 h integrated noise exposures for 105 combinations of location and job title in seven buildings. The Wilcoxon paired t-test was used to compare the estimates provided by the site hygienist with the matrix estimates for the same locations and although the site hygienist’s estimates were generally lower, the pairings revealed a strong correlation with our matrix ($P < 0.001$).

As an additional test of predictive validity, an exercise for this exposure matrix is currently underway using audiograms to determine whether an exposure–response relationship exists between hearing loss, a known health outcome, and exposure indices (cumulative, average intensity, etc.) derived from the matrix.

In recent studies using retrospective exposure assessments, few mention validation tests for their exposure estimates. Most epidemiological publications devote only one or two paragraphs to an overview of the assessment method. Details on how assessments were developed, validated and tested for reliability are often omitted, a deficiency noted by Stewart (1999) in her discussion of future challenges to retrospective exposure assessments. Some papers detailing methods will have been published separately, but this is certainly not the case for all. It would seem that more attention is required to ensure that occupational disease studies using exposure–response analyses do not reach flawed conclusions.

CONCLUSIONS

An exposure assessment approach that uses sampling results combined with guides for estimating exposure at each location appears to have been used for few other epidemiological health studies. The extent to which this approach was superior was not determined. Further validation exercises will provide an indication of the predictive validity of the noise estimates, which will help to determine whether this method has any future value. Also, further work could determine whether the method should be limited to noise or if it could be widened to chemical, biological or other physical agents. Potentially, data from previous studies could be reassessed using this method, comparing outcomes of each.

Finally, it is worth noting that the hygienists reported the method to be simple to use and straightforward in its application. Although its value has not been determined conclusively, the authors believe the method deserves further scrutiny because of its potential use in situations where sampling results are available but job title information is inadequate.

Table A1. Procedures required when noise survey information is not available

<table>
<thead>
<tr>
<th>Specific condition</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job title was used in other buildings where noise measurements had been collected</td>
<td>For all cells with this job title, use the median of this specific job title</td>
</tr>
<tr>
<td>Job title is a combination of 2 or more job titles, and this combination was used in other buildings where noise measurements had been collected</td>
<td>For all cells with this job title, use the median of this specific job title</td>
</tr>
<tr>
<td>Job title is a combination of 2 or more job titles, and this combination was not used in other buildings, but each of the individual elements of the job title was used where noise measurements had been collected</td>
<td>Determine the median of each job title separately, then calculate and use the arithmetic average of the individual job title elements</td>
</tr>
<tr>
<td>Job Title was not used in other buildings where noise measurements had been collected</td>
<td>An occupational hygienist manually chooses the closest similar job title from an alphabetical list of all job titles where noise measurements had been collected</td>
</tr>
<tr>
<td>Job title is a combination of 2 or more job titles, the combination was not used in other buildings where noise measurements had been collected</td>
<td>For job titles used previously, determine the median. For job titles not used previously, an occupational hygienist manually chooses the closest similar job title from an alphabetical list of all job titles where noise measurements had been collected. For the job title combination, calculate the arithmetic average of the two individual (Pascal converted) job title medians</td>
</tr>
</tbody>
</table>

*Some worker job titles were listed as a combination of two or more job titles e.g. ‘process worker/machinist’. For these it was assumed that the worker was performing both jobs for equal duration.
Was there a period of time, particularly in the early days, when no worker would normally have ever worn hearing protectors (HPs), or only worn them for specific tasks? If so, are there any records of which areas, and which years?

When did the wearing of HPs become compulsory in noisy areas?

When did the wearing of HPs become commonplace in noisy areas?

When was the provision of HPs commonplace for workers who asked for them?

At what noise level did the wearing of HPs become compulsory, initially?

Did this ‘action level’ change over time?

What types of HPs were supplied, i.e. when were cotton wool plugs introduced, superseded by foam plugs and by ear-muff type HPs? Are there any records or recollections?

Was there a central purchasing policy for HPs? If so, are there any records of which types were bought in which years (for use in particular buildings)?

Were there any special rules for certain trades or tradesmen, e.g. woodworkers?

Were there any differences, particularly in the early days, in any of the above points between different buildings, within either site?

Were there any differences in these policies between company sites? i.e. was there a company-wide policy?

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Table A2. Hearing protection questionnaire

1. Was there a period of time, particularly in the early days, when no worker would normally have ever worn hearing protectors (HPs), or only worn them for specific tasks? If so, are there any records of which areas, and which years?

2. When did the wearing of HPs become compulsory in noisy areas?

3. When did the wearing of HPs become commonplace in noisy areas?

4. When was the provision of HPs commonplace for workers who asked for them?

5. At what noise level did the wearing of HPs become compulsory, initially?

6. Did this ‘action level’ change over time?

7. What types of HPs were supplied, i.e. when were cotton wool plugs introduced, superseded by foam plugs and by ear-muff type HPs? Are there any records or recollections?

8. Was there a central purchasing policy for HPs? If so, are there any records of which types were bought in which years (for use in particular buildings)?

9. Were there any special rules for certain trades or tradesmen, e.g. woodworkers?

10. Were there any differences, particularly in the early days, in any of the above points between different buildings, within either site?

11. Were there any differences in these policies between company sites? i.e. was there a company-wide policy?

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APPENDIX

See Tables A1 and A2.

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