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Occupational noise exposure of utility workers using task based and full shift measurement comparisons

David Michael Lowry *, Lin Fritschi, Benjamin J. Mullins

School of Population Health, Curtin University, Perth, WA, Australia

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ABSTRACT

Introduction: The main purpose of this study was to determine if a combination of area noise measurements and task activity diaries give a reasonable estimate of full-shift dosimeter measurements in a cohort of utility workers. Few studies have been conducted to evaluate the efficacy of using task-based noise exposures to estimate full shift time weighted average (TWA) noise exposures.

Methods: Estimates of full shift time TWA noise exposures for a group of utility workers (n = 224) were calculated using dosimeter measurements. Area noise measurements using a sound level meter were used to recreate the TWA for each personal dosimetry sample based on detail provided in the task activity diary for each sample. Full shift TWA noise exposures were compared to corresponding area noise measurements using simple linear regression analysis.

Results: Associations between full shift TWA measurements and task-based area measurements were closely associated, with R^2 values above 0.85 for all job roles.

Discussion: Task-based noise exposure analysis has the potential to be widely used in the utilities industry. While full-shift monitoring to determine TWA exposures is useful, the changing work environment, variability in tasks and equipment, and varying workday hours, limit the ability of the 8-hr TWA to accurately characterise the exposures and associated health risks for utility workers.

1. Introduction

Exposure to noise constitutes a significant health risk in the occupational environment. There is sufficient scientific evidence indicating that excessive and prolonged noise exposure can induce hearing impairment, hypertension and ischemic heart disease, sleep disturbance and general annoyance [1]. A number of studies have also suggested a positive relationship between excessive noise exposure and susceptibility to occupational injuries [2] as well as increased risk of further hearing deterioration [3]. In addition, whilst noise is considered a physical factor for damage to the cochlea, combined exposure to noise and certain chemical substances – collectively referred to as ototoxins - can impair the cochlea, the vestibulo-cochlear apparatus, the eighth cranial nerve or the central nervous system [4]. Excessive noise exposure in high temperatures may also present a high risk for noise induced hearing loss (NIHL) [5].

Methods for assessing occupational noise exposure have largely focussed on full-shift TWA sampling conducted on workers, however task-based methods have an advantage over full-shift methods in that they provide a more direct understanding of the primary sources of high noise exposure [6]. This has a benefit not only in targeting effective noise control interventions in the workplace, but also in estimating exposure levels for a range of task combinations. Task-based measurements can also allow for the characterisation of full-shift exposure whilst also permitting assessment of short-term hazards which might not be identified through a standard full-shift exposure sampling protocol [7]. Taking measurements at the task level has been shown to be a useful method for determining hazardous exposures in complex dynamic environments [8]. Furthermore, epidemiologic studies benefit from task-based exposure assessments because they support the validity of cumulative exposure histories by limiting misclassifications which can occur when reconstructing past exposures through employment records or work histories [9].

Characterisation of noise exposure for workers who undertake tasks in varied occupational settings and conditions is especially challenging, given the changing work environment in which these professions operate. Therefore, a realistic measure of noise dose utilising full-shift measurements alone would not be expected to be representative of true

* Corresponding author.
E-mail address: David.Lowry@riotinto.com (D.M. Lowry).

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exposure experienced over a typical shift. In addition, full-shift TWA measurements do not provide information that can be used to identify the source of intense noise exposures experienced. Therefore, determination of noise exposures at the task level for utility workers may be more useful, particularly when developing effective engineering controls to reduce exposure and prevent NIHL. One such group are utility workers, whose highly variable tasks and working conditions present a range of potential occupational noise exposures. Utility workers perform a wide variety of semi-skilled and skilled maintenance duties in the installation, construction, repair, and general maintenance of electrical, water, communications, and power generation assets. Workers who fall into this group are typically trade-qualified and occupy five distinct job roles – electrician, plumber, communication technician, fuel delivery driver and power station operator. In Australia, approximately 144,200 persons were employed in the utilities industry in 2020 [10].

Task based exposure assessment strategies have previously been employed for workplace chemical exposures [7, 8, 11, 12] and occupational noise [13, 14, 15, 16, 17]. However, only three peer-reviewed studies could be found directly comparing full shift and task-based estimates of exposure to noise (summarised in Table 1). These studies demonstrate that the accuracy of the exposure assessments depend on how well tasks are defined and the ability of statistical models to account for variability in noise exposures. As an example, clearly defining beginning and ending times for each task increases the agreement between estimated and measured daily noise exposures. The studies also indicate there is generally agreement between time-at-task information collected from direct observation and worker self-reports [18, 19, 20] Overall, the studies found moderate to good agreement between measured and task-based estimated daily noise exposures.

The main purpose of this study is to determine if a combination of area noise measurements and task activity diaries give a reasonable estimate of full-shift dosimeter measurement in a cohort of utility workers.

2. Methods

2.1. Personal noise dosimetry

Personal sampling data were collected with the assistance of personnel from a registered utility responsible for providing the critical services of electrical generation and distribution, water and wastewater, hydrocarbons, and communications to a number of mining operations and five townships located in the Pilbara region in North-Western Australia. The inclusion criteria for this study were personnel employed by the utility in the job categories of electrician, plumber, communications technician, and power station operator. A stratified sampling method was employed and the number of employees to sample was calculated as outlined in Table A-2 of the NIOSH publication *Occupational exposure sampling strategy manual* [22]. Personal noise samples were collected and analysed as per *AS/NZS 1269-2005 Occupational Noise Management – Part 1* [23]. Workers were selected randomly whenever possible using a random number table.

Equipment used to conduct noise sampling consisted of personal noise dosimeters (type 4448, Brüel and Kjær, Nærum, Denmark) calibrated pre and post sampling with a sound calibrator (type 4231, Brüel and Kjær, Nærum, Denmark). No significant shift in calibration was detected for any individual measurement. The dosimeters measured sound pressure levels in decibels (dB) using an 'A' frequency weighting, and the measuring range was 50–140 dB (L_{Aeq}) using no additional threshold level and a 3-dB exchange rate. The dosimeters logged noise data each minute and $L_{Aeq,T}$ for the total duration of the measurement period was stored. Sampling times were representative of working periods of individuals monitored, which were at least eight hours of a twelve-hour shift. A total of 224 dosimeter measurements were captured.

Participants were instructed to keep track of their activities during the day and to fill out a logbook on their time spent at different tasks during the measurement period. In addition, participants were asked to state their use of hearing protection devices.

Table 1. Summary of peer reviewed studies comparing full shift and task-based estimates of exposure to noise.

Study aim	Methods and results	Key findings
To evaluate the agreement between task-based estimated and full-shift noise exposures [6].	Task-based noise exposures from 189 subjects on 502 work shifts were used in six linear regression models to obtain estimates of full-shift noise exposures. These models varied in complexity, from estimates using task-based noise exposures alone to estimates using task-based noise exposures grouped by equipment, work location and trade. Agreement between task-based estimates and measured full-shift noise exposures ranged from an $R^2 = 0.11$ to an $R^2 = 0.90$.	The study found that the R^2 increases when the specificity of the task definitions increases. This study also found that task-based estimates of full-shift exposure include a high degree of error when the task-based noise exposures are highly variable.
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 [18, 19, 20].	A cohort of construction workers (n = 25) had noise exposures measured by dosimeters, and time-at-task information recorded on activity cards or questionnaires. Simple linear regression was used to determine the agreement between the task-based estimated and dosimetry measured daily noise exposures. The relationship between dosimeter measured daily noise exposures and task based estimated daily noise exposures calculated from activity cards and questionnaires had an $R^2 = 0.62$, and $R^2 = 0.59$ respectively.	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 dB(A).
To compare estimated and measured daily noise exposures [21].	Eight estimates of daily noise exposures were calculated for each dosimeter measured daily noise exposure (n = 189). Estimates were calculated using time-at task data collected by direct observation, worker diary, and supervisor summary. Estimated daily noise exposures were calculated using either the arithmetic or geometric mean task-based noise exposures. Agreements between estimated daily noise exposure and measured daily noise exposures ranged from 0.70 – 0.77 for direct observation, 0.63–0.71 for worker reports, and 0.49–0.62 for supervisor assessments.	The study found that a high degree of agreement can be achieved between task-based and dosimetry-based estimates of full-shift exposures. The task-based approach that uses worker reports combined with task AM or GM levels yielded similar results to the more time-intensive direct observation method to estimate full-shift exposures.

2.2. Calculation of personal noise dosimetry measurements

For the different job categories the mean $L_{Aeq,T}$ measured with dosimeters was calculated. Using the equation $E_1 = (10^{(LAeq/10)}) * T$ with L_{Aeq} being the equivalent noise level measured by the dosimeter and T the duration of the dosimeter measurement, an exposure value (E_1) for each dosimeter measurement was calculated. For each job category, the mean $L_{Aeq,T}$ measured by the dosimeters was calculated using the equation $L_{Aeq,12h} = 10 * \log((E_1 + E_2 + \ldots)/12h)$, where 12h was replaced with the sum of the durations of the dosimeter measurements in hours. 224 complete and independent full-shift personal measurements were made for the analysis.

2.3. Area noise measurements

Area noise measurements were made based on the task details outlined in each corresponding full-shift personal sample to replicate full-shift exposure. Area measurements of noise levels were conducted in accordance with *AS/NZS 1269-2005* [23] using a sound level meter (hand-held analyser type 2250, Brüel and Kjær, Nærum, Denmark). A similar method of sample collection is detailed in ISO 9612 wherein the sound level meter microphone is positioned at the location of the worker's head during normal performance of a job or task [24].

In each measurement position, 45-second measurements were completed, and A-weighted equivalent noise levels ($L_{Aeq,45s}$) were recorded. The area measurements were limited to locations where the utility personnel are likely to spend time during the course of planned or unscheduled maintenance work, based on the observations made within the corresponding full-shift measurement task activity logbook. A member of the work group was present at each location to demonstrate typical distances from noise sources. With the worker in position, the sound level meter microphone was located approximately 0.1 m horizontally from the entrance of the external canal of the ear receiving the noise level. The measurement duration of an individual source was sufficiently long for the noise exposure level to be representative of the activities being performed by the worker as required to obtain an L_{eq} reading which had stabilised within ±0.5 dB.

2.4. Calculation of area noise measurements

Mean, median and percentiles of noise levels were calculated for each measurement location. The quantity used for averaging the results was calculated from the measured $L_{Aeq,45s}$ by,

$$\frac{p2}{p02} = \left(\frac{LAeq,45s}{10}\right) \quad (1)$$

where p is the sound pressure that corresponds to $L_{Aeq,45s}$ and p_0 is a reference value set at 20 μPa. The corresponding mean sound pressure level was calculated as,

$$\overline{LAeq,45s} = 10 \ \log \left(\frac{p}{p0}\right)^2 \quad (2)$$

The task based estimated $L_{Aeq,12h}$ was calculated based on mean noise levels during typical working conditions. For each measurement location, an exposure value (E_1) was calculated as,

$$E_1 = (10^{(LAeq/10)}) * T \quad (3)$$

where L_{Aeq} is the mean noise level at the location, and T is the mean hours spent at that location during a 12 h shift for each job category. The exchange rate used in the equation is 3 dB. $L_{Aeq,12h}$ for each job category was then calculated as,

$$L_{Aeq,12h} = 10 * \log((E_1 + E_2 + \ldots)/12h) \quad (4)$$

The fit to the data uses the following equation and is calculated as,

$$dB(A)_D = M * dB(A)_T + C \quad (5)$$

Where M is the slope of the line and C is the intercept. T is the mean hours spent at the task location.

2.5. Comparison of full-shift dosimeter measurements and area measurements

Each full-shift measurement was broken down to the task level through the review of its corresponding task activity diary. Tasks were assessed in the field using a sound level meter to recreate the exposure measured in the full-shift sample. This exercise was repeated for all personal measurements across all five job roles. An example is shown in Table 2.

2.6. Statistical analysis

All calculations and descriptive statistics were completed using IHSTAT (https://www.aiha.org/public-resources/consumer-resources/apps-and-tools-resource-center) an exposure statistics application developed by the American Industrial Hygiene Association (AIHA). IHSTAT is an Excel application capable of calculating exposure statistics with the use of lognormal (or normal) parametric statistics. Simple linear regression analysis was conducted using Stata version 15 (StataCorp LP) to compare full-shift and task-based methods of exposure assessment.

Table 2. Evaluation of normalised daily noise exposure using forty five second long average noise levels $L_{Aeq,T}$ by observed task activity (Electrician job role example).

Sample 005 – Activity: Asset Inspection and Equipment Repair

Task	*Measured Noise Level L Aeq,Ti*	*Duration of Exposure Ti*	*Pascal Squared*	*Partial Noise Exposure E A,Ti*	*Total Daily Noise Exposure E A,T*	*Normalised Noise Exposure Level L Aeq,8h*
	dB(A)	*Hours*	*Pa 2*	*Pa 2h*	*Pa 2 h*	*dB(A)*
TP1 inspection - near louvers	88.50	0.15	0.283	0.042		
TP2 inspection - near louvers	90.90	0.15	0.492	0.074		
TP3 inspection - near louvers	91.70	0.15	0.592	0.089		
In between louvers	83.20	0.10	0.084	0.008		
Yale Veracitor Forklift with beeper	92.90	0.15	0.780	0.117		
Pedestal Grinder	91.90	0.15	0.620	0.093		
Sander	85.20	0.15	0.132	0.020		
16oz shot peen hammer	112.10	0.05	64.872	3.244		
Breaks and other Activities	65.00	11.45	0.001	0.014		
					3.701	91

Table 3. Descriptive statistics from personal noise dosimetry results.

Job Role	Number of samples taken (n)	Geometric Standard Deviation (GSD)	Mean		Maximum		Minimum	
			% dose	dB(A)	% dose	dB(A)	% dose	dB(A)
Fuel Delivery Driver	39	3.279	60.723	82.84	444.3	91.46	3	69.82
Communications Technician	35	3.863	12.03	75.83	55.5	82.45	0.3	59.84
Electrician	50	3.331	41.18	81.16	243.7	88.86	1.8	67.60
Plumber	50	3.128	41.42	81.19	267.3	89.26	0.4	61.10
Power Station Operator	50	3.535	26.43	79.24	150	86.75	0.2	58.10

3. Results

The mean dB(A) from the full-shift TWA measurements was below the occupational exposure limit (OEL) for all job roles (Table 3). However, the maximum level was above the OEL for all job roles except the communications technician.

The simple linear regression analysis indicated excellent agreement between the task-based and full-shift measurements (Figures 1, 2, 3, 4, and 5) with R^2 values above 0.85 for all job roles. For all job roles, the simple linear regression analysis calculated a coefficient of determination of 0.91 for the agreement of full-shift and task-based measurements showing a good fit for the model against the data (Figure 6). The fit to the data is of the form $dB(A)_D = M * dB(A)_T + C$. A summary of fits and R^2 values is given in Table 4.

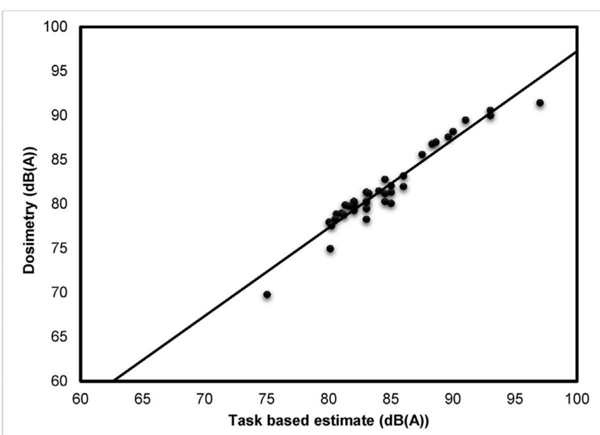

Figure 1. Comparisons of full-shift noise dosimetry with task-based estimates using area measurements for job role Fuel Delivery Driver.

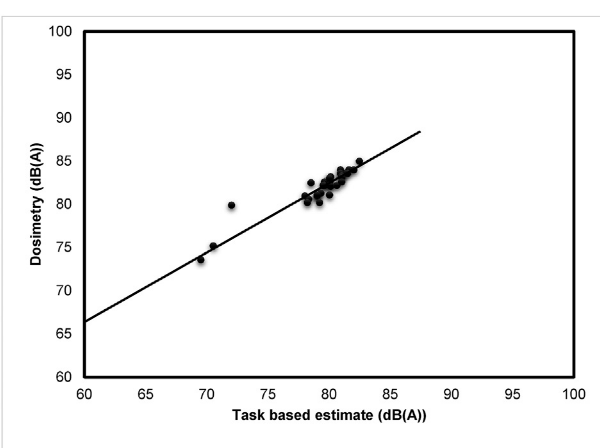

Figure 2. Comparisons of full-shift noise dosimetry with task-based estimates using area measurements for job role Communications Technician.

4. Discussion

The current study aimed to investigate exposure to occupational noise as experienced by utility workers using a combination of area noise measurements and task activity diaries to reasonably estimate full-shift dosimeter measurements. The results of this study indicate that task-based estimates of noise exposure can be useful in forecasting full-shift noise exposure, when calculated using specific tasks undertaken by job role. The coefficients of determination for all five job roles indicated agreement between full-shift dosimeter measurements and estimates made using area measurements. Considering the variability in the tasks described in the task activity diaries, the task-based estimates are likely to fall within the expected range, providing a good estimate for daily noise exposures.

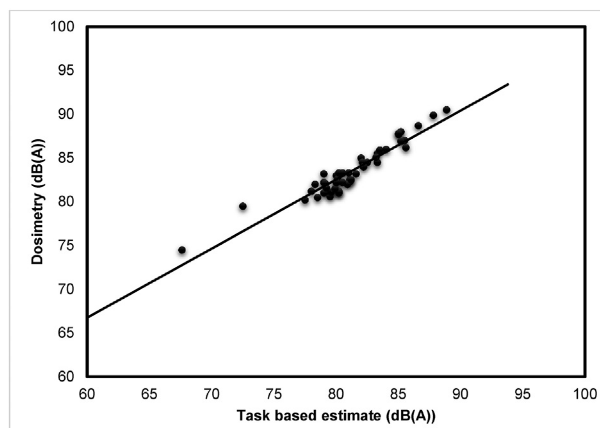

Figure 3. Simple linear regression model comparing full-shift noise dosimetry with task-based estimates using area measurements for job role Electrician.

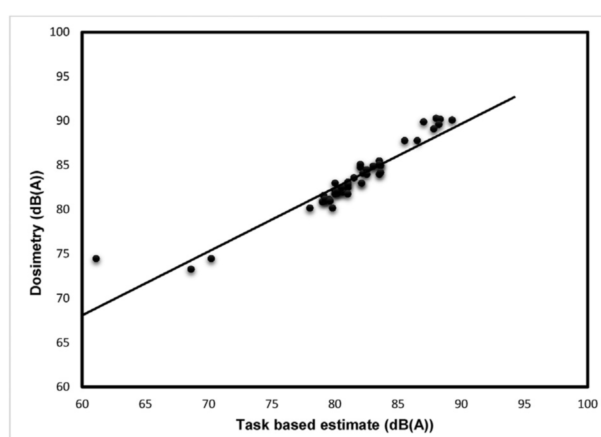

Figure 4. Simple linear regression model comparing full-shift noise dosimetry with task-based estimates using area measurements for job role Plumber.

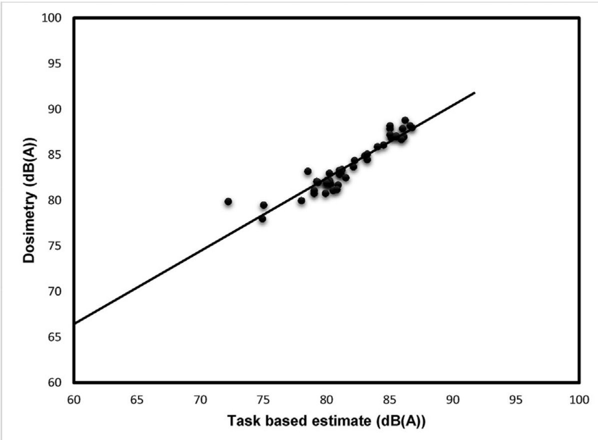

Figure 5. Simple linear regression model comparing full-shift noise dosimetry with task-based estimates using area measurements for job role Power Station Operator.

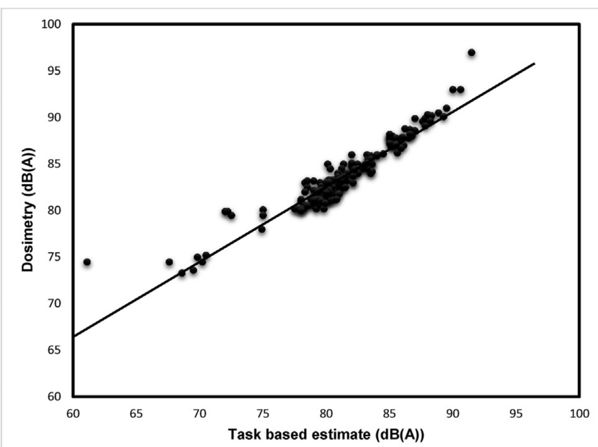

Figure 6. Simple linear regression model comparing full-shift noise dosimetry with task-based estimates using area measurements for all job roles.

Table 4. Summary of simple linear regression fits and R^2 values by job role.

Job Role Dataset	M	C	R^2
Fuel Delivery Driver	0.996	2.334	0.932
Communications Technician	0.803	18.184	0.935
Electrician	0.788	19.466	0.888
Plumber	0.719	24.884	0.885
Power Station Operator	0.800	18.416	0.936
Combined Dataset	0.806	18.049	0.911

The three studies in the literature comparing full shift and task-based estimates of exposure to noise [6, 18, 21] highlighted that clearly defining beginning and ending times for each task increases the agreement between estimated and measured daily noise exposures, and there is generally agreement between time-at-task information collected from direct observation and worker self-reports. In general, these studies found moderate to good agreement between measured and task-based estimated daily noise exposures. In estimating task-based exposure to noise, the definition of *task* is paramount. A task can be described as an overall activity, whereby a set of sub-tasks may be present, or can be described at the sub-task level in first instance. For the purpose of accuracy, the more specific the description of the task to be measured, the better the precision in assessing the task, and hence the more credible the output data of the task-based measurement taken [6].

The current study demonstrates that, provided a task is defined accurately with the assistance of the operator completing the task, then assessment of these tasks can also be accurate enough to accommodate variability between tasks in a dynamic environment. A worker's input into tasks completed on a day that they were sampled is crucial to understanding the key elements of the worker's shift that may have contributed to exposure values measured. This information is known to be unreliable when collected retrospectively [13], therefore the task activity diaries within this study were completed with each worker directly after their shift to increase task recall accuracy. This appears to be a key point of difference in the agreement between area and personal measurements within the context of this study (ranging 0.885–0.936), compared to other studies [6, 12, 13].

From a practical standpoint, the good correlation demonstrates that the calculation given ($dB(A)_D = M * dB(A)_T + C$) provides an equivalency factor between dosimetry and area measurements for noise. The fitted equations, given the strong agreement between individual job roles and to the whole dataset, suggest that this calculation may work for all occupations and provide a standard agreement between the two methodologies dependent on equipment utilised. The implication for the occupational hygienist is that, providing task characterisation is accurate, TWA exposures have the potential to be accurately characterised utilising a static sampling method, meaning statistically valid representation across multiple members of a work group over a fixed period may not be necessary to estimate noise exposure.

5. Conclusion

This work builds upon similar research conducted by Seixas et. al [6] and Virji et al [21] wherein the agreement between task-based estimated and full-shift noise exposures and comparisons between estimated and measured daily noise exposures were assessed respectively. Both studies found that agreement can be observed between task-based and full-shift estimates, however this is largely contingent on factors such as specificity of task definition and worker reports [6, 21]. Building upon these determinants, the current study utilised worker input into tasks completed on the day that sampling was completed to increase task recall accuracy, and this appears to be a key factor in the agreement between area and personal measurements.

Task-based noise exposure analysis has the potential to be widely used in the utilities industry. While full-shift monitoring to determine TWA exposures is useful, the changing work environment, variability in tasks and equipment, and varying workday hours, limit the ability of the 8-hr TWA to accurately characterise the exposures and associated health risks for utility workers. For some utility providers, access to occupational hygiene services may be limited; meaning a complete noise survey conducted to determine personal exposures may not be viable. An alternative noise exposure analysis methodology, developed from a comprehensive task-based exposure database, is thus an attractive option for estimating the personal noise exposures of workers with irregular tasks, such as those in the utilities industry.

Declarations

Author contribution statement

David Michael Lowry: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Lin Fritschi and Benjamin J. Mullins: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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