THE RELIABILITY OF PERSONAL NOISE DOSIMETERS UNDER STEADY-STATE AND VARIABLE NOISE EXPOSURE

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ABSTRACT

Three groups of I5 industrial workers were identified according to their pattern of exposure to noise: a) steady-state, b) periodically fluctuating and c) randomly variable. A personal dosimeter was worn by each worker for three consecutive days. The long term exposure was also assessed by means of sound level meter sampling procedure. The standard error of measurement of the dosimetry was ± 1.10, ± 1.56 and ± 2.86 dB for the three types of exposures respectively. Dosimetric and SLM data acheived the same result within 0.5 dB for the first 2 groups. An average difference of 3.4 dB was obtained with the third group.

SOMMAIRE

Trois groupes de I5 travailleurs industriels ont été recrutés en fonction de la configuration temporelle de leur exposition professionnelle au bruit. Il s'agissait a) de bruits stables, b) de bruits dont le niveau subit des variations périodiques et c) de bruits dont le niveau varie de manière aléatoire. Chaque travailleur a porté un dosimètre individuel durant trois jours consécutifs. L'exposition à long terme a également été évaluée par échantillonnage sonométrique. L'erreur-type de mesure dosimétrique atteignait respectivement ± 1.10, ± 1.56 et ± 2.86 dB pour les trois types d'exposition. Les mesures dosimétriques et sonométriques ont donné le même résultat à 0.5 dB près pour les deux premiers types d'exposition. Un écart moyen de 3.4 dB, en faveur des mesures sonométriques, a été obtenu pour le groupe de travailleurs dont l'exposition était aléatoire.

The widespread use of personal dosimeters have been justified by the need to measure directly the exposures to fluctuating noise, and more especially for noise fluctuations that depend on motions of the individuals in different worksites. The meaningfulness of the measure in terms of risk of hearing loss is a function of its reliability: it must represent an accurate estimate of the long-term exposure [1]. Sources of error have been identified for personal exposure meters: the microphone location [2-3], and its interaction with the nature of the sound field [4-5], the accuracy of the frequency response complying to Type 2 sound level meter tolerances limits [6], the limited dynamic range of the device [7] and its response to high level impulses [8-10]. The variability of the exposure to be measured has also been considered [11] but few studies have attempted to quantified the actual contribution of this source of error. In a study on mining operations, the 95 % confidence interval of the mean of 10 dosimetric results was estimated to be 10% for jobsites involving relatively stable noise levels and 45 % for sites involving highly variable exposures [12]. Overall, the mean for 5 dosimeter results on the same sites and occupations layed, to 95 % confidience, within ±3 dB of the true mean.

The aim of the present investigation was to assess the reliability of personal dosimetry for different patterns of exposures in industry. Three categories of exposures were defined for the purpose of this study:
- category I (C1): job assignments that involve constant daily exposure to steady-state noise without motion in space;
-category 2 (C2): job assignments involving displacements in different noisy area that are predictible in space and time, or exposure to time-varying noise, the variations being determined and predictable for a workday an repeated from one day to another;
-category 3 (C3): job assignments that are partially or totally unpredictible, involving varying exposures within a workday and from one day to another.

It was hypothesized from previous results [12] that the dose measurements over a workday would be highly reliable for the first two categories and relatively unreliable for the third one.

METHODS

Selection of the industrial settings

In order to minimize the possible influence of other sources of variation, the plants selected had to meet the following criteria: absence of audible discrete impact/impulse noises or predominantly high frequency noise (above 3 kHz). A weaving mill and a food processing plant were found to meet these criteria.

Subjects

For each of the three categories of exposure, a group of I5 volonteer workers was selected. Their job assignment and pattern of noise exposure had to fit the definitions given above. Subjects in group C1 were production workers. Group C2 comprised production workers and maintenance personnel assigned to a restricted area in the production line. Workers belonging to group C3 were responsible for the general maintenance in the factory .

Equipment

Ten Dupont MK1 dosimeters were used. They were submitted to a thorough verification and calibration prior to the experiment. The calibration was checked before and after every day of measurement. They were set to operate with a 5 dB exchange rate and a threshold of 80 dBA. A Bruel and Kjaer integrating sound level meter (model 2225), equiped with a BK-4175 microphone, was also used for a parallel assessment of the exposures of the 45 subjects.

Procedure

Each subject worn the same dosimeter for a full 8-hour work shift during three consecutive days. They received instructions to prevent artifact in the measurements. The microphone, attached to the clothing, was located at the shoulder.

Exposure measurements with the sound level meter involved the following steps: the worker was first met to obtain a detailed description of his work organization and schedule, then measures of L_{eq60s} were obtained for each activity or job performed during a representative workday. For the subjects belonging to group C3, a list of assignments within a "typical" week or month period was first obtained; the sampling of the noise exposure levels was then performed accordingly.

RESULTS

Table 1. Mean, standard deviation (s), minimum and maximum dose in dBA (time weighted average) for three consecutive days (8-hour periods) for three categories of exposures. The corresponding results obtained with the sound level meter (SLM) are also given.

	Mean	S	min.	max.
Group C1				
day 1	94.96	6.58	86.4	106.4
day 2	94.50	6.41	85.9	105.9
day 3	94.25	6.13	86.8	103.9
SLM	94.15	6.47	85.9	103.1
Group C2				
day 1	87.92	7.47	77.2	101.5
day 2	88.01	7.31	73.5	101.6
day 3	88.49	6.44	81.0	101.2
SLM	88.08	6.68	79.1	101.2
Group C3				
day 1	85.78	6.06	74.4	98.1
day 2	84.32	8.52	69.7	100.0
day 3	86.28	7.04	71.9	97.4
SLM	89.32	4.26	82.9	99.2

The mean results presented in Table I are in agreement with our assumption: for exposures to steady-state noise (C1) and to predictable fluctuating noise (C2), the average dosimetric readings for a group were highly reproducible from one day to another and they were very similar to those obtained with a SLM. For relatively unpredictable time-varying noise (C3), the daily mean doses showed variations; the standard deviations are also more variable and tend to be higher than in the other groups. The range of doses extend from much lower minimum values to approximately the same maximum values. Moreover, there is a clear disagreement between the dosimetric and SLM results. These observations are confirmed by the results of the analysis of variance (randomized block design) on the factors "repetition of measurements" and "method of measurement" as shown in Table 2.

Table 2. Results of one-way analysis of variance on the effect of the repetition of measurements with dosimeters and method of measurement, for each category of exposure.

Source of variation	Mean square	F	Probability	Degrees freedom
Repetition of meas.				
Group C1	1.95	1.63	0.21	2,28
Group C2	1.38	0.51	0.61	
Group C3	15.56	1.41	0.26	
Method of meas.				
Group C1	1.67	4.96	0.04	1,14
Group C2	0.01	0.03	0.86	
Group C3	84.81	8.40	0.01	

The results from Table 2 demonstrate that there was no systematic variation in daily noise dose measurements. But one will note that the variability (in dB squared) was much higher for group C3. When comparing SLM results with the logarithmic average of the dosimeters results, significant differences are obtained for categories C1 and C3. In the first case, the mean difference is equal to 0.5 dB in favor of the dosimetric readings. This is explained by a very slight but systematic overestimation of the time spent away from the noise (e.g. in the lunch room) when interviewing the workers about their work schedule. This small bias was probably present for the other two categories, but it would have been outweighted by the higher intra-individual variability in the exposure along the day. The effect of the mode of measurement with category C3 is explained by the fact that with the SLM method, the exposures were estimated over 40-hour and 160-hour periods and then converted to daily 8-hour doses. The limited 3-day dosimetric sampling did not take into account some of the most severe exposures occuring over a typical week or month interval.

In the absence of any systematic daily variation in dosimetric results, the random error was further analysed by computing the standard error of measurement: it is based on the reliability coefficient as indicated in the following equation [13]:

$$S_e = S (1 - R_{xx})^{1/2} \quad (1)$$

where S_e = standard error
S = standard deviation
R_{xx} = reliability coefficient

Table 3. Reliability coefficients, standard error and 95% confidence intervals of time weighted averages obtained from dosimetric measurements in dB for the three categories of exposures.

Group	R_{xx}	S_e (dB)	$\pm 1.96 S_e$ (dB)
C1	0.97	1.10	±2.16
C2	0.95	1.56	±3.06
C3	0.82	2.86	±5.61

Assuming that the measurement error is independant of the magnitude of the measure and that it is normally distributed, the values given in Table 3 represent estimates of the variability of individual results; this allows to define confidence intervals of individual exposure levels measured by means of personal dosimeter. Thus, for 95% of the cases in group C1, the results obtained is within ± 2.2 dB of the true dose. For group C2 and C3, the margin of error extends over 6.2 and 11.2 dB respectively. It implies for example that a dosimetric result of 90 dB-8hour means that the true exposure level is somewhere between 87.8 and 92.2 dBA in group C1, between 86.9 and 93.1 dBA for a worker in group C2 and between 84.4 and 95.6 for an individual belonging to group C3.

DISCUSSION

Our hypothesis is confirmed by the present results obtained with group C3: unless it is conducted on a homogeneous group of workers [14], personal dosimetry is relatively unreliable when evaluating daily exposures that are partially or totaly unpredictable. An appropriate identification of the exposure variables is necessary to accurately assess representative daily doses. Repeating the measurement over three consecutive days was not sufficient to achieve this accurate estimation: averaging the doses over three days of measurement would only reduce the variablility by a factor of 1.7 (that is the square root of 3). The margin of error of the average would be ± 3.2 dB, a range of values that cannot be considered as negligeable. Consequently, at least for this category of exposures, a systematic analysis of the work organization within the appropriate time scale combined with an adequate sampling of the noise levels with a precision SLM is probably more reliable. Furthermore, it was less time consuming to perform direct measurements at several sites and for several activities than repeating personal dosimetry over three days (which were insufficient to achieve a representative estimate of the individuals long-term exposure levels).

However, the reliability of the SLM survey method should also be assessed for this type of unpredictable exposures; independant estimates of the long-term exposure of general maintenance personnel may turn out to be relatively variable, unless considerable time is devoted to the survey of the exposure of each worker. This is suggested by the results of a study conducted on foundry workers [15]. Dosimetric measurements were performed over the number of days necessary to acheive a long term representative dose at a level of precision of ±2 dB for a 95 % condfidence interval. It required up to 23 days of measurements for some jobsites like maintenance. Then, sound level meter measurements were conducted over five days selected at random. The difference in microphone location (shoulder vs free-field) was taken into account by means of a uniform correction factor for all comparisons. The 5-day samples of SLM measurements underestimated the long term dose by as much as 7 dB in the case of jobs involving subtantial movements, working in confined spaces and tasks where the operator works close to the noise source and frequently changes position relative to the source.

The results obtained in the present experiment with exposure categories C1 and C2 did not confirm our hypothesis at the level of individual measurements. Despite a careful selection of the workers in accordance with the definition of our exposure categories, only group estimates can be said to be reliable. The individual readings are subject to a significant daily variation; even if they are averaged over three days of measurement, their margin of error is still significant: ± l.2 dB for group C1 and ± 1.8 dB for group C2. Considering that, using the SLM, it takes only a few minutes to obtain several measures of exposure of a worker belonging to group C1, it certainly represents a more valid and pratical method of dose assessement. But it is also the case for workers belonging to group C2, even though the sampling of the noise levels for differents activities require more time; attaining a higher degree of reliability can be achieved in less survey time using an intergrating sound level meter and analysing the work organization than undergoing personal dosimetry over several days with the same workers.

Considering the influence of the variability of exposure and the other sources of error of personal dosimetry [l-l0], one can conclude that this approach to noise exposure measurement is of limited use in industrial settings [l6].

REFERENCES

1. Hétu, R. & Phaneuf, R. A procedure of risk appraisal for noise-induced hearing loss at the level of a single entreprise. Proc. 12 th International Congress on Acoustics, 1986, B5-3.

2. Christensen, L.S. & Hemingway, J.R. Sources of error in noise dose measurements. Bruel & Kjaer Technical Review, 1973, 3-13.

3. Asztely, J. & Kleiner, M. On placement of personal noise meter microphones. INTER-NOISE, 1981, 851-856.

4. Mery, J., et al. Evaluation du risque de surdité professionnelle: utilisation des dosimètres de bruit. Arch. Mal. Prof., l977, 38: 315:327.

5. Erlandsson, B., et al. Comparison between stationary and personal noise dose measuring systems. Acta Otolaryngol., 1979, Suppl. 360: 105-108.

6. Carito, A.P., Michael P.L. & Prout, J.H. Are american national standards institute sound level meter tolerance limits adequate for sound dosimeters. J. Acoust. Soc. Am.,1977, 61, Suppl. 1, S 26.

7. Fairman, T.M. Variations in noise dosimeter readings of fluctuating noise. Wright-Patterson AFB, 1982, Report no. AFRMRL - TR-82-21.

8. Swensson, J. Dosimeter response to impulsive noise - measurement errors and their consequences. INTER-NOISE, 1978, 225-227.

9. Rockwell, F.H. Real and imaginary OSHA noise violations. Sound and Vibration, l981, l5 (3): 14-16.

10.Earshen J.J. Industrial noise exposure monitoring: dosimetry vs area measurements. INTER-NOISE,1982, 559-562.

11.Passchier-Vermeer, W., Berg, R. & Revekamp, M. Personal sound exposure meters. INTER-NOISE, 1981, 863-868.

12.Jones, C.O. & Howie, R.M. Investigations of personal noise dosemeters for use in coalmines. Ann. Occup. Hyg., 1982, 25(3), 261-277.

13. Ferguson, G.A. Statistical Analysis in Psychology & Education, l971, Third edition, pp 362-374.

14. Behar, A. & Plener, R. Noise exposure - sampling strategy and risk assessment. Am. Ind. Hyg. Assoc. J., 1984, 45(2), 105-109.

15. Shackleton, S. & Pieny, M.D. A comparison of two methods of measuring personal noise exposure. Ann. Occup. Hyg., 1984, 28(4), 373-390.

16. Heggie, A.S. & Miller, T.D. When to use audio dosimeters. American Machinist, April l981.

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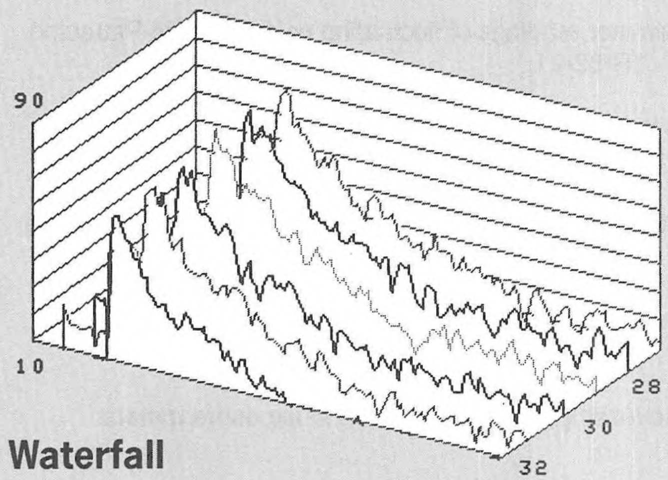

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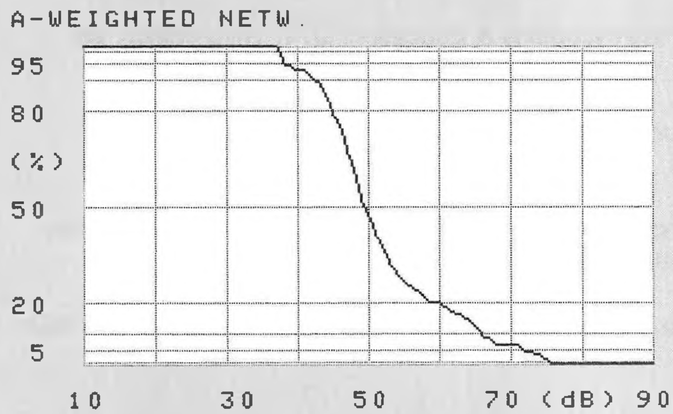

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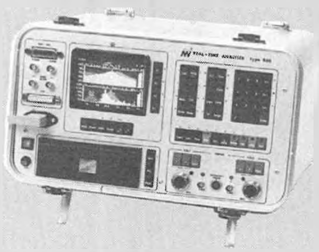

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