

Measurement of Effective Noise Exposure of Workers Wearing Ear-Muffs

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This paper presents the methodology and the results of binaural measurements of exposure to noise for 91 industry workers wearing ear-muffs. The results revealed that 18.7% of the workers were exposed to noise of equivalent A-weighted sound pressure levels of over 80 dB(A) and 7.7% to levels of over 85 dB(A). The measured levels were compared with those calculated with the octave-band method according to Standard No. EN 458:2004. The differences ranged from –3 dB(A) to 26.5 dB(A); their statistical distribution did not indicate any data which could suggest derating laboratory measurements. The main causes of exposure to noise higher by over 3 dB(A) than that theoretically predicted were the bad technical condition of ear-muffs (32.2% of the cases) and an incorrect way of wearing them (15.2%).

noise exposure hearing protectors ear-muffs real-world attenuation

1. INTRODUCTION

According to Directive 2003/10/EC [1] employers are obliged to “assess and, if necessary, measure the levels of noise to which workers are exposed” (p. 40). When workers use hearing protectors, the assessment of noise levels to which they are exposed is usually done with a method recommended by Standard No. EN 458:2004 [2]. Four methods of assessing A-weighted sound pressure level effective to the ear are recommended for continuous noise. Those methods differ in their requirements regarding their input data and in their accuracy. The octave-band method is the most accurate one; it is based on the sound attenuation of hearing protectors and the octave-band sound pressure levels of workplace noise. Sound attenuation is measured in laboratories, in certification processes according to Standard No. EN 24869-1:1992 [3].

The discrepancy between the attenuation of hearing protectors measured in laboratories for certification purposes and real-world attenuation is well known [5]. A popular way of dealing with this problem is to lower the laboratory-measured attenuation values. Laboratory measurements could be derated by various values: 4 dB for all types of hearing protectors [6], 9 dB for ear-plugs, 5 dB for ear-muffs, 3 dB for custom-moulded ear-plugs [7], 25% of the measured value for ear-muffs, 50% for user-formed ear-plugs, 75% for other ear-plugs [8] and subtracting double standard deviation from the mean sound attenuation value to calculate the declared assumed protection value (APV) [9]. The idea of derating laboratory-measured values is based on a global approach to the problem, without an analysis of the reasons for a discrepancy between laboratory-measured and real-world attenuation of hearing protectors [10].

There are three possible reasons why protection can be lower than predicted. The first and the most common one is that the hearing protectors do not fit well (because they are incorrectly worn, because the worker has long hair, because the worker wears spectacles or other personal protective equipment). The second reason can be the aging of the hearing protectors. Workers usually use ear-muffs as long as there are no signs of their physical damage. However, absence of any visible damage does not guarantee stability of attenuation values [11, 12]. The third reason is the extent to which the methodology of laboratory subjective sound attenuation tests corresponds to the performance of the hearing protectors in the real world [13].

This paper aims to present the methodology and the results of measurements of exposure to noise of workers wearing ear-muffs, to compare the A-weighted sound pressure levels measured under ear-muff cups with values calculated with the octave-band method and to conclude about the possible reasons why real exposure is higher than that theoretically predicted.

2. METHODOLOGY

Individual exposure to noise was measured for 91 volunteers: 13 workers from the steel industry, 28 from the furniture industry, 23 from the food industry, 3 from the building industry, 12 persons working in a chemical plant

and 12 workers of a heat and power plant. The workers used independent ear-muffs or ear-muffs attached to industrial helmets. Before the measurements they were informed about the aim and the methodology of investigations, and the ear-muffs were examined to evaluate their technical condition. The workers were asked to fit and wear the hearing protectors in the usual way. For each worker the following information was reported: the technical condition of ear-muffs, time they had been worn, the way the ear-muffs were worn, evaluation of how the cushions fitted and the causes why they did not fit well (e.g., incorrect position or adjustment of the headband; deformation of the cushions; the worker's spectacles, long hair or atypical shape of the head/ears).

The measurements were carried out with the use of a Svan 948 four-channel sound analyser (Svantek, Poland). The sound pressure levels in octave bands (centre frequency range: 125–8000 Hz), the equivalent and the maximum A-weighted sound pressure levels and the peak C-weighted sound pressure levels were measured. The measurement time corresponded to the representative time of each worker's individual exposure to noise. Two microphones were placed at the workers' conchae under the cups of the ear-muffs and two microphones were fixed outside the cups (Figure 1). The way the analyser was mounted is shown in Figure 2. Some uncertainties associated with the measuring levels outside and under ear-muff cups might be possible.



Figure 1. The mounting of the microphones.



Figure 2. The mounting of the sound analyser.

The values of the equivalent *A*-weighted sound pressure level measured under the ear-muff cups were compared with the values calculated according to Equation 1 [4]:

$$L'_A = 10 \log \sum_{f=125}^{8000} 10^{0.1(L_{Af} - APV)}, \quad (1)$$

where L_{Af} —equivalent *A*-weighted sound pressure level in the octave bands of noise, measured with microphones mounted outside ear-muff cups, APV —assumed protection value of the ear-muffs,

$$APV = M_f - \alpha s_f, \quad (2)$$

where M_f , s_f —mean sound attenuation and standard deviation in the frequency bands of the ear-muffs (data taken from information for users given by the manufacturer), α —a constant which might have various values depending on the protection performance value.

Protection performance was assumed to be 84% and $\alpha = 1$. This corresponded to a requirement in Standard No. EN 352-1:2002 [14] on supplying the user of hearing protectors with information on the value of APV , with $\alpha = 1$.

The levels measured under the cups were compared with limit and action values. In Poland

there are three exposure limit values: daily noise exposure level of 85 dB(A), maximum *A*-weighted sound pressure level of 115 dB(A) and peak *C*-weighted sound pressure level of 135 dB(C). There are also two exposure action values: daily noise exposure level of 80 dB(A) and peak *C*-weighted sound pressure level of 135 dB(C).

To conclude the study of the possible causes of discrepancies between measured and calculated values, the measurement results were analysed in the context of information obtained from the workers.

3. RESULTS AND DISCUSSION

3.1. Actual Noise Exposure of Workers

The equivalent *A*-weighted sound pressure levels, maximum *A*-weighted sound pressure levels and peak *C*-weighted sound pressure levels measured under two ear-muff cups, as cumulated distribution functions, are shown in Figures 3, 4 and 5. The cumulated value presents the percentage of all the studied cases for which the noise level measured under the cups was lower than the given value.

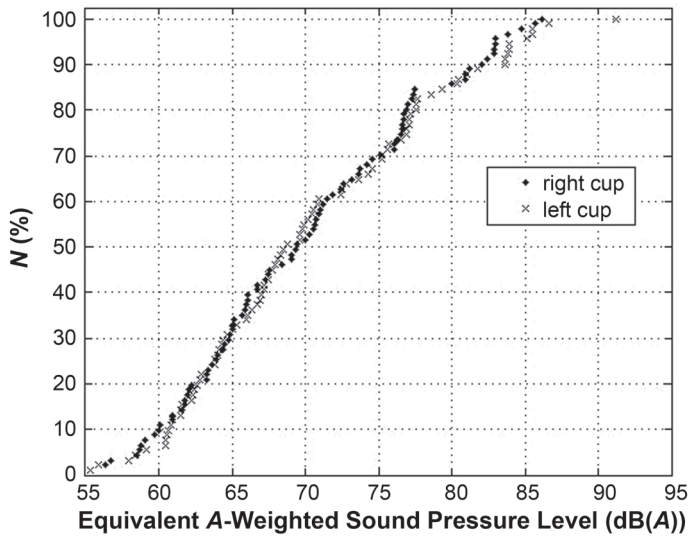


Figure 3. Cumulated distribution function of the equivalent A-weighted sound pressure level measured under ear-muff cups. Notes. *N*—all studied cases of ear muffs for which the noise level measured under the cups was lower than the given value.

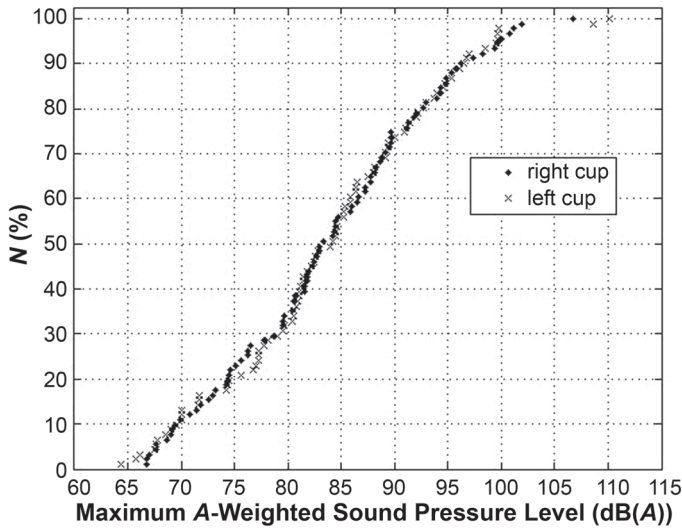


Figure 4. Cumulated distribution function of the maximum A-weighted sound pressure level measured under ear-muff cups. Notes. *N*—all studied cases of ear muffs for which the noise level measured under the cups was lower than the given value.

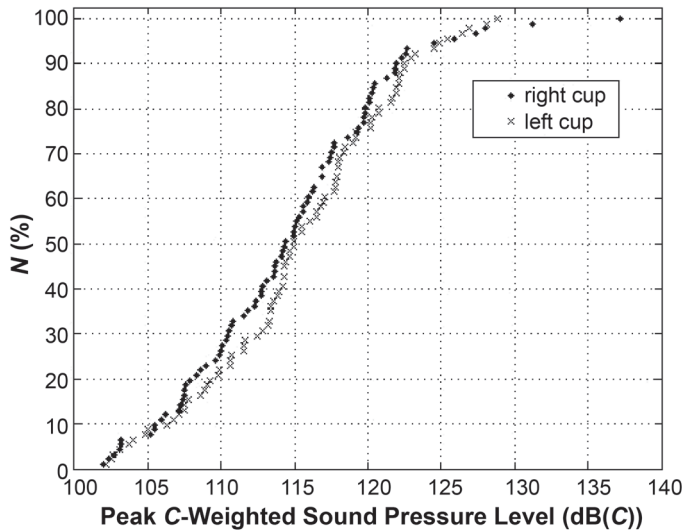


Figure 5. Cumulated distribution function of the peak C-weighted sound pressure level measured under ear-muff cups. Notes. *N*—all studied cases of ear muffs for which the noise level measured under the cups was lower than the given value.

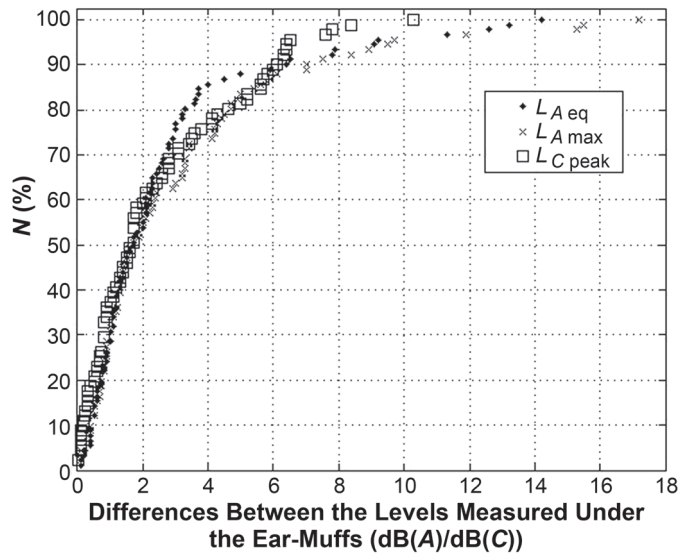


Figure 6. Cumulated distribution function of the differences between the levels measured under the right and the left cups of ear-muffs.

The results of the measurements show that for 17 workers the equivalent *A*-weighted sound pressure levels were higher than 80 dB(A), for 10 workers under both ear-muff cups and for 7 workers under one cup. For 7 workers the equivalent *A*-weighted sound pressure levels were higher than 85 dB(A) under one cup. For 25 workers the equivalent *A*-weighted sound pressure levels under both ear-muff cups were lower than 65 dB(A). Only one worker was exposed to noise of a peak *C*-weighted sound pressure level higher than the limit value of 135 dB(C). The measured maximum *A*-weighted sound pressure levels for all cases (under 182 cups) were lower than limit value of 115 dB(A). The cumulated distribution of the absolute values of the difference between the levels measured under the right and left cups of the ear-muffs is shown in Figure 6.

The differences between the levels measured under the right and left cups were higher by 3 dB for 26% of the measured equivalent *A*-weighted sound pressure levels, for 37% of the maximum *A*-weighted sound pressure levels and for 31% of the peak *C*-weighted sound pressure levels. The greatest differences were 14.2 dB(A), 17.2 dB(A), 10.3 dB(C), respectively. The main observed causes of those significant differences were the ill-fitting cushions because the hearing protectors

were not worn correctly, an incorrect adjusting of the ear-muffs on the head, atypical shape of the workers' heads or ears, and bad technical condition of cushions.

3.2. Differences Between Measured and Predicted Noise Levels

The differences between the measured equivalent *A*-weighted sound pressure level and the level calculated according to Equation 1 [4] for two cups of 90 ear-muffs (180 cases) are shown in Figure 7. The values of difference ranges are rounded to an integral number of decibels with a 3 dB(A) step.

A comparison of the measured equivalent *A*-weighted sound pressure levels under the cups of the ear-muffs and the computed values revealed that for 65.6% of all the tested cases, the measured values were higher than the values theoretically calculated by over 3 dB(A). For 23.3% of the cases the measured values were higher by no more than 3 dB(A). For 16.7% of the cases, the observed difference was 12–15 dB(A). For 11.1% of the cases the measured levels were lower than those theoretically calculated but by no more than 3 dB(A). The maximum difference value was 26.5 dB(A).

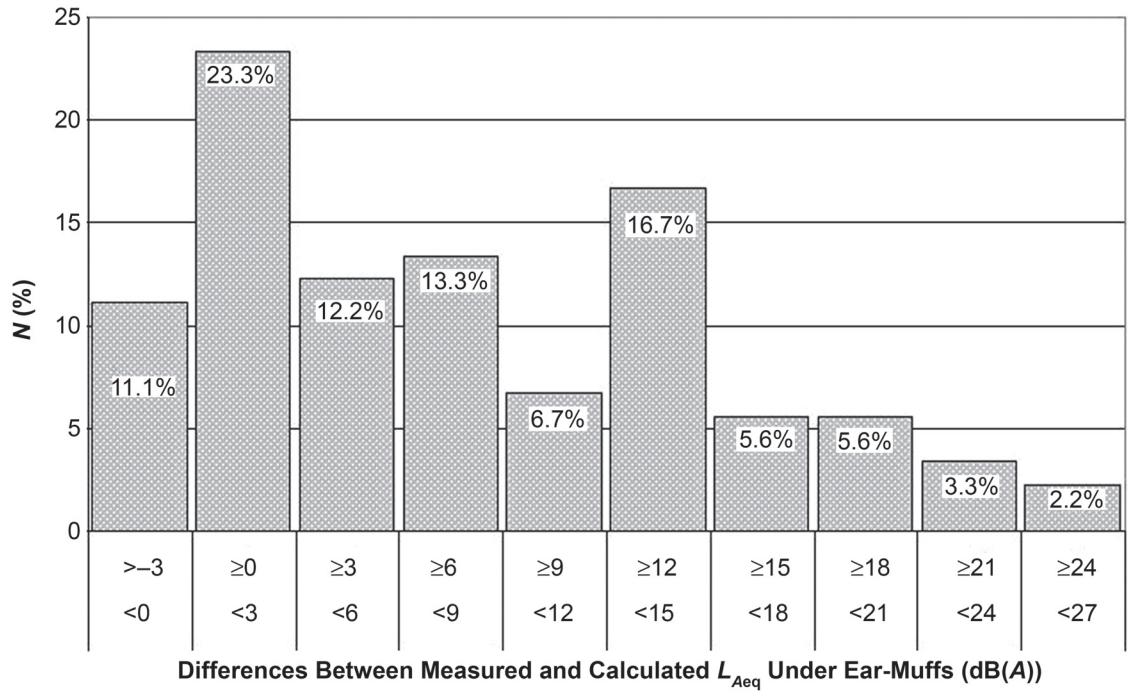


Figure 7. Distribution of the differences between measured and calculated equivalent A-weighted sound pressure levels under ear-muff cups. Notes. N—all studied cases of ear muffs, N = 180.

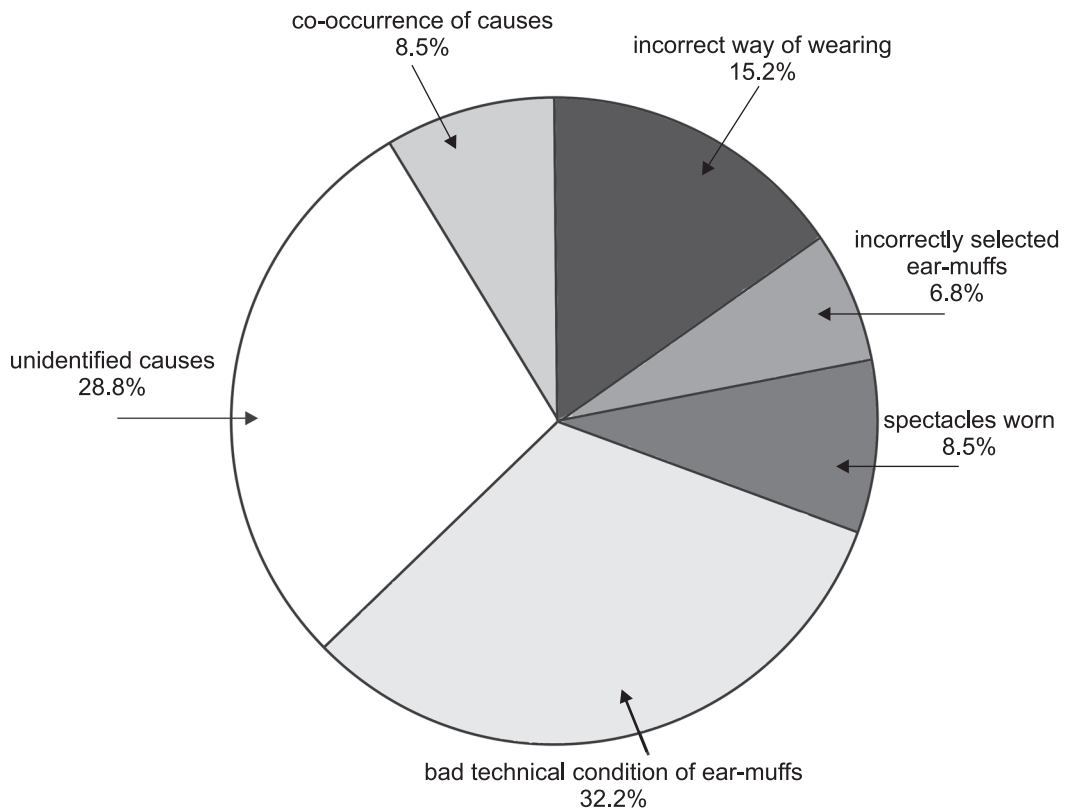


Figure 8. Causes for higher exposure to noise than suggested by the theoretically computed values.

3.3. Causes of Differences Between Measured and Predicted Noise Levels

Figure 8 illustrates the distribution of the observed causes of exposure to noise higher by over 3 dB(A) than that theoretically calculated. Inspection of the technical condition of the ear-muffs and of the way they were worn reveals that a bad condition of the ear-muffs (mainly of the cushions) was the most likely reason (32.2%, 19 workers). The next observed causes were incorrect way the ear-muffs were worn (15.2%, 9 workers), ill fitting cushions because the workers wore spectacles (8.5%, 5 workers), incorrectly selected model of ear-muffs for atypical head shapes (6.8%, 4 workers). Concurrent causes, bad technical condition and spectacles, were observed for 5 workers. It was not possible to identify the possible causes for 17 workers (28.8%).

4. CONCLUSIONS

1. The fact that workers wear ear-muffs does not mean that their hearing is correctly protected against noise. For 18.7% of the 91 tested workers wearing ear-muffs the equivalent A-weighted sound pressure levels under ear-muff cups were higher than 80 dB(A) and for 7.7% higher than 85 dB(A). One worker was exposed to noise of the peak C-weighted sound pressure level higher than 135 dB(C).
2. For 65.6% of all the tested workers the levels of noise to which they were exposed were 3 dB(A) higher than the levels estimated according to the recommendations in Standard No. EN 458:2004 with the octave band method [2]. The maximum observed difference between the measured and the calculated values was 26.5 dB(A). The statistical distribution of those differences does not correspond to any derating of laboratory measured attenuation values of ear-muffs.
3. Binaural measurements of exposure to noise are justified. In about 30% of the cases the levels measured simultaneously under both ear-muff cups differed by more than

3 dB(A)/3 dB(C). The maximum observed difference was 17.2 dB(A).

4. The main reason why the measured noise levels were higher than the theoretically predicted ones was the bad technical condition of the ear-muffs (32.2% of cases). The next one was that ear-muffs were worn incorrectly (15.2% of cases). Developing criteria for the lifetime for hearing protectors and providing information on lifetime to users would be very helpful. Workers should be trained in the maintenance of ear-muffs and in their correct use.

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