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Naples 2003

Headphone Noise: Occupational Noise Exposure Assessment for Communication Personnel

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For communication personnel exposed to noise emitted by headphones, the sound pressure level measured at the position of the exposed person (but the person absent) does not adequately represent the sound exposure. The first section of this paper reports comments concerning the legislation, the relevant international standards and the state-of-the-art of researches in this field. Then, the second section reports the results of an experimental study undertaken in four different occupational settings in order to detect whether a risk of hearing damage exists for the workers exposed to noise emitted by headphones. During the recordings a headphone identical to that worn by the telephone operator has been positioned on a manikin as to reproduce the same auditory condition. In order to assess the noise exposure, the recordings have been post processed by means of different frequency dependent transformations. The analysis of the results have shown that for some workers the risk of hearing loss exists. The implementation of a sound level limiter directly connected to the headphone has shown a good evidence: the output level never exceeds the defined threshold and the attenuator reacts in a very short time, providing a reduction of 10 dB in 0.3 seconds.

1. INTRODUCTION

In spite of rapid growth in the communications industry in the last century, relatively little research has been published on occupational noise exposure for communication personnel. This lack of information has probably been due to the difficulties in the measurement set-up and in the assessment of the exposure itself. Moreover, telephone calls are typically verbal communications that, even if amplified, are considered a natural task and are not commonly associated to a hearing risk. Nevertheless, there is a high number of persons exposed to noise emitted from headsets and a high number of complaints are related to an over-exposition to this kind of noise.

Researches in this field have shown non uniform data. Experiments undertaken on telephone operators by Glorig et al. [1], Alexander et al. [2] and Juan et al. [3] tend to exclude a hearing loss risk connected to occupational noise exposure. On the contrary, a study undertaken by Chiusano et al. [4] on people continuously wearing a headset in a U.S. Department of Defence facility, by Ianniello [5] on telephone operators and by Dajani et al. [6] on telephone cable maintenance workers and airport ground crew show that this risk could actually exist.

In the last decade, we have undertaken four different experimental studies concerning workers wearing headphones [7]: the first in a tape-recording division of a newspaper, the second and the third in a telephone central office and the fourth in a bank call-centre. In this paper, a review of these studies is performed in order to have data as representative as possible.

2. LEGISLATION AND INTERNATIONAL STANDARDS

The directive 86/188/EEC (Article 2, paragraph 1 and Annex I, paragraph 3.2) and its Italian transposition D.L. 277/91 (Article 39, paragraph 1 and Annex 6, paragraph 3.1) provide for noise measurements addressed to hearing risk assessment in the workplace. The measurements should preferably be made at the position occupied by the worker's ears during work, with the person concerned being absent in order to avoid any effect on the sound field. If it is necessary for the worker to be present, the microphone should be located at a distance (10 cm) from the person's head which will reduce, as far as possible, the effects of diffraction and distance on the measured value. If the microphone must be located very close to the person's body, appropriate adjustments should be made to determine an equivalent undisturbed pressure field and to account for the modification produced by the body; in fact, the sound pressure level measured with the worker present is different from that determined in the same measurement point in the person's absence [5].

When dealing with communication headsets, the application of the first method is wrong. That is, noise measurements performed in the absence of the operator with the microphone closed to the headset does not take into account the strong coupling occurring between the sound source and the ear of the exposed worker. Nevertheless, the application of the second method is still absurd. That is, noise measurements performed 10 cm outside the worker's ear are collected outside the headset too and give information of the environmental background noise rather than that emitted by the headset. Therefore, the application of the third method is the only one admitted and noise measurements must be performed very closed to the ear and must then be post-processed for adequate correction. In particular, for communication personnel the sound pressure value has to be detected within the area between the sound source and the ear; for example, at the cavum conchae or in the ear canal.

In this respect, a series of international standards (ISO 11904) have been drafted specifying methods for the determination of sound immission from sources placed closed to the ear. Part 1 of the series [8] describes measurements carried out using miniature or probe microphones inserted in the ears of human subjects (microphone in real ear – *MIRE technique*). Part 2 [9] describes measurements carried out using a manikin equipped with ear simulators including microphones (*manikin technique*).

By applying a frequency-dependent pressure transformation to the sound levels recorded within the ear, typical sound pressure levels external to the ears that could have produced the internal measured values are recovered and can be used for comparison with accepted standards for assessing noise exposure. This frequency-dependent transformation is based on the gain exerted by the ear at different frequencies; that is, its *frequency response*. The resonance gain of the ear canal appears at 2500 Hz, while that of the concha comes out at 5-6 kHz. The gain level is around 10 dB [10,11].

3. EXPERIMENTAL STUDY

3.1 Occupational settings

The experimental study has been undertaken in four different occupational settings:

- a tape-recording division of a newspaper. In this site, the workers listen to articles dictated on the phone by outside locations and then double-check the articles while listening to their

magnetic tape recordings. In the first part of their job the operators use telephone handsets with fixed gain but in the second part they wear supra-aural earphones with a variable gain.
- telephone central office of a government organisation. In this site, the workers have to connect incoming calls to the right internal extension. The operators could use either telephone handsets with fixed gain or supra-aural earphones and insert earphones with a 3-level gain.
- the same telephone central office as before, after the enlargement of the room. The operators have also new supra-aural earphones with adjustable gain, provided with a sound limiter.
- bank call-centre. In this site, the workers answer to incoming telephone calls of their costumers. The operators have supra-aural earphones with adjustable gain, provided with a sound limiter.

3.2 Instrumentation and measurement procedure

The measurement protocol was simple. A commercially available Bruel & Kjaer 4128 head and torso simulator was used. It consists of a dummy head simulating the human head and external ear, with microphones located at the eardrums. The output from each microphone is a close approximation of the acoustic signal at the level of the median or average human ear exposed to a similar sound field. The output signals have been acquired by means of the Larson Davis 2900 dual-channel digital frequency analyser.
At each site, the manikin is positioned in the same environment as the listener, so that environmental sounds impinging on the listener and the manikin are as similar as possible.
For telephone installations provided by two output signals, two headsets of the same make and model are directly connected to them. In cases where a unique output signal is available, it is fed into a signal splitter that produces two output signals that are electrically independent and identical in shape and level to the original one. One headset is then worn by the operator and the other is fitted on the manikin's head in a way that closely resembles the listener's use.
Recordings are taken during normal working conditions including telephone conversations and temporary breaks in between. Short-time periods of 15-30 minutes are taken in medium or heavy communications traffic for a total recording time of 18 hours.

3.3 Data processing

For each of the ear simulators integrated in the manikin, the sound pressure level is measured in one-third octave frequency bands. Then, each of the band levels is adjusted with the manikin diffuse-field frequency response to obtain corresponding diffuse-field related one-third octave band sound pressure levels. These levels are adjusted using A-weighting constants and subsequently combined to obtain the diffuse-field related equivalent continuous A-weighted sound pressure level. As an example, the effect of these frequency-dependent transformations is shown in Figure 1 where the spectral adjustment has been applied to a noise measurement carried out at the bank call-centre. Diffuse-field related equivalent continuous A-weighted sound pressure level is recovered for assessing noise exposure according to existing standards.
As to the frequency response, it is possible to choose between manufacturer's and standardised values [9], as well as between diffuse-field and frontally incident plane sound wave (free-field). As shown in Figure 2, these values differ from one another by 2-3 dB at most, except for frequencies above 6300 Hz where differences are higher. In any case, the latter frequencies are not relevant for our research because the telephone band-pass filter has a range of 300-3400 Hz.

3.4 Sound level limiter

In the experimental study, particular attention has been addressed to the sound level limiter used in the telephone central office II. Its efficiency has been proved in laboratory by means of different sound signals generated with CoolEdit software and a suitable soundcard (Event Layla). These test signals have been fed through the level limiter into the supra-aural earphone worn by the manikin. Then, the recordings made with the manikin have been analysed with the same software.

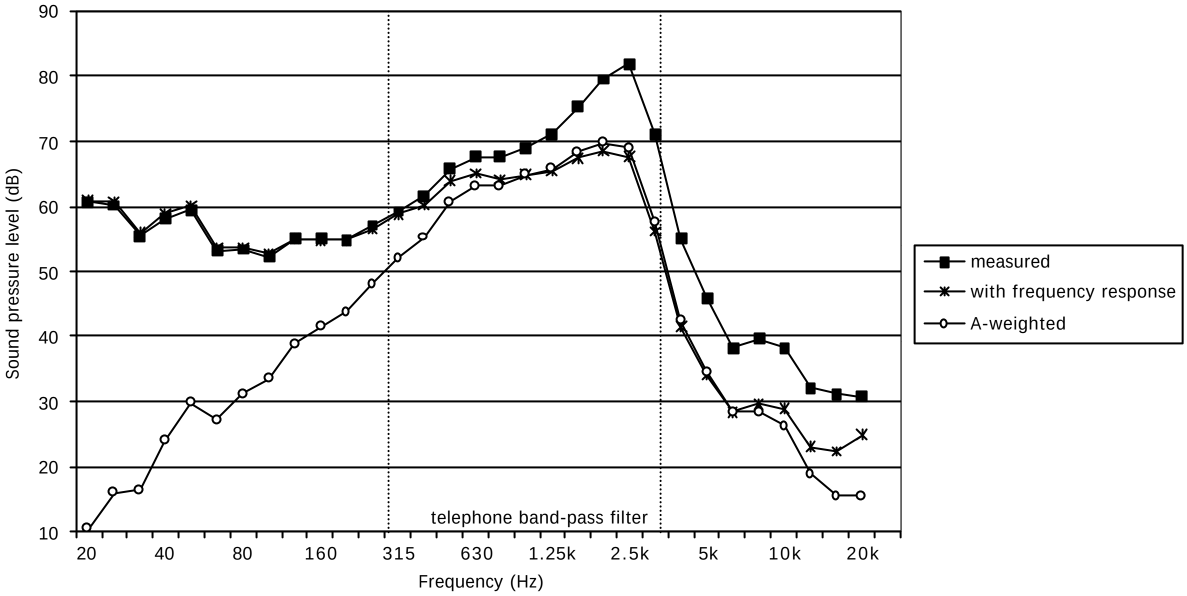

Figure 1. *The effect of the frequency response and the A-weighting filter on a recording.*

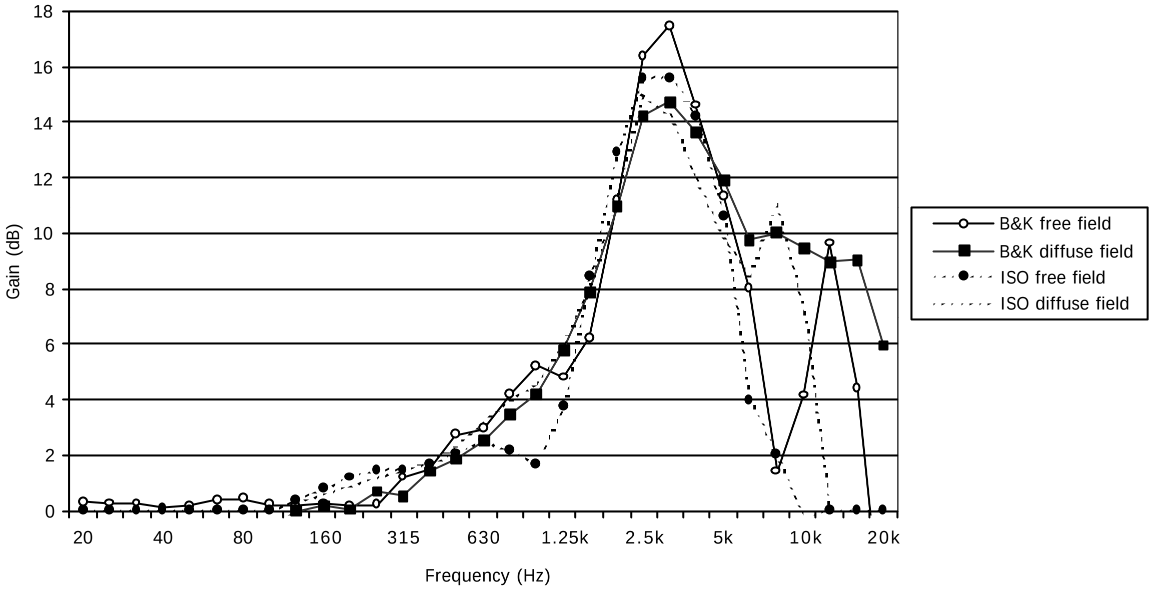

Figure 2. *Manufacturer's and standardised values of free and diffuse field frequency responses.*

4. RESULTS AND DISCUSSION

For communication personnel, noise exposure is affected by different factors here reported in descending order of importance:

- speakers' voice level. This factor depends on the speaker himself/herself and sometimes on the amplification level of the headset (there have been cases where the speaker's voice was 20-30 dB higher than the average value);
- workers' own voice. This sort of *echo effect* plays the operator's voice back into the headset, through the microphone of the device itself (in the bank call-centre, the operator's voice level was higher than the speaker's one in 3 out of 11 cases and similar in 2 cases);
- background noise. This factor depends generally on the contemporary presence of a great number of operators working in the same place and could influence noise exposure either directly (as a communication masker) or indirectly (as a disturbance that induces the operator to raise the speaker's voice level).

Table 1 reports the diffuse-field related equivalent continuous A-weighted sound pressure levels obtained with the manikin manufacturer's diffuse-field frequency response according to the procedure explained in paragraph 3.3. The diffuse-field frequency response has been selected because of the suggestions made up by Ianniello [5], Dajani et al. [6] and Brammer et al. [12].

The noise exposure levels reported in Table 1 are extremely variable: from a minimum value of 50 dB(A) to a maximum value of 87 dB(A). Moreover, in 16 cases (17%) the level of 80 dB(A) is exceeded (this happens always and only in the telephone central office I). By these data we can conclude that the risk of hearing loss could exist for some workers in certain conditions.

Table 1: *Diffuse-field related equivalent continuous A-weighted sound pressure levels*

occupational setting	number of recordings	number of workers and workplaces	headset type	amplification level	sound pressure level dB(A)			
					mean	std.dev.	min	max
newspaper division	5	3	telephone handset	fixed	66.8	8.1	58.2	79.7
	6	1	Siemens handset	fixed	67.4	5.2	61.9	76.3
	17	3	supra-aural earphone	under the operator's control	63.3	5.6	50.0	73.2
telephone central office I	6	3	telephone handset	fixed	76.6	1.7	74.4	79.0
	3	2	supra-aural earphone	level I	71.8	1.9	69.7	73.5
	6	4	supra-aural earphone	level II	77.8	1.7	75.9	80.7
	6	4	supra-aural earphone	level III	81.8	1.7	79.9	84.1
	3	2	insert earphone	level I	77.3	1.3	75.9	78.5
	6	4	insert earphone	level II	80.3	2.3	76.7	83.0
	6	4	insert earphone	level III	84.2	1.7	82.4	87.0
telephone central office II	8	3	supra-aural earphone with level limiter	level a	69.5	1.8	67.8	73.1
	6	2	supra-aural earphone with level limiter	level b	75.2	1.0	73.7	76.2
	6	2	supra-aural earphone with level limiter	level c	75.7	0.6	74.9	76.6
bank call-centre	12	12	supra-aural earphone with level limiter	under the operator's control	73.0	2.7	68.3	76.7

The noise exposure levels have been calculated also with the manikin manufacturer's free-field frequency response and with the standardised free and diffuse field frequency responses reported in ISO 11904-2. For all the 96 recordings, the absolute value of the differences between the manufacturer's diffuse field related equivalent A-weighted level and the related equivalent A-weighted level obtained with the other three curves shown in Figure 2 is always lower than 1.7 dB (the average difference is 0.35, 0.58, 0.40 dB, respectively). In conclusion, the differences shown in Figure 2 have little effect on the noise exposure levels.

As to the sound level limiter, laboratory tests have shown a good evidence. If the input level were to exceed a defined threshold, for example 100 dB, the output level that is fed into the headset would be maintained under 100 dB in the first ms, reduced of 1-4 dB in the subsequent 10-15 ms, here maintained for 180 ms and then reduced of 9 dB in the subsequent 80-100 ms.

In conclusion, the output level never exceeds the defined threshold of 100 dB and provides a reduction of 10 dB (from 100 to 90) in 0.3 seconds.

5. CONCLUSIONS

Although the literature review [1,2] does not show evidence of hearing loss for headset wearing communication workers, we can conclude that the risk of hearing loss could exist for these operators in certain conditions. Therefore, this risk has to be carefully taken into account.

If the noise exposure levels exceed 80 dB(A), an exploration of appropriate and effective control measures should be undertaken. Some control options include the adoption of sound level limiters, a training on the correct use of hearing headsets and the reduction of the background noise in order to improve the signal to noise ratio.

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