

## UNCERTAINTY ANALYSIS OF NOISE EXPOSURE MEASUREMENTS FOR HEADPHONE USERS

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**Abstract:** Noise emissions from sources located close to the ear, such as the headphones of telemarketing operators are determined using the international standard ISO 11904. The MIRE and manikin techniques are applied simultaneously to estimate the levels of noise exposure. The uncertainties from different sources are estimated for the determination of the diffuse-field related equivalent continuous A-weighted SPL from an earphone.

**Keywords:** uncertainty, occupational noise, telemarketing.

### 1. INTRODUCTION

The installation of call centers where phone operators use headsets is increasing rapidly worldwide, in order to provide quick satisfaction of consumer demand [4,5]. An operator exposure to noise from communication headsets above specified limits can result in permanent hearing loss. Adequate measurement and monitoring of an operator's noise dose is therefore necessary [7,8].

Noise exposure levels can be very different for the same headphone used by different operators, depending on head geometry, acoustic impedance of the ear, position of the headphone, etc. The noise dose of an operator depends not only on the type of headphone, but also on the ambient noise in the workplace, including the layout of the room, distance between operators, acoustic characteristics of the workplace, quality of the headset, and maintenance and volume of the headphone [7,8].

The ISO 11904 standard is used for measuring the noise exposure of headphone users, considering two methods: Part 1 – microphones in real ears (MIRE) technique; and Part 2 – manikin technique [2].

The uncertainty calculations for these measurements are considered in this paper and comparisons of results are presented.

### 2. NOISE EXPOSURE ACCORDING TO ISO 11904

The ISO 11904 standard describes the methods for the determination of sound emissions from sound located close to the ears. In this situation the Sound Pressure Level (SPL) is measured at the position of the exposed person.

#### 2.1. Microphones In Real Ears (MIRE) technique

In this technique a mini-microphone is positioned inside the outer human ear canal according to the MIRE description for the mounting of the microphone. The time-averaged equivalent sound pressure level  $L_{\text{ear,exp,f}}$ , in decibels (dB), ref. 20  $\mu\text{Pa}$ , is measured in third-octave frequency bands. This parameter is called ear canal equivalent continuous sound pressure level.

#### 2.2. Manikin technique

In the case of the manikin technique, the sound pressure levels are obtained through the exposure of a manikin head equipped with an ear simulator to a test noise, measured in third-octave frequency bands, defined as  $L_{M, \text{exp,f}}$ .

For both techniques each SPL band is adjusted to give a diffuse-field sound, where  $\Delta L_{DF,f}$  corresponds to the real ear and  $DL_{DF,f}$  to the manikin and the SPL frequency band for the diffuse-field sound  $L_{DF,f}$  is determined. To calculate  $L_{DF,f}$  the diffuse-field frequency response is subtracted from the ear canal sound pressure level  $L_{\text{ear,exp,f}}$  using the following equation for the MIRE technique:

$$L_{DF,f} = L_{\text{ear,exp,f}} - \Delta L_{DF,f} \quad (1)$$

Similarly, for the manikin technique:

$$L_{DF,f} = L_{M, \text{exp,f}} - DL_{DF,f} \quad (2)$$

The standardized values of the diffuse-field frequency response for selected ear canal measurement positions of the MIRE technique and for the ITU-T P. 58 diffuse-field frequency response of the manikin technique are presented in Table 1, according to clause 9 of ISO 11904-1. The calculation of the diffuse-field related sound pressure level was carried out using the values of  $\Delta L_{DF,f}$  and  $DL_{DF,f}$ .

In Fig. 1 shows an example of how to calculate the total noise dose  $L_{DF,f+A_f}$  considering the values for the diffuse-field frequency response of the manikin technique and the A-weighted correction curve.

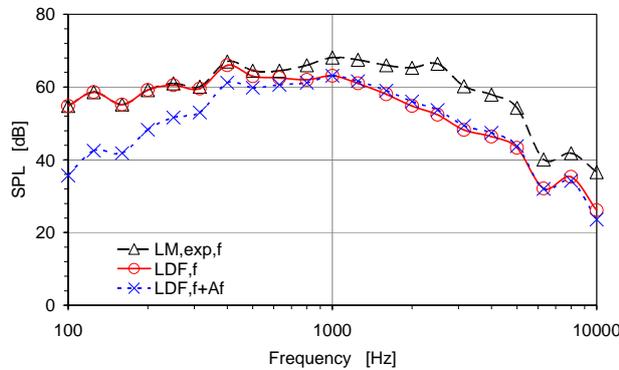
For each of the operators, five measurements of the noise levels were taken, in third-octave frequency bands, in the

range 100-10 kHz, these being adjusted with the diffuse-field frequency response. In Figures 2 and 3 they are given as examples of the SPL results obtained with the MIRE and manikin techniques, respectively.

**Table 1. Diffuse-field frequency response for the MIRE ( $\Delta L_{DF,f}$ ) and the manikin ( $DL_{DF,f}$ ) techniques.**

Frequency (Hz)	Diffuse-field response (dB)	
	$\Delta L_{DF,f}$	$DL_{DF,f}$
100	0.0	0.0
125	0.2	0.0
160	0.4	0.0
200	0.6	0.0
250	0.8	0.5
315	1.1	0.5
400	1.5	1.0
500	1.7	1.5
630	2.1	2.0
800	2.5	4.0
1000	2.9	5.0
1250	3.6	6.5
1600	4.7	8.0
2000	6.4	10.5
2500	8.2	14.0
3150	5.8	12.0
4000	3.0	11.5
5000	5.1	11.0
6300	6.9	8.0
8000	5.6	6.5
10000	-0.9	10.5

(Adapted from standard ISO 11904)



**Fig. 1. SPL of the manikin technique measurement, diffuse-field and A-weighting curves.**

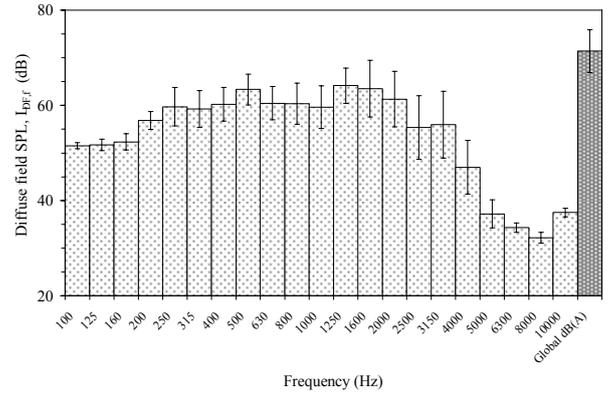
### 2.3. Noise exposure for MIRE and Manikin techniques

The effect of the external ear canal frequency response function on MIRE and manikin technique measurements was corrected and adjusted by the A-weighting curve and then an equivalent global (total dose) value was calculated, as shown in Equation 3:

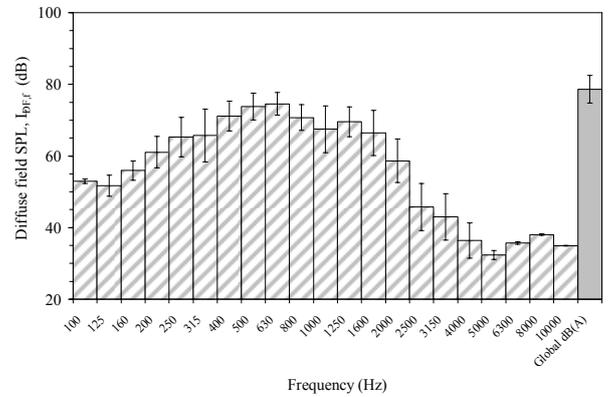
$$L_{DF,Aeq} = 10 \log \sum 10^{(L_{DF,f} + A_f)/10} \quad (3)$$

where  $L_{DF,Aeq}$  is the diffuse-field related equivalent continuous A-weighted SPL in decibels, and the constant  $A_f$  is specified in the IEC 61672 standard. The range of third-

octave frequency bands (f) from 100 Hz to 10 kHz was used in the measurements and calculations.



**Fig. 2. Diffuse field sound pressure level for the MIRE technique.**



**Fig. 3. Diffuse field sound pressure level for the manikin technique.**

Figure 4 shows the measurement set-up for the manikin and MIRE techniques, in the evaluation of sound exposure from sources placed close to the ear, i.e., telemarketing operator headphones. A Brüel & Kjær dynamic signal analyzer was used to record the sound pressure of the mini-microphone (real human ear) and ear simulator (manikin head). The DPA mini-microphone, model H17546 and microphone amplifier MPS 6010 were used in the MIRE technique. With the telemarketing operator in the actual workplace, the mini-microphone was placed at the entrance of the ear canal. The worker was requested to adjust the phone volume controls as desired, and carry out work activities as normal. The mini-microphone and the respective amplifier were connected to a portable computer to record the sound pressure using dynamic signal analyzer software. The SPLs produced by the earphone in the normal work situation were estimated in the third-octave frequency bands.

The standardized manikin head was equipped with a silicon external ear, with characteristics similar to the human ear and a Brüel & Kjær ear simulator, model 4157, coupled to the Brüel & Kjær external auditory canal simulator, model DB 2012, with a Brüel & Kjær, model 2804 microphone amplifier, manufactured according to the standards IEC 711-1981 and ANSI S3.25-1979.

The manikin was installed in the same workplace, close to the telemarketing operator, where it received an identical operator headphone. The operator and manikin phones were connected to the same phone line in order to guarantee that the same signal was received simultaneously by the two phones. The noise exposure produced by the respective phones was then measured through the two techniques. In Figure 4 the experimental configuration is presented.

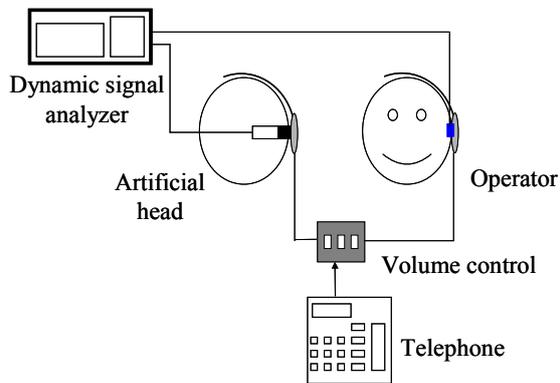


Fig. 4. Measurement set-up used in the MIRE and manikin techniques to determine the sound exposure from headphones.

In the diagram presented in Figure 4 the noise signal under test that arrives at the telemarketing center enters the system through the telephony system and passes to the volume regulated headphone. The telephone receiver has two outputs, for two phones to operate simultaneously, one of them coupled to the manikin with the ear simulator and the other fitted on the telemarketing operator with a mini-microphone at the ear canal entrance. The noise signals measured by the mini-microphone and ear simulator were registered by a digital signal analyzer, in terms of the sound pressure level in the third-octave frequency bands.

The noise exposure test group was composed of thirty-two telemarketing operators, headphone users, of both sexes. Of the thirty-two operators selected, sixteen of them worked in the operator information section, called the receptive section. The other sixteen operators worked in the operator sales section, named the active section.

The values for the levels shown in Figures 5 and 6 represent the average of five measurements for each telemarketing operator and the standard deviations are also given. Table 2 shows the average levels and standard deviation values for the sound exposure measurements, for the 32 telemarketing operators, applying the two evaluation techniques: real ear with mini-microphone and manikin with ear simulator.

The average total sound exposure using the MIRE measurement technique was 76.2 dB(A) with a standard deviation of 4.1 dB(A), and using the manikin technique it was 78.5 dB(A) with a standard deviation of 4.8 dB(A), as shown in Table 2.

Table 2. Average and standard deviation (SD) values of the sound exposure measurements for 32 telemarketing operators.

Operator	Noise exposure, $L_{DF,Aeq}$ dB(A)			
	MIRE		Manikin	
	Average	SD	Average	SD
1	71.4	4.5	78.6	3.9
2	72.1	3.7	81.4	2.7
3	65.4	4.2	74.5	2.7
4	73.3	3.3	78.8	4.4
5	75.2	3.1	82.6	2.6
6	71.2	4.7	67.3	0.9
7	74.4	4.5	76.2	3.8
8	76.1	7.2	69.3	2.0
9	83.2	6.2	89.5	6.5
10	73.2	2.1	81.6	2.7
11	80.1	5.2	86.4	6.6
12	86.4	2.3	79.8	2.1
13	76.8	0.5	79.0	1.8
14	74.0	1.1	80.8	1.0
15	78.4	2.8	80.2	2.9
16	71.3	6.8	73.5	4.5
17	80.1	4.7	85.2	3.8
18	81.3	6.5	82.3	5.0
19	79.7	1.2	80.8	1.5
20	78.3	5.3	81.6	6.2
21	79.5	2.7	78.7	2.6
22	74.5	5.1	74.3	2.8
23	77.0	5.6	76.8	3.9
24	75.9	3.9	77.9	3.5
25	75.1	3.4	74.5	3.0
26	75.4	2.4	82.5	1.9
27	76.2	1.9	73.9	2.6
28	73.7	3.1	74.1	1.3
29	73.3	3.8	74.6	2.9
30	80.0	1.2	82.7	1.7
31	76.5	1.6	79.5	1.1
32	79.3	2.3	74.1	1.5
<b>Global</b>	<b>76.2</b>	<b>4.1</b>	<b>78.5</b>	<b>4.8</b>

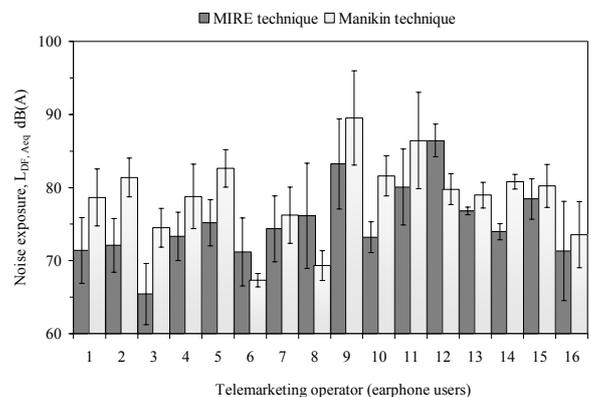


Fig. 5. Sound exposure level of the 1-16 telemarketing operators. Error bars show the standard deviation for the five measurements.

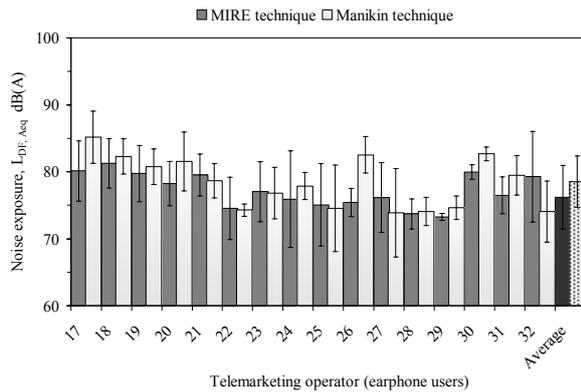


Fig. 6. Sound exposure level of the 17-32 telemarketing operators and total average level. Error bars show the standard deviation for the five measurements. The average bars present the standard deviation for the 32 mean values.

### 3. UNCERTAINTY ANALYSIS USING ISO 11904

The uncertainty of the final results using the MIRE technique (Part 1 of ISO 11904) is the extent to which a limited number of subjects represent a population. For the manikin technique the uncertainty is the extent to which the manikin represents an average human.

For each of the techniques, the uncertainty depends on the diffuse-field frequency response, which was taken from tables in the respective standards or determined individually for the participating humans or the particular manikin used.

According to the standard ISO 11904 - Part 1 and ISO GUM, the uncertainties can be estimated for the level  $L_{DF,Aeq}$  from a supra-aural, open-type earphone, considering the following characteristics:

- miniature microphones (mini-microphones);
- the individual diffuse-field frequency responses of the test subjects;
- pink noise or noise which simulates speech and music according to IEC 60268-1 as the test signal input to the earphone (headset);
- the mean result of measurements on both ears of eight test subjects;
- six measurements on one ear of each of eight test subjects;
- a supra-aural, open-type earphone using always the left capsule (speaker) on the left ear and/or the right capsule (speaker) on the right ear;
- the reference measurement of the frequency response should be repeated immediately after the measurement of the sound under test and should be carefully checked by comparison with the first measurement, if unexpected deviations occur the whole measurement procedure should be repeated.

From the documentation of the equipment used in the measurement set-up, it is possible to estimate the uncertainties or influences during the use of the measurement system.

The form used to illustrate the sources of uncertainties associated with the calibration can be shown in a cause and effect diagram. Figure 7 presents the results of research on

the sources of uncertainties related to the measurement techniques in the format of a cause-effect diagram.

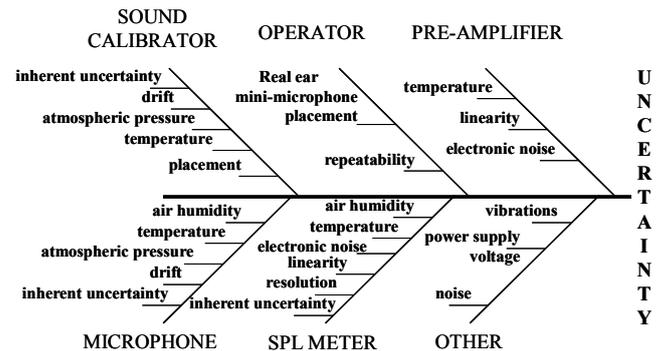


Fig. 7. Cause-effect diagram of the possible uncertainty sources applying the MIRE and manikin techniques.

Table 3 shows the uncertainties originating from different sources in the measurement system using the MIRE technique. The corresponding components are evaluated as type B uncertainties. The expanded uncertainty is based on the standard deviation multiplied by  $k=2$ , providing a confidence interval of approximately 95%.

Table 3. Uncertainty budget of the measurement chain using the MIRE technique.

Uncertainty sources	Raw value ( $\pm$ dB)	Probability distribution	Dividing factor	Standard uncertainty ( $\pm$ dB)
Sound level calibrator	0.4	Normal	2.0	0.2
Set-up Measurement adjustment	0.2	Rectangular	1.732	0.115
Resolution of the measuring instrument	0.05	Rectangular	1.732	0.029
Atmospheric conditions; temperature, humidity, and barometric pressure	0.4	Rectangular	1.732	0.23
Microphone frequency response	0.2	Rectangular	1.732	0.12
Uncertainty from analyzer and its frequency band filters	0.12	Rectangular	1.732	0.07
Power supply voltage	-	-	-	-
Background and electronic noise	-	-	-	-
<b>Expanded uncertainty (95%)</b>			<b>2.0</b>	<b>0.71</b>
<b>Combined standard uncertainty</b>				<b>0.355</b>

The uncertainty sources related to the sound level calibrator and the atmospheric influences on the set-up measurement gave the largest values in the uncertainty budget, 0.2 dB and 0.23 dB standard uncertainty, respectively.

The global value of the uncertainty balance, expanded uncertainties  $U$ , is approximately 0.7 dB. If a white or pink noise were used, according to the standard characteristics, with appropriate stability, the expected values for the deviations would be between 0.7 dB and 2.2 dB, in other

words, around the value calculated for the uncertainty of the set-up measurement and the value calculated in the example from the ISO 11904-1 standard.

The expanded uncertainty  $U$  estimated in Table 3 does not include the variations produced by the conversations of the operators during their work activities. These variations are not considered as an uncertainty source. The standard deviation values showed in Table 2 can be used to quantify the variations of sound exposure during the conversations of operators.

### 3. CONCLUSIONS

The ISO 11904 standardized techniques were applied in the quantification of noise exposure, for 32 telemarketing operators, headphone users, during the normal carrying out of activities in the workplace. A mini-microphone installed at the entrance of the operator ear and a manikin with an ear simulator were used to satisfy the criteria and recommendations of Parts 1 and 2 of this standard, respectively. The assessment of noise exposure from sound sources placed close to the ear was carried for two employment sections: receptive and active.

The uncertainties of the noise exposure measurement system for headphone users, applying the MIRE and manikin methods, were calculated considering the ISO 11904-1 and ISO GUM standards.

There were differences in the results of the two techniques applied in telemarketing center. However, it can be concluded that these differences are small and the equivalent continuous levels of sound exposure, determined in dB(A), from the Brazilian legislation point view, are very similar. For instance, there was a difference of 2.3 dB(A) between the average global values of the two measurement techniques.

In summary, for the measurement of the sound exposure levels for telemarketing operators, headphone users, it is possible to apply the technique that uses the placement of a mini-microphone in a real ear and/or the manikin technique with ear simulator, since the results obtained through the two methods are coherent.

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