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Measurement of Noise from Sources Close to the Ears Using Manikins

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Abstract

When a noise source is close to the ear of the exposed person traditional field values are non-obtainable. In this case measurements made in the ears of humans (or by a manikin) can be used for assessment of the exposure, if properly processed to yield values comparable to traditional field values (as described in ISO 11904). This paper presents measurements of noise from headphone-type sources using manikins, and comparing these with corresponding measurements from humans. It is concluded that results from manikin measurements, in general, do not well substitute measurements with humans.

1. Introduction

Human noise exposure is normally evaluated using measurements of the exposing sound field at the position of an exposed person, but without his/her presence in the field. This method is easy to handle in real life, and i) the frequency weighting curves, ii) the procedure in general (incl. our knowledge about effects of noise), and iii) current legislation have all been established with a reference to such free-air measurements. When the noise source is close to the ear such free-air values do not exist. In this case the measurements need to be processed to yield values comparable to traditional free-air values. The result is the *free-field related* sound pressure level or the *diffuse-field related* sound pressure level, depending of the choice of free-air reference field.

1.1. Free-field related and diffuse-field related sound pressure levels

The basic idea of the method is to find the free-air sound pressure, $p_{free-air}(t)$, which would result in the same sound pressure at the ear, $p_{ear,exp}(t)$, as observed from the noise during exposure. The terms are connected by the head-related transfer function, the $hrtf(t)$, and if lower-case variables are used for functions of time, $p_{free-air}(t)$ should fulfil:

$$p_{ear,exp}(t) = p_{free-air}(t) * hrtf(t) \quad (1)$$

In the frequency domain, the corresponding equation is:

$$P_{ear,exp}(f) = P_{free-air}(f) \cdot HRTF(f) \quad (2)$$

and by re-arrangement to yield the $P_{free-air}(f)$:

$$P_{free-air}(f) = \frac{P_{ear,exp}(f)}{HRTF(f)} \quad (3)$$

The method thus includes two steps, 1) measurement of the sound at the ear during exposure to the noise in question, and 2) measurement of the head-related transfer function for the relevant free-air sound field.

The relevant free-air reference fields are considered to be 1) a free field with frontal indicidence, and 2) a diffuse field. There are arguments in favour of both of these types of reference fields. Much of the current knowledge of hearing and specifications to weighting functions are found with free-field frontal sound indidence. But most of the experience with noise exposures and hearing damages are presumably from situations with near diffuse field properties.

In logarithmic terms, with the dependency of f implied, and using ΔL to denote the HRTF, Equation (3) results in the following:

$$L_{FF} = L_{ear,exp} - \Delta L_{FF} \quad (4)$$

$$L_{DF} = L_{ear,exp} - \Delta L_{DF} \quad (5)$$

where FF and DF indicate free-field respectively diffuse-field related sound pressure levels. These results can subsequently be subjected to weighting etc. depending of the application in question.

The procedure, including subsequent A-weigthing, is described in the ISO 11904 series, which currently includes two parts: Part 1 specifying measurements using human subjects (the *m*icrophone *i*n *r*eal *e*ars technique, MIRE-technique) [1], and Part 2 specifying measurements using a manikin (the manikin-technique) [2]. In the following, subscripts H and M are used in $L_{ear,exp}$, ΔL and L to indicate *H*uman (MIRE) and *M*anikin values.

1.2. Arguments against proposed method

Since it must be assumed that the effects of noise on humans—in particular a possible damage of the ear—is a result of the actual exposure of the eardrum, it might seem somewhat foolish to measure this exposure precisely, but nevertheless, convert the values to free air and, in the end, evaluate the exposure by means of free-air methods and criteria. Not only will the free-air methods and criteria be less accurate in predicting the effects of the noise, but also the conversion to such values will introduce additional uncertainty.

This roundabout way is necessary at present, since nearly all legislation as well as nearly all our knowledge about effects of noise on humans is based on free-air measurements. Recent years' technological achievements in microphone technique might in the future lead to an increased insight into actual eardrum exposures and thus facilitate the development of more accurate criteria. However, for the moment, the conversion to free-air values seems to be the only practical possibility.

1.3. Purpose of study

It is the purpose of the present study to compare measurements obtained with manikins (manikin-technique) with measurements of the same sound exposure obtained using humans (the MIRE-technique). Emphasis is given to the procedure for determination of ΔL_M, where three methods are identified, 1) the use of the manikin's own HRTF, 2) the use of standardized data for manikin HRTFs, and 3) the use of human HRTFs (adapted for use with manikins). The study is presented in further detail in Hammershøi and Møller [3].

2. Methods

A set of MIRE measurements, $L_{ear,exp,H}$, was obtained using human headphone transfer function measurements from a previous study, Møller et al. [4] including 40 human subjects. Exposure corresponding to supplying the headphone terminals with eletrical pink noise was simulated, and the levels in third octave frequency bands were computed. A total of 14 sound sources are included, of which most are traditional supra- and circum-aural Hi-Fi headphones, and a few are sources completely free of the ear.

$L_{FF,H}$ and $L_{DF,H}$ were computed using the individual HRTFs (from Møller et al. [5]) for $\Delta L_{FF,H}$ and $\Delta L_{DF,H}$. Finally, the average of the MIRE measurements across 40 human subjects was computed.

A set of manikin measurements, $L_{ear,exp,M}$, was obtained using a similar procedure, including headphone transfer function measurements for the same 14 headphones with three commercially available manikins. These data have not previously been published, but the methods were identical to those used for the measurements on humans (Møller et al. [4]).

$L_{FF,M}$ and $L_{DF,M}$ were obtained using three different methods for determination of $\Delta L_{FF,M}$ and $\Delta L_{DF,M}$ as described in the following.

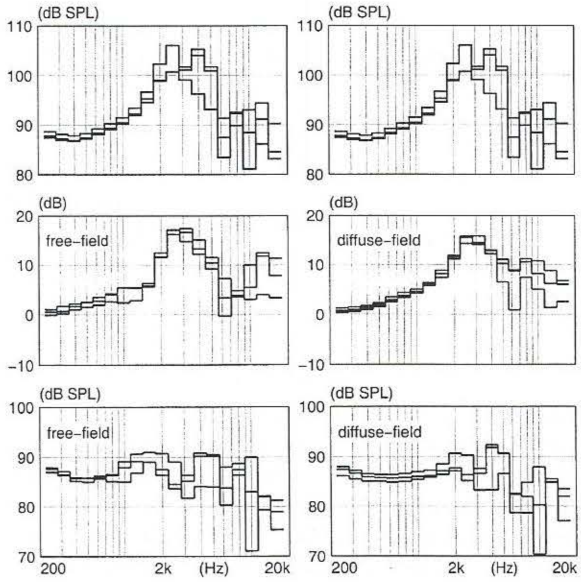

Figure 1: *Top panels show $L_{ear,exp,M}$ for the Sony MDR 102 headphone supplied with pink noise of 500 mV from 20-20k Hz, measurements with three manikins overlayed. Middle panels show ΔL_{FF} and ΔL_{DF} using method 1 (individual manikin). Bottom panels show the L_{FF} and L_{DF}.*

2.1. Method 1: ΔL_M from individual manikin HRTFs

One set of $L_{FF,M}$ and $L_{DF,M}$ were obtained using the manikin's individual HRTFs as $\Delta L_{FF,M}$ and $\Delta L_{DF,M}$. The HRTF data for the individual manikins (preliminarily reported in Hammershøi and Møller [6]) were obtained using methods similar to Møller et al. [5]. The data for one headphone is shown in Figure 1, where it can be seen that $L_{FF,M}$ and $L_{DF,M}$ vary considerably between manikins, though the exposure is—in principle—the same (same headphone and same voltage on the headphone terminals).

With this method *any* possible flaw in the individual manikin design, which results in a "non-standard" frontal or diffuse-field HRTF—but could leave the manikin otherwise suitable for measurement of sources close to the ear—, has direct impact on the result. The significance of any such error may be minimized with the use of proper standardized values for $\Delta L_{FF,M}$ and $\Delta L_{FF,M}$.

2.2. Method 2: ΔL_M from manikin specifications

A second set of $L_{FF,M}$ and $L_{DF,M}$ was obtained using the free-field frequency responses from the international standards, which specify the acoustics of manikins. These are the IEC 60959 [7] and the ITU-T P.58 [8], which has a high degree of similarities. The nominal values of the front HRTF specifications are the same in

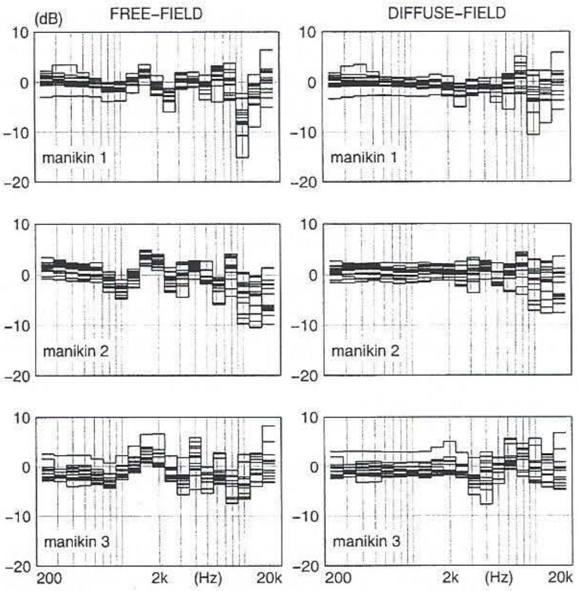

Figure 2: *Left column shows* $L_{FF,M}$ *minus* $L_{FF,H}$ *and right column shows* $L_{DF,M}$ *minus* $L_{DF,H}$ *using method 1 for determination of* ΔL_M *(individual manikin HRTFs).*

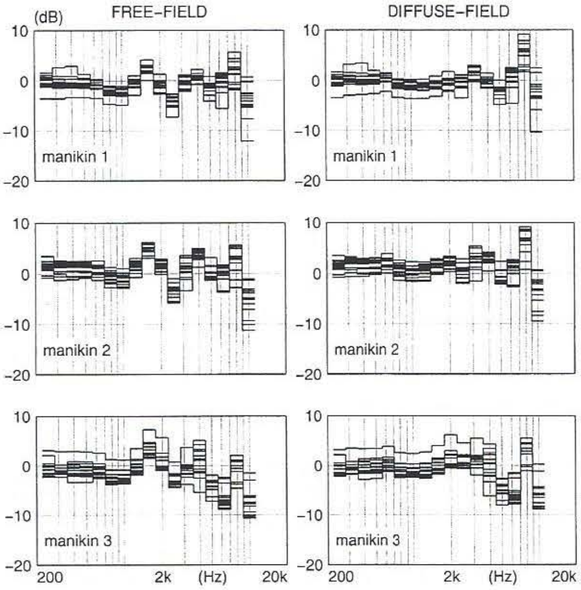

Figure 3: *Left column shows* $L_{FF,M}$ *minus* $L_{FF,H}$ *and right column shows* $L_{DF,M}$ *minus* $L_{DF,H}$ *using method 2 for determination of* ΔL_M *(values from IEC 60959 and ITU-T P.58).*

the two mentioned standards, and these were used for $\Delta L_{FF,M}$. No diffuse-field specification is given in the IEC 60959, why the $\Delta L_{DF,M}$ was taken from the ITU-T P.58).

2.3. Method 3: ΔL_M from human HRTFs adapted for use with manikins

A third set of $L_{FF,M}$ and $L_{DF,M}$ was obtained using human HRTFs adapted for use with manikins as $\Delta L_{FF,M}$ and $\Delta L_{DF,M}$ (see also Hammershøi and Møller [3]). $\Delta L_{FF,M}$ and $\Delta L_{DF,M}$ were computed as the average human front-HRTF, respectively diffuse-HRTF, measured at the entrance of the ear canal while blocked, and subsequently multiplied with the transfer function of the manikin ear simulator (IEC 60711). This corresponds to a human eardrum HRTF corrected for the difference between the sound transmission within the human ear canal and that within the standardized ear simulator. All computations were carried out before conversion to third octave frequency bands values.

3. Results

The differences between the three sets of $L_{FF,M}$ and $L_{DF,M}$, and $L_{FF,H}$ and $L_{DF,H}$ were computed. The results are shown in Figures 2, 3 and 4.

Figure 2 shows differences between manikin and mean human data for free-field and diffuse-field related spectra with 14 headphones as sound sources. From Figure 2 it is seen that there are systematic deviations between the values determined from measurements on humans and manikins. The deviations are most distinct for the free-field related spectra, in particular in the frequency range between 800 Hz and 2 kHz, where the deviations show a very similar structural pattern for all headphones. The deviations in the $L_{DF,M}$ are less than for the $L_{FF,M}$.

Figure 3 shows the results with the second method—the use of free-field frequency responses from tabled values of IEC 60959 and ITU-T P.58. From this figure, it can be seen that when standardized values are used for ΔL_M there are problems similar to those seen, when the ΔL_M is based on data for the individual manikin (Figure 2). For $L_{FF,M}$ there are in fact slightly larger deviations for 1.6 kHz and 2.5 kHz. Also for $L_{DF,M}$ the use of standardized values gives deviations, which for some frequencies are larger in amplitude than when individual manikin data are used for ΔL_M. This can be seen for manikin 1 at 5 kHz, for manikin 2 at 8 kHz, and for manikin 3 at 5 and 6.3 kHz.

The results of using method 3 is presented in Figure 4. From this figure, it can be seen that, in general, a nice improvement is obtained by using the more "human-like" data. In particular, the large deviations for the $L_{FF,M}$ at 1.6 and 2.5 kHz decrease significantly. This indicates that the impact of possible shortcomings may be reduced. It should, however, be noted that considerable deviations (in the magnitude of 3-6 dB) are typical in the individual third octave frequency bands. The consequence of this will obviously depend on the source spectrum, and may

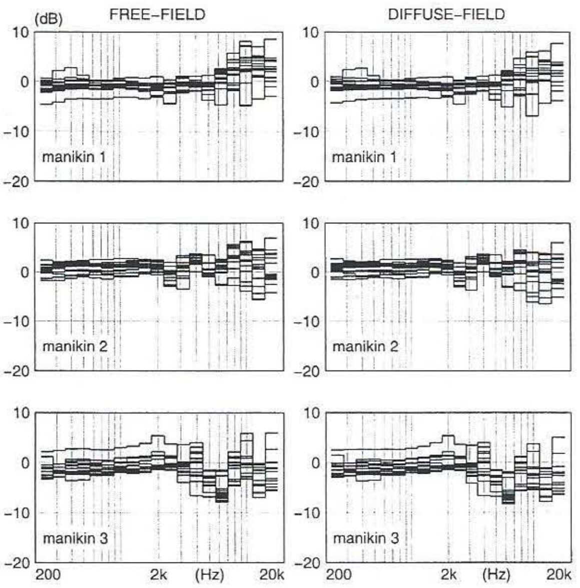

Figure 4: *Left column shows $L_{FF,M}$ minus $L_{FF,H}$ and right column shows $L_{DF,M}$ minus $L_{DF,H}$ using method 3 for determination of ΔL_M (human HRTFs adapted for use with manikins).*

lead to deviations of much larger scale.

4. Discussion

In this investigation, free- and diffuse-field related sound pressure levels for 14 headphones using both the MIRE technique and the manikin technique were compared. It was found that the use of the indvidual manikin HRTFs for ΔL_M gave results in poor agreement with results from humans. This was also the case for the results obtained with the use of standardized values for ΔL_M. The systematic deviation between MIRE and manikin results was decreased with the use of more human-like data for ΔL_M.

In the process of tabling values of ΔL_M the advantage of using method 3 was understood, and the data described in Section 2.3 are tabled in the ISO/FDIS 11904-2 [2]. As already mentioned, the use of these data does not ensure results, which are in perfect agreement with the results that can be obtained with the use of the MIRE technique.

With measurements on manikins, in principle only a single measurement will be made, and the method will not—like with measurements on humans—include averaging of results from several individuals with the possibility of diminishing the effect of an atypical geometry. It is therefore of paramount importance that the manikin performs acoustically like an average human. Conformence with the IEC 60959 and ITU-T P.58 ensures some similarity with human data, although there is evidently no guarantee that the manikin will perform as an average human. In Hammershøi and Møller [3] this is further discussed, and it is observed that both the free- and diffuse field frequency responses of manikins and the specifications in the mentioned standards could be in better agreement with data for humans.

5. Acknowledgements

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