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EFFECT OF MEASUREMENT METHOD ON AN EARMUFF'S FREQUENCY RESPONSE

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Light, medium and heavy earmuffs' amplitude frequency response was measured using transmission loss technique with a microphone placed in subject's ear (MIRE – microphone in real ear) and on an artificial test fixture (ATF). Measurements were conducted in frequency range up to 9 kHz employing maximum length sequence (MLS). This method shows details of earmuffs' amplitude frequency response, in contrast to sound attenuation data obtained in octave bands according to the EN-ISO 4869-1 standard. The study compared ATF data with results measured on a person when soft tissues influenced the ripples of the obtained frequency response. Results were also judged against the sound attenuation data of the real ear at threshold (REAT) method used in certification of hearing protectors.

Keywords: noise attenuation, hearing protector, earmuff, measurements on subjects, MIRE technique.

1. Introduction

In many instances using the artificial test fixture (ATF) to determine a hearing protector device's (HPD, e.g., earmuffs) noise reduction is a must. Such a situation occurs, for example, when testing levels are too high to expose humans or when measurements are performed *in situ* for long periods. Physical properties with regard to the shapes of the head and the external ear canal as well as lack of adequate simulation of soft tissues make the ATF only a rough approximation of the human head and ear. Therefore, an important issue often raised is whether measurements of the HPD's noise reduction performed on the ATF properly represent values that can be obtained on a human ear.

The purpose of this study was to test the differences which may occur in measurements of the amplitude frequency response of an earmuff performed on the ATF and on a human ear using the microphone in real ear technique (MIRE).

2. Method

The amplitude frequency response of three earmuffs was measured using the transmission loss method both on an ATF made according to the ISO 4869-3 standard [1], and with the use of the MIRE technique on a human subject. Transmission loss between a measurement point situated outside the earmuff and one under the earmuff was determined. Measurements on the ATF involved recording a signal outside the earmuff and under the earmuff by Brüel & Kjær microphones type 4192 equipped with Brüel & Kjær type 2669 preamplifiers. A microphone used for the measurements under the earmuff was installed in the ATF.

In the case of the MIRE technique both the signal outside the earmuff and the one under the earmuff were recorded using miniature Knowles Electronic BL 1785 microphones. The microphone under the earmuff was placed at the entrance to the subject's external ear canal. It was attached to the subject's skin using a medical tape. In this way the microphone was in the same place when successive earmuffs were tested. Both for the MIRE and ATF measurements, the external microphone was placed at a distance of 10 cm from the entrance to the ear canal or the side surface of the ATF.

Measurements were conducted in a semi-anechoic, sound-insulated rectangular room (dimensions $L \times W \times H = 8 \times 5 \times 3$ m). Signals were reproduced with a set of four JBL SR4722A loudspeakers located on a square foot plan. The subject or the ATF was located in the midpoint of the four-loudspeaker system; the distance between the midpoint and any of the loudspeakers equaled 1 m.

Signals recorded with the microphones were delivered to a Brüel & Kjær type 2690 (Nexus) signal conditioning amplifier, and then to an input of M-Audio Audiophile soundcard. Amplitude frequency response measured as the transmission loss was calculated in a Matlab 7.4 programming environment.

All measurements were performed using the maximum length sequence (MLS) test signal [2, 3]. We had considered using the MLS test signal to determine earmuffs' frequency response earlier [4] as well as using the results in a simulation of earmuffs' response to impulsive noise [5].

Employing the MLS sequence to measure the impulse response is equivalent to impulse stimulation of a system under test with about 25–30 dB gain in signal-to-noise ratio. In this study, the Fourier transform of the measured impulse response was used to obtain the amplitude frequency response of the earmuff. The test signal sequence of the order of 15 was used, which corresponds to the length of the sequence of 32767 samples. Sampling frequency equaled 44.1 kHz. The amplitude frequency response was determined in frequency steps smaller than 1 Hz.

3. Hearing protectors tested

Three earmuffs were measured; they varied in sound attenuation, as described by the Single Number Rating (SNR, [6]) parameter, by 14 dB. These were an Unico Graber Sonico 85 earmuff (light earmuff), Bilsom Leightning L1 (medium size earmuff), and Peltor Optime III (heavy earmuff). The single number rating (SNR) parameter value for these earmuffs was 21, 30 and 35 dB, respectively. The tested hearing protectors were new and in a good condition.

4. Results and discussion

Figure 1 shows the earmuffs' attenuation (transmission loss) in 1/3-octave bands measured on a subject (horizontal lines, left panels) and on the ATF (horizontal lines, right panels). For comparison, filled squares illustrate the earmuffs' sound attenuation measured according to the ISO EN 4869-1 [7] standard (REAT method). The open square at 2000 Hz in Fig. 1 represents the earmuffs' sound attenuation measured in this study with this same subject who participated in the MIRE measurements.

On the average, the measurement with the MIRE technique provided results in closer agreement to the REAT results than the measurements on the ATF, especially in the frequency range of 300–700 Hz. In the frequency range below 300 Hz, for light and medium earmuffs, the MIRE technique underestimated the earmuffs' attenuation. In the frequency range over 700 Hz, the MIRE technique provided lower attenuation values than REAT. Measurements on the ATF yielded more variability in the results in the low frequency range. In medium and high frequency ranges, the measurements on the ATF often yielded higher values of attenuation than those obtained with REAT.

For the purpose of this study, to obtain a single number describing the earmuffs' wide-band attenuation, comparable to the SNR parameter, a wide-band energy-equivalent RMS parameter, the $\mathrm{WB}_{\mathrm{RMS}}$ was calculated. The $\mathrm{WB}_{\mathrm{RMS}}$ is defined in equation (1), and expressed in decibels.

$$\mathrm{WB}_{\mathrm{RMS}} = 20\log_{10}\sqrt{\frac{1}{n}\sum_{i=1}^{n}(10^{L_i/20})^2}\,, \tag{1}$$

where n – number of frequency bands, L_i – attenuation in i-th frequency band.

A comparison between the $\mathrm{WB}_{\mathrm{RMS}}$ and SNR parameters is shown in Fig. 2. The $\mathrm{WB}_{\mathrm{RMS}}$ parameter increases with an increase in SNR values. It is important that the slope of this increase is equal to 0.9970 for data obtained by the MIRE technique, whereas this slope is only 0.5141 for measurements conducted on the ATF. For the MIRE technique, values of the $\mathrm{WB}_{\mathrm{RMS}}$ are about 7.8 dB smaller that the SNR value.

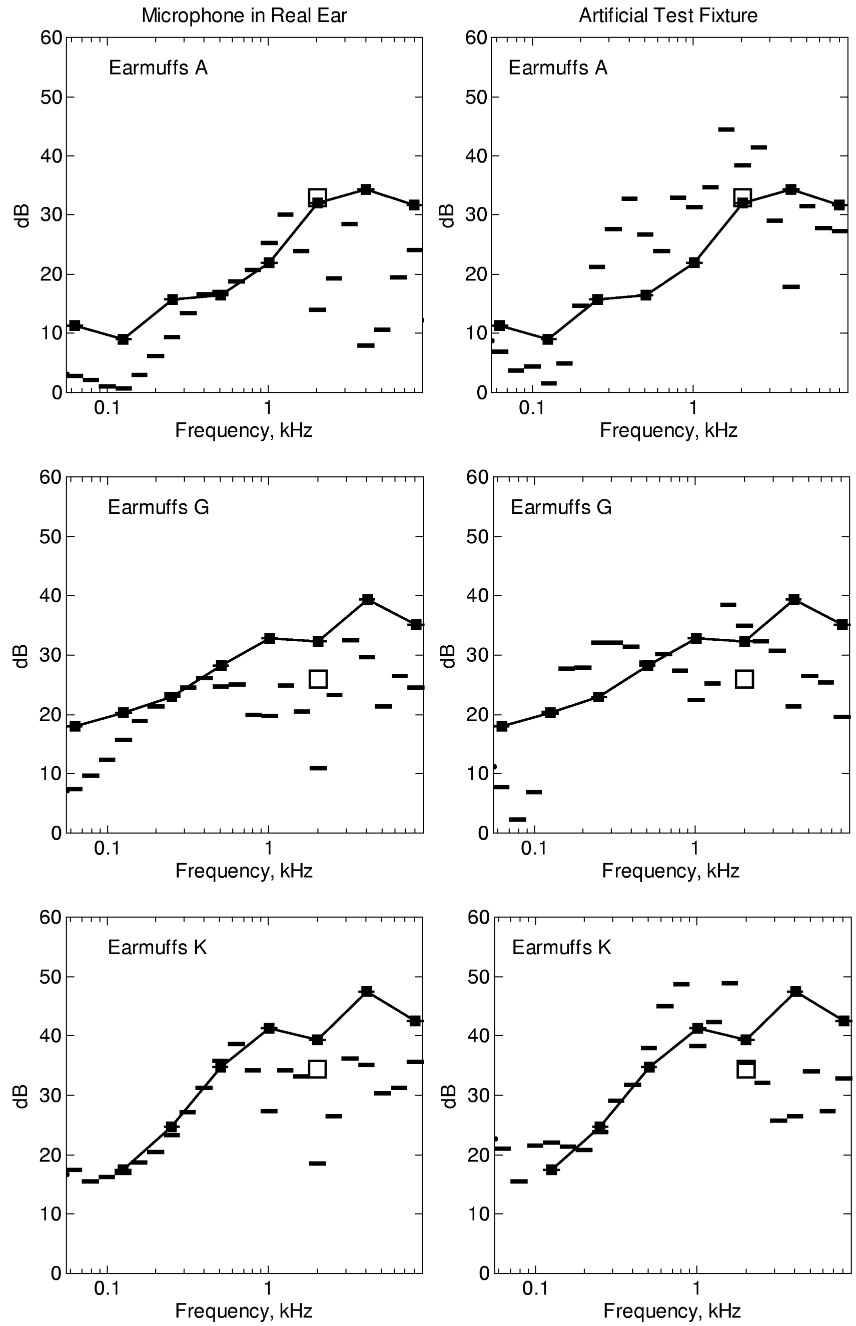

Fig. 1. Amplitude frequency response of earmuffs. Left panel: MIRE technique on a subject; right panel: measurements on the ATF. Horizontal lines: MIRE or ATF measurements in 1/3-octave bands. Solid squares connected with line: earmuffs' attenuation as measured by the manufacturer according to the ISO EN 4869-1 standard. The open square illustrates measurements performed accordingly to the ISO EN 4869-1 standard in this study on a subject who participated in MIRE measurements.

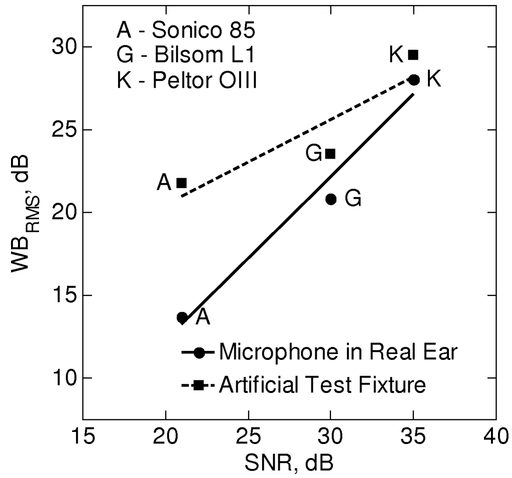

Fig. 2. Comparison of wide-band energy-equivalent RMS value calculated from data in Fig. 1 with the earmuffs' SNR value.

5. Conclusion

Results of this study can be summarized as follows:

- Variability in transmission loss measurements using the MIRE technique is smaller than variability in measurements performed on the ATF.
- Attenuation (transmission loss) in 1/3-octave bands measured with the MIRE technique is smaller than earmuff sound attenuation determined with the REAT method. Therefore, the MIRE measurements can be considered as a safe estimate of the more time consuming REAT measurements.
- Wide-band attenuation expressed with the $\mathrm{WB}_{\mathrm{RMS}}$ parameter reflects more accurately the differences among earmuffs for data obtained using the MIRE technique than using the ATF (its change better corresponds to the change in the SNR value).

Acknowledgment

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