Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Determination of earmuff transmittance with the use of MIRE technique and with artificial test fixtures

Jan Zera (1,2) and Rafal Mlynski (1)

(1) Central Institute for Labour Protection - National Research Institute, Warsaw, Poland
(2) Institute of Radioelectronics, Warsaw University of Technology, Warsaw, Poland

PACS: 43.50.Pn, 43.66.Vt, 43.50.Hg

ABSTRACT

The purpose of the study was to determine earmuff transmittance by measurements made on human subjects, with the use of the microphone-in-real-ear (MIRE) technique and methods in which a human subject is entirely substituted by a measurement instrument, such as an artificial text fixture (ATF) or an acoustic manikin. The MIRE measurements were conducted on five subjects. The latter kind of measurements was conducted with the use of an ATF made according to the ISO 4869-3:2007 standard, a modified ATF with a 2-cm^3 chamber, a Kemar manikin, and a Brüel&Kjaer 4100 manikin. In all conditions the earmuffs were measured in an anechoic chamber, with the use of a maximum length sequence (MLS) test signal. Results obtained for human subjects demonstrate substantial frequency-selective peaks and dips in the earmuff frequency response. Such an effect cannot be observed with the use of the real-ear-at-threshold (REAT) method, according to the ISO 4869-1:1990 standard, and measurements conducted at seven one-octave steps, from 125 Hz to 8 kHz. A comparison of results obtained with the use of ATFs and acoustic manikins with those collected with the MIRE technique makes it possible to estimate how accurately does each of the measurement methods represent conditions in which the hearing protector is worn by a real user.

INTRODUCTION

Hearing protector attenuation determined with the use of the REAT (ISO 4869-1:1990) method provides data on sound attenuation in 1/3-octave noise bands, at seven octave steps, from 125 Hz to 8 kHz. Although such data are considered sufficient in conditions of exposure to broadband industrial noise, a more detailed knowledge of the frequency response of the hearing protector may be needed for the assessment of protection during exposure to narrowband and tonal components, and, if phase information is added, may be used for prediction of the impulse noise time waveform under the hearing protector.

The purpose of this study was to determine hearing protector attenuation as a continuous function of frequency. The measurements were conducted with the microphone-in-real-ear (MIRE) technique, on five human subjects, as well as with the use of two artificial test fixtures (ATFs) and two acoustic manikins. The two ATFs were a coupling device made according to the ISO 4869-3:2007 standard and a modified ATF with a 2-cm^3 chamber. The acoustic manikins were Kemar (Burkhard and Sachs, 1975) and Brüel&Kjaer type 4100. Results make it possible to discuss differences between earmuff attenuation specified as sound attenuation determined by the REAT method, measured with the MIRE technique on human subjects, and measured with the use of ATFs and acoustic manikins.

METHOD

The measurements were conducted in free-field conditions in an anechoic chamber, 250 m^3 in volume. Earmuff frequency response was measured using a maximum length sequence (MLS) signal reproduced through a loudspeaker (Tonsil Bolero) located at a distance of 2 m, in front of the subject, an ATF or of an acoustic manikin. Signal generation and recording were carried out with the use of a Brüel&Kjaer PULSE system.

MIRE measurements

The subject sat on a chair with head leaned back against a support, to avoid head movement. The measurement signal was captured by a Knowles Electronics BL1785 ceramic miniature microphone placed at the entrance of the ear canal and attached to the subject's face by a sticking plaster. The subject was faced toward the loudspeaker to imitate the most typical position of a hearing protector user and a source of noise. Subject's position toward the loudspeaker was monitored with the use of laser pointers.

The MLS signals were presented and recorded interchangeably either with earmuffs donned and doffed. Such procedure accounted for the variability of the earmuff placement on the subject's head and assured that the constant error of measurement was minimized. The subjects placed the earmuffs on their heads by themselves and adjusted them to obtain best possible fit in a way that resembled placing a hearing protector during its regular use. The three MLS sequences were recorded in each measurement condition and served to determine the frequency response of the earmuff.

Measurements on the ATFs

The ATFs (flat plate, ISO 4869-3:2007, and modified ATF with the 2 cm^3 chamber) were positioned at a point corresponding to the position of the subject's head during MIRE measurements. The signals were recorded with the use of a Brüel&Kjaer type 4192 (1/2') microphone mounted in the ATF. Recordings were made either with or without earmuffs placed on the ATF. Three MLS signal recordings were made with earmuffs repeatedly replaced on the ATF to account for differences in the earmuff placing on the device.

Measurements with acoustic manikins

Acoustic manikins (KEMAR and Brüel&Kjaer type 4100) were placed at a point in space occupied by the subject's head during MIRE measurements. Signals were captured by the microphones of the manikin (Brüel&Kjaer 1/2'). Other details of the procedure were same as in ATF measurements.

In all conditions earmuff frequency response was determined by subtracting responses calculated from the MLS test signals recorded with an earmuff donned and doffed. The frequency response represents therefore the insertion loss of an earmuff.

RESULTS

Inter-subject differences

Figure 1 shows inter-subject differences observed in measurements of insertion loss made for three earmuffs with the use of MIRE technique. The examples were selected to demonstrate a typical variability range of results. For instance, the data obtained for the Peltor Optime II earmuff (Figure 1, top panel) show that there is almost no difference in attenuation across subjects at frequencies below 800 Hz and the variability at 1 kHz is very small. More importantly, the irregularity of attenuation, amounting to about 5 dB in a frequency range from 0.8 to 4 kHz has an almost identical pattern for all subjects.

Such a pattern of data is different from that seen in Figure 1 (middle panel) for the Bilsom Viking V1 earmuff. In this case the differences across subjects amount to 10 dB in the frequency range below 800 Hz. Above 1 kHz, peaks and dips in the earmuff response occur at different frequencies, depending on the subject.

The largest inter-subject dispersion is seen for the 3M 1430 earmuff (Figure 1, bottom panel). Below 2 kHz, earmuff attenuation measured on subjects S1, S2, and S5 is by 10 or more decibels larger than for S3 and S4. In the high frequency range, insertion loss measured on S2 and S5 shows maxima at about 2.5 kHz whereas for S1 and S3 peak attenuation occurs respectively at about 3.2 and 3.8 kHz. Such discrepances of individual data are smoothed when the results obtained from five subjects are averaged.

It is worth to note the differences between insertion loss values and REAT measurements made according to ISO 4869-1:1990 standard, shown by plus symbols in Figure 1, at frequencies spaced by one octave. In low frequency range, sound attenuation determined by the REAT method is in many cases larger than insertion loss derived from MIRE measurements. In high frequency range, MIRE method yields higher values for the Peltor Optime II earmuff but not for the two other ones. The REAT technique commonly yields higher attenuation values at low frequencies than MIRE measurements but at high frequencies the effect is opposite: MIRE measurements result in higher attenuation, especially when there is a wide plateau in the frequency response, such as that seen in Figure 1 (upper panel) for the Peltor Optime II earmuff, at frequencies between 0.8 and 5 kHz.

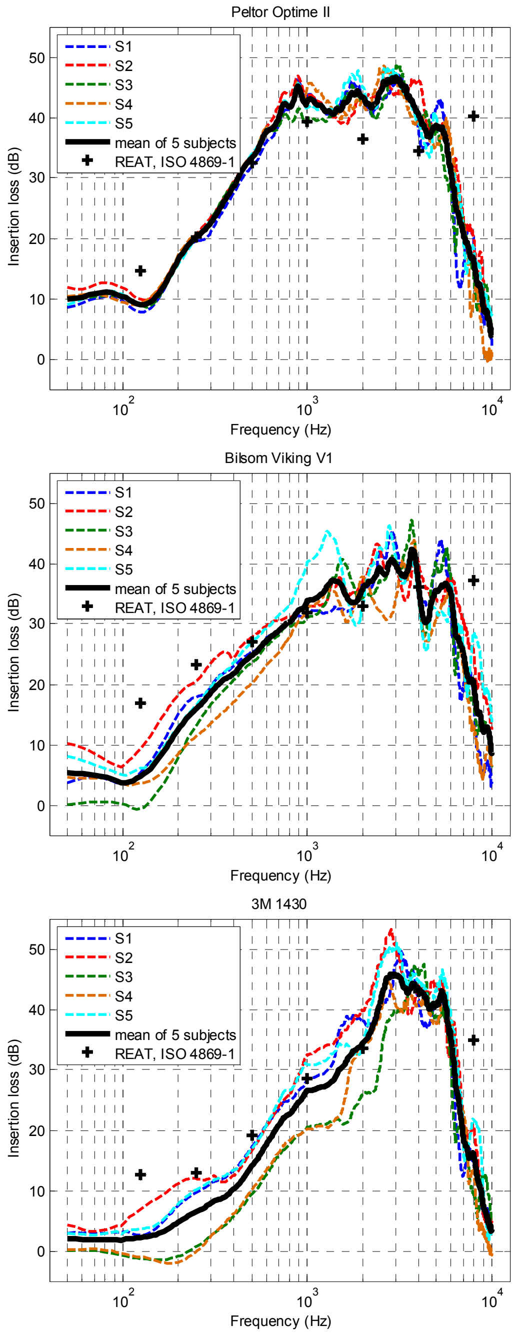

Figure 1. Insertion loss of a Peltor Optime II, Bilsom Viking V1, and a 3M 1430 earmuffs. Data measured with the MIRE technique on five subjects (dashed lines) and their mean (solid black line). Sound attenuation determined according to the REAT method (ISO 4869-1:1990) is shown by plus signs for a comparison (data declared by manufacturers)

Variability of earmuff frequency response

Figure 2 shows insertion loss values determined with the MIRE technique on human subjects. The data are means across five subjects plotted in separate panels for 3M, Peltor and Bilsom earmuffs. Examples were selected to show characteristic differences between different models of the same manufacturer. For instance, at frequencies below 2 kHz insertion loss of the light 3M 1430 model is by more than 10 dB lower than that of the three other models (Figure 2, top panel). The SNR parameter is 23 dB for the 1430 earmuff and ranges from 26 to 32 dB for the other 3M models. This range of SNR values is in good agreement with the range of insertion loss values of the same earmuffs.

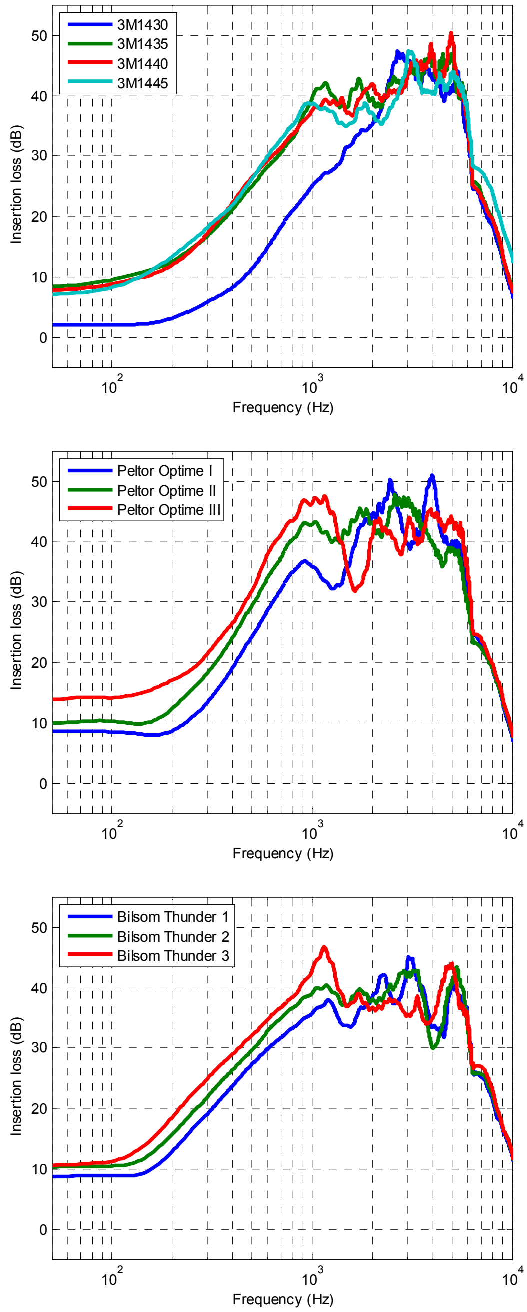

Figure 2. Insertion loss of a the 3M (1430, 1435, 1440, and 1445), Peltor (Optime I, Optime II, and Optime III), and Bilsom (Thunder 1s, Thunder 2s, and Thunder 3s) earmuffs. MIRE method, average of 5 subjects

An unexpected result was obtained for the 3M 1435, 1440, and 1445 earmuffs. Insertion loss measured for these models is very similar in the entire frequency range, especially below 1 kHz. Nevertheless, those earmuffs differ by 6 dB in the SNR parameter value, and by 8 dB in the L parameter value representing attenuation at low frequencies. In this case insertion loss does not well correspond to SNR and L parameter values determined from hearing threshold measurements made on human subjects.

Insertion loss of Peltor earmuffs is shown in the middle panel, in Figure 2. In the low frequency range, the differences between insertion loss values are in good agreement with the 8-dB difference in the L parameter value. It is apparent that attenuation of Optime I earmuff at 900 Hz is much lower than attenuation of Optime II and Optime III earmuffs in this frequency range. Although insertion loss of Optime III reaches over 45 dB at 1 kHz, attenuation of this earmuff decreases by more that 15 dB at about 1800 Hz. Such a drop is not seen in the case of attenuation determined with the REAT method, according to the ISO 4869-1:1990 standard. For Peltor earmuffs, the Optime II model displays a wide flat pattern of insertion loss from about 800 Hz to 6 kHz. Attenuation exceeds 40 dB and it is not smaller than that of the Peltor Optime III earmuff, the model with highest attenuation.

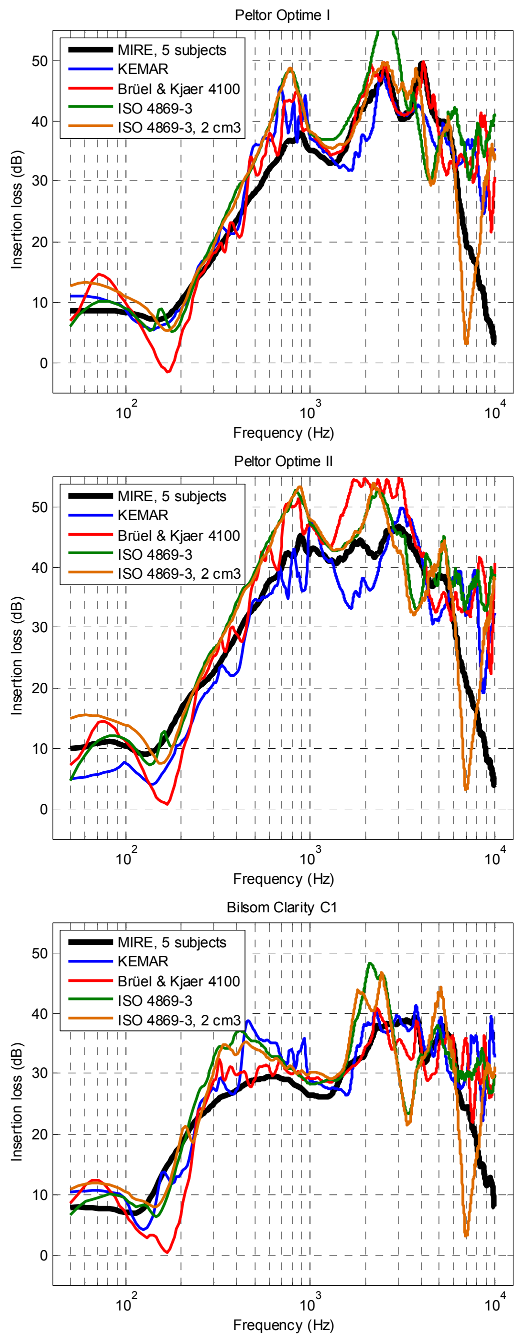

Figure 3. Insertion loss measured on the Kemar manikin, Brüel&Kjaer 4100 manikin, ISO 4869-3:2007 ATF, and the ATF equipped with the 2 cm^3 chamber compared to average MIRE data of five subjects (Peltor Optime I, Peltor Optime II, Bilsom Clarity C2 earmuffs)

The most regular increase in insertion loss is seen for the Bilsom Thunder earmuffs. This increase corresponds with the 6-dB increase in the SNR parameter value (difference between 3S and 1S models). Bilsom earmuffs also display most even insertion loss at frequencies above 1 kHz.

Measurements on ATFs and manikins

Figure 3 shows insertion loss values measured on the Kemar and the Brüel&Kjaer 4100 manikins, the ISO 4869-3:2007 ATF, and an ATF equipped with a 2-cm^3 chamber. The examples were selected to show typical differences observed between measurements made with the use of those devices. For comparison, also plotted are results of MIRE measurements averaged across five subjects. For the Peltor Optime I earmuff (Figure 3, top panel) results obtained with the use of ATFs and manikins are in fairly good agreement with MIRE measurements. The most notable difference is that insertion loss values determined on ATFs and manikins yield less regular functions along the frequency scale than measurements on subjects. Despite of such an effect the measurements made on ATFs and manikins well reflect the relation of insertion loss to frequency.

Results determined on ATFs and manikins, and those obtained with the MIRE method are less convergent for the Peltor Optime II earmuff (Figure 3, middle panel). In this case MIRE measurements yield a nearly flat response in a range of 0.8–4 kHz. In contrast, the data obtained on ATFs and manikins show distinct peaks and dips, amounting to 20 dB. The differences between frequency responses determined with the use of various coupling devices are substantial. For instance, measurements on the Brüel&Kjaer 4100 manikin yield an over 10 dB larger insertion loss than MIRE measurements at 2 and 3 kHz whereas the use of Kemar manikin results in an almost 10 dB lower insertion loss, in comparison with MIRE measurements, in a range of 1.5–2.5 kHz.

For Bilsom Clarity C2 earmuffs (Figure 3, bottom panel) the general course of the relation of insertion loss to frequency determined by MIRE measurements is preserved, although a substantial influence of resonances is seen when the ATFs and manikins are used. These resonances are related the differences between (Berger, 2005) transfer functions of open ear (TFOE) of the coupling devices and are also apparent, although to a lesser degree, in other panels. The variability of transfer functions results from different couplings to the incoming acoustic signal when the microphone is uncovered or covered by the earmuff. For instance, the flat plate ISO 4869-3:2007 ATFs frequency response changes by less than 2 dB at frequencies up to 10 kHz but the same device equipped with a 2-cm^3 chamber displays a 20-dB dip at about 1.5 kHz and an over 30-dB peak at 7 kHz. For subjects tested with the MIRE method, the location of a 20-dB dip varies along the frequency scale, within a range of 2–3 kHz. The influence of this effect is seen, for example, as a notch at 7 kHz, in ATF measurements made with the use of a 2-cm^3 coupler and appears for flat plate ISO 4869-3:2007 coupler as a difference resulting from its flat frequency response in contrast to an irregular course of the TFOE of a human ear.

As a general summary, it is worth to note that when averaged over 22 earmuffs tested, a smaller root-mean-square difference was observed between frequency responses measured with the use of Kemar and Brüel&Kjaer 4100 manikins and subjects than between the both ATFs and subjects. Due to lower attenuation of the manikins' hard surfaces frequency responses of earmuffs measured with the use of manikins were more variable than those determined on subjects. A larger disagreement of earmuff frequency responses measured on ATFs with MIRE data resulted from larger discrepancies between the characteristics of ATFs and human heads.

SUMMARY

The main findings of the present study are as follows:

a) The differences between the frequency responses of an earmuff measured on different subjects ranges from a few to over 10 decibels.

b) Earmuff frequency response measured with the MIRE method and sound attenuation determined by the REAT method are only in rough agreement. Usually the REAT data yields higher values than MIRE measurements at low frequencies. Above 1 kHz the sound attenuation determined with REAT are lower than those obtained with the MIRE method.

c) Measurements of earmuff attenuation (insertion loss) as a continuous function of frequency provide information on specific resonances of the earmuff. Such effects cannot be detected when sound attenuation is measured with the REAT method.

d) The use of acoustic manikins and artificial test fixtures yields results which show stronger resonsnt peak and dips in the frequency response. In certain cases such irregularites in the frequency reflect the effects observed in the measurements made with the MIRE method.

ACKNOWLEDGMENTS

This work was supported by the Polish Ministry of Labour and Social Policy, grants No. 3.S.02 and 3.S.03, and by the Polish Ministry of Science and Higher Education, grant No. 3.R.01.

REFERENCES

ISO 4869-1:1990 Acoustics -- Hearing protectors -- Part 1: Subjective method for the measurement of sound attenuation

ISO 4869-3:2007 Acoustics -- Hearing protectors -- Part 3: Measurement of insertion loss of ear-muff type protectors using an acoustic test fixture

E.H. Berger (2005) "Preferred Methods for Measuring Hearing Protector Attenuation", Poceedings of the *Internoise 2005, Rio de Janeiro, 07-10 August 2005*

M.D. Burkhard and R.M. Sachs (1975) "Anthropometric Manikin for Acoustic Research" *J. Acoust. Soc. Am.* **58**, 214–222