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Technical note

Insertion loss testing of active noise reduction headsets using acoustic fixture

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Abstract

Active Noise Reduction (ANR) technique has been available for hearing protectors and communication headsets for years. However, no standard testing method for ANR headsets has emerged. In this study, we measured insertion losses of four types of commercially available ANR headsets using an Acoustic Test Fixture (ATF) to examine the feasibility of using ATF for this kind of measurement. The measurement outlined required a minimum of instrumentation and was relatively simple to implement. The results show that this method should be especially useful for testing of prototypes and for quality control as well.

Keywords: Hearing protector; Headset testing; Active noise reduction; Passive insertion loss

1. Introduction

Although originally patented as early as in 1930s [1], the technique of Active Noise Reduction (ANR) did not find practical application in the hearing protection field for a long period of time. Only in the last 20 years has ANR been introduced in the industry of hearing protectors, primarily due to advances in signal processing technology. An ANR hearing protector has its low frequency attenuation increased by electronic means, which is implemented by employing a feedback-processing

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loop, where the intruding signal is re-introduced with a 180° phase shift. As a result, the sound pressure level is significantly reduced at those frequencies.

ANR is only effective in the low frequency range, below 500 Hz, because of physical limitation whose examination goes beyond the scope of this paper. It is well known that the sound energy that damages the hearing of noise-exposed people is found in the frequency above 500 Hz. Therefore the mere use of ANR does not reduce the risk of hearing loss. However, it does reduce the upward spread of masking[1] effect. By doing so, it increases significantly the speech intelligibility, thus improving oral communication in noisy environments such as airplane and helicopter cabins, armored cars, engine rooms, etc.

Presently, there are several manufacturers of ANR headsets. Some even provide parts so that a do-it-yourself user can transform his/her regular earmuffs to an ANR headset.

There are several types of ANR headsets. Most of them are the supra-aural type where the muff sits on top of the pinna (lighter, less expensive devices), or the circumaural type when the pinna is completely enclosed inside the muff (heavier, most effective device). Circumaural muffs can also be an integral part of a flying helmet, including a microphone for communication purposes.

Another difference among ANR headsets is whether they include communication circuitry or not. Some products, also known as ‘‘comfort’’, are designed for only reducing the low-frequency background noise. They are intended to increase comfort in the background of low frequency noise and are used mainly for passengers in airplanes. The other, more elaborate, type takes advantage of the reduced upward spread of masking to improve communication. For that purpose, protectors of this type have the facility of connecting a signal-carrying wire inside the muff. Those are headsets used for pilots in planes and helicopters, as well as operators of engine rooms, armored cars, etc.

2. Measurable characteristics of ANR headset

In a conventional hearing protector, sound attenuation and comfort are two important characteristics. Sound attenuation is routinely tested, and there are national and international standards [2,3] prescribing the procedure of measurement. Comfort, however, due to its subjective nature, is not routinely measured and there is no standard procedure for that purpose. Nevertheless, there is a consensus in the scientific and user communities that comfort is a very important factor that should be measured.

Besides the attenuation and the comfort, there are other characteristics that can be measured in an ANR headset. The attenuation at different sound levels is perhaps the most important one. There is an assumption that the attenuation does not

[1] Upward spread of masking effect is masking by a signal with frequency lower than that of the signal being masked. For instance, in an engine room, most of the sound energy is found below 500 Hz. However, this noise can easily mask conversation where most of the energy has frequencies higher than 500 Hz [12].

change with sound levels [4] in conventional protectors, at least not within the "normal" range of sound levels found in most operations [3]. This may not be valid in ANR headsets, since the sound level range may exceed the range within which the electronic circuit operates in a linear way. At high levels, the circuit may even generate spurious signals, deteriorating the communication quality.

In ANR communication headsets, intelligibility is another characteristic that can be measured. Since the main purpose for this type of protectors is to improve the intelligibility, the measurement of this character becomes very important.

The objective of the present study was to examine the feasibility of using an Acoustic Test Fixture (ATF) for the measurement of insertion loss of protectors. Therefore, at current stage, neither test of the influence of varying sound levels on the performance of the ANR protectors, nor test of intelligibility was examined.

3. Existing testing methods

There are several standardized procedures for measuring the attenuation of conventional earmuffs. The most commonly cited is the ISO 4869 [2], making use of the REAT[2] procedure. This procedure accounts for the anatomical variations among real people by using human subjects. It also includes all sound pathways as well as other characteristics such as mechanical compliance of the human skin, bone conduction, occlusion effect, etc. The same procedure is used in the ANSI S12.6-1997 [3] method.

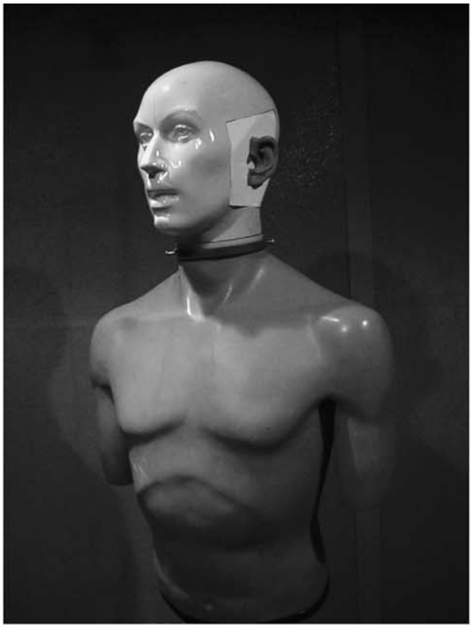
Another way of measuring the attenuation of protectors is by using the MIRE[3] procedure, where a miniature microphone is inserted in the auditory canal of the wearer's ear and sound pressures are measured with and without the protector in place. The characteristic measured using this procedure is Insertion Loss (IL) in dB The main advantage of the MIRE technique is minimizing the subjectivity of the test, for the subject just "lends" his head during the test. However, the involvement of human subjects increases the cost of testing and also limits the test conditions to avoid any potential hazard to the subjects.

Acoustic test cells are also used for testing ANR headsets [5]. They are intended to measure insertion loss at low frequencies (<250 Hz) and at very high sound levels (>100 dB), which may be hazardous for a test on human subjects. But this method does not account for differences among the anatomic characteristics.

Finally, there are methods [6,7] that use an ATF [Fig. 1(a)], a device which, in some models, has the shape of a human head. The microphone in an ATF is located inside the head and a tube connects acoustically the microphone to the outside. The tube has the effect of an auditory canal in a real human ear. The hearing protector being tested is located in such a way as to cover completely the opening of the tube

[2] REAT: Real-Ear Attenuation at Threshold is a technique that measures the attenuation of a protector as the difference between the sound levels at the hearing threshold of the listener with and without the protector in place.

[3] MIRE: Microphone In Real Ear.



(a)

(b)

Fig. 1. Experiment materials: (a) ATF, (b) headsets.

to ensure that occlusion will occur. The microphone's output is used for the analysis of the signal. An ATF is used as a substitute for the REAT and MIRE evaluations in screening and performance comparisons, due to the distinct advantage of time and cost effectiveness. Further comparison between ATF data and REAT data may be done using some mathematical models [8,9].

We are not aware of any standard for testing ANR headsets. The objective of the study here was to examine the feasibility of using an ATF for this kind of measurements. Testing hearing headsets using ATF is a physical measurement with the advantages of faster, simpler, and less expensive than conducting psychoacoustic measurements [10].

4. Materials and method

4.1. Headsets [Fig. 1(b)]

A total of five headsets were employed in this study, of which two were supra-aural and three circumaural. Details of the headsets are as follows:[4]

- **Headset-1**: A supra-aural type headset, used mainly as a comfort device in airplanes. It included a plug connecting to the airplane entertainment center or to sound reproducing equipment. Manufacturer's brochure claimed up to 10 dB cancellation at 300 Hz and a cancellation range of 40–1500 Hz.
- **Headset-2**: Same application as Headset-1. From the manufacturer's brochure, the cancellation range was 20–1500 Hz and the reduction was 15 dB between 150 and 300 Hz.
- **Headset-3A and -3B**: Both of the circumaural type. No technical specifications regarding the ANR performance were published in the manufacturer's brochure.
- **Headset-4**: A circumaural type aviation headset. No technical specifications regarding the ANR performance were published in the manufacturer's brochure either.

4.2. Instrumentation (Fig. 2)

The ATF used in the study is a binaural implementation of a mannequin with one instrumented ear [11]. Features of the mannequin include circumaural areas, pinna and auditory canals fabricated with simulated skin and tissue that retains the correct dynamic mass and textural properties of human flesh. The auditory canal is terminated in Zwislocki type DB100 coupler and Bruel & Kjaer type 4134 microphone, which simulate the acoustical impedance of human ears. The measurements were done using the instrumented ear.

[4] No manufacturer and headphone model type is identified in this paper according to conditions of contracts with the manufacturers.

Tests were carried out in an IAC double wall, double room Audiometric Cabin. A pink noise signal, generated by a General Radio Random Noise Generator Type 1382, was amplified by two Rotel Stereo Integrated Amplifiers type RA-930AX (50W) and fed into the room via four Mirage Speakers type M-90IS and four horn-loaded piezoelectric loudspeakers Motorola type KSN1016. The signal entering the ear of the ATF was detected by the microphone in the coupler and analyzed by a Bruel & Kjaer type 2144 Real Time Analyzer (RTA).

Measurements were performed in 1/3-octave bands at the center frequencies from 20 to 8000 Hz.

4.3. Measurement method

Measurements were carried in the following three steps:

(a) The Open-Ear Spectrum (OE) was measured with the sound signal on and no headset on the ATF.

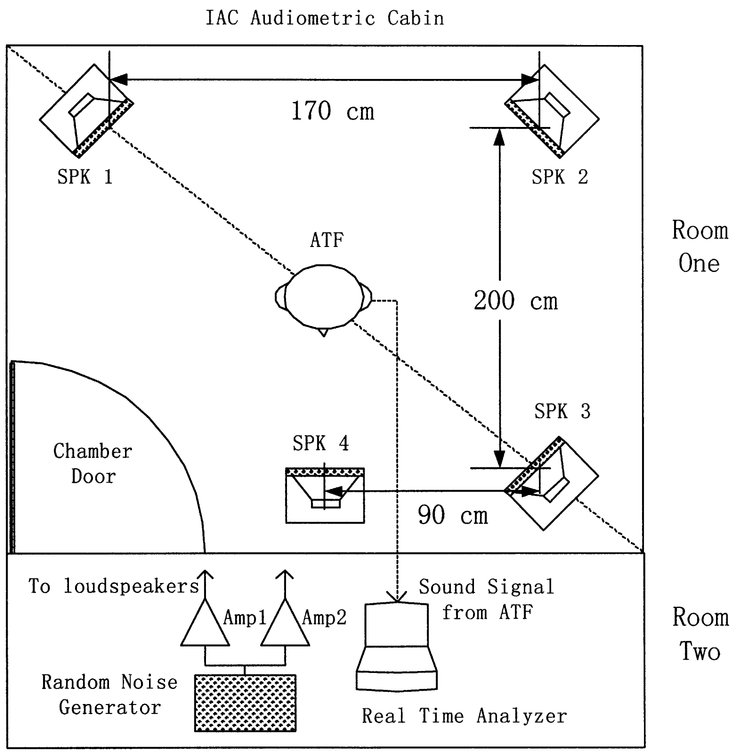


Fig. 2. Test set-up. The ATF and speakers were located in Room One and the signal generator, amplifiers and RTA were located in Room Two of the IAC cabin.

(b) Without changing the sound signal, the Passive-Protected-Ear Spectrum (PP) was measured with the headset donned. The ANR system of the headset was off at this step.
(c) The Total Protected Spectrum (TP) was measured with the ANR system switched on, while keeping other conditions same as in step (b).

Steps (b) and (c) were repeated 20 times in each measurement session, without altering the sound signal. The purpose was to examine the changes of the insertion losses resulting from repeatedly donning and doffing the headset. A study of those variations is in progress.

From the spectra in steps (a)–(c), the following IL was calculated for each one of the 1/3-octave band frequencies:

- **Passive Insertion Loss** (IL_P): the insertion loss of the headset with the ANR off

$$IL_P = OE - PP \ \ (\text{dB}) \tag{1}$$

- **Total Insertion Loss** (IL_T): the total insertion loss of the headset with the ANR on

$$IL_T = OE - TP \ \ (\text{dB}) \tag{2}$$

- **Active Insertion Loss** (IL_A): the insertion loss due to the effectiveness of ANR only

$$IL_A = PP - TP \ \ (\text{dB}) \tag{3}$$

In a variation of the above procedure, the pinna was removed from the ATF and the procedure was repeated several times. It was concluded that without the pinna, there were no significant changes in the ILs from repeated measurements.

5. Measurement results

The results of measurement are summarized in Tables 1–3 and Figs. 3–12.

Table 1 shows the background noise, open-ear spectra (OE) and their equivalent dBA levels used for the measurements of the headsets. Five headsets were tested at different times. It can be seen that all tests were performed at approximately the same sound level. Fig. 3 shows the spectra of the noise signal used in testing.

The passive insertion loss IL_P, the active insertion loss IL_A and the total insertion loss IL_T were calculated as per Eqs. (1), (2) and (3) respectively.

To illustrate the calculation process, an example of obtaining IL_P, IL_A and IL_T, using the first testing trial of Headset-1 is summarized in Table 2. Using OE of Table 1 and the PP column, the IL_P column was calculated by Eq. (1). Similarly, the IL_A data were calculated using the values of PP and TP with Eq. (2). Finally, the IL_T data were calculated, as the difference between OE and AP by Eq. (3).

Table 1
Open-ear (OE) spectra of the five ANR headsets and the background noise[a]

Frequency (Hz)	OE (Pink noise signal)					Background noise (dB)
	Headset-1 (dB)	Headset-2 (dB)	Headset-3A (dB)	Headset-3B (dB)	Headset-4 (dB)	
20	67.8	67.8	67.1	68.0	68.7	21.5
25	67.2	67.1	67.6	67.7	67.9	20.1
31.5	68.4	68.8	68.2	68.3	68.6	19.4
40	66.3	69.3	68.4	66.1	69.1	18.1
50	67.7	75.9	72.7	68.8	74.4	15.7
63	67.4	72.7	67.1	67.2	72.2	16.6
80	77.4	73.4	74.5	75.5	76.5	14.9
100	71.9	67.3	68.0	70.6	68.3	<10.0
125	62.8	63.6	65.3	63.0	62.7	16.8
160	65.4	66.8	68.2	66.0	66.3	12.0
200	57.7	56.8	56.0	57.9	56.9	<10.0
250	58.8	51.9	54.2	58.1	54.1	12.2
315	60.4	55.9	59.2	60.6	57.2	11.2
400	65.9	63.1	66.0	67.6	62.3	<10.0
500	62.2	58.1	57.4	61.7	58.8	11.9
630	53.9	64.9	65.1	54.3	65.6	10.8
800	59.5	66.3	66.6	61.6	67.8	<10.0
1000	63.7	66.7	66.5	64.1	67.6	<10.0
1250	68.5	68.3	67.9	69.6	69.1	<10.0
1600	60.6	68.0	63.8	64.8	66.1	<10.0
2000	61.4	71.7	73.1	58.9	69.8	<10.0
2500	72.1	72.5	75.0	68.9	72.8	<10.0
3150	69.8	76.7	73.8	67.5	76.7	<10.0
4000	64.4	71.1	69.7	66.5	70.1	<10.0
5000	65.9	68.4	63.0	64.8	64.9	<10.0
6300	61.1	60.2	57.1	61.2	57.7	<10.0
8000	62.1	69.5	64.9	64.8	64.5	<10.0
Equivalent dB(A)	78.0	82.1	81.5	77.3	81.7	17.92

[a] 1/3 octave band levels and their equivalent dBA levels for testing the headsets are shown.

The data of the remaining 19 testing trials of Headset-1 and of other four headsets were calculated with identical procedures. The data obtained with pinna on the ATF are summarized in Figs. 4–8. The results from testing Headsets 1–3A that were obtained without pinna on the ATF are shown in Figs. 9–11.

6. Discussion

It was observed that there were significant variations among the calculated values of different ILs at different frequencies. For the data of Headset-1 obtained at 1 kHz, for instance, Table 3 shows the minimum, mean and maximum values of IL_P,

Table 2
An example of obtaining IL_p, IL_A and IL_T using the first testing trial of Headset-1

Frequency (Hz)	PP (dB)	TP (dB)	IL_P (dB)	IL_A (dB)	IL_T (dB)
20	68.3	68.9	−0.5	−0.6	−1.1
25	67.7	67.8	−0.4	−0.2	−0.6
31.5	67.8	68.4	0.6	−0.6	0.0
40	67.5	67.9	−1.2	−0.3	−1.6
50	67.7	67.8	0.0	−0.1	−0.1
63	66.9	65.4	0.5	1.5	1.9
80	77.0	75.5	0.3	1.5	1.8
100	71.6	69.4	0.3	2.3	2.6
125	63.0	59.2	−0.2	3.8	3.6
160	65.7	61.3	−0.3	4.5	4.1
200	58.2	54.2	−0.5	4.0	3.5
250	59.2	54.4	−0.4	4.7	4.3
315	60.7	55.2	−0.3	5.5	5.2
400	66.3	60.1	−0.4	6.3	5.8
500	62.6	56.4	−0.5	6.3	5.8
630	54.6	51.3	−0.7	3.3	2.6
800	61.9	59.5	−2.5	2.4	0.0
1000	66.5	62.6	−2.7	3.9	1.2
1250	69.0	64.8	−0.4	4.1	3.7
1600	65.9	65.4	−5.3	0.5	−4.8
2000	69.5	69.9	−8.1	−0.5	−8.6
2500	70.5	72.7	1.6	−2.2	−0.6
3150	67.5	69.9	2.3	−2.4	−0.1
4000	58.4	55.5	6.0	3.0	8.9
5000	51.8	52.1	14.1	−0.2	13.9
6300	59.3	59.6	1.8	−0.3	1.5
8000	53.3	55.0	8.8	−1.7	7.1

Table 3
The min, mean and max values of ILs of Headset-1 obtained at frequency 1 KHz with and without pinna on ATF

	IL_P	IL_A	IL_T
With pinna on ATF			
Min	−15.9	2.2	0.1
Mean	−3.4	4.1	0.7
Max	−2.1	16.9	1.2
Without pinna on ATF			
Min	−3.4	3.4	0.0
Mean	−2.1	6.0	3.9
Max	−0.9	8.3	7.4

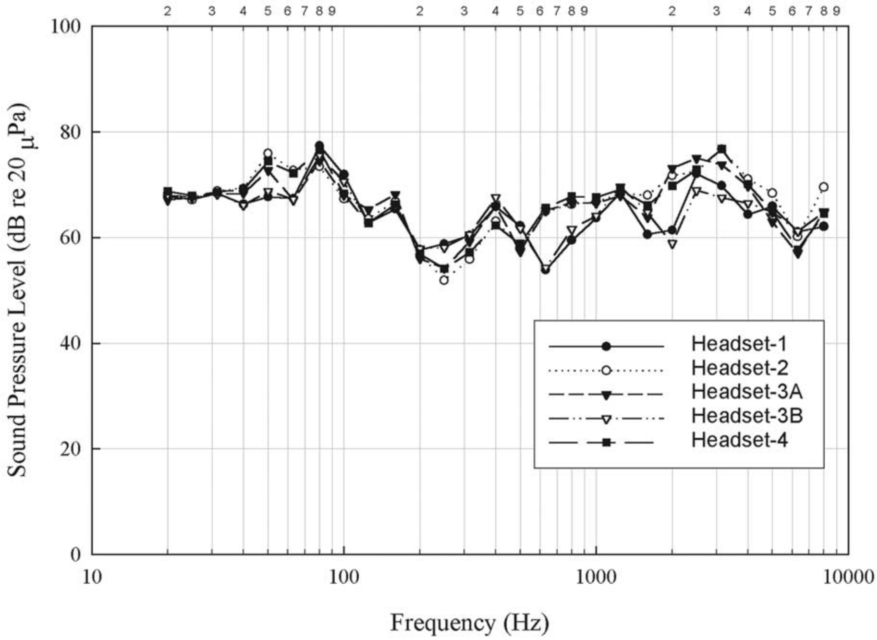


Fig. 3. Open-ear spectrum (OE) of Headset-1.

IL_A and IL_T. The data in the upper part of the table were acquired with pinna on ATF, while the data in lower part not. Figs. 4–8 show all those data acquired with pinna on. At each frequency point, the standard deviation observed is shown as the upper bar and the lower bar from the mean value. The mean values of ILs of all of the headsets are summarized in Fig. 12, where the symbol '*' indicates the supra-aural type headsets.

As is expected, the high frequency range of the noise is attenuated by the passive insertion loss of the headsets. In Fig. 12(a), the mean values of IL_P do not exceed 10 dB below 300 Hz, but they reach as high as 38 dB (Headset-4) above 1000 Hz. On the other hand, the low frequency is attenuated by active noise reduction. We can see in Fig. 12(b) that the attenuation above 500 Hz usually is less than 5 dB, while it is as high as 25 dB (Headset-4) between 100 and 200 Hz. Thus, ANR headsets obtained broadband noise attenuation both in low and high frequency band, as is shown in Fig. 12(c).

Negative attenuation can be observed between 1000 Hz and 2000 Hz in Fig. 12(c). The cause of this phenomenon may be due to the sound leakage of the supra-ear type earmuff and resonance at those frequencies. Another cause could be the feedback circuit that causes amplification at those frequencies where the ANR device is no longer canceling sound. It is apparent that the circumaural type headsets achieves higher IL for both IL_P and IL_A, and consequently have better performance.

Another obvious observation from the experiment is the poor repeatability of the IL results in successive tests. That is, the results of the tests from the same protector

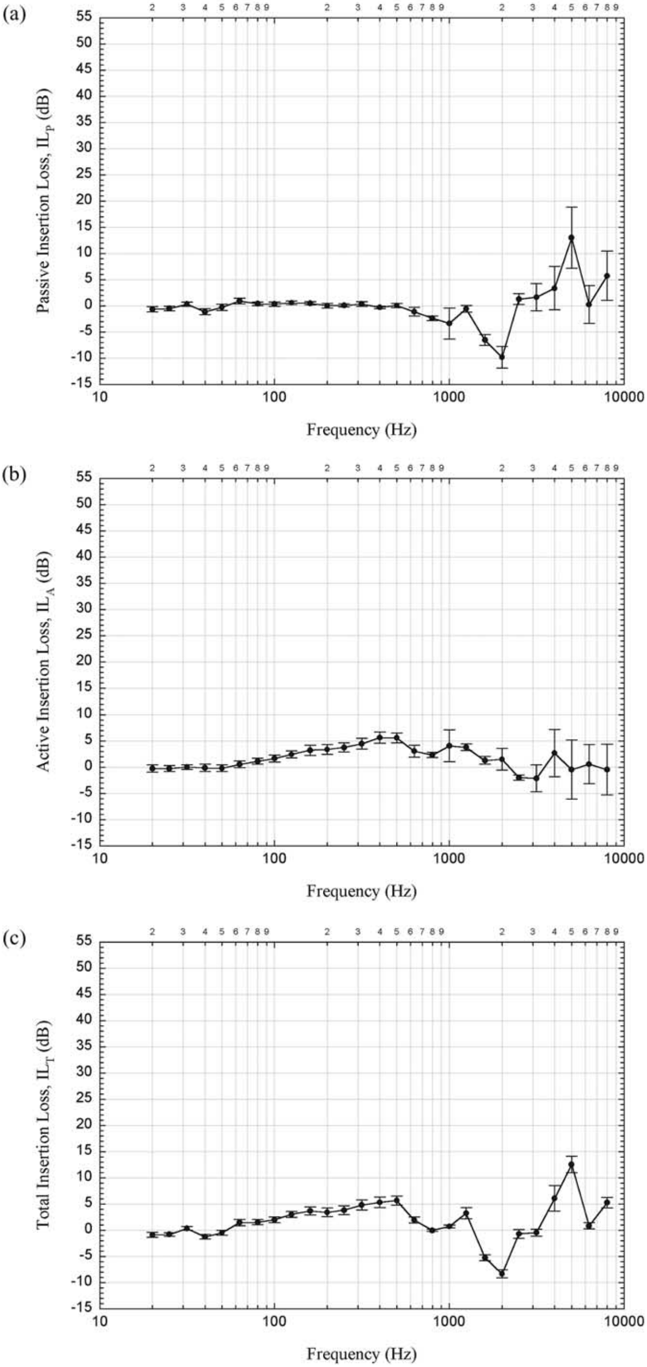


Fig. 4. (a) IL_P (b) IL_A and (c) IL_T of Headset-1 with pinna on ATF.

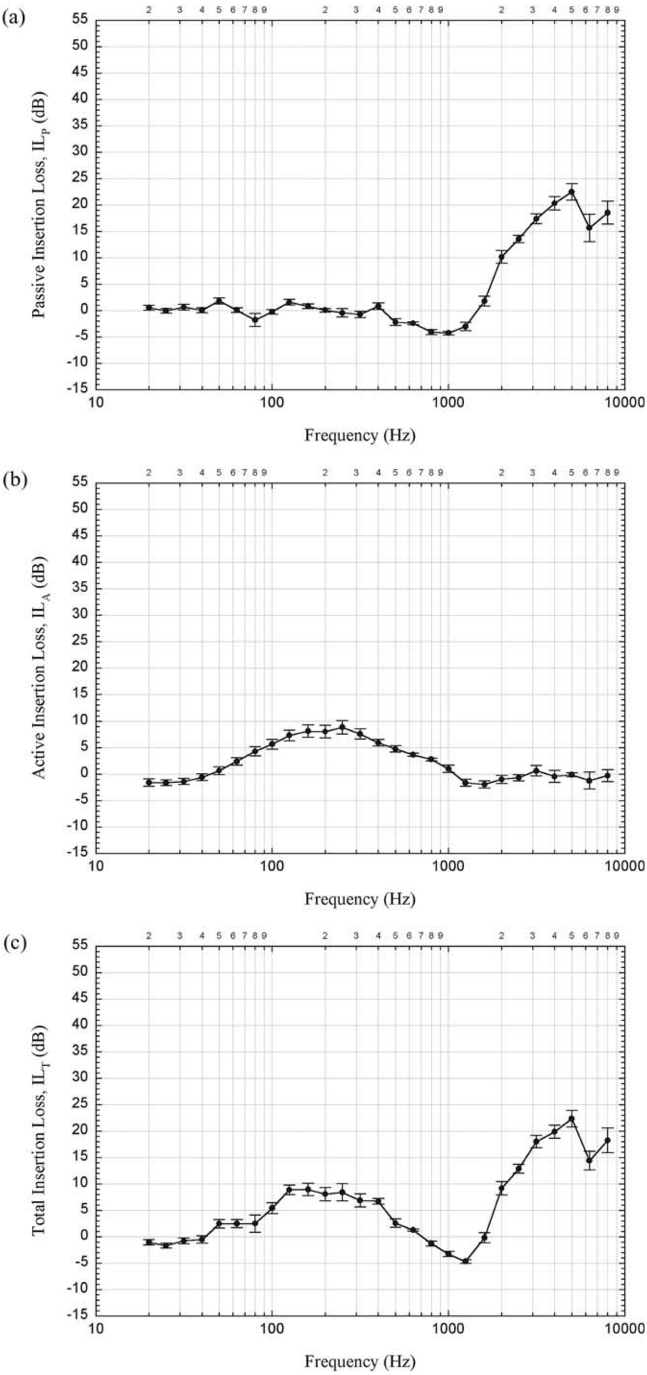


Fig. 5. (a) IL_P (b) IL_A and (c) IL_T of Headset-2 with pinna on ATF.

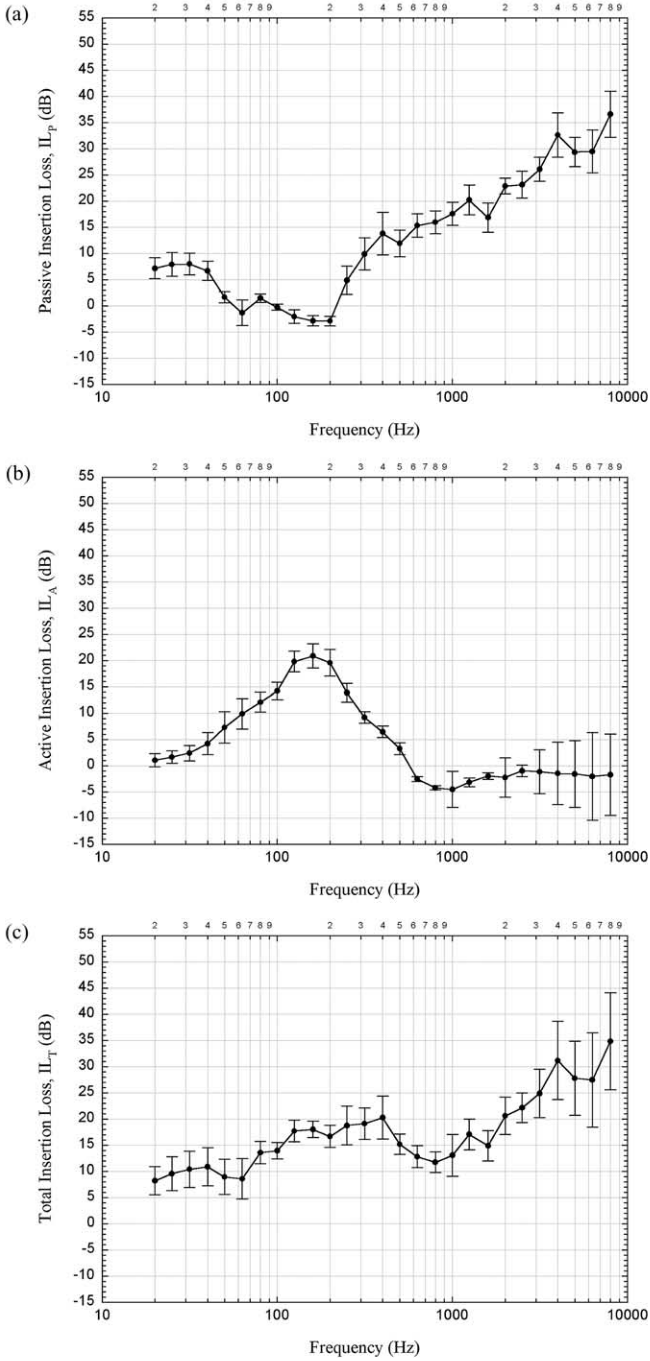


Fig. 6. (a) IL_P (b) IL_A and (c) IL_T of Headset-3A with pinna on ATF.

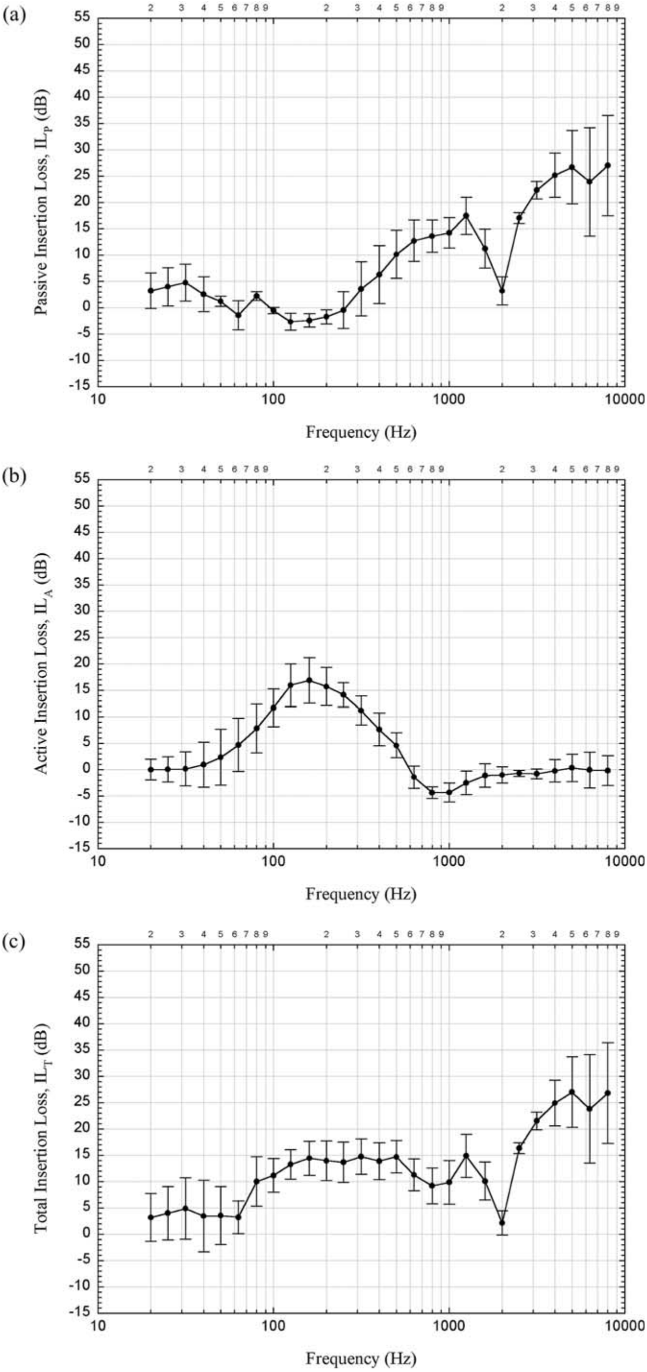


Fig. 7. (a) IL_P (b) IL_A and (c) IL_T of Headset-3B with pinna on ATF.

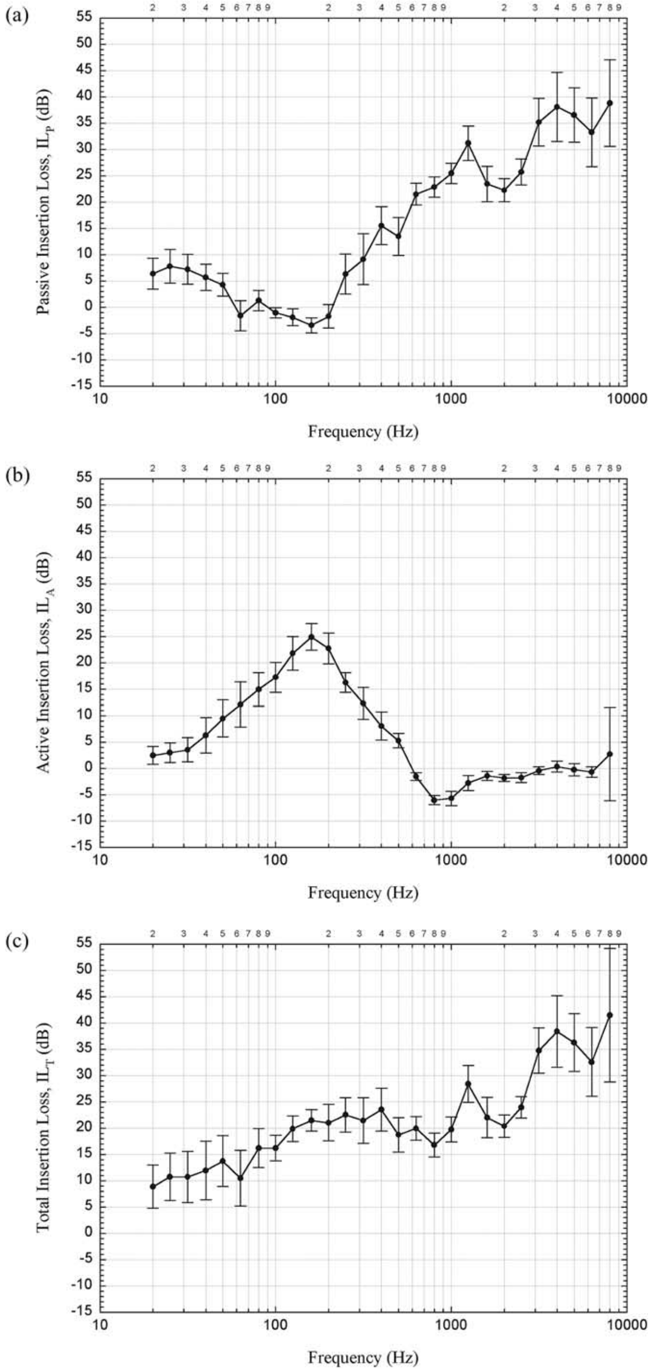


Fig. 8. (a) IL_P (b) IL_A and (c) IL_T of Headset-4 with pinna on ATF.

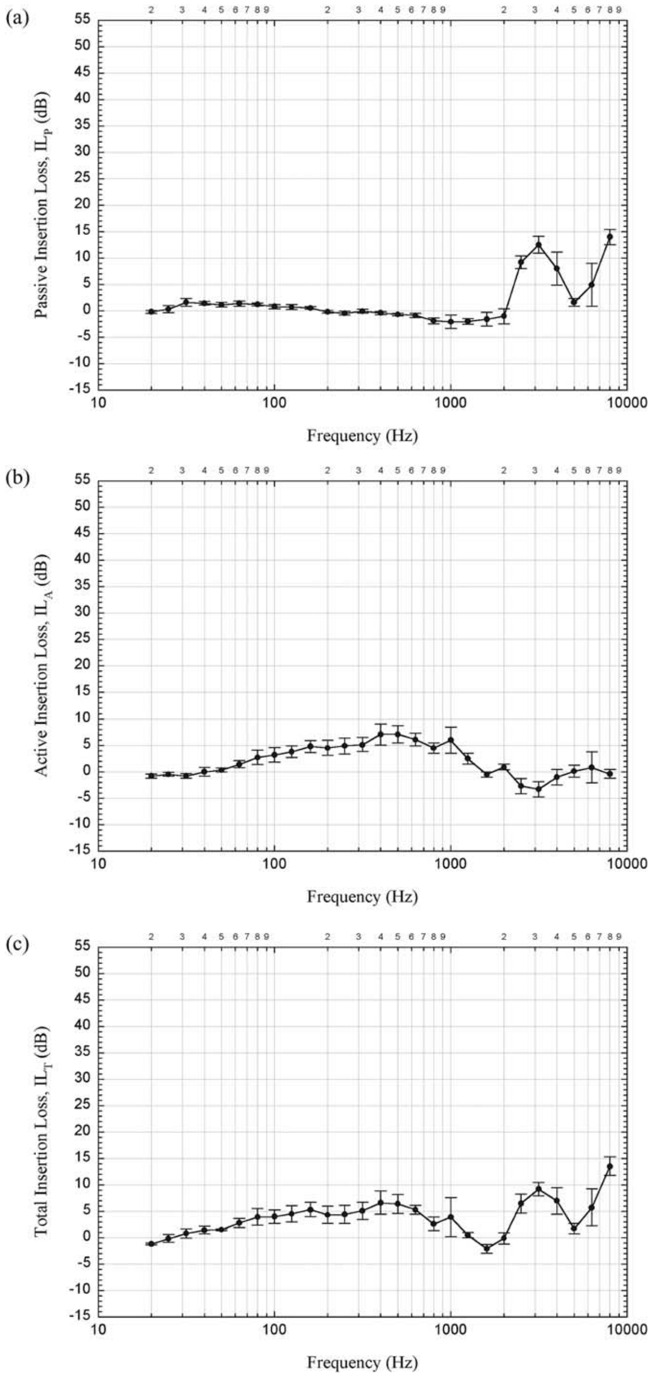


Fig. 9. (a) IL_P (b) IL_A and (c) IL_T of Headset-1 without pinna on ATF.

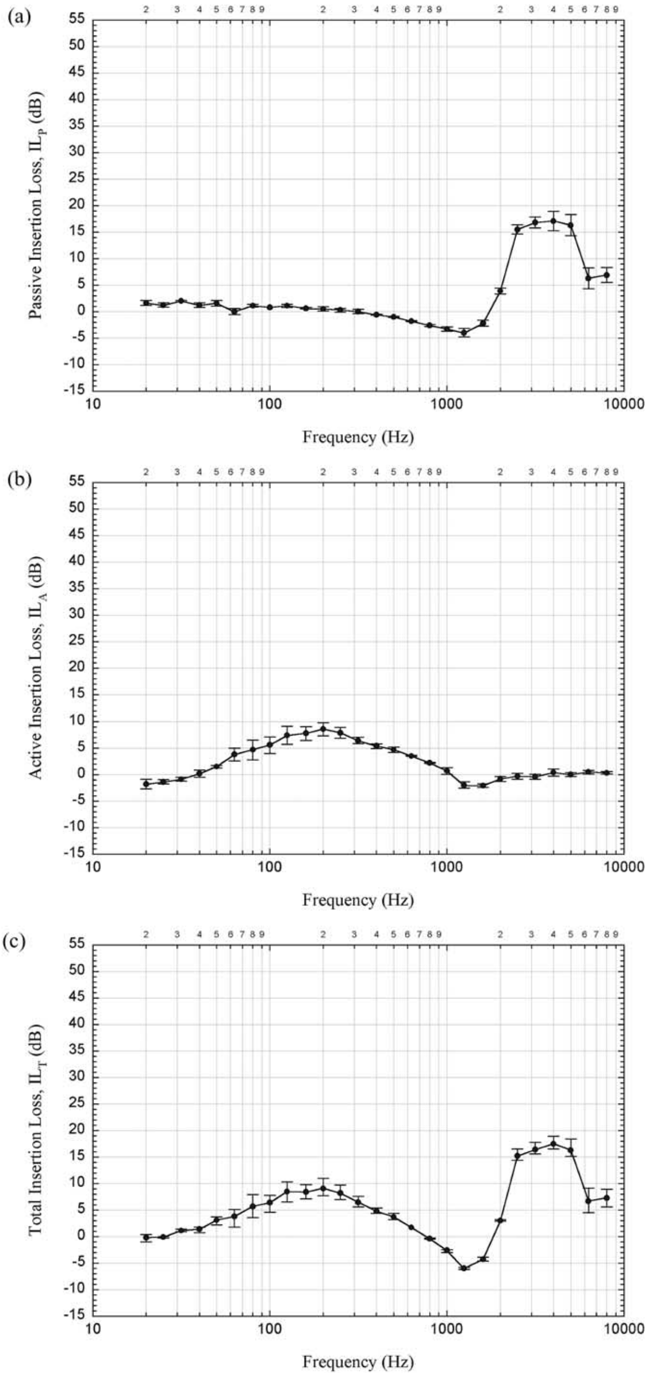


Fig. 10. (a) IL_P (b) IL_A and (c) IL_T of Headset-2 without pinna on ATF.

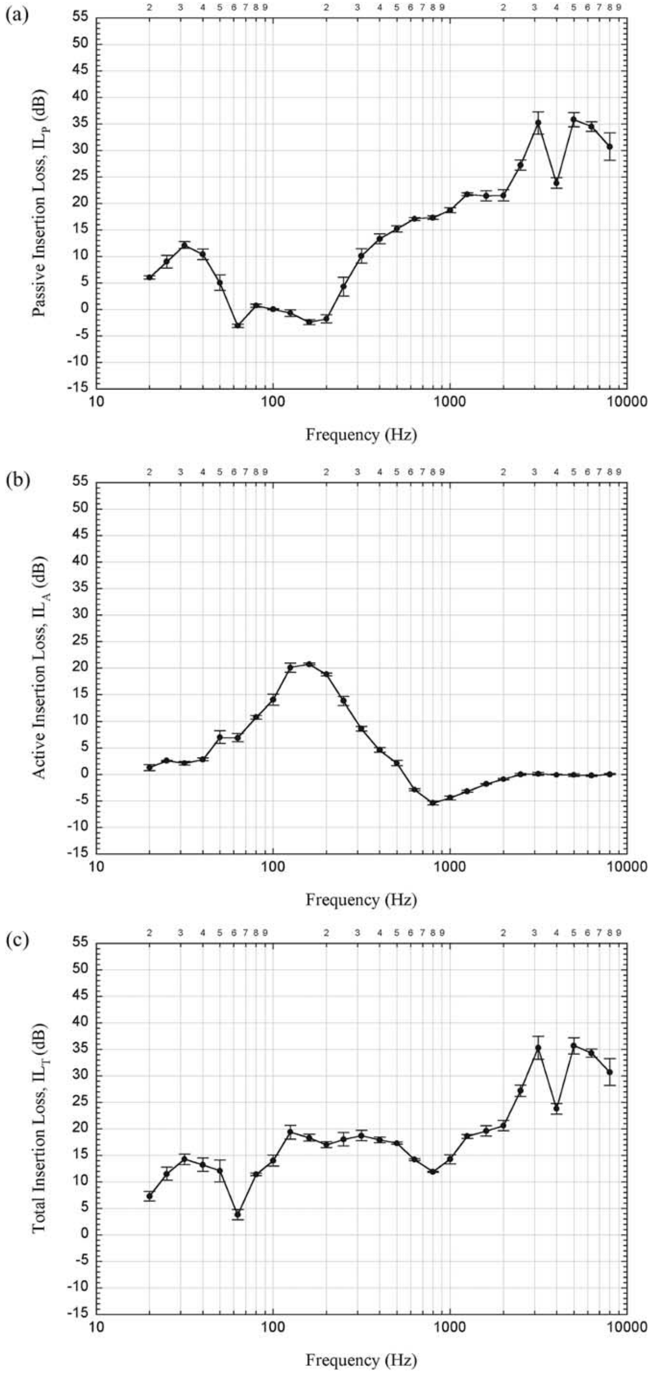


Fig. 11. (a) IL_P (b) IL_A and (c) IL_T of Headset-3A without pinna on ATF.

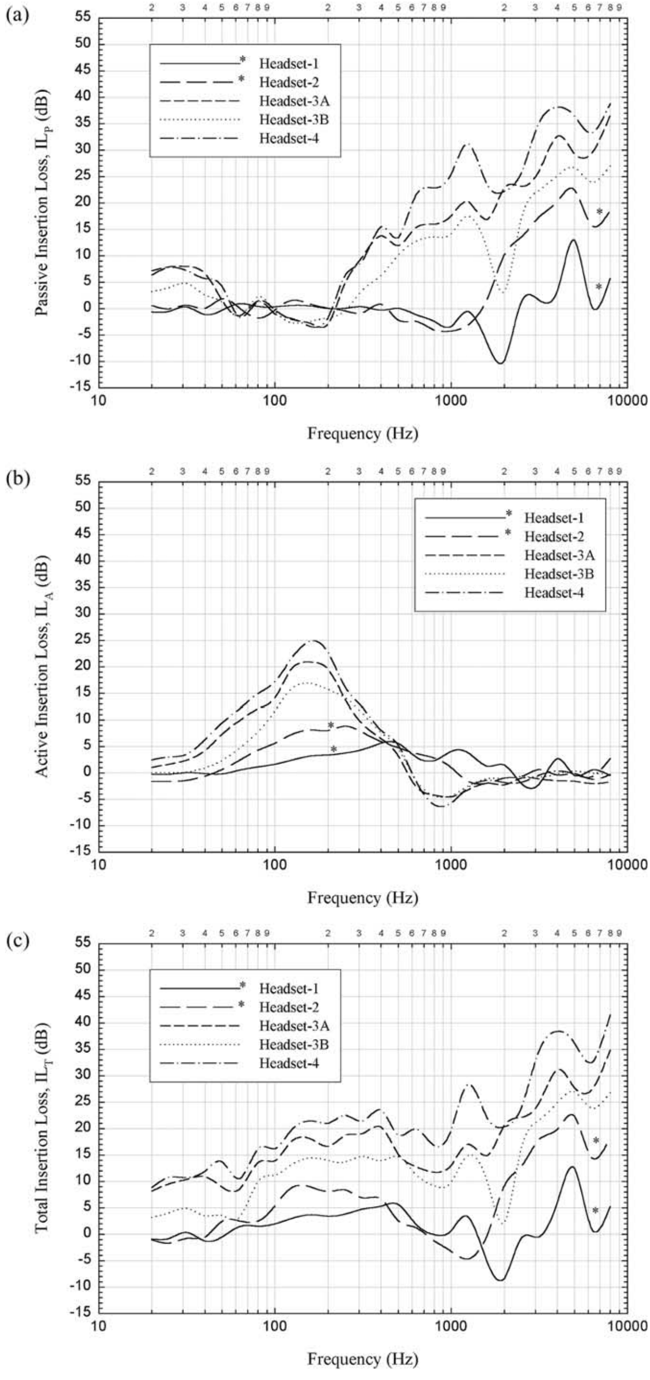


Fig. 12. Mean values comparison of (a) IL_P (b) IL_A and (c) IL_T of the five headsets (*supra-aural type headsets).

at a given frequency point varied considerably (e.g. in Figs. 6 and 7). One of the causes may be the influence of pinna. We know that the performance of the ANR circuit depends greatly on the relative positions of the earmuff and the sampling microphone in the earcup. Because of the presence of the pinna, the microphone might change its position in each fitting, and the difference of the positions could contribute to the difference of the IL results. These can be further verified by comparing Figs. 4–6 (with pinna) with Figs. 9–11 (without pinna), where the range of the data obtained without pinna is smaller than that with pinna.

7. Conclusions

A method for the measurement of IL of ANR headsets using an ATF and the results of its application are presented. It allows for a minimum of instrumentation and is relatively simple to implement. It requires an audiometric booth, a signal generator, speakers, and a RTA. The ATF is an essential part of the instrumentation. The background noise inside the booth is not important, since measurements can be easily implemented at a level of 80 dBA or higher. In addition, non-involvement of human subjects reduces the overall cost and makes the tests easy to perform. As an example, the 20 IL tests of one headset were completed within only an hour. The method becomes especially useful for testing prototypes, since it allows for quick modifications of device for a subsequent re-test. It may be also useful in the case of quality control, because it allows for testing large quantity of headsets in a short time.

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