Measurements in the Open and Closed Ear Canal: Comparison Between Different Artificial Head Concepts

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1 Introduction

The use of Acoustic Test Fixtures (ATF) in the field of hearing protection has become essential for assessing the performances of hearing protectors facing high-level impulse noises. However, using this tool can be limited and, under certain conditions, does not reflect the actual behavior observed in subjects. As part of Huiyang Xu's thesis work [1], the IRSST designed a new and more realistic artificial head. This results from a desire to consider tissue or bone conduction to obtain a realistic occlusion effect compared with measurements on subjects. It integrates both the morphological characteristics of a subject's head, using medical imaging studies (MRI), and the physical characteristics of the head's constituent materials. This difference in comparison to commercially available ATF (or the ISL ATF) is interesting because, to date, measurements with ATF still require post-measurement compensations based on empirical results to take tissue or bone conduction into account [2].

In the context of joint discussions with the IRSST, this study aims to carry out various characterizations of this head and compare them with those obtained with other ATF in the ISL laboratory.

This paper evaluates the characteristics of solid transmission of acoustic waves from bone conduction transducer to the ear canal. The measurements are carried out simultaneously on the IRSST artificial head, on one ISL ATF equipped with two different external ears, and on three subjects to compare existing tools and the actual human response.

2 Material and method

Solid transmission of acoustic waves is assessed by:

- measuring the occlusion effect: sound pressure difference between the open and occluded ear canal;
- measuring the transmission delay in the same configuration.

2.1 Material

The ISL ATF used to compare measurements has two different types of external ear:

- One ear with a homogeneous pina and ear canal made of a flexible silicone-type material with a realistic morphology (noted ATF1).
- Another ear with a simplified pina made of a rigid silicone-type material and decoupled from the silicone ear canal (noted ATF2 and referenced in standard S12.42 [2]).

The three subjects (two men and one woman) participating in the experiment were laboratory members, trained to wear hearing protection and with different morphology. The performed measurements did not affect the hearing system, and the subjects were informed of the protocol before each measurement. Although the ISL ATF is instrumented to measure the acoustic pressure in the ear canal, a microphone probe, shown in Figure 1, had to be used due to the absence of a technical solution for similar measurements using the IRSST head and on the subjects. This figure also shows the two earpieces to hold the microphone, used to realize measurements either in the open ear or in the occluded ear.

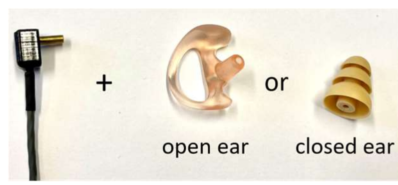

Figure 1: Microphone probe used for measurements, and earpieces used to hold it in the ear canal, depending on the type of measurement (open or closed ear).

Figure 2 shows a schematic diagram of the measuring device and a photograph of the system installed on the IRSST head. The transducer is of the electrodynamic type, designed for stealthy military headgear and has already been used in Blondé-Weinmann et al. (2021) [3].

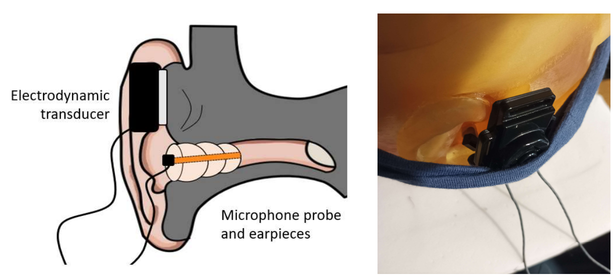

Figure 2: Experimental evaluation of the solid transmission (schematic illustration and photograph).

2.2 Measurement of the occlusion effect

The objective is to estimate the transfer function between the transducer input and the sound pressure in the ear canal measured by the probe microphone. The signal used is a sine sweep between 80 Hz and 8 kHz. The transfer function is determined when the ear is open (TF_{open}) and when the ear is closed (TF_{closed}). Three transfer function measurements are

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performed for each configuration. Between each measurement, the transducer is repositioned close to the tragus. The occlusion effect (OE) corresponds to the difference between these two averaged log-magnitude transfer functions:

$$OE = TF_{closed} - TF_{open} . \quad (1)$$

2.3 Measurement of the transmission delay

The goal is to estimate the transmission delay of a wave delivered by the electrodynamic transducer positioned on the tragus and propagated to the ear canal. The method employed is based on the minimum-phase method [4]. That is, to consider the global system $G(j\omega)$ as the superposition of a pure delay τ and a minimum-phase function $H(j\omega)$ of phase θ as follows:

$$G(j\omega) = e^{-j\omega\tau}.|H(jw)|e^{-j\omega\theta} . \quad (2)$$

The transfer function $G(j\omega)$, is measured using a series of 10 Gaussian pulses, with 1 ms duration, transmitted by the transducer for each configuration. Using Equation 2, the delay τ is estimated.

3 Results

3.1 Occlusion Effect

The transfer functions (TF_{open} and TF_{closed}) were used to deduce the average occlusion effect induced by transducer stimulation. Figure 3 shows the average OE depending on the head used. Only the average over the three subjects is shown in this figure.

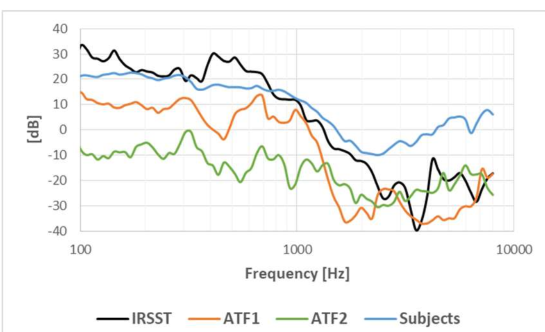

Figure 3: The occlusion effect determined by Equation 1.

In the low-frequency range (< 2 kHz), we observe:

- ATF1 (soft silicone ear) has a slight occlusion effect (about 10 dB).
- ATF2 (with the rigid silicone pina decoupled from the canal) shows no occlusion effect.
- The IRSST head has an occlusion effect of 25 dB, in line with measurements on subjects.

3.2 The transmission delay

Figure 4 shows the transmission delays of the wave delivered by the transducer, deduced from the recording of the probe microphone for an "open" and "closed" ear canal. The results obtained on the three subjects have been averaged.

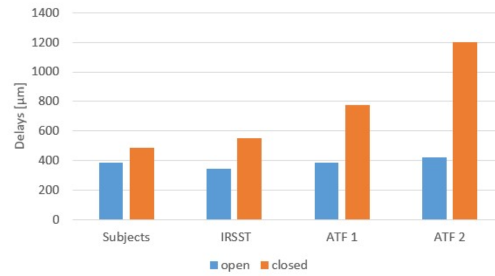

Figure 4: Transmission delays of wave delivered by an electrodynamic transducer for the open and closed ear canal

The transmission delay for the open ear canal is approximately 400 µs for all heads, with the smallest value for the IRSST head. The transmission delay for the closed ear canal is very different depending on the head, with very long delays for both ATFs. The delay on the IRSST head is of the same magnitude as the delay obtained on the subjects.

4 Discussion & conclusion

The IRSST has developed an innovative artificial head to consider tissue and bone conduction. This head corroborates subject measurements for the objective occlusion effect in the low-frequency range (<2 kHz), unlike traditional ATF. Given the transmission delays from cutaneous stimulation to the air in the ear canal, the IRSST head stands out for transmission paths close to those of a real ear and marks a break with other ATF. Other measurements, not described in this paper, have been carried out, such as the performance of hearing protection and the Transfer Function in Open Ear (TFOE), this time using air sound waves.

References

[1] Huiyang XU, « A finite element model of a human head and a corresponding acoustic test fixture to assess the objective occlusion effect induced by earplugs under bone-conducted stimulation » (2022). PhD Thesis, Montréal, École de technologie supérieure, https://espace.etsmtl.ca/id/eprint/3168/.

[2] Berger E., Standard ANSI/ASA/S12.42 2010. American National Standard Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures. New York, American National Standards Institute.

[3] Blondé-Weinmann C., Zimpfer V., Joubaud T., Hamery P., Roth S., "Characterization of cartilage implication in protected hearing perception during direct vibro-acoustic stimulation at various locations." Applied Acoustics 179 (2021): 108074

[4] Blondé-Weinmann C., Zimpfer V., Joubaud T., Hamery P., Roth S., "Numerical and experimental investigation of the sound transmission delay from a skin vibration to the occluded ear canal." Journal of Sound and Vibration (2022): 117345