EFFECTS OF THE HARDNESS OF ACOUSTIC TEST FIXTURES' EARS ON THE EVALUATION OF EARPLUG'S DIRECT TRANSMISSIONS FACING HIGH-LEVEL IMPULSE NOISES.

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1 Introduction

The performance of hearing protectors is limited by both (i) indirect transmissions through the outer ear tissues and (ii) direct transmissions through the protector. In the case of high-level impulse noises, it has been shown that these direct transmissions can induce displacements of the protector in the auditory canal axis that are proportional to the acoustic pressure measured at the eardrum [1]. These displacements can result from (i) inertial effects, where the plug moves like a rigid body, and (ii) deformation effects resulting from structural deformations of the protection [2,3]. For ethical reasons, the performance evaluation of protectors facing high-level impulse noises requires using an Acoustic Test Fixture (ATF). Nevertheless, it doesn't fully reflect the behavior of a human ear. Therefore, a posteriori correction based on continuous noise measurements is used to account for tissue conduction. Nevertheless, there is no correction for impulse noise nor the ATF's effects on the direct transmissions. A new experimental study is performed to understand the role of the ATF ear's material hardness on the protector's direct transmissions.

2 Method

Impulse noises of various levels were generated using explosive charges to stimulate a medium-hardness (shore 95A) earplug built in our laboratory. Table 1 lists the impulse wave characteristics (peak amplitude and A-duration) obtained from the weapons and charges.

Table 1: Charge type and corresponding impulse wave characteristics at 7 meters.

impulse peak level	charge type	impulse A-duration
[dB]	[-]	[ms]
156	detonator	0.8
167	17g relay	1.8
177	220g C4	2.5
180	400g C4	2.9

The earplug was inserted in the canal of an ATF with two ears of different hardness (low and medium). The employed ATF has been developed at the ISL to comply with the ANSI/ASA S12.42-2010 requirements. The ear canal is cylindrical and mechanically independent of the rest of the ear. The earplug velocity was measured with an OPTOMET SWIR Laser Doppler Vibrometer (LDV). The laser beam orthogonally targeted the exterior earplug base, and the sampling frequency was 51.2 kHz. The sensor's dynamic range was refined for each measurement to record the signal variations best. The measures follow an experimental protocol already used and validated with a high-speed camera in the past [4]. It bases on the temporal decomposition of the measured velocity to separate the useful signal (earplug velocity) from the perturbations 1 and 2 (respectively, laser beam and laser-vibrometer body). Then LDV, the ATF, and the source respect a precise arrangement specified by Figure 1. The values of distance d_i in Figure 1, approximate related propagation duration $T(d_i)$, and approximate perturbation duration T_{Pi} are given in Table 2.

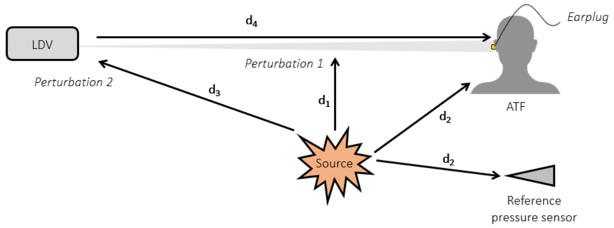

Figure 1: Positioning of the source, ATF, and sensors.

Table 2: Estimated distance d_i and related propagation duration $T(d_i)$ for the sensor positioning. A propagation speed in the air of 343 m/s is used. Durations T_{P1} and T_{P2} of the perturbations 1 and 2 arise from previous estimations measured in Blondé-Weinmann et al. (2022) [4].

i	d_i [m]	$T(d_i)$ [ms]	T_{Pi} [ms]
1	2.0	6	10
2	7.0	20	10
3	14.1	41	?
4	20.7	-	-

For each impulse level, the earplug's velocity was evaluated with the LDV, the closed ear canal acoustic pressure was measured with the ATF microphone, and the stimulating pressure was estimated with a pressure reference sensor manufactured at the ISL from a KISTLER-6031 quartz sensor. Each level was measured twice to detect an unexpected variability that could occur from a defect in impulse generation. If this happened, a third measurement was made to keep two iterations with equivalent characteristics to achieve an average. Then, the earplug's maximal displacement and ear canal peak acoustic pressure for the three stimulation levels were compared for the two ATF ears' hardness.

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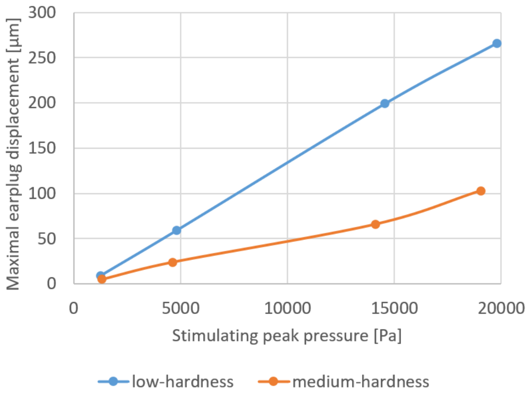
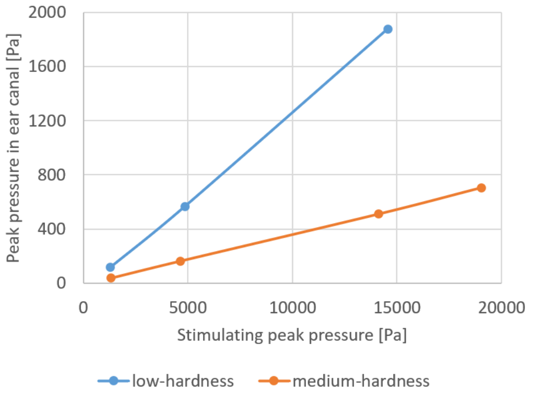
3 Results

Figures 2a and 2b show, respectively, the relationships between the maximum peak pressures in the occluded ear canal and the maximum insertion displacements of the plug in the two ATF ear canals (of low and medium-hardness material) for the four peak impulse levels.



(a) Maximal earplug displacement as a function of the peak amplitude of the incident impulse wave.



(b) Peak pressure in the ear canal as a function of the peak amplitude of the incident impulse wave. The 180 dB measurement for the soft ear was removed as it exceeded the dynamic range of the artificial head microphone.

Figure 2: Effect of ATF ear hardness on the maximum displacement of an earplug and resulting ear canal peak pressure.

Each curve has a proportional relationship to the peak stimulation pressure. This proportionality is given by β, the ratio between the peak pressure in the ear canal and the maximum displacement of the protection in the canal. The values for β and related peak Noise Reduction (pNR) are given in Table 3.

Table 3: Pressure increase in the occluded ear canal following a micrometer displacement of the outer lateral face of the protection (β) and related pNR.

hardness	β [Pa/μ]	pNR [dB]
soft	10.7	19
medium	7.2	29

A low-hardness ear induces more displacement of the plug and a higher peak sound pressure in the canal during high-level impulse noise. Moreover, the soft material also generates a higher peak pressure in the ear canal for the same displacement.

4 Discussion

Direct transmissions induced by earplug displacements are greater for a low-hardness ear than a medium-hardness ear. Given the properties of the human ear, it may be that soft material is more representative of reality. So, depending on the material, the evaluation of the protector's performance can be greatly altered. This effect results in a pNR highly dependent on the ear material used for the ATF ear. In the case of a medium-hardness ear, the average pNR is 29 dB for all measurements, compared with 19 dB for a low-hardness ear. This raises the question of the representativeness of ATFs for evaluating the performance of protectors facing high-level impulse noise. It also raises questions about the materials used for the protectors themselves. It is conceivable that, for an ear with a given hardness, a protector of different hardness will induce direct transmissions of different significance and pNR of different values. As demonstrated in [1], the value of β is inversely linked to the pNR, indicating a relation between the earplug displacement and the earplug performances. It seems that earplugs made of the hardest materials are better able to move among the soft tissues of the outer ear by compressing the outer ear tissues in the direction of the canal, thanks to a Poisson effect. It may be advisable to work on the materials used for protectors to limit this effect.

5 Conclusions

Using a LDV and an ATF equipped with different ears, it has been shown that direct transmissions through the same protector depend on the ear's hardness. These results call for further improvements in the materials used in ATFs to get as close as possible to human ear tissues.

References

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