Results of Human Studies with Linear and Nonlinear Earplugs:
Implications for Exposure Limits

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Abstract: Soldiers equipped with linear and nonlinear earplugs have been exposed to large impulses (weapon noises) and audiometric tests have been performed just before and after the exposures. New nonlinear perforated earplugs are efficient for repeated exposures up to 190 dB peak when they are well fitted. From various TTS studies we can conclude that: (i) the peak pressure attenuation grossly underestimates the protection afforded by the earplugs when used in conjunction with the classical criteria for weapon noises (CHABA, MIL-STD, Pfander or Snoerenburg criteria), (ii) the LAeq8 attenuation values, based on objective Insertion Loss measurements performed with a specially designed Artificial Test Fixture, give in most exposure conditions a good evaluation of the auditory hazard.

INTRODUCTION

The impulse noises produced by weapons are highly hazardous and are frequently the cause of acoustic trauma (1). Therefore, the use of well-fitted and very effective Hearing Protector (HP) is necessary during shooting exercises. However, wearing HP deteriorates the performance of the soldier. If the security and/or the operational abilities are impeded, the risk is that the HP will be left off. Designing a HP for military use must take into account as well the protection against hearing hazard as the operational angles of the problem (2).

Earplugs are widely used by the military. They are light, compact, easy to maintain, and are readily compatible with other head equipment. Moreover, nonlinear earplugs allow speech communication, detection and localization of the acoustic sources in about the same conditions as for unprotected ears (3).

In order to choose an earplug to protect the ear against impulse noises produced during training or combat, it is necessary: (i) to determine the attenuation afforded by the HP, and (ii) to assess its efficiency on human subjects.

ATTENUATION MEASUREMENTS: METHODS

To determine the attenuation afforded by earplugs at very high-level impulse noises, the measurements performed by means of the subjective method: Real-Ear-At-Threshold (REAT) (ISO 4869-1) are not suitable. This method does not allow to evaluate the attenuation of the peak pressure under the HP. Moreover, undergoing the action of large impulses an earplug may exhibit nonlinearities (designedly or not). For that reason, the attenuation should be measured in the actual exposure conditions for which the earplug is intended to be used. The Microphone-In-Real-Ear measurement technique is not suitable either: peak level and pressure-time history of the impulses cannot be measured close to the tympanicum. Moreover, this technique is impossible to use as a routine with high-intensity impulses because of the security of the subjects. Therefore, the only possibility to assess the actual behavior of earplugs when exposed to large impulse noises is to use an artificial head with an ear simulator (4).

There are two main methods to decide whether the attenuation afforded by a HP is sufficient. (i) by measuring the pressure-time signature of the impulse under the HP and introducing the peak pressure and the duration into the classical Damage Risk Criteria (DRC) for weapon noises, (ii) by measuring the signal close to the head and using the IL characteristics of the HP corresponding to the type of the impulse to calculate the equivalent dose of acoustic energy to which the subject would be exposed unprotected.

HUMAN STUDIES

To assess the actual efficiency of the HP, soldiers equipped with well-fitted linear and nonlinear earplugs have been exposed to large impulse noises. Audiograms were performed on each subject just before the exposure, then 5 minutes and 1 hour after exposure.

20 subjects equipped with linear E.A.R. foam earplugs were exposed to 20 howitzer rounds (175 dB peak, duration: 8 ms, global LAeq8: 109 dB). Only one ear out of forty exhibited a TTS larger than 10 dB which had recovered 1 hour later (5). The peak pressure and the LAeq8 attenuation values (IL) afforded by the E.A.R. foam
earplugs were about 30 dB (Insertion Loss values were measured with a specially designed artificial head with an ear simulator) (4). If we enter the peak pressure and the duration of the signal recorded under the plug into the classical DRC for weapon noises (6), we observe that the exposure is just on the limit. On the other hand, a subject equipped with those plugs and exposed to 20 howitzer rounds is in the same conditions as an unprotected subject exposed to a LAeq8 of 79 dB (as far as A-weighting and isoenergy principle are valid for such exposures).

11 subjects equipped with nonlinear RACAL Gunfinder earplugs were exposed to 10 howitzer rounds (global LAeq8: 106 dB). No TTS larger than 10 dB was observed at any frequency (5). The peak pressure and the LAeq8 attenuation (IL values) afforded by the RACAL Gunfinder earplugs was about 20 dB. The exposure is beyond the limit of the classical DRC. However, a subject equipped with those plugs is in the same conditions as an unprotected subject exposed to a LAeq8 of 86 dB.

16 subjects equipped with nonlinear ISL/E A.R. Ultrafit earplugs (3) were exposed to 7 mortar rounds (185 dB peak, A-duration: 2.5 ms, global LAeq8: 110 dB). No significant TTS was observed after the exposure. The peak pressure and the LAeq8 attenuation (IL values) afforded by those plugs was about 33 dB. The exposure is beyond the limit of the classical DRC. However, a subject equipped with those plugs is in the same conditions as an unprotected subject exposed to a LAeq8 of 77 dB.

14 soldiers equipped with nonlinear ISL/E A.R. Ultrafit earplugs were exposed to Friedlander waves with peak pressures from 174 dB to 193 dB (A-duration: 1.5 ms) (7). When the plugs were perfectly fitted, in all but one subject no significant TTS was observed after the exposure to 6 impulses of 190 dB (global LAeq8: 114 dB). Here again, the exposure is beyond the limit of the classical DRC. However, a subject equipped with those plugs is in the same conditions as an unprotected subject exposed to a LAeq8 of 81 dB. As for the most part of those human studies, the assessment of the hearing protection which is based on LAeq8 measurements (IL) is in agreement with the audiometric results, whereas the assessment based on the use of the classical DRC is inappropriate.

CONCLUSION

From those studies we conclude that:

(i) it is actually possible to protect the ear when exposed to very high-level impulse noises despite the fact that the peak pressure at the protected ear is over the limits fixed by ISO 1999 (140 dB) and the classical DRC for weapon noises. Those results do question the use of the "peak pressure" as a relevant parameter to evaluate the hearing hazard on protected ears: the risk corresponding to a long rise time impulse (as recorded under a HP) is much lower than the risk corresponding to a Friedlander wave of the same peak pressure with an almost instantaneous rise time (as impinging on an unprotected ear),

(ii) presently, the best estimate of the protection afforded by earplugs is given by the amount of attenuation (Insertion Loss measurement) of the A-weighted acoustic energy measured at the level of the microphone of an Artificial Test Fixture (a specially designed artificial head with an ear simulator). In spite of the fact that such measurements generally overestimate the Insertion Loss of earplugs (as compared to REAT measurements performed with precise experimenter fit on human subjects) (8), that contention remains valid in most of the cases.

REFERENCES