

Attenuation of Earplugs Worn in Combination with Earmuffs

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If the attenuation that can be provided by a single hearing protection device (HPD) is inadequate for a given noise exposure and if noise control procedures are impracticable, the only remaining alternative is to use dual protectors, i.e. an earplug plus an earmuff. Such a combination can provide additional protection but it has long been recognized that the resultant noise reduction falls short of the algebraic sum of the attenuation of the individual devices¹. This EARLog, #13², examines the utility of combining HPDs and suggests generalized guidelines for the description of their performance.

The Procedure

All of the results in this EARLog are based upon real-ear attenuation at threshold tests conducted by the staff of the E-A-R Division Acoustical Laboratory in conformance with ANSI S3.19-1974. Some of the data are new and previously unpublished, but most are from Berger (1983)³.

The Protectors

Three types of earplugs and four earmuffs were evaluated both singly and in various combinations. The results for the individual earplug and earmuff tests are depicted in Figures 1 and 2. The data span the range of attenuation values that are offered by products on the market today.

The fiber plug was chosen to represent one of the lowest attenuation devices that would likely be in current industrial usage. It was inserted according to manufacturer's instructions, i.e. no attempt was made to pack it tightly into the ear canal. The premolded plug was a V-51R (1 flange, 5 sizes). It was carefully sized and then fitted under experimenter supervision. The vinyl foam plug used in the study represented one of the other major types of inserts currently available. It was tested with three distinctly differ-

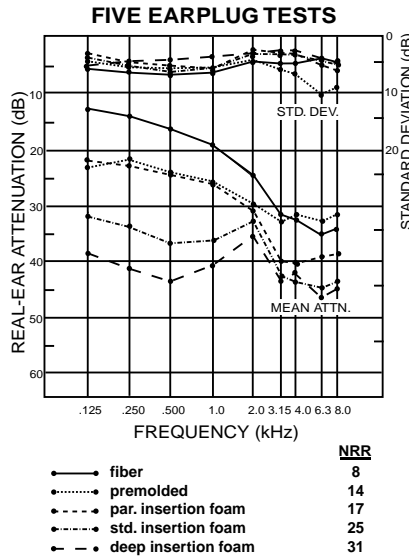


Figure 1

ent experimenter insertions: partial (about 15-20% of the plug in the ear canal), standard (typical laboratory fit with 50-60% in the canal), and deep, which was the maximum depth of insertion that could be practically achieved (80-100% in the canal).

Muffs #1 and #2 were small volume (<120 cm³) with foam and liquid filled cushions respectively. Muff #3, also possessing foam filled cushions, was much larger (335 cm³). Muff #4, a damped lead earmuff weighing over 7 lbs, was a research device constructed especially for this study.

The Results

Representative data for a plug and a muff worn individually and in combination are shown in Figure 3. The attenuation of the combination at individual frequencies is at least 5 dB better than either device alone, but significantly less than the al-

gebraic sum of the individual values. This is due both to mechanical coupling of the plug and the muff via the body tissues and the volume of air trapped between them, and to limitations on attenuation created by the bone conduction pathways.

Bone conduction (BC) refers to flanking sound paths that permit transmission of energy to the inner ear through the bones and tissue of the skull, thus bypassing the HPD. It imposes a limit on the real-ear attenuation that any protector can provide since regardless of how well the device seals the ear canal and prevents sound from entering, energy can still reach the inner ear. One estimate of the BC limits³ to HPD attenuation is shown by the bold line in Figure 3.

Although combinations of other devices were found to perform similarly to those depicted in Figure 3, no easy rule of thumb could be devised to predict combined attenuation based on the results for single devices. The incremental per-

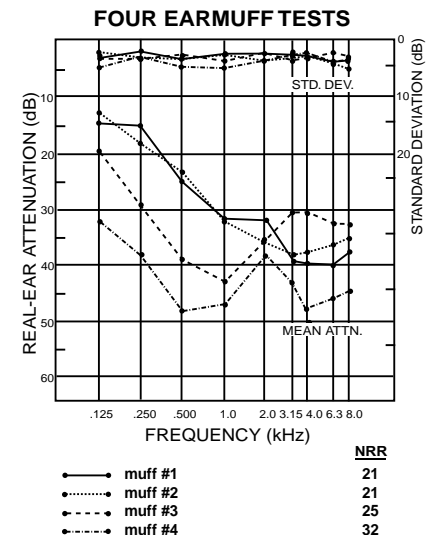


Figure 2

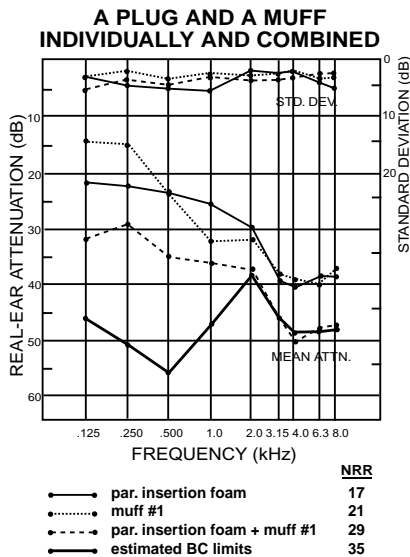


Figure 3

formance gain at individual frequencies was found to vary from approximately 0 - 15 dB over the better of the individual HPDs, except at 2 kHz where no combination exhibited a gain of greater than 3 dB. The gain in the Noise Reduction Rating (NRR) for the double protection combinations ranged from 7 - 17 dB when compared to the plugs alone, 3 - 14 dB when compared to the muffs alone, and 3 - 10 dB when compared to the better of the two individual devices.

An example of the performance of each of the earplugs worn in combination with muff #2 is shown in Figure 4. For the lower and middle frequencies the attenuation varied by approximately 20 dB across the different combinations as a function of the attenuation of the earplug. In contrast, above 2 kHz the net performance was BC limited (c.f. Figure 3) and was equivalent for all combinations. When the performance of different muffs worn over selected earplugs was examined, it was found that the net attenuation was essentially independent of the particular earmuff, suggesting that in such cases the choice of earmuff was relatively unimportant³.

Discussion

As has been discussed in this series of articles² and in the recent literature⁴, the attenuation of HPDs in real-world environments falls short of laboratory predictions. To assess the effects of field fitting on the performance of dual HPDs, one test was conducted with a purposely misfitted device, a partially inserted foam earplug.

The partial insertion test was designed to approximate utilization that is attainable in the field with limited instruction and motivation. This was validated by measuring the laboratory attenuation of E-A-R® foam earplugs using 92 untrained listeners who fitted the plugs themselves according to the manufacturer's instructions, but without supervision⁵. Many of them had not previously worn HPDs. The NRR from that study agreed within 1 dB with the value shown in Figure 1 for the partially inserted foam earplug. Therefore, the Figure 3 data for the partially inserted E-A-R® Plug combined with the E-A-R® Muff (muff #1) may be assumed to provide an indication of what can realistically be obtained with a comfortable combination of lightweight protectors.

No similar attempt was made to "real-worldize" the fitting of the other plugs or any of the muffs in this study. Therefore all of the double HPD data will reflect an upper bound on the values attainable under field conditions, especially since one must consider both the reduced comfort of dual HPDs and the fact that when an earmuff is worn over an earplug, observation and enforcement of the correct usage of the plug becomes more difficult.

Conclusions

When the real-world attenuation of a single HPD is inadequate, which is likely to be the case if equivalent 8-hour A-weighted exposures exceed 105 dB the utilization of double HPDs is an alternative that should be considered. This is especially important when the noises are dominated by lower and middle frequencies, since it is in this frequency range that the attenuation of single HPDs will be the lowest, making the extra protection provided by the combination most necessary. The performance of the combined devices is relatively unaffected by

the earmuff that is selected but at the frequencies below 2 kHz is strongly influenced by the choice of earplug. At and above 2 kHz all plug-plus-muff combinations that were studied provided attenuation that was limited only by the flanking bone conduction pathways to the inner ear.

VARIOUS EARPLUGS IN COMBINATION WITH ONE EARMUFF

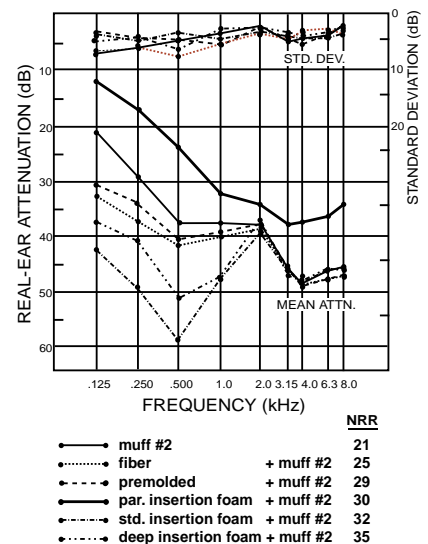


Figure 4

References and Footnotes

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