EARLOG® 4

Fourth in a comprehensive series of technical monographs covering topics related to hearing and hearing protection.

The Performance of Hearing Protectors in Industrial Noise Environments

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Characterization of the attenuation properties of hearing protection devices (HPDs) is most often accomplished in the laboratory[1] by examining the performance of trained and motivated subjects using optimally fitted HPDs. The crucial question is - How does this relate to the real world? And the obvious answer - poorly. Employees are seldom adequately instructed in the correct utilization of HPDs and even less often properly motivated to wear them. And if devices come in multiple sizes or are uncomfortable to wear, the problem is compounded.

In the past few years a number of studies have been conducted that shed some light on the matter of real world (RW) performance, i.e. performance for employees in industrial noise environments. In this, EARLog #4, we will discuss some of the more significant findings, and integrate the data to yield some interesting conclusions.

Laboratory Approximations of Real World Performance
When a HPD is tested in a laboratory, the procedures, if modeled after actual usage conditions, can yield results indicative of RW performance. Waugh, of the National Acoustic Laboratories (NAL) in Australia, has attempted to do just that. In a recent publication[2], the NAL reports attenuation data for 75 earmuffs and 19 inserts that were all tested at that facility.

The NAL has a subject pool consisting of 35-40 of its employees. The HPDs are tested on 15 people, 1 time each. Devices undergo a series of physical tests (vibration, impact, temperature cycling, etc.) prior to being tested for attenuation. Subjects are given the manufacturers' instructions and very little experimenter supervision. The test procedure is an absolute threshold shift method similar in detail to the ANSI Z24.22[3] standard, with the data corrected[4] to 1/3 octave-band values.

The NAL tests yield lower mean attenuations and higher standard deviations than data gathered for manufacturers in U.S. testing laboratories. As the following discussion will show, the data from NAL can be used to make good engineering approximations of the RW performance of HPDs.

In-Field Measurements of Real World Performance
An alternative approach to answering the question of how well HPDs actually perform in use, is to take the threshold shift experiment to the subject. At least three experimenters have done this [5-9] by setting up their measurement facilities at industrial plant sites and using noise exposed employees as their subjects. Although the employees were aware that they would be subjects, they were not aware of the exact times of their tests and were carefully monitored to assure that they did not readjust their protectors once they had been notified to proceed to the test booth.

The three studies that will be considered included 613 subjects at 7 different plant sites using 5 inserts and 1 earmuff. Although the 3 studies varied in their exact measurement techniques, appropriate controls were incorporated to insure the validity of the results.

In Figures 1-4 mean attenuation data for 4 devices as measured via different methods is presented. In Figure 1 we see very good agreement between the NIOSH[5,6] and Padilla[9] field studies at 500 Hz (Padilla only measured at 500 Hz). We see that the field attenuation data are only about 40-60% of the decibel values of the manufacturer's reported attenuation data. NAL's data fall between these two data

ATTENUATION DATA FOR V-51R INSERT PROTECTOR BY FOUR METHODS

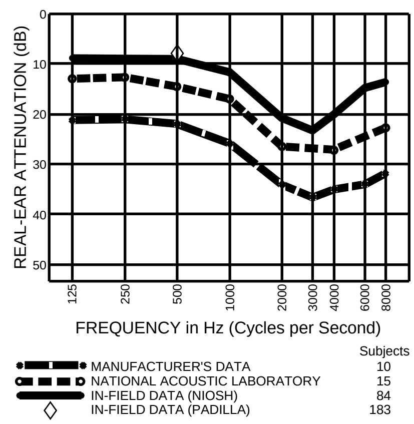

Figure 1

ATTENUATION DATA FOR SWEDISH WOOL INSERT PROTECTOR BY THREE METHODS

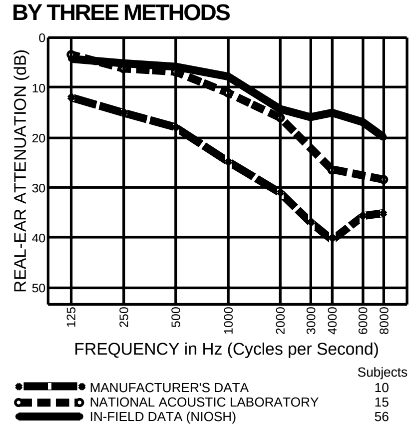

Figure 2

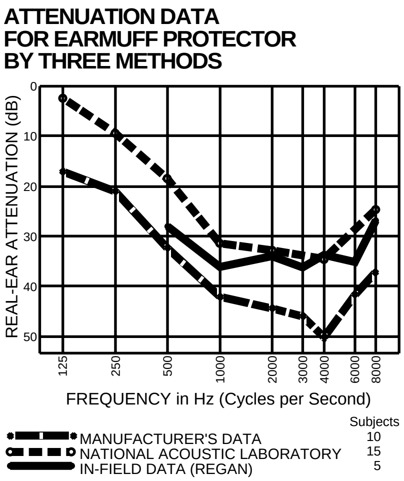

Figure 3

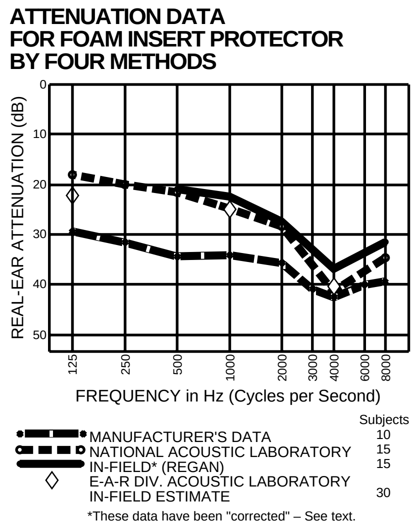

Figure 4

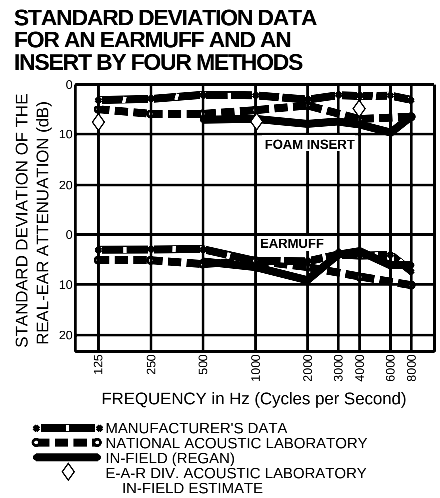

Figure 6

sets, only about 5 dB above the field data, except at the two highest frequencies. Remember, although NAL uses very minimal subject instruction, they do fit multi-sized plugs correctly whereas it is likely that missizing often occurs in the field.

Figure 2 shows similar results, this time for Swedish wool, with very good agreement between NAL and field data, except again at 4 kHz and 8 kHz.

Figure 3 compares Regan's[7,8] field data for an earmuff to NAL data. This time, agreement is again good (within 4 dB) except at 500 Hz where NAL data are low. It is important to note that this result shows that standard laboratory data also overestimate the RW performance of earmuffs. This has also been confirmed in a soon to be released MSHA[10] study that used miniature microphones to measure earmuff performance in the field. The results indicated performance at only 20-75% of the decibel values of the laboratory data with larger discrepancies at lower frequencies.

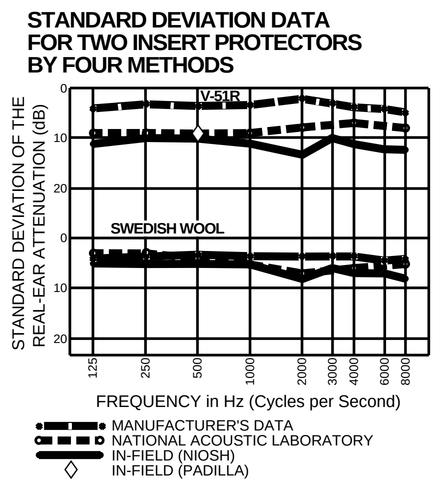

Figure 5

Figure 4 shows comparison data for foam earplugs (E-A-R® Plugs). The field data, from Regan, are for foam earplugs that were early prototypes, sold in limited quantities, and considerably more difficult to use than the present model, available since 1974. His data were corrected by 1 to 5 dB, by using laboratory data comparing the prototype and current model foam plugs. The "corrected" foam data agree well with NAL data and demonstrate attenuation of 60-90% of the manufacturer's reported data. Also of interest in Figure 4, are the three points marked by diamonds. These are preliminary data for 30 subjects from the E-A-R Division Acoustics Laboratory. The data were gathered in strict accordance with ANSI S3.19,[11] procedures but with instructions and subject selection intended to simulate RW conditions. Note the excellent agreement with the NAL data and very good agreement with Regan's field data.

Figures 5 and 6 depict standard deviation data for the various devices measured via the four test methods. The general trend is for the field and NAL data to be in reasonable agreement and both somewhat higher than manufacturer's laboratory data. That this is not always the case, is partially explained by the fact that the standard deviation tends to vary in proportion to the mean attenuation, so that devices with lower mean attenuations have a reduced expected range of attenuation values as well.

Observations

1. Manufacturers' laboratory data overrate the RW performance of HPDs. For a comfortable protector, this data can indicate the protection that conscientious, well-trained users will receive. For an uncomfortable device it is virtually meaningless.
2. Manufacturers' laboratory data are useful for research and development and may yield an indication of the rank ordering of various HPDs.
3. Laboratory experiments, such as the NAL work, which are designed to simulate RW performance can provide useful indications of the actual attenuation typically provided by HPDs.

Another Estimate of Real World Performance

Another method of investigating the actual protection afforded employees by the HPDs that they are using, is to measure their hearing levels before and after a workday's noise exposure. Royster [12,13] has just completed and reported on such work. His subject population consisted of 101 employees in two very different acoustical environments at two different plant sites. Seventy of the subjects (Population A) worked in a textile plant with steady noise levels at an L_{eq} = 95 dBA. The other thirty-one subjects (Population B) worked in a steel plant with intermittent noise levels, but the same L_{eq} = 95 dBA. During the experiments, the textile workers wore either a V-51R type insert (American Optical) or a foam plug (E-A-R® Plugs). The steelworkers wore either a 3-flange plug (Norton) or a foam plug (E-A-R® Plugs) for the first four hours of each work shift. Population B employees wore no hearing protection in the afternoons as per company policy.

HEARING LEVEL CHANGE BETWEEN THE BEGINNING AND END OF AN 8-HOUR WORK SHIFT

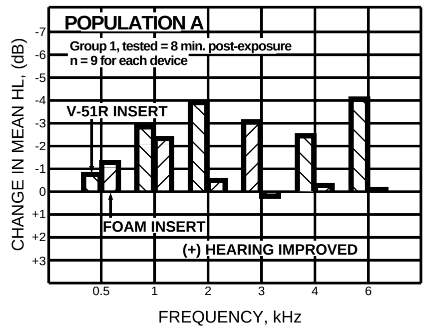

Figure 7

HEARING LEVEL CHANGE BETWEEN THE BEGINNING AND END OF A 4-HOUR WORK SHIFT

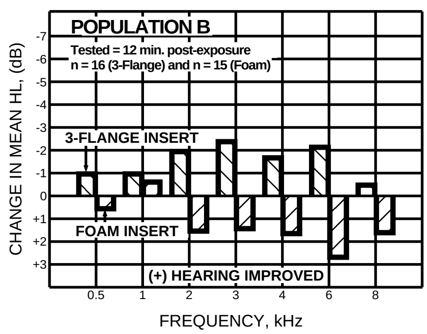

Figure 8

All subjects participating in the study had been wearing the pre-molded inserts for at least 4 years as part of the ongoing hearing conservation programs at these two companies. On the day of the test, the subjects that were selected to wear E-A-R® Plugs instead of their standard HPDs, were handed the plugs and given only 15-30 seconds of instruction on utilization of the device.

A comparison of the measured change in mean hearing level over an 8 hour shift [i.e. temporary threshold shift (TTS)] for Population A for the two HPDs is shown in Figure 7. The comparison for Population B is shown in Figure 8, this time using data for a 4 hour shift. Notice the differences between the performance of the foam plug and the pre-molded inserts, which are significant at 2, 3, and 6 kHz for Population A and at 2, 3, 4, and 6 kHz for Population B (P<.05). The fact that Population B employees who used the foam ear plug show improved hearing levels at many frequencies may be partially due to the elimination of TTS. This small residual TTS could be due to the inadequate protection received from the 3-flange inserts combined with the unprotected 4 hour afternoon exposures which these employees received.

Royster concluded from this data that the V-51R and 3-flange inserts were unacceptable for use in noise environments with daily A-weighted L_{eq}s equal to or greater than 95 dB. Analysis of the existing 4-9 years of audiometric data for these two populations supported this contention.[13,14] Furthermore, Royster determined that the foam earplug would be acceptable for use in these 95 dB environments and is currently conducting a longitudinal survey at one of the plants to verify this supposition.

Single Number Ratings Applied to Real World Data

In EARLog #2,[15] the concept of single number HPD ratings was discussed and an explanation of the EPA proposed [16] NRR values was presented. The NRR incorporates a 2 standard deviation(2σ) correction and a 3 dB spectral safety factor. These corrections are intended to insure protection for 98% of the population who "correctly" wear the HPD in 98% of the environments where the devices will be used. By "correctly" we mean, wear the HPD in the same manner as did the subjects who were used to generate the test results.

TABLE **1**

NRR VALUES BASED ON MANUFACTURERS' LABORATORY DATA AND NAL DATA

HEARING PROTECTOR	NRR^*_{MFG}	NRR^{**}_{NAL}	$NRR^{***}_{NAL,\,1\sigma}$
V-51R	18	0	9
Swedish Wool	16	1	6
Earmuff	25	6	13
Foam Insert	29	14	19

* NRR based on manufacturers' laboratory data with 2σ correction.

** NRR based on NAL data with 2σ correction.

*** NRR based on NAL data with 1σ correction.

In Table 1, the NRRs for the four HPDs that have been discussed, are presented. These NRRs were calculated using the manufacturers' laboratory data as well as the NAL data. Note that for two devices the NRR based on the NAL data is ≤1. This simply says that if we wish to examine the least possible protection we are likely to find (i.e. only 2% of the population will receive less protection than this) that the overall protection provided by these two devices is virtually zero.

It may be that with RW or estimated RW data, a 2σ correction is too severe and that we should examine a 1σ correction (84% protection, i.e. 16% will get less than this number). These values are also shown in Table 1. (In fact, the single number rating listed in the NAL report is the SLC_{80}, which is very similar in concept[15,17] to the NRR, except that it uses a 1σ correction and lacks a spectral safety factor.) Even these more "optimistic" values demonstrate that certain insert protectors may be suitable for noise exposures only slightly greater than 90 dBA, a supposition substantiated by the Royster study cited above.

Conclusions

There appears to be a less than adequate correlation between manufacturers' (laboratory) attenuation data and the RW performance of HPDs. Suitably designed laboratory tests, such as the work performed by the NAL, can provide reasonable estimates of RW performance. Comparison between NAL data and in-field data from three authors substantiates this fact. This is an important point, because it suggests that existing HPD test methodologies, such as ANSI S3.19-1974[11], can be effectively utilized with only simple modifications regarding subject selection, training, fitting and HPD preparation procedures.

The NAL and in-field data suggest, for example, that the E-A-R foam earplug should be more effective in use than other insert hearing protectors. This was confirmed independently by an in-field TTS study which found that E-A-R Plugs performed significantly better than V-51R and 3-flange inserts in a 95 dBA noise environment.

Finally, if a single number rating is to be used with RW type data, such as the NAL data, perhaps a 1σ instead of a 2σ correction is more appropriate. This suggestion is reasonable, since an attempted 98% protection criterion may be feasible if unrealistically high laboratory data are utilized, but is certainly extreme if RW estimated data are developed and used for NRR calculations.

References and Footnotes

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NOTE: For more current information on real-world performance and NRR-related issues see EARLog #20, *The Naked Truth About NRRs.*

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