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Measurement of Insert-type Hearing Protector Attenuation on the End-user: A Practical Alternative to Relying on the NRR

Introduction

Hearing protectors are labeled with a Noise Reduction Rating (NRR) that is derived from laboratory measurements of the attenuation provided to trained and motivated human subjects in a 'sterile' environment. As intended, these measurements represent a *best-fit* condition. The literature indicates that the average attenuation provided to end-users of hearing protectors is often only a fraction of the labeled values. Because of this, various derating schemes are employed, including the 50% derating suggested in the OSHA inspector's Technical Manual and the variable derating according to protector-type suggested in the 1998 NIOSH criteria document on occupational noise exposure.

De-rating the labeled NRR provides a better estimate of the average attenuation realized by a population of end-users. However, field measurements indicate that attenuation provided across end-users is highly variable (standard deviation > 10 dB), so many wearers will receive much greater attenuation than the *average*, and many will receive much less attenuation than the *average*. Therefore, if hearing protectors are selected according to a de-rated NRR, some individuals will still be under-protected and some will receive excessive attenuation, leading to potential communication problems. A solution to this problem is to base the selection process on objective data obtained by measuring the attenuation provided to each end-user of insert-type hearing protectors.

Steel Industry Experience

A Pennsylvania steel company has shown that individual hearing protector fit-testing can be effectively integrated into the annual audiometric evaluation. Almost all HPD wearers at this plant wear insert-type devices, and the attenuation provided by these devices has been measured on each end-user in 1998 and 1999. The results of the 1998 measurements show the wide variability of attenuation provided by insert-type protectors and distinct characteristics of specific devices.

Initially, the attenuation provided by insert-type hearing protectors was measured for 389 steel workers in June of 1998. The workers were allowed to choose HPDs from a selection of several single-size foam plugs and one single-size reusable plug. Before the attenuation measurement, the employees were individually instructed to wear the protectors as they would while on-the-job. The attenuation measurement session was performed immediately after the annual audiometric examination, which included a video on proper hearing protector fitting techniques. Attenuation measurements were made binaurally using one-third octave bands of noise as test stimulus at six center frequencies: 250, 500, 1000, 2000, 3150, and 4000 Hz.

The attenuation measurement process involves using automatic audiometric techniques to measure hearing thresholds both with and without the hearing protectors in place. The attenuation provided the end-user at each test frequency is essentially the difference between these two threshold measurements. The headphones used in this process are specially designed to be unobtrusive and do not affect the fitting of the plugs. Eight employees were tested per hour, which was also the rate of administering the annual audiometric examination.

A new rating system, the Personal Attenuation Rating (PAR), was devised for reporting the results of this study. The PAR was developed as a simple single-number measure of hearing protector attenuation provided to the end-user. The PAR is analogous to the NRR, i.e., the PAR is equal to the A-weighted noise reduction provided in a 'flat' noise exposure.

For example,

Sample PAR Calculation

Octave Band Center Frequency in Hz	250	500	1000	2000	3150	4000
Assumed Exposure in dB SPL	100	100	100	100	100	100
A-weighting in dB	-8.6	-3.2	0	+1.2	+1.2	+1.0
A-weighted exposure	91.4	96.8	100	101.2	101.2	101.0
Overall level = 107.4 dBA						
Measured Attenuation in dB	19.4	22.4	25.1	30.1	32.8	39.3
A-weighted exposure minus attenuation	72.0	74.4	74.9	71.1	68.4	61.7
Level under protector = 79.8 dBA						

PAR = 107.4 - 79.8 = 27.6 dB

Figure 1 is a scattergram of all of the attenuation measurements made during the 1998 measurement session.

Personal Attenuation Rating (PAR)
All HPDs

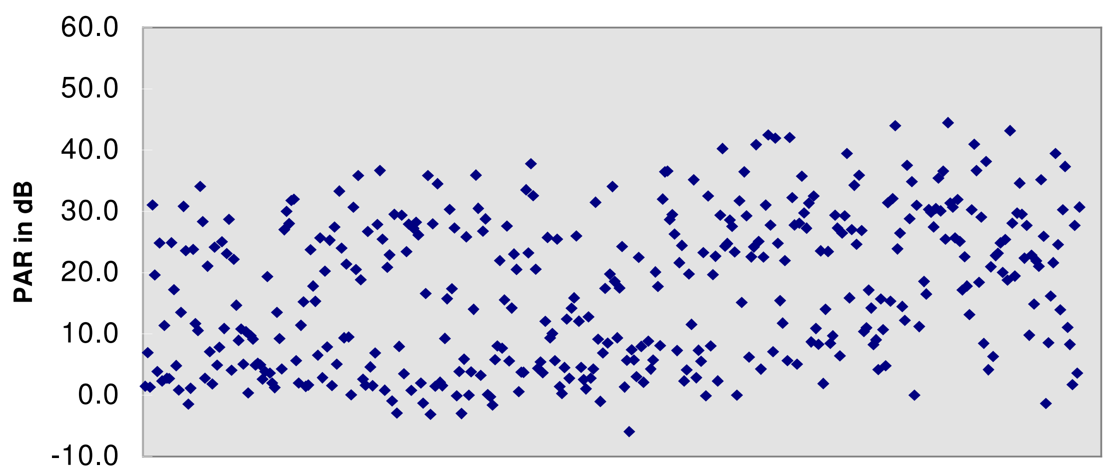

Figure 1. PAR ratings for all attenuation measurements.

Over one-third of the employees were fitted with a specific reusable multi-flange silicone plug. The mean PAR for workers fitted with this device was 12.0 dB and the standard deviation of the PARs was 11.3 dB. About one-quarter of the employees were fitted with a specific molded urethane foam plug. The mean PAR for workers fitted with this device was 19.1 dB and the standard deviation of the PARs was 11.6 dB.

Figure 2 indicates that the distribution of PARs across all workers and all HPDs was bimodal, i.e., most workers either received relatively high attenuation or relatively low attenuation. Figure 3 presents a breakdown of the distribution of PARs according to plug type, revealing the cause of the overall bimodal distribution; more than half of the foam plug wearers received greater than 20 dB of attenuation and more than half of the silicone reusable plug wearers received less than 10 dB of attenuation.

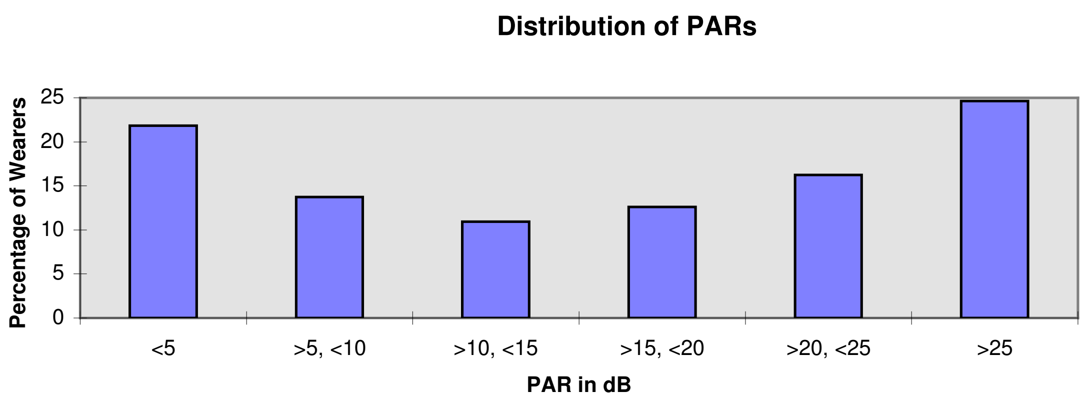

Figure 2. Distribution of PARs across all plug types.

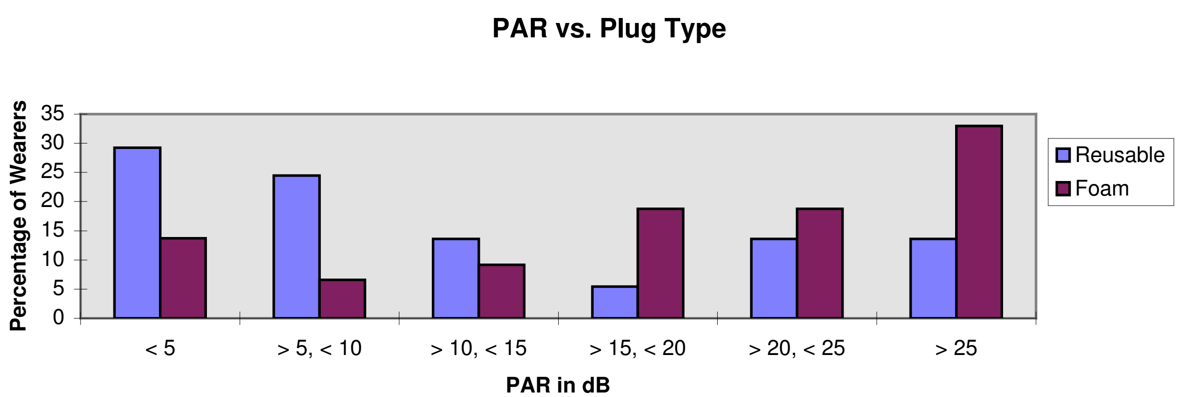

Figure 3. Distribution of PARs according to plug type.

In Figure 3, the foam plug data is derived from measurements across 193 wearers of five specific models of foam plugs (28% PVC foam, 72% urethane foam). The reusable plug data is derived from measurements across 147 wearers of a specific reusable plug.

An interesting difference between the reusable plug and the foam plugs was the performance in the higher frequencies. Figure 4 indicates that the foam plugs provided greater than 20 dB of attenuation at 4000 Hz for virtually all wearers. As Figure 5 indicates, the reusable plug wearers received highly variable protection at 4000 Hz, with 22% receiving less than 10 dB of protection.

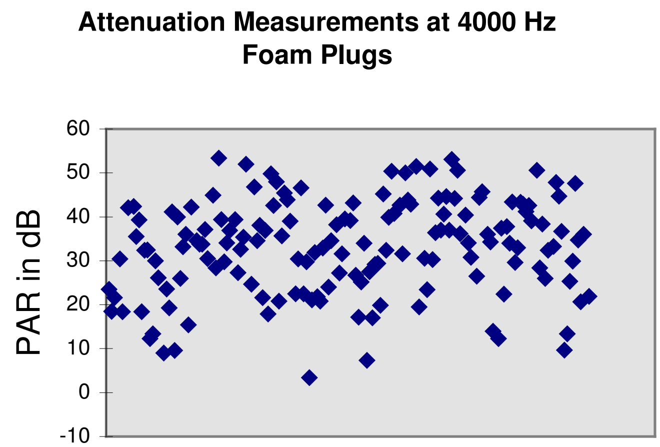

Figure 4. Attenuation measurements at 4000 Hz for the foam plugs.

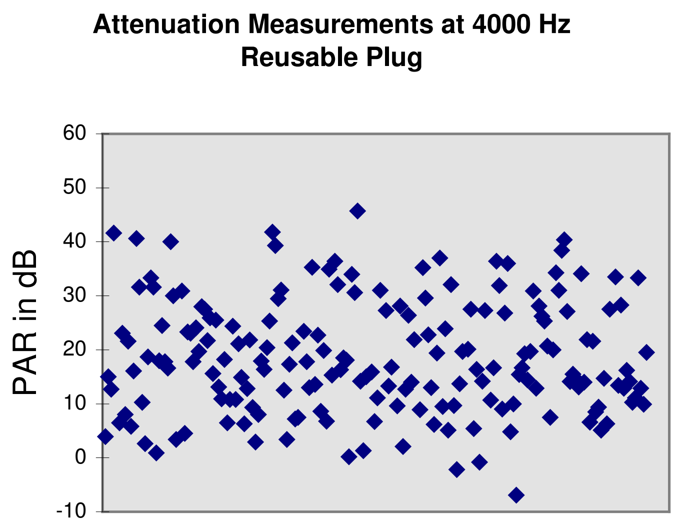

Figure 5. Attenuation measurements at 4000 Hz for the reusable silicone plug.

Reasons for poor performance

Many reasons exist for poor hearing protector performance in the field. These include improper initial selection, poor fitting of the protectors (both intentionally and unintentionally), ineffective training and poor manual dexterity. In the steel industry study, most of the end-users indicated that they selected HPDs based primarily on comfort. Visual inspection of wearers of the single-sized reusable plug indicated that in many cases the plug was too small to effectively seal the canal.

Some workers at the steel industry stated specifically that they wouldn't insert hearing protectors deep into the canal because they needed to communicate on-the-job. The communication requirement makes analyzing hearing protector performance a particularly complicated issue, since some workers were inserting the high attenuation HPDs only deep enough to provide low-to-moderate attenuation, affording them some protection while allowing better perceived communication.

Workplace conditions are also a factor in HPD fitting; in relatively dirty environments, repeated fitting of conventional foam plugs is difficult. Plugs with a handle, like the silicone reusable plug, can be more hygienic and easier to fit repeatedly with dirty hands or with gloves; this characteristic is at least partially responsible for the popularity of this device in the mill.

There is room for improvement in the methods and materials used for HPD fit-training. Even though these workers had just seen a video on proper fitting techniques, many did not follow the suggested guidelines while fitting their protectors prior to the attenuation measurement session. Some employees inserted foam plugs without rolling them down, after rolling down only slightly or after flattening the plugs between the thumb and forefinger. Some wearers of both foam and reusable plugs inserted both plugs simultaneously without pulling on the pinna with the opposite hand. One case of intentional misuse was noted when an employee fitted one-half of a PVC foam plug in each ear.

Conventional training material presented repeatedly to a group of employees becomes too familiar and is easy to ignore. Individual fit-testing personalizes the hearing conservation program and emphasizes the importance of proper fitting techniques. If the objective data is presented to the wearer in an easy-to-understand and interesting manner, the fit-testing procedure not only documents effective hearing protector usage, but it also becomes an effective training and motivational tool for both the wearer and the program administrator.

Follow-up to Initial Measurement Session

In December of 1998, about 100 employees of the steel mill were retested for insert-type hearing protector attenuation. These individuals were specifically selected because their initial measurements had indicated that they received poor attenuation (PAR < 8 dB). Figure 6 is a scattergram of the initial test data for these individuals from the testing performed in June of 1998.

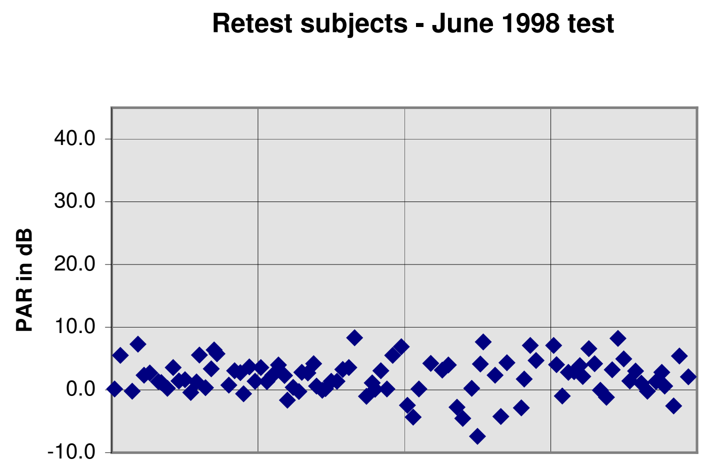

Figure 6. Scattergram of initial attenuation test data.

The first December retest was performed under the same conditions, i.e., the employees were wearing the HPDs that they had selected themselves and they were told to wear the HPDs as they did on-the-job. Figure 7 is a scattergram of this follow-up test data. Some subjects received greater attenuation in the initial retest; it is possible that the HPD fit-testing performed a few months earlier had increased awareness of proper device usage. In general, the attenuation provided to these individuals remained low.

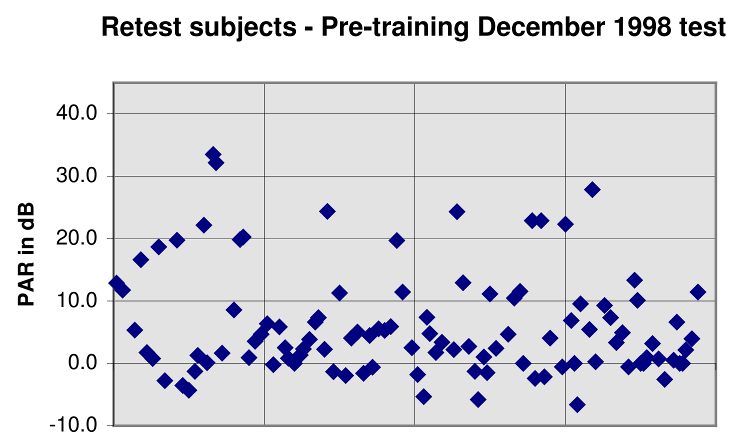

Figure 7. Scattergram of pre-training retest attenuation data.

Immediately following this test, each employee was given a short (literally 2-3 minutes) retraining session on proper fitting techniques for insert-type hearing protectors. They were issued a sized plug which was selected by the test administrator after a visual inspection of their ears. Wearers that had been using reusable plugs were issued multi-size reusable plugs and wearers that had been wearing foam plugs were issued multi-size foam plugs. They were then instructed to fit the new protectors for maximum attenuation. Figure 8 presents the results of the second test during this session, following the re-instruction and refitting.

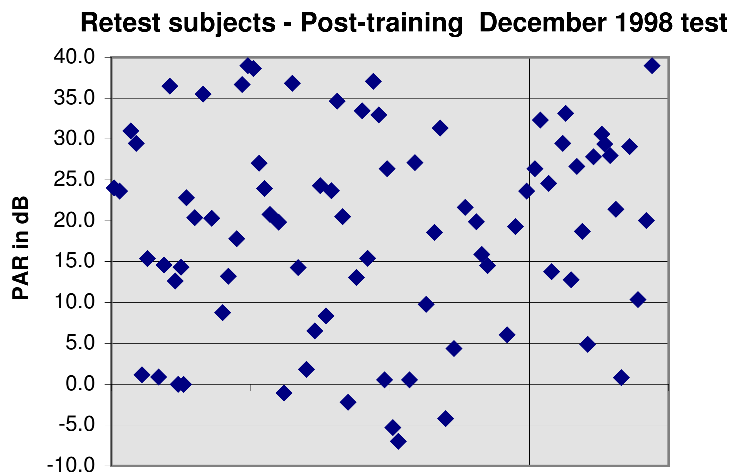

Figure 8. Scattergram of post-training retest attenuation data.

The second (post-training) retest resulted in an average improvement in attenuation provided to the end-users of 14 dB. While all wearers initially were evaluated with a PAR of less than 8 dB, 60% of wearers received a PAR of greater than 15 dB after retraining and refitting. Figure 9 is a bar graph presenting the improvement after the refitting and retest.

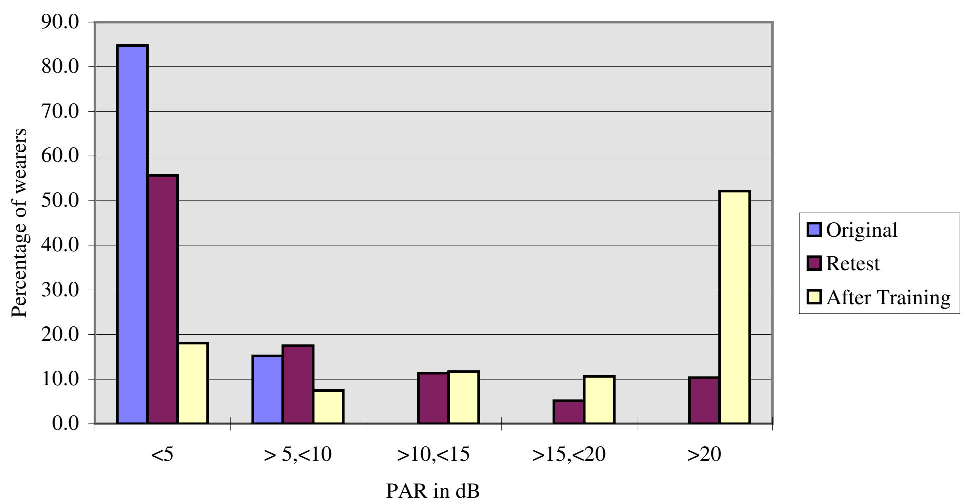

Figure 9. Bar graph of original data and pre- and post-training retest data.

Discussion

The post-training attenuation measurements were higher than the previous measurements because of both the specific fitting instructions and the improved fit of the reissued protectors. Greater improvement could have been achieved if more time were available for the training and refitting process. Some insert-type HPD wearers are difficult to fit properly; these individuals may need to try several sizes and styles of plugs before finding a device that provides adequate protection and comfort. For some wearers, it is likely that no off-the-shelf HPDs will provide effective attenuation, and that alternative solutions, such as muffs or custom-molded plugs, will be required.

Individual fit-testing of end-users provides industry with valuable documentation of the effectiveness of hearing protectors in the field. Hearing loss compensation cases are supported by existing literature on the relatively poor field effectiveness of HPDs. The only defense against this type of claim is to perform an objective measurement of the attenuation provided to the end-user after he or she has fitted the device.

Hopefully, the high variability of field attenuation data will encourage the hearing conservationist to select hearing protectors based on comfort and ease-of-fit instead of relying on the highest NRR. Obviously, fitting the steel workers with high attenuation (NRR >= 27) devices did not guarantee effective protection. The marketing advantage of a high rating encourages HPD manufacturers to strive for higher and higher NRRs. The attenuation represented by these high ratings is not realized in the field if the device is uncomfortable or difficult to wear properly. This study demonstrated that some highly rated devices can provide little or no protection if they are worn improperly.

An Easy Solution?

There is no easy solution that will ensure that end-users receive adequate protection while using conventional off-the-shelf insert-type hearing protectors. The field monitoring process does, however, document that the wearer is at least *capable* of achieving appropriate attenuation without undue discomfort or unusual fitting requirements. It is a common sense approach that is beneficial to both the employee and employer; the end-user is guaranteed effective protection with acceptable comfort and documentation is provided that HPDs were selected properly and that wearers were trained effectively.