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The Naked Truth About NRRs

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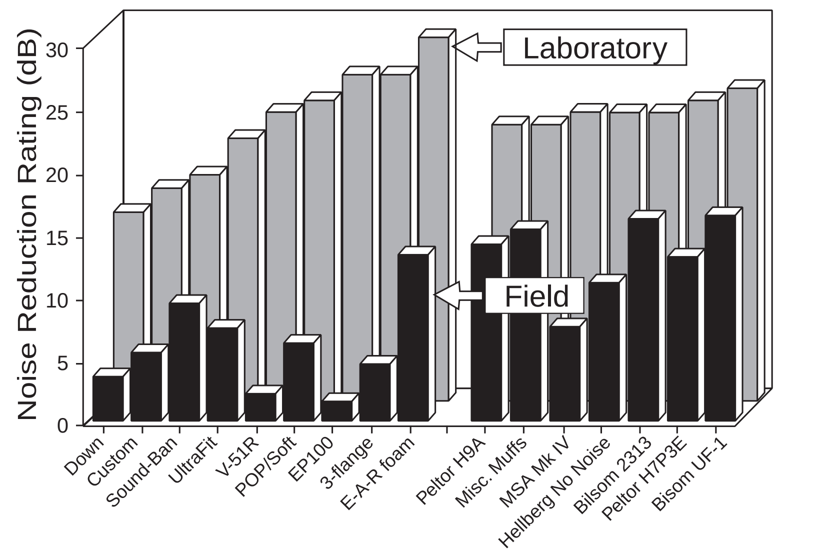
Since hearing protection devices (HPDs) are worn primarily for the purpose of noise reduction it is not surprising that hearing conservationists place great significance upon the sound attenuation that such devices can provide. Not only is attenuation, generally expressed in terms of a Noise Reduction Rating (NRR),[9] an important and often pivotal factor in making purchasing decisions, but it is also frequently utilized for determining effective at-the-ear exposures in particular noise environments. Emphasis on noise reduction data as a purchasing criterion, and reliance on such numbers for predicting protection, are both unwarranted and potentially deleterious to the effectiveness of a hearing conservation program (HCP). This EARLog will tell you why.[3]

Real -World Studies

In the latter part of the 1970s hearing conservationists began to investigate the amount of protection that HPD users were actually achieving in the work place, typically called field or real-world attenuation. Field attenuation is often measured by having noise exposed employees participate in real-ear attenuation at threshold measurements. This can occur on-site by taking measurement equipment to the work place, or off-site, by having employees report with their own HPDs to an independent test facility. For on-site measurements, hearing protected employees are taken from their work stations, either with or without warning, and are then tested in a nearby measurement chamber. In the case of earmuff users, an alternative is to directly measure on-the-job noise reduction by fitting them with a pair of dosimeter-type microphones mounted inside and outside their earmuff cups.

By 1992 there were at least 20 available studies providing measurements of real-world attenuation. Those studies span greater than 80 industries in seven countries, with a total of over 2600 subjects. For additional details and/or for a list of the available field studies see Berger.[7]

Figure 1 - Comparison of NRRs published in North America (labeled values based upon laboratory tests), to real-world "field" attenuation results derived from 20 separate studies.



The data, which for purposes of simplification are expressed in terms of the NRR, are summarized using dark bars in Fig. 1. Similar findings are apparent when octave-band analyses are compared[4] as is illustrated in Figs. 2 and 3.

In Fig. 1, the devices are grouped into two general categories, earplugs and one canal cap on the left, and earmuffs on the right. Devices and/or device types were selected to assure a minimum sample size of greater than 30 subjects (summed across studies) for each data bar shown. For some categories the sample size was very large, as in the case of the E-A-R® foam earplug, for which the data represent 575 subjects from 11 studies.

The 80 industries that were studied in order to generate the results shown in Fig. 1 probably represent today's better HCPs. This presumption is based upon the increased likelihood of finding higher-quality HCPs among companies interested in and choosing to participate in the complicated and time-consuming research of the type required for real-world evaluations. In fact, the HCPs which were examined in two of the more recent real-world studies whose data appear in Fig. 1, were specifically selected because the authors believed them to be exemplary. The findings from those two studies did tend to indicate better than average real-world attenuation, but unfortunately failed to surpass all other existing data and thus did not confirm the authors' optimistic expectations.

Labeled vs. Field Data

For purposes of comparison to the field data, Fig. 1 also provides the associated labeled NRRs, shown by the lighter colored bars. The labeled values are based upon manufacturers' published North American laboratory results.

Laboratory testing of HPDs in North America is conducted in conformance with standards developed by the American National Standards Institute.[1,2] The procedures call for determining "***optimum performance values** which may not usually be obtained under field conditions.*"[2] Optimum performance values, as opposed to estimated real-world values, have historically been specified for laboratory test-

Figure 2 - Premolded earplugs: labeled vs. field results. Data averaged across 5 different products, 9 studies, 556 subjects.

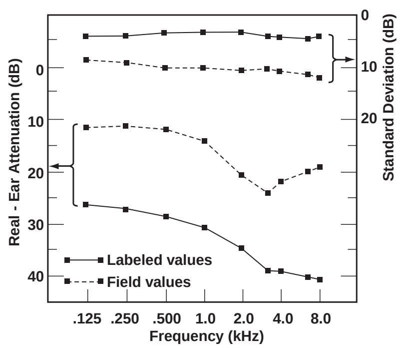
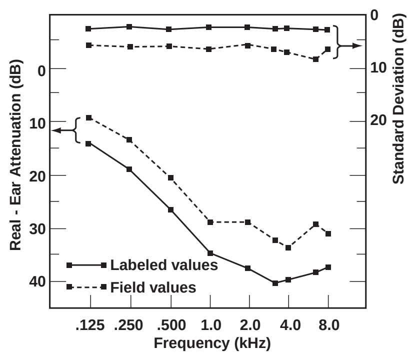


Figure 3 - Earmuffs: labeled vs. field results. Data averaged across 6 different products, 5 studies, 169 subjects.



ing because U.S. standards groups have felt that those values could be more consistently repeated, and were useful for rank-ordering HPDs. However, current data as described herein, and reported by Berger,[6] suggest otherwise. Nevertheless, ANSI S3.19/S12.6-type data *are the only* ***standardized values*** that regulators and manufacturers currently have available for labeling and informational purposes.

The labeled NRRs in Fig. 1 were computed, as per the Environmental Protection Agency,[9] by subtracting a two-standard deviation (SD) correction from the mean attenuation values in order to estimate the minimum noise reduction theoretically achieved by 98% of the laboratory subjects (NRR_{98}). The field data were computed in the same manner except that only a 1-SD correction was included, thus estimating the minimum attenuation achieved by 84% of the actual wearers (NRR_{84}). A 1-SD correction simplifies examination of real-world data, since the 2-SD correction used in the labeled NRRs (i.e. NRR_{98}) would cause many field NRRs to become negative numbers. Further justification for using a 1-SD correction with real-world NRRs is based upon practical, psychophysical, and statistical considerations.[7]

Observations Regarding the Field Data

The most obvious feature of Fig. 1 is the very poor correspondence between the magnitude of lab and field NRRs. Measured as a percentage of the laboratory-rated attenuation, the field NRRs for earplugs yield only 6 to 52% of the labeled values (averaging about 25%), and for earmuffs, from 33 to 74% (averaging about 60%).

Not only do the absolute values disagree, but so too do the relative rankings. Although the labeled values are arranged in ascending order from left to right within each category in Fig. 1, the same does not hold true for the field data. Furthermore, the labeled values suggest that earplug attenuation is typically equivalent to or greater than that of earmuffs, whereas the field data indicate otherwise. With the exception of the foam earplug, only earmuffs can generally be expected to provide 10 dB or more of real-world protection for 84% of the exposed population.

Casual observers of Fig. 1 may find single-digit field NRRs, with values dropping even below 5 dB, to be unbelievable. However, the magnitude of the real-world results in qualitatively supported by analyses of audiometric data from existing HCPs and be real-world studies of temporary threshold shift.[7,16]

Additionally, one must recall that the field NRRs in Fig. 1 represent the minimum attenuation achieved by at least 84% of the real-world subjects, *not* their average attenuation. Since the NRR_{84} includes a subtractive 1-SD correction, which usually amounts to 8 dB or more for earplugs, the attenuation achieved by half of the wearers (NRR_{50}) which is computed with a 0- SD correction, is about 8-dB larger. For example, a real-world NRR_{84} of 4 dB is typically equivalent to an NRR_{50} of 12 dB (see Fig. 4). And, in this example, if one asks what is the protection achieved by the top few percent of the wearers, approximately another 2 SDS (16 dB) must be added, yielding an NRR of 28 dB.

Wearing Time

Wearing time is an important parameter since it can decrease the effective protection provided by an HPD, to even less than is shown in Fig. 1. For example, if an HPD with an NRR of 20 dB is not worn for as little as 30 minutes in an 8-hr work shift, its effective NRR is reduced by 5 dB (see EARLog 5[3]). Since the data in Fig. 1 represent attenuation for a single point in time when the HPD is actually being worn, they say nothing about the effects of such disuse. Accounting for this factor can alter the relative field protection reported in Fig. 1, since wearers may be prone to remove and replace some HPDs more than others, depending upon various factors such as comfort, ease of donning and removal, and the interference of the protector with auditory communications.

Importance of Motivation and Training

Current research has demonstrated that a very good estimate of the real-world attenuation achieved in the better programs can be obtained by testing *totally naive HPD users in a laboratory protocol with absolutely no individual training by the experimenter.*[6] When tested under those conditions, the attenuation of HPDs still equals or exceeds average real-world data of the type shown in Figs. 1-3.

The fact that completely untrained test subjects obtain more attenuation than occupationally- exposed workers who would have been expected to be trained and motivated, and to have benefitted from many months of practice in using their HPDs, is truly amazing! It suggests that today's typical, or even above-average HCPs, are ineffective in fully motivating and training employees to consistently and properly wear their HPDs.

Better Estimates of Field Performance

If the goal is to estimate the protection achievable in the upper quartile of today's industrial and military HCPs, then the "truth" probably lies somewhere between the labeled and field data in Fig. 1.

One approach to reducing lab/field discrepancies would be to increase field performance. In fact, all agree that industrial hearing conservation practice needs to improve if better real-world HPD performance is to be achieved. Improvements would be valuable in the areas of fitting and training of HPD users, education and motivation of the work force, enforcement of proper HPD utilization, program management, and the development of easier-to-use and more comfortable hearing protectors.

At the same time, however, laboratory tests of hearing protector attenuation that yield data which more closely correlate with existing, or even potential field performance must be identified. Those methods must more realistically model training and fitting procedures that are achievable in practical applications. For example, because of their test practices, laboratory data from some Australian and European facilities already indicate lower laboratory-rated attenuation, especially for earplugs.[5] In the U.S. an ANSI working group which is cognizant of such findings (S12/WG11), has reviewed recent research and conducted some of its own in order to develop a procedure to provide more accurate estimates of real-world performance[6] (see E-A-RLog #21).

Is the NRR the Problem?

Some have argued that the method of computing the NRR from the octave-band data has inherent inaccuracies,[11] and have proposed more accurate (but also more complex) rating methods such as the HML three-number system embodied in a current draft international standard.[10] Yet, the principal portion of the lab/field discrepancies are due to the laboratory data themselves and not the method of manipulating them into single or multi-number ratings.[4] Even if one ignores the NRR altogether, and computes protection using the full complement of laboratory-measured octave-band attenuation values, the real-world predictive capability of the data is not substantially improved.

Disregard Small Differences in NRRs

When comparing NRRs as a criterion for selecting HPDs, one must consider the inability of current labeled data either to accurately predict absolute attenuation, or even to properly rank order HPD performance. Of equal importance is the inherent within-laboratory and between-laboratory variability in test data.[8] Considering these facts, one can state that differences in the NRR of less than 3 dB have no practical importance, and even 4- to 5-dB changes are of questionable significance unless closely controlled data are being compared (cf. ref. 10).

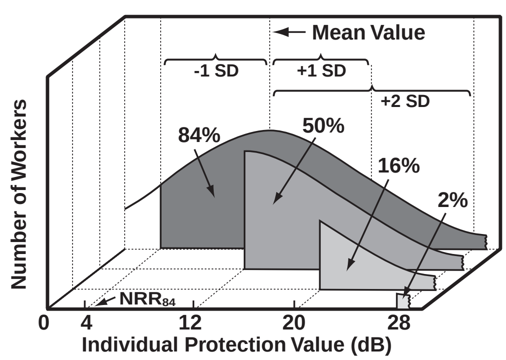
OSHA's 50% Derating

In Appendix B of the Hearing Conservation Amendment[13] OSHA explicitly states that the adequacy of an HPD for a given noise exposure (i.e. whether it can attenuate the exposure to either 90 or 85 dBA, as required) shall be calculated using the manufacturers' labeled NRRs or octave-band data. Subsequent to promulgation of the Amendment, OSHA issued administrative guidelines to field inspectors on how to compare the protectiveness of HPDs and hearing conservation programs to hat afforded by engineering and/or administrative noise controls.[14,15] The intention of this assessment of *relative performance* was to clarify when, in spite of the presence of a hearing conservation program, citations for failure to implement noise controls would be issued.

OSHA's written guideline is that if noise controls are feasible, citations will be issued when "hearing protectors alone may not reliably reduce noise levels" to those specified in the standard. This is evaluated by dividing the labeled NRR by two (i.e. derating by 50%). Although interpretations and enforcement are regionally variable, OSHA is likely to find HPDs unreliable "when employee exposure levels border on 100 dBA"[14], and when other indications, such as a high incidence of standard threshold shifts (STSs), provides supporting evidence of HCP inadequacy.

Thus, for questions of HPD *adequacy* the NRR is taken at its labeled value, but for questions of *relative performance*, the NRR is derated by 50%. These seemingly contradictory positions are confusing not only to those trying to comply with the law, but also to OSHA compliance officers themselves.

Figure 4 - Distribution of individual protection values (NRR with a 0-SD correction) for a group of real-world users with an NRR_{84} of 4 dB, i.e. 84% achieve at least 4 dB of protection. The SD is 8 dB and the average NRR is 12 dB (NRR_{50}). Note: 16% and 2% of the users, respectively, exceed NRRs of 20 and 28 dB.



The 50% derating cited above has no relationship to the well-known 7-dB correction specified in Appendix B of the Amendment. The 50% derating adjusts labeled values to better reflect real- world performance, whereas the 7-dB correction accounts for use of the NRR with A instead of C-weighted sound levels (see EARLog 12[13]). When using both the derating and the correction together, 7 dB is subtracted prior to derating by 50%. Because of the potential to use either or both of these adjustments, the situation becomes even more bewildering (see Table I).

The Danger of High Labeled NRRs

The average NRR on devices sold in North America today is over 22 dB. This number clearly overstates the protection afforded to most occupationally noise-exposed workers. Such NRRs are dangerous because they mislead the buyers and users of HPDs. Taking an NRR of 22 at face value, a hearing conservationist is led to presume that his or her work force will be protected for time-weighted average exposures up to 107 dBC (to achieve a protected exposure of 85 dBA). Since 97% of industries have TWAs below 100 dB,[12] this reasoning would suggest that almost all workers in almost all environments will be protected if only they are simply given hearing protection.

We have come to learn that such expectations are far from the truth. Fostering such expectations leads to hearing conservation programs in which inadequate attention is paid to the aspects of a program that can make it work - training, motivation, supervision, and enforcement.[3]

HPDs vs. Noise Controls

For the uninitiated, the real-world HPD data in this EARLog may be shocking. The inclination may be to dismiss hearing protectors as ineffectual and resort only to engineering noise controls. This would be a mistake. Although noise controls are generally preferred, one must consider that in many instances it is difficult to achieve even 10 dB of noise reduction in a retrofit noise control application, and 10 dB is what the more effective HPDs can provide for most of the work force. Many of the types of problems which afflict HPDs also impact the performance of engineering noise controls. For example, one of the most commonly used treatments is an enclosure.

Table I - Application of OSHA - specified computation for an HPD with a labeled NRR of 21 dB

	NRR for use with dBC measurements	NRR for use with dBA measurements
ADEQUACY per hearing Cons. Amendment, Appendix B	21	21 - 7 = 14
RELATIVE PERFORMANCE vs. noise controls	21 / 2 = 10.5	(21 - 7) / 2 = 7

EXAMPLE: Unprotected Time-Weighted Average (TWA) exposure = 100 dBA.
To assess ADEQUACY per Appendix B, the protected TWA is computed as:
100 dBA - 14 = 86 dBA, current hearing protection is legally adequate.
To assess **RELATIVE PERFORMANCE**, i.e. comparison of field attenuation to engineering or administrative controls, the protected TWA is computed as: 100 dBA - 7 dB = 93 dBA;
since this exceeds 90 dBA, feasible engineering controls must be implemented.
NOTE: when using muffs and plugs together, OSHA adds 5dB to NRR of higher-rated HPD. For field effectiveness, 5dB is addd after 50% adjustment, as in:
$NRR_{plug} = 29$; $NRR_{muff} = 21$; field NRR for use with dBA = [(29 - 7)/2] + 5 = 16 dB.

If it is not well fitted, or left partially ajar, or circumvented by an inconvenienced employee, or its gaskets and seals age, deteriorate, or break, then its performance will be degraded in a manner similar to that observed for poorly fitted and misused HPDs. Likewise, an employee may complain, "I can't hear my machine when I wear these earmuffs," but in terms of noise reduction and change in sound quality, there is little difference between putting the box on the employees head (e.g. donning an earmuff), or putting the box around the machine.

Most engineering control procedures, except for some source noise control accomplished through equipment redesign, required maintenance and periodic adjustment or replacement to remain effective. Furthermore, except for enclosures, retrofit noise reductions of 10 dB or more are often difficult to achieve and maintain. Thus HPDs can be, and often are, required as an effective adjunct to engineering controls in the majority of industrial noise environments.

Recommendations

Existing North American hearing protector attenuation data and the associated labeled NRRs provide a very poor indicator of the protection that will typically be achieved by the majority of employees in industrial and military hearing conservation programs. Efforts must be expended to develop more realistic standardized testing procedures so that published attenuation values can provide useful estimates of actual protection. In fact, such work is currently underway.[6]

Meanwhile, labeled NRRs must be derated. A 50% derating such as OSHA requires for evaluation of relative performance, is justifiable in order to reduce the existing NRRs from the unattainable to the achievable. Furthermore, treating earplugs and earmuffs differentially (i.e. a somewhat larger derating for earplugs) may be warranted. However, protector brand-specific deratings are premature until additional real-world attenuation results become available.

Rather than relying upon labeled NRRs in selecting HPDs, factors that should be considered are comfort, field attenuation, human engineering, compatibility, durability, cost, styling and availability. It is not possible to rank order these items in a manner suitable for all applications, but most would agree that comfort and field attenuation should be weighed most heavily. General estimates of attenuation can be gleaned from data such as provided in Fig. 1.

The practice of purchasing only HPDs that will meet the highest noise attenuation requirements within a plant, on the presumption that control of HPD usage is impossible and therefore any device which is purchased may end up being used anywhere within the plant, should be discouraged. Instead HPDs should be approximately matched to the noise exposure requirements of groups of similarly-exposed individuals, and control of usage within the plant should become part of the educational process.

For the majority of industrial noise exposures, those up to equivalent eight-hour levels of about 95 dBA, 10 dB of actual delivered on-the-job protection is all that is necessary. Most conventional hearing protectors, when properly sized and fitted, and consistently worn, can fulfill that requirement. As the sound levels increase so that exposures exceed 95 dBA, choices should be limited to the more protective devices. These have been shown to be foam earplugs and most earmuffs (as indicated in Fig. 1), or a combination of the two.

The hearing protector selection process should consist of more than merely scanning manufacturers' specification sheets and price lists. Wear test the products you intend to use, both on yourself (for extended periods of a few hours or more) and on small groups of employees. By developing your own firsthand knowledge and combining it with employee feedback, you not only improve the likelihood of selecting products your employees will accept, but you also will better motivate your workers by involving them in their own hearing conservation program.

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