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Chapter 29

International Review of Field Studies of Hearing Protector Attenuation

Elliott H. Berger, John R. Franks, and Fredrik Lindgren

When a manufacturer designs a hearing protection device (HPD), a hearing conservationist specifies its use, or a purchaser selects it for a particular application, one question foremost in their minds is just how much noise reduction (also called attenuation) the device will provide. Until the middle 1970s this question was always answered using test data obtained under closely controlled conditions in a laboratory setting. The degree to which such data corresponded with actual use, often called "real-world" performance, was not only unanswered, but also rarely if ever asked. This changed in the latter part of the 1970s as studies began to appear in the literature that presented the results of attenuation experiments conducted in the real world. Subjects in the studies were persons actually wearing HPDs for protection from occupational noise.

Although there have been at least 22 reported studies worldwide since 1975, that have examined real-world attenuation of HPDs,[1-22] and a review paper published in 1983 that summarized the data from the 10 studies available at that time,[23] controversy still exists concerning real-world attenuation. The debate centers around the extent of the divergence between values measured in the laboratory under ideal and commonly standardized conditions and those values observed in the real world, and how to best use laboratory data to predict real-world performance for particular applications. Herein we update Berger's 1983 summary, and provide a definitive picture of the real-world attenuation of hearing protectors circa 1994. We also present representative laboratory test data so that its validity (or realism), that is, the accuracy with which it predicts real-world performance, can be assessed.

Estimation of effective protected noise exposures when hearing protectors are worn not only requires valid HPD attenuation data, but also accurate noise exposure measurements as well as a suitable computational scheme with which to utilize such values. Noise measurements and predictive methods are not the subject of this chapter, but the results of such computations are of course heavily influenced by the attenuation data described herein. A recently issued ISO standard[24] describes three computational approaches. The reader is also encouraged to review Lundin[25] and Waugh[26] for background analyses and discussion.

Real-World Data Sample

The first reported data on field performance of HPDs appeared in 1975.[19] Since then, we are aware of at least 21 additional studies available worldwide.[1-18,20-22] The total data base comprises results from over 90 different industries, in seven countries (Argentina, Canada, Finland, Germany, Netherlands, United Kingdom, and United States) with a total of approximately 2900 subjects.

Field measurements have been conducted by independent researchers, government-sponsored investigators, and staff employed by the industries supplying the data. In all cases, the test subjects were workers or military personnel exposed to noise who were tested in most cases while wearing their own HPDs.

The facilities that have been studied most likely represent the better hearing conservation programs in existence. This presumption is based upon the increased likelihood of finding higher quality programs among companies and organizations interested in and choosing to participate in the complicated, time-consuming, and costly research of the type required for real-world evaluations. In fact in at least two of the more recent studies, the locations were selected specifically because the authors believed them to be exemplary.[9,18]

Candid Versus Scheduled

Subject participation in field studies has been based upon either *candid* selection or *scheduled* testing. Candid studies are the type in which subjects know that their work site is under investigation and that they will be asked to participate, but they do not know when. The researcher selects them without warning and then escorts them to the test facility while monitoring them to assure that they do not readjust the fit of their HPDs. Scheduled tests describe situations in which either the subjects are notified in advance and asked to come to the test facility bringing their HPDs with them to fit at the time of the test, or may be of the type where subjects are fitted with earmuffs instrumented with small microphones to measure the interior and exterior noise levels while they wear their HPDs during the work day.

At face value it might seem that candid studies would provide a truer picture of actual real-world usage than would scheduled studies. For the scheduled test it would appear axiomatic that the subject would purposely fit the device differently, a better fit because the testing is under the watchful eye of the experimenter or the subject wants to look good; a poorer fit because the subject wants to sabotage the test results.

For four of the insert HPDs evaluated, there were enough studies of both types to examine the effect of scheduling. Although for three of the earplugs, the scheduled tests tended to show higher attenuation values by a few decibels in terms of the Noise Reduction Rating (see Real-World Data and Metrics Utilized in This Report), the candid and scheduled data agreed within a few tenths of a decibel for the device on which the largest number of studies were conducted (E·A·R®/Decidamp earplugs, see Table 29-1). The foam earplug is also the one for which attenuation can be varied most easily and dramatically by subject-insertion method, and thus would have been anticipated to be the one most susceptible to bias on the part of the test subjects. For the remainder of this chapter, the data from both the candid and scheduled procedures will be pooled for analysis and discussion.

REAT Procedure

Two principal methods have been used to measure real-world attenuation: real-ear attenuation at threshold (REAT) and microphone in real ear (MIRE). For a complete discussion see Berger.[27]

REAT can be conducted with all types of hearing protectors as long as the facility presents the test signals in a sound field, even if the sound field is only that found in a small portable audiometric booth. However, because of potential background-noise masking problems, as well as cost and convenience considerations, it is generally easiest to conduct field REAT measurements using large circumaural earcups with built-in loudspeakers to generate the requisite sound field for the open and occluded measurements. Even so, masking of low-frequency open thresholds can occur. This will lead to underestimates of REAT. With headphone-based REAT procedures only earplug type HPDs can be evaluated.

Typically, under field application of REAT, a subject is first tested with the HPD in place as it was worn on the job, followed by an open threshold. The difference is the presumed real-ear attenuation. Because of possible learning effects between the occluded and open audiograms, the open threshold values may be spuriously improved by a few decibels simply due to better test-taking skills on the second test, and hence the REAT increased. This potential error, which can lead to overestimates of attenuation, is in the opposite direction to that caused by background-noise masking effects noted above.

An interesting alternative REAT procedure, the reference-earmuff method, was utilized in one study to measure earmuff and semiaural device attenuation.[21] The authors selected it because they were concerned about room noise producing masking of the open ear thresholds, which can easily occur under field test conditions. They sought a method like that of headphone-based REAT in which thresholds are always measured inside noise-excluding earcups. But, they wanted to be able to test earmuffs, an option that would be precluded by a headphone-based procedure.

The solution was to establish both real-ear attenuation and the occluded threshold levels for test subjects wearing a reference earmuff in the laboratory. In the field, measurements were taken of the occluded thresholds (no unoccluded values were measured in the field) for both the product being field tested (candid subject fit) and the reference earmuff (experimenter-supervised fit). The attributed attenuation was then calculated as the laboratory attenuation of the reference earmuff plus (or minus) the difference between the occluded thresholds of the reference earmuff and the test HPD, under field conditions. The accuracy of this method is strongly dependent upon the particular attenuation values selected for the reference earmuff, and the presumption that the attenuation of the reference earmuff achieved by the field test subjects closely approximates the values found in the laboratory using a different panel of listeners.

MIRE Procedure

The MIRE procedure, as implemented in field studies, consists of mounting small microphones inside and outside a hearing protector while it is worn by an employee on the job. The "test noise" is the actual noise to which the employee is occupationally exposed. The attenuation values that are reported can either be the differences in spectral sound pressure levels recorded by the two microphones, or the differences in time-averaged values of the A-weighted sound pressure levels (i.e., noise doses).

Because of the intrusiveness of mounting interior and exterior microphones, field MIRE measurements, unlike REAT, can only been applied to circumaural HPDs. The advantage of MIRE is that it allows a continuous monitoring of the noise levels, and an objective measurement independent of the subjects' ability to take an audiogram. The disadvantage is the limitation of being able to only test earmuffs, and the fact that the experimenter and the procedure may directly influence the subjects' use of the HPDs. This may enhance attenuation as a result of the additional attention the wearer receives, or reduce attenuation if the cabling and microphones interfere with the earmuff's ability to properly seal and block noise.

MIRE is best measured via an insertion loss (IL) protocol in which the sound levels in the canal are measured with and without the HPD in place. This directly corresponds to the paradigm inherent in REAT, and is how MIRE is normally implemented in the laboratory. However, for practical reasons the implementation of MIRE in field studies is always done with interior (canal-, or concha-measured) and exterior noise levels simultaneously recorded to yield a noise reduction (NR) value instead of an IL value.

In the NR protocol the reference microphone is the exterior microphone. It records lower sound levels than the ear canal mounted reference microphone used in the IL method, because it does not benefit from the amplification of the transfer function of the open ear. Thus, the difference between the occluded measurement (interior microphone) and the open measurement (exterior microphone) is less than occurs with IL procedures. Because most authors do not correct their field-measured MIRE values, they tend to provide low attenuation estimates, by about 5 dB or so, at and above 3 kHz.

Laboratory Data Base

For purposes of comparison to the field data summarized herein, various graphs and tables also provide the associated labeled test data based upon manufacturers' published North American laboratory results.

Laboratory testing of HPDs in North America is conducted in conformance with standards promulgated by the American National Standards Institute.[28,29] The procedures call for determining *"optimum performance values which may not usually be obtained under field conditions"* (author emphasis). Optimum performance values, as opposed to estimated real-world values, have historically been specified for laboratory testing because US standards groups have felt that those values could be more consistently replicated, and were useful for rank-ordering HPDs. However, current data as described herein, and reported by Berger[30] suggest otherwise. Nevertheless, ANSI S3.19/S12.6 type data *are the only standardized values* that regulators and manufacturers in the United States currently have available for labeling and informational purposes.

In Europe, testing has been conducted according to ISO 4869.[31] The procedure is essentially the same as in the American standards, but the subject fitting practices are described somewhat differently and have typically been interpreted in ways that yield lower laboratory attenuation values, especially for insert-type HPDs, than do the tests reported by manufacturers on the other side of the Atlantic ocean.[32] Sample European data appear in selected octave-band charts to follow.*

Real-World Data and Metrics Utilized in This Report

The data reported in the 22 field studies are mean attenuation and standard deviation values. It is those data that are graphically presented in the accompanying figures. The authors' values have been utilized as reported. If they measured NR and failed to correct the values to estimate IL, then the NR measures were reported. Only in one instance were the raw data adjusted.[9] In that case background noise measurements were available to confirm that the low-frequency open thresholds were masked, spuriously reducing the measured real-ear attenuation. The values were mathematically corrected.[33] In some cases where authors reported data at fewer frequencies than required for computation of the Noise Reduction Rating (NRR), the NRR was estimated based upon empirical relations between attenuation at key octave bands and overall attenuation.[30]

The NRR was selected as a simplified single-number metric of an HPD's overall real-world attenuation, because it is standardized for labeling purposes,[34] it has been in use for over a decade, and it is well known in the hearing conservation community. For a given set of data and a given theoretical percentage of the population protected, the NRR is approximately 3 dB less than the Single Number Rating (SNR), the single-number metric defined in the recently released international standard, ISO 4869-2.[24]

The *labeled* NRRs were computed per the US Environmental Protection Agency, by subtracting a 2-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})*.

The 2-SD deduction required in the labeled NRRs (i.e., NRR_{98}S) causes many field-measured NRRs to become negative numbers. A smaller 1-SD subtractive correction can avoid this problem. A 1-SD correction is also more in keeping with the practices of most of the non-North American community. With more realistic test data (i.e., larger SDs) it provides a better balance between adequately

*In this report, European data consist of results taken from manufacturers' European published data sheets, as well as data from the Karolinska Institute, Stockholm, Sweden.

protecting a majority of wearers and avoiding overprotection of a minority. Additional justification for use of a 1-SD correction stems from consideration of the heightened impact of outliers when 2-SD corrections are used, the reduction of between-study variability when only 1 SD is accounted for, and the variability of the susceptibility of individuals within a population to noise-induced hearing loss.[35]

The issue of whether field attenuation data are suitably normal to apply Gaussian-based SD corrections was examined by comparing estimates of the actual 84th percentile, to those obtained by subtracting 1 SD from the mean attenuation values. The data consisted of five 50-subject, and one 100-subject, subject-fit attenuation data sets, for four earplugs and two earmuffs. Both over- and underestimates of the true 84th percentile occurred, with the average error being 0.5 dB and the maximum error 3.1 dB. Examination of the same question using the real-world data of previous reports,[8,10] leads to errors of typically <2 dB, with the maximum differenc between the 84th percentile and a 1-SD estimate of that value, being 4.2 dB.

Tabular Overview

The authors were able to gather from the 22 reports nearly 100 sets of data on approximately 40 different devices, each data set being defined as the attenuation at one or more frequencies for one HPD for one group of subjects. The results for all of the devices, sorted into five insert and two circumaural categories (excluding three HPDs which did not easily fit into any of the groupings), and averaged across studies, are summarized in Table 29-1. Individual devices and/or subcategories were selected so that similar products were assembled together, and so that the number of subjects for each subcategory was greater than 30. Another requirement for a device to be individually listed in a row was that published US laboratory test data had to be available for inclusion in the data set. Data from 2879 subjects out of a total possible population of 2945 subjects are included in Table 29-1.

For each row, the number of studies contributing data as well as the total number of subjects are shown, along with the real-world NRR_{84} averaged across the group of studies noted for that row. The labeled NRR_{98} based upon manufacturers' North American published laboratory test results is also reported. The last column provides the relationship between the real-world NRR_{84} and the labeled NRR_{98} as a percentage. The field NRRs for earplugs yield only 5–52% of the labeled values (averaging about 25%), and for earmuffs, from 47 to 76% (averaging about 60%).

Representative Octave-Band Results

Representative field-performance data are presented in Figures 29-1–29-8, to illustrate the types of octave-band results observed in the various studies. The data include the results for: the earplug shown to provide the least attenuation under real-world conditions; an earplug with average real-world attenuation and very low interstudy variability; the earplug with the highest average real-world attenuation; and the earmuff on which the most real-world studies have been conducted. Figures 29-1, 29-3, 29-5, and 29-7 provide the individual data from each of the studies, and 29-2, 29-4, 29-6, and 29-8 present the data averaged across real-world studies with a comparison to both North American published manufacturers' data and representative European test data.

The results indicate that depending upon interpretation of the relevant test standard and implementation of subject selection, training, and fitting practices by the researcher, laboratory data may provide a more valid (European) or less valid (American) estimation of field performance. An American accredited standards working group, S12/WG11 (Field Effectiveness and Physical Characteristics of Hearing Protectors) as well as the National Institute for Occupational Safety and Health are cognizant of the problem and are currently conducting research and developing a new laboratory test method to address these issues.[36]

Table 29-1 Real-World (RW) Data Summary from 22 Independent Studies

Device Type	Device	No. Studies	No. Subjects	Mean RW NRR_{84} (dB)	Labeled NRR (dB)	NRR_{84}/ Labeled NRR (%)
Foam	E·A·R/Decidamp	15	633	13.4	29	46
Premolded	Ultra Fit	3	58	7.3	21	35
	V-51R	5	308	2.2	23	10
	Misc. 3-flange	2	31	4.5	26	17
	EP100	5	153	1.4	26	5
Fiberglass	Down	2	84	3.5	15	23
	POP	6	196	7.8	22	36
	Soft	3	80	4.7	26	18
Custom	Custom	6	447	5.4	17	33
Semiaural	Sound-Ban #10/#20	2	42	9.3	18	52
Earplugs (average)			2032	6.0	22.3	27
Earmuffs	Bilsom UF-1	2	41	16.3	25	65
	MSA Mk IV	4	89	10.8	23	47
	Peltor H9A	1	34	14.0	22	64
	Misc. Muffs	11	450	15.3	23	66
	Bilsom 2313	2	56	17.5	23	76
Cap-mounted	Hellberg No Noise	1	58	11.0	23	48
Earmuffs	Peltor H7P3E	1	36	13.0	24	54
	Misc. Cap Muffs	3	83	16.3	22	74
Earmuffs (average)			847	14.3	23.1	62
Grand average			2879	10.1	22.7	45

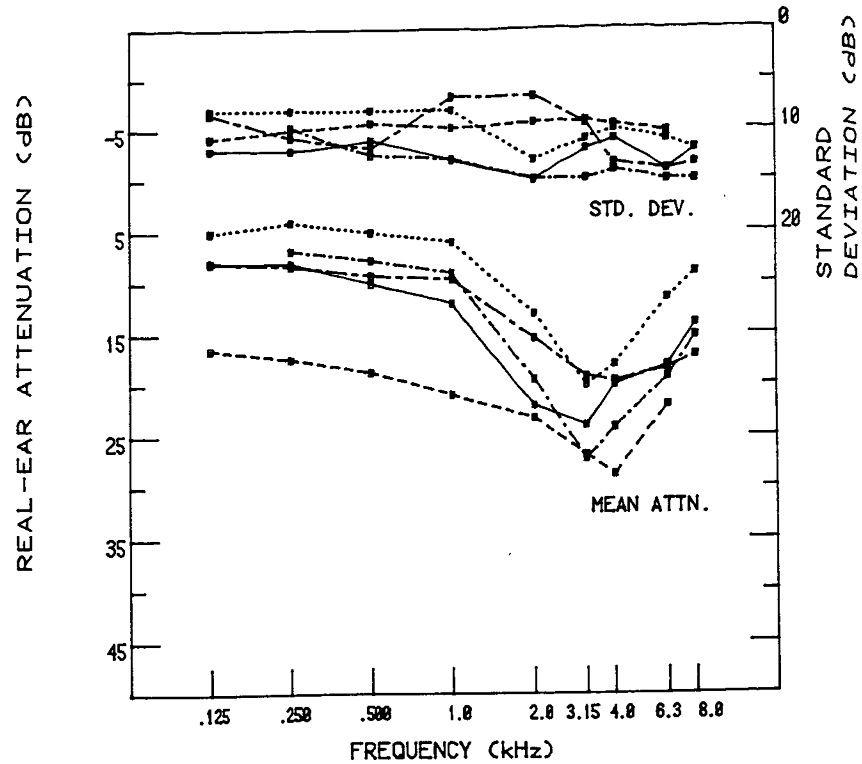


Figure 29-1 Real-world performance of the Willson EP100 premolded earplug (five studies, 153 subjects).

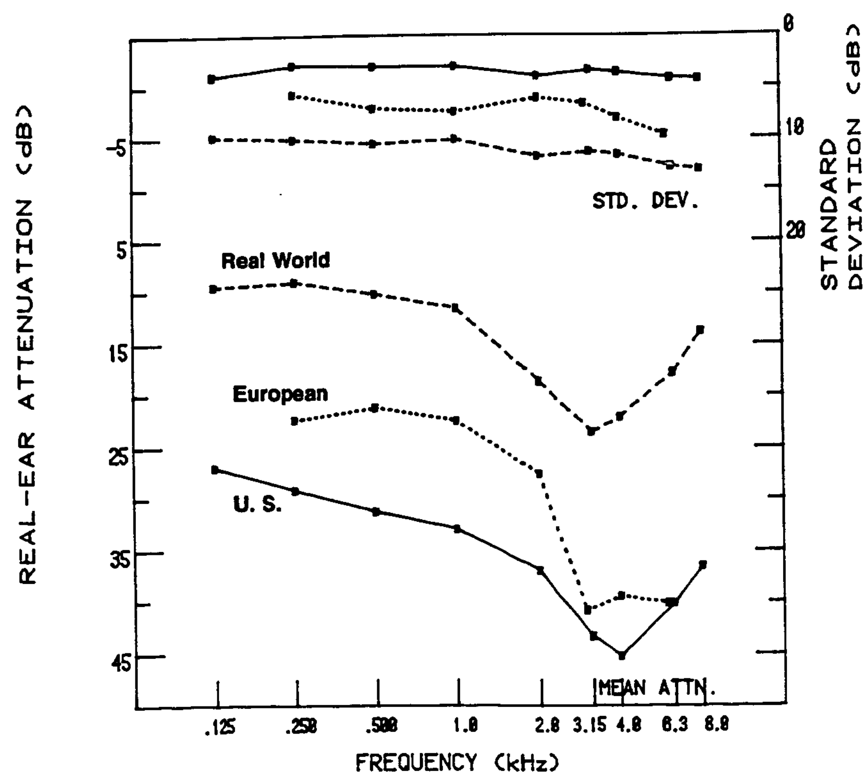


Figure 29-2 Willson EP100 earplug: real-world attenuation compared to manufacturer's US test data and European laboratory results.

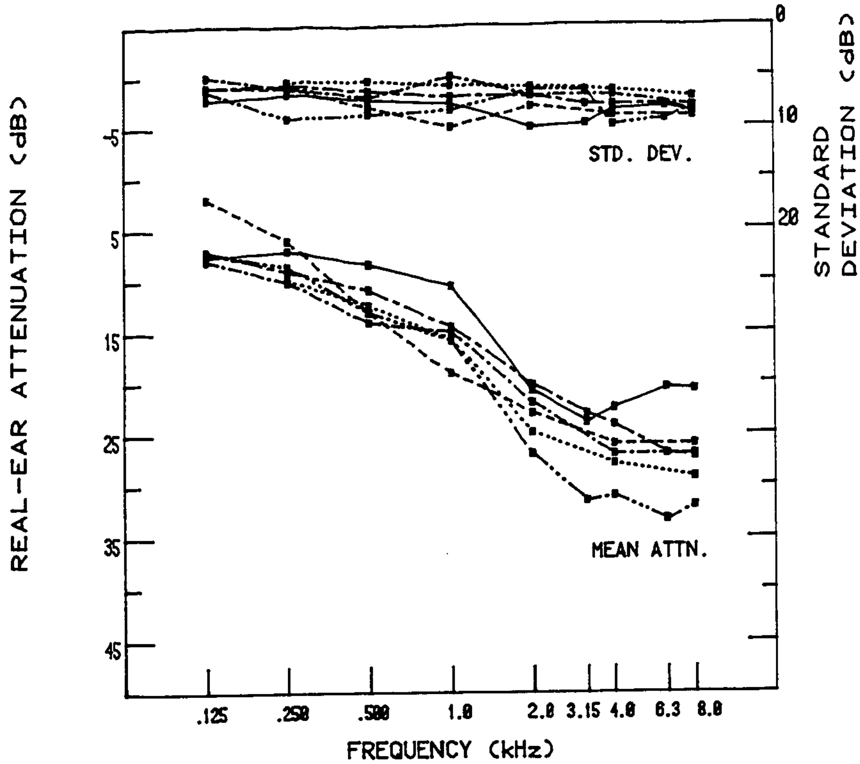


Figure 29-3 Real-world performance of the Bilsom P.O.P. sheathed fiberglass earplug (six studies, 196 subjects).

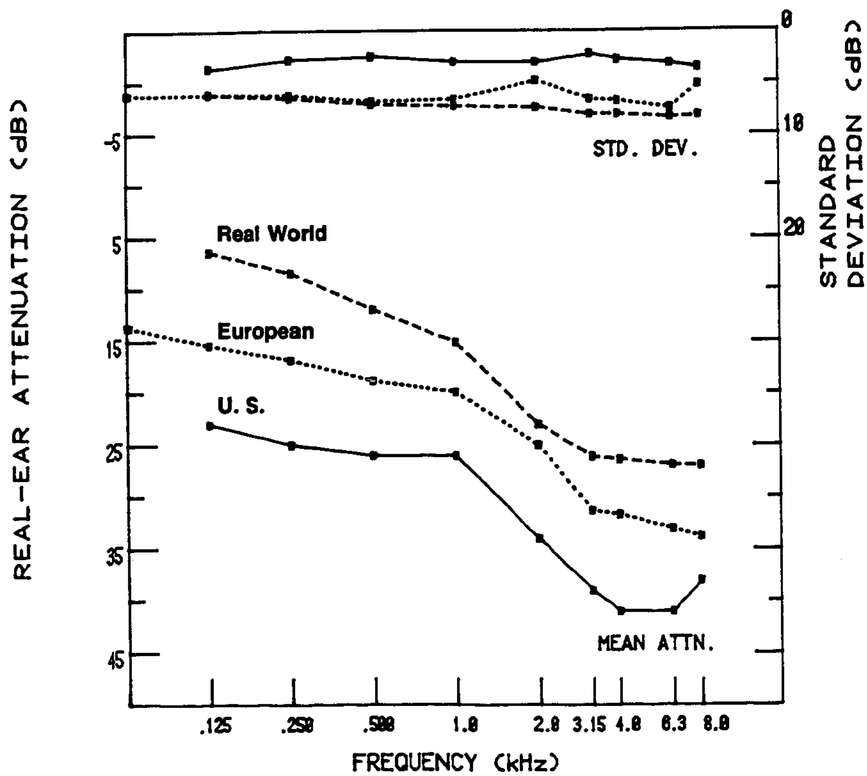


Figure 29-4 Bilsom P.O.P. earplug: average real-world attenuation compared to manufacturer's US test data and European laboratory results.

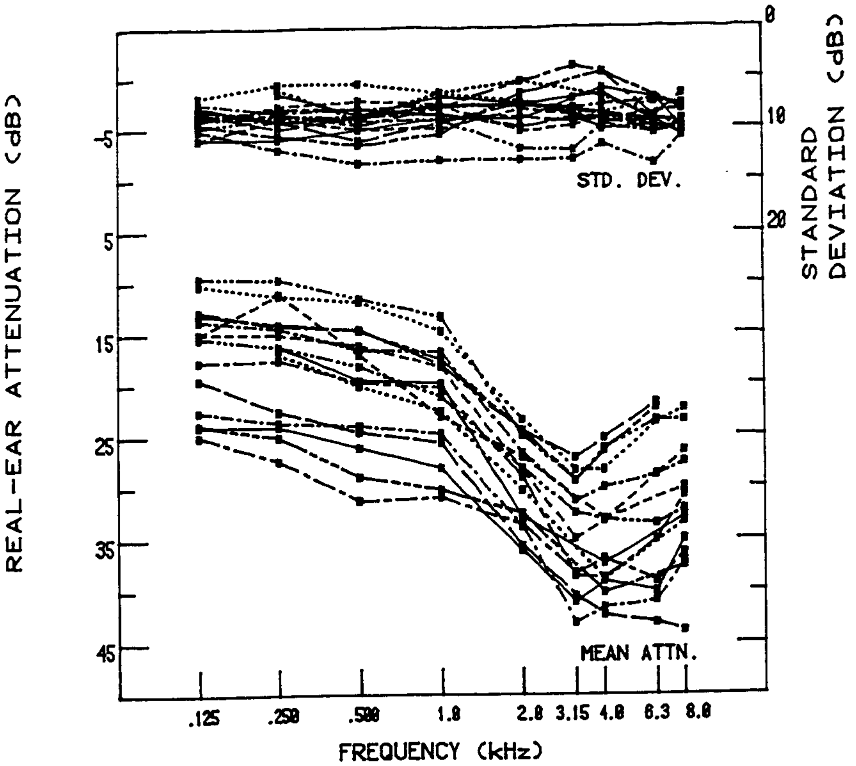


Figure 29-5 Real-world performance of the E·A·R/ Decidamp foam earplugs (12 studies, 633 subjects).

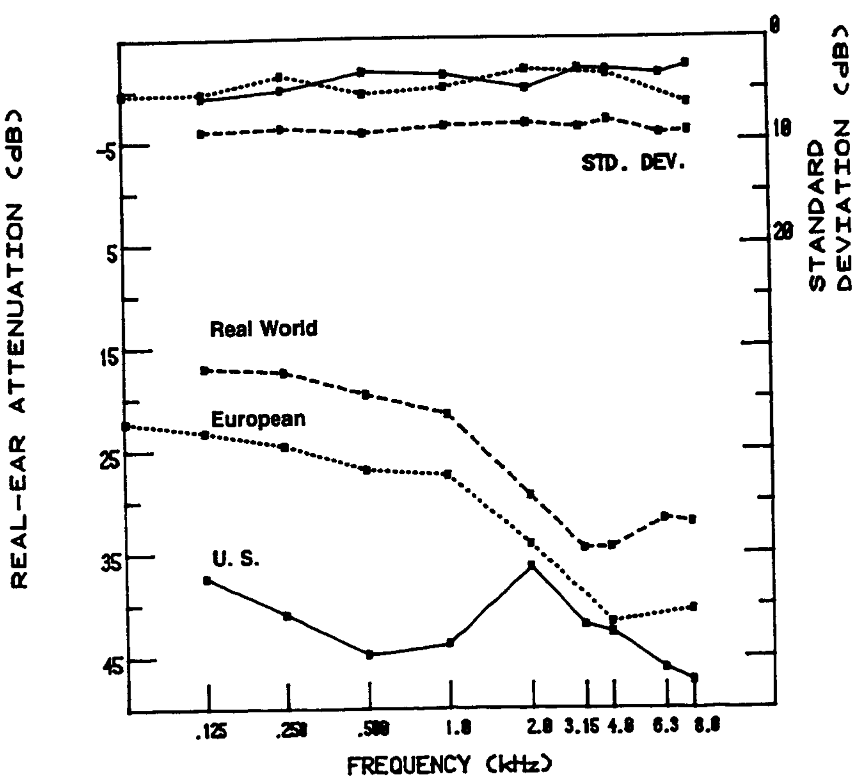


Figure 29-6 E·A·R/Decidamp earplugs: average real-world attenuation compared to manufacturer's US test data and European laboratory results.

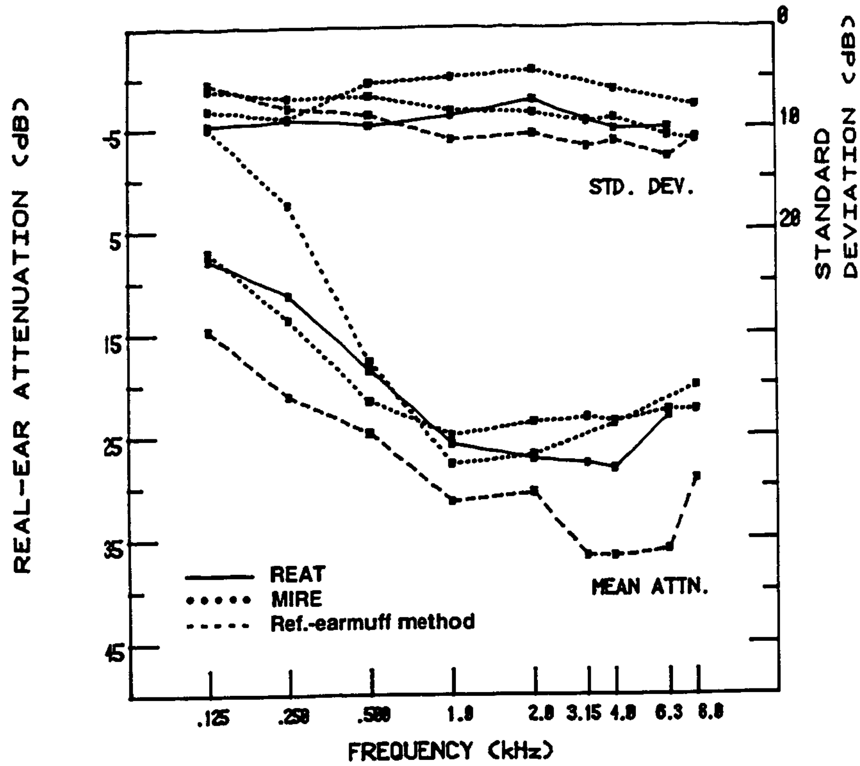


Figure 29-7 Real-world performance of the MSA Mark IV earmuff (four studies, 89 subjects).

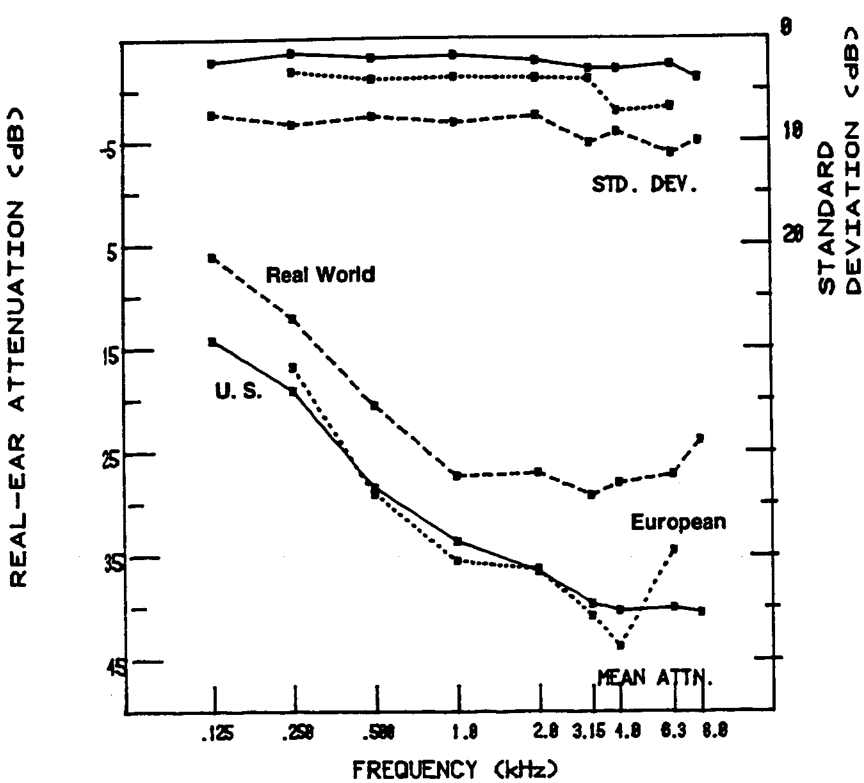


Figure 29-8 MSA Mark IV earmuff: average real-world attenuation compared to manufactrer's US test data and European laboratory results.

Following are specific observations about the data:

(1) Based upon real-world data, the lowest attenuating earplug among devices thus far tested, is the EP100. This is due to low mean attenuation values and high variability. Four of the five field studies agree rather closely (within 7 dB up through 2 kHz) (Figures 29-1, 29-2).

(2) The P.O.P. earplug exhibits a very tight range in mean attenuation values and SDs across field studies. The spread in data is about what would be expected from a typical interlaboratory as opposed to an interworkplace study (Figures 29-3, 29-4).

(3) The E·A·R/Decidamp earplug provides potentially high degrees of protection, but also a wide range of attenuation and SD values across 12 separate studies. The variability is probably due to the fact that foam plugs, although they seal the ear well regardless of insertion depth, can provide dramatically differing values of attenuation depending upon the depth of insertion. Insertion depth of foam earplugs is a parameter that is heavily influenced by subjects' training and motivation to properly use the product, and also may be affected by the amount of noise reduction the wearers require or desire. (Figures 29-5, 29-6).

(4) The earmuff data include measurements from three different types of studies. The fact that the data from the reference-earmuff method are the highest shown, may be due to the way in which those real-world employees actually wore their earmuffs, or may be experimental artifact as discussed earlier. The averaged earmuff results shown in Figure 29-8 are representative of those found for other earmuffs, with the exception of the real-world SDs that tend to be high for this particular product. The differences between US and European mean attenuation values are insignificant, but the SDs are higher for both the European and the real-world data than for the US results (Figures 29-7, 29-8).

(5) Figure 29-9 provides a comparison of standard headband earmuffs to hard hat attached earmuffs. Despite the dissimilarity in the way the two types of earmuffs interface to the head, no practical differences were found in their real-world performance, that is, mean attenuation values were within 2.6 dB, and SDs within 1.2 dB at all frequencies.

Real-world data and US test data were compared for three earplugs and one earmuff for which there were sufficient samples for analysis. The mean real-world attenuation values were found to be statistically significantly smaller, and the associated SDs significantly larger, than for US laboratory data. There was more degradation in earplug than in earmuff performance, as would be anticipated due to the greater difficulty in fitting and inserting earplugs than earmuffs, but the differences were unique to the HPD tested. A similar analysis was not performed for the European laboratory data. However, as has been previously observed,[32] they appear to provide a closer approximation to real-world values than do the US data.

REAT Versus MIRE

Figure 29-10 depicts the real-world data for more than 16 models of earmuffs separated into nine REAT (501 subjects) and four MIRE (315 subjects) studies. Four interesting observations are apparent:

(1) Over the middle frequencies from 500 to 2000 Hz, where both methods are devoid of experimental artifact, the mean attenuation results of the two procedures are in nearly exact agreement, despite the wide diversity of samples and studies that are combined to produce the averaged results. No evidence is seen of any aberration due to learning effects, which would have caused the REAT values to exceed the MIRE data.

(2) As is well-documented in the literature, REAT yields spuriously high values of attenuation at the low frequencies due to physiological noise masking the thresholds in the occluded condition, and hence inappropriately increasing the occluded/open threshold shift.[27] At such frequencies an ob-

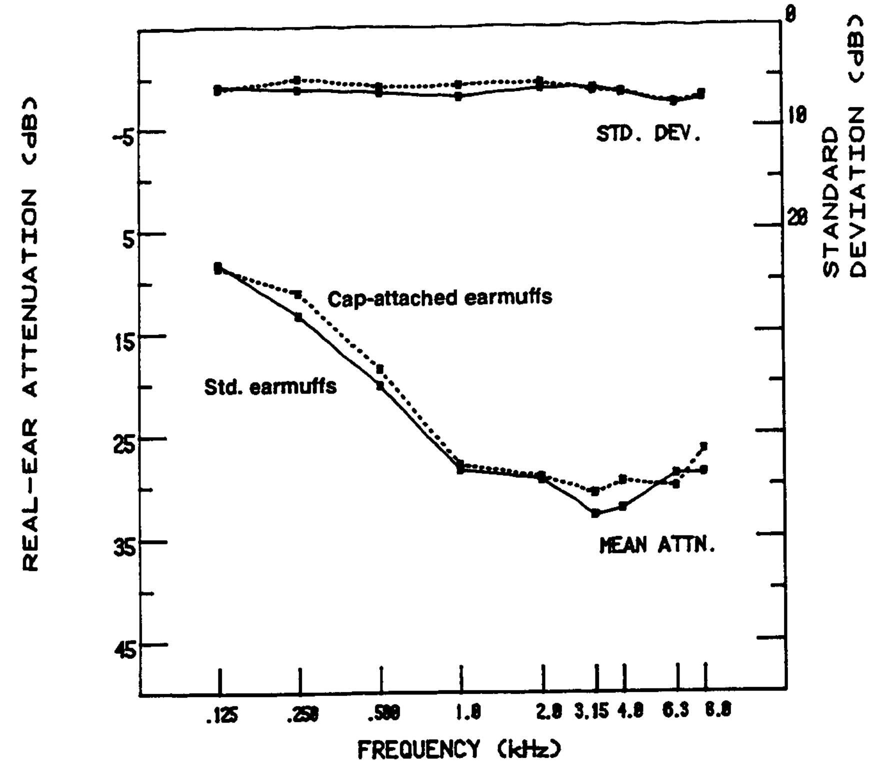


Figure 29-9 Comparison of standard earmuffs (eight studies, 324 subjects) to cap-attached earmuffs (four studies, 177 subjects) using real-world REAT data.

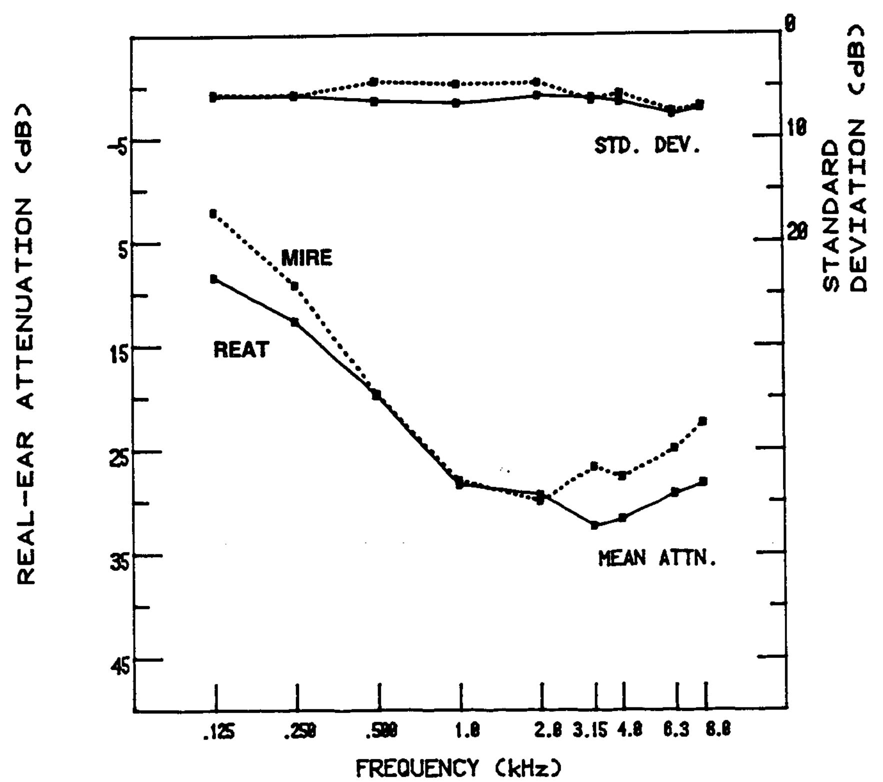


Figure 29-10 Comparison of real-world earmuff attenuation measured using REAT (nine studies, 501 subjects) and MIRE (four studies, 315 subjects) procedures.

jective measurement such as MIRE is more appropriate. The REAT/MIRE disparity in Figure 29-10 is seen to be from 6 to 3 dB at 125 and 250 Hz, respectively, in agreement with previously reported laboratory results.

(3) As discussed earlier, field implementation of the MIRE procedure is typically based upon NR instead of IL measurements, which leads to underestimates of attenuation above 2 kHz. This can be clearly noted in Figure 29-10. Therefore, REAT data, which are devoid of high-frequency artifact, provide the better assessment of attenuation at high frequencies.

(4) Concern is sometimes expressed that real-world REAT studies yield excessively high values of SD because subjects are not adequately trained in taking threshold audiograms, and thus their threshold variability contaminates results. If so, one would expect that an objective measurement such as MIRE, which does not include a threshold-variability component, would indicate lower SDs, and thus provide SD estimates more representative of the true variability in fit of the HPDs between subjects. This was not the case. At four of the seven test frequencies the SDs are essentially identical for both methods; from 500 to 2 kHz where differences exist, they amount to less than 2 dB.

Discussion

To more easily compare device types and gain a perspective of the attenuation attainable in the real world, data for three-flanged premolded earplugs, custom-molded earplugs, sheathed fiberglass earplugs, vinyl foam earplugs, and earmuffs, are compared in Figure 29-11. Foam earplugs provide the highest attenuation at 125 and 250 Hz and above 2 kHz, and earmuffs the most attenuation in the middle-frequency range, from 500 to 1000 Hz. In addition to the octave-band data, the NRR_{84} and the HML values[24] were also computed with a 1 SD correction and listed below the graph. They tell a similar story.

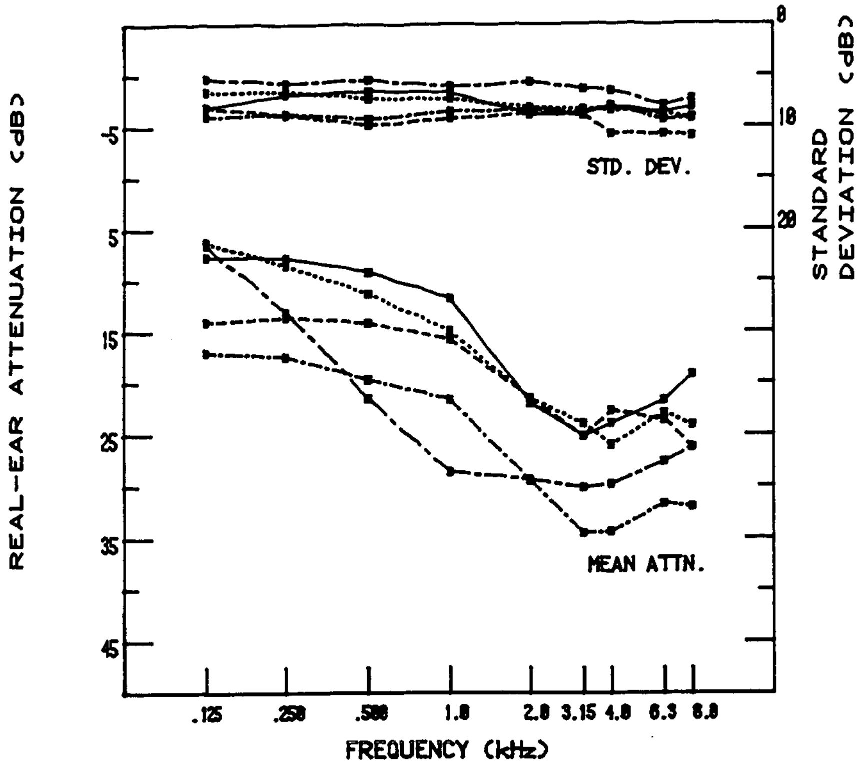
Note that the earmuffs show the smallest SDs at all frequencies, again confirming the greater ease with which they can fit, or be fitted by, a wide-ranging group of people.

The NRRs of the five device types were tested by a one-way analysis of variance, and found to have a significant device effect at $p < 0.001$. However, subsequent tests demonstrated that the custom-molded, fiberglass, and three-flanged groups were not significantly different at the $p < 0.05$ level, and that likewise the differences were not significant between the foam earplug and earmuff categories. Thus in terms of overall protection, the real-world data suggest that it is not possible to make fine distinctions between types of hearing protectors. To a first approximation only two categories can be distinguished: one consisting of the higher attenuation devices of foam earplugs and earmuffs, and the other consisting of lower attenuation devices comprised of the remaining principal types of (nonfoam) earplugs.

As an additional summary of the real-world data, Figure 29-12 provides an overview in terms of the field NRR_{84}s versus the manufacturers' published laboratory NRR_{98}s. The same trends emerge as were apparent in Figure 29-11. Measured as a percentage of the laboratory-rated attenuation, the field NRRs for earplugs yield only about 25% of the labeled values, and for earmuffs about 60%. It is especially clear that the American laboratory data not only provide a poor indication of the absolute values of field performance, *but of the rank ordering of those values as well.* This means that no single correction factor can be applied to existing laboratory data to estimate field performance. This is also demonstrated by the data in the last column of Table 29-1 that lists the real-world NRR_{84} as a percentage of the labeled NRR.

Especially misleading is the fact that the laboratory data would suggest that in general, earplugs provide the highest overall protection whereas, with the exception of foam earplugs, the reverse is true under field conditions.

Although the current report is intended primarily to provide a real-world data base for use in future research, it is instructive to discuss potential reasons for the divergence be-



Device Type	NRR_{84}	HML_{84}
Custom Molded	6	12 - 5 - 3
Sheathed Fiberglass	7	13 - 7 - 4
3-Flanged	7	12 - 7 - 6
Foam Plug	13	20 -13 -11
Earmuffs	15	23 -16 - 8

Figure 29-11 Summary of real-world data for hearing protectors separated into five categories.

tween laboratory data (primarily those of US origin) and field performance, most substantially for earplugs, but to a noticeable extent for earmuffs as well. The problem of predicting real-world performance has been extensively studied by S12/WG11 and has been the subject of research presentations as well as work in progress on a draft standard.[36]

A portion of the lab/real-world divergence is due to less than desirable quality in real-world hearing conservation practices in areas of fitting and training of HPD users, enforcement of proper HPD utilization, education and motivation of the work force, and program management. And the fact must be considered that user fitting of HPDs in the real-world is strongly affected by comfort, convenience, and interference with communications, whereas in the laboratory environment these parameters are considerably less important than attenuation.

Much of the divergence between laboratory and real-world data is also attributable to inappropriate laboratory practices and consequent unrealistic test results. It is just those practices, in the areas of subject selection, fitting, and training, as well as experimenter involvement and consistency across facilities, that are being addressed by S12/WG11. Based upon results of a four-facility interlaboratory study

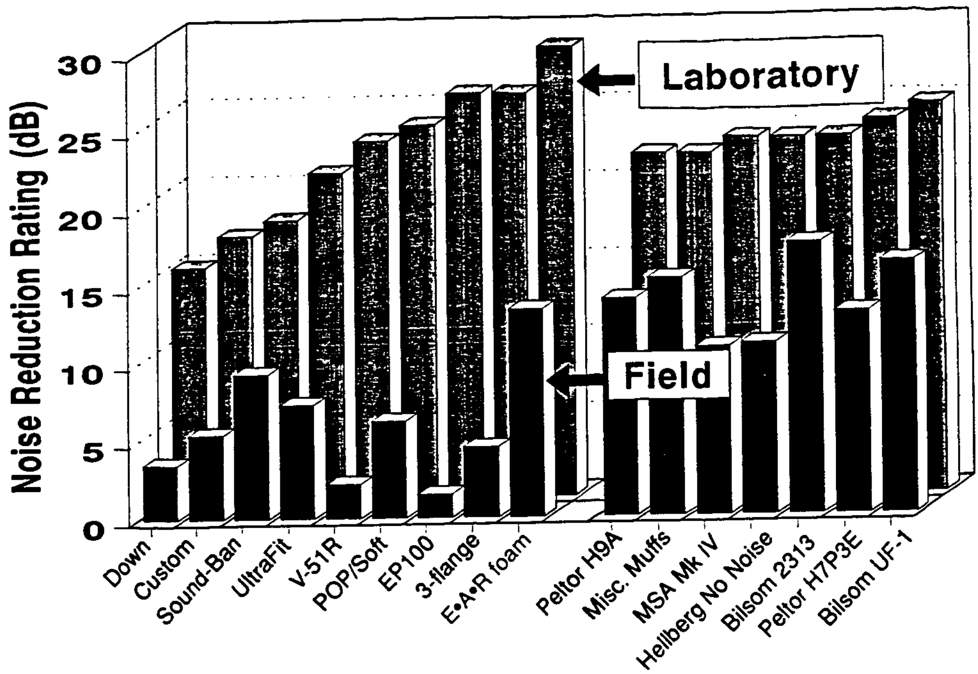


Figure 29-12 Comparison of NRRs published in North America (labeled values based upon laboratory tests), to real-world "field" attenuation results derived from 22 separate studies.

conducted under the auspices of the working group, there is optimism that a solution can be devised.[36]

Conclusions

Although the data base has grown substantially larger since the appearance of the earliest studies and summary reports,[23] the conclusions remain the same: real-world performance of HPDs, especially earplugs, demonstrates less attenuation and greater variability than currently standardized laboratory tests would predict. Measured in terms of the overall protection achieved by 84% of the workforce, earplug attenuation varies from a low of 1 dB for one type of premolded earplug to a high of 13 dB for foam earplugs, and about 11–17 dB for earmuffs.

Because field data are normally examined in terms of a value achieved by 84% of the users, the attenuation values appear quite low. However, field SDs are normally around 8–10 dB, and thus when the protection values are increased by 1 SD to estimate a mean value instead of an 84th percentile value, considerably larger amounts of attenuation are predicted. The selection of the statistical adjustment to include in the computation depends upon the goals of the specifier.

Field attenuation values are low enough that in many actual environments, even when only 10 dB of attenuation is required, it is questionable whether certain HPDs can provide the degree of protection needed for the majority of the workforce. Such findings may appear incredible to some observers, but the magnitude of the results is qualitatively supported by analyses of audiometric data from existing hearing conservation programs, and by real-world studies of temporary threshold shift.[37]

On a global basis there is no question that the existing group of 22 studies provides a clear indication of field performance, but additional data are required if specific guidance is to be developed for a wide variety of individual devices. HPDs that are in particular need of additional field studies are the semi-insert/semiaural types of hearing protectors as well as dual hearing protection, that is muffs and plugs worn in combination, the latter category for which (to the authors' knowledge) no published data on real-world attenuation are yet available.

Current research has demonstrated that a 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.*[36] When tested under those conditions, the attenuation of HPDs still equals or exceeds average real-world data of the type shown here. The fact that subjects completely untrained in the use of HPDs 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 hearing conservation programs, are ineffective in fully motivating and training employees to consistently and properly wear their HPDs.

Regardless of these issues and the research that is still needed to better define field performance possibilities, use of HPDs remains key to the prevention of occupational noise-induced hearing loss. If only hearing protection devices were worn properly and consistently, such causes of hearing loss would cease to exist.

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