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Field Investigations of Noise Reduction Afforded by Insert-Type Hearing Protectors

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NIOSH conducted field investigations in 1977 and 1981 to determine the actual noise reduction afforded to industrial workers who used insert-type hearing protectors (earplugs) daily. *In-situ* attenuation tests of 420 workers at 15 industrial plants were conducted to determine the noise reduction provided by earplugs as they were worn during the workday. The workplace results, when compared to manufacturers' best-fit laboratory test results, indicated that 50% of the workers tested were receiving less than one-half the potential attenuation of the earplugs.

Introduction

The prevention of noise-induced hearing loss is a major concern of many industries. The ideal method for achieving this prevention is to reduce the noise level at the source. This is not always possible, due to engineering or economic constraints. For this reason, personal hearing protectors are used to provide reduced noise exposures. Although hearing protectors are not the permanent answer to noise exposure reduction, the Occupational Safety and Health Administration (OSHA) noise regulation requires their use as a temporary solution until adequate engineering control reduces or eliminates the noise hazard.[1] Therefore, it is essential to document the effectiveness of these devices since many workers rely on them for hearing protection.

The National Institute for Occupational Safety and Health (NIOSH) conducted two field investigations to determine the actual effectiveness of hearing protectors as they are worn in the workplace.[2,3] Two questions related to earplug effectiveness were of concern to us: 1) Do earplugs, as worn at the workplace, differ in effectiveness due to their construction characteristics?, and 2) How close to manufacturers' (or distributors') quotations are earplugs' effectiveness when the data are obtained under actual working conditions? The first field investigation conducted in 1977 included an evaluation of three types of earplugs: one preformed twin-flanged type, one preformed single-flanged type commonly known as V-51R, and one user-formed acoustic wool type. The second field investigation conducted in 1981 used the same test protocol to furnish field data on additional earplug designs, including acoustic wool, custom-molded, and user-molded expandable foam (see Figure 1). This paper presents the results from both field investigations in order that comparisons can be made among earplugs evaluated in both studies.

Distributors of hearing protectors provide means and standard deviations of attenuation in decibels (dB) derived from "experimenter (best) fit" laboratory test results on ten subjects tested three times at the audiometric frequencies 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. These data are obtained using methodology established by the American National Standards Institute (ANSI) to determine the real-ear attenuation of hearing protectors (ANSI Z24.22-1957,[4] ANSI S3.19-1974[5]). OSHA inspectors use these "laboratory" data to assess compliance of an industrial establishment in reducing noise exposure levels to acceptable limits.[1]

Several investigators have studied the effectiveness of hearing protectors by making quantitative and qualitative measurements.[6-9] Both types of measurements are important because the potential attenuating capabilities cannot be achieved if the worker refuses to wear, or wear properly, the protectors issued. The comfort, sizes available, and ease of insertion and removal are all important in analyzing an earplug's effectiveness. Even though properly worn earplugs can afford adequate protection from noise hazards, earplugs are generally worn incorrectly.[6] This means that the laboratory attenuation data provided by distributors may greatly overestimate a worker's actual protection.

Methods and Materials

Experimental Design

Six different industrial plants were included in the 1977 field investigation and ten different plants were included in the 1981 field investigation. The experimenters chose each plant according to the type of earplug used. One of the plants included in 1977 was repeated in 1981; however, only the 1981 data from this plant are included in this paper because the two sets of data were gathered in many instances from the same subjects. It has been discussed previously that the 1977 and 1981 attenuation results from this plant as a function of frequency compare well in both magnitude and curve shape.[3]

At each plant all workers who used a particular earplug type were categorized by "physical activity", either active (*e.g.*, production-line worker) or passive (*e.g.*, supervisor), and by "noise exposure", either high (usually greater than 90 dBA) or low (usually less than 90 dBA). (The workers' noise

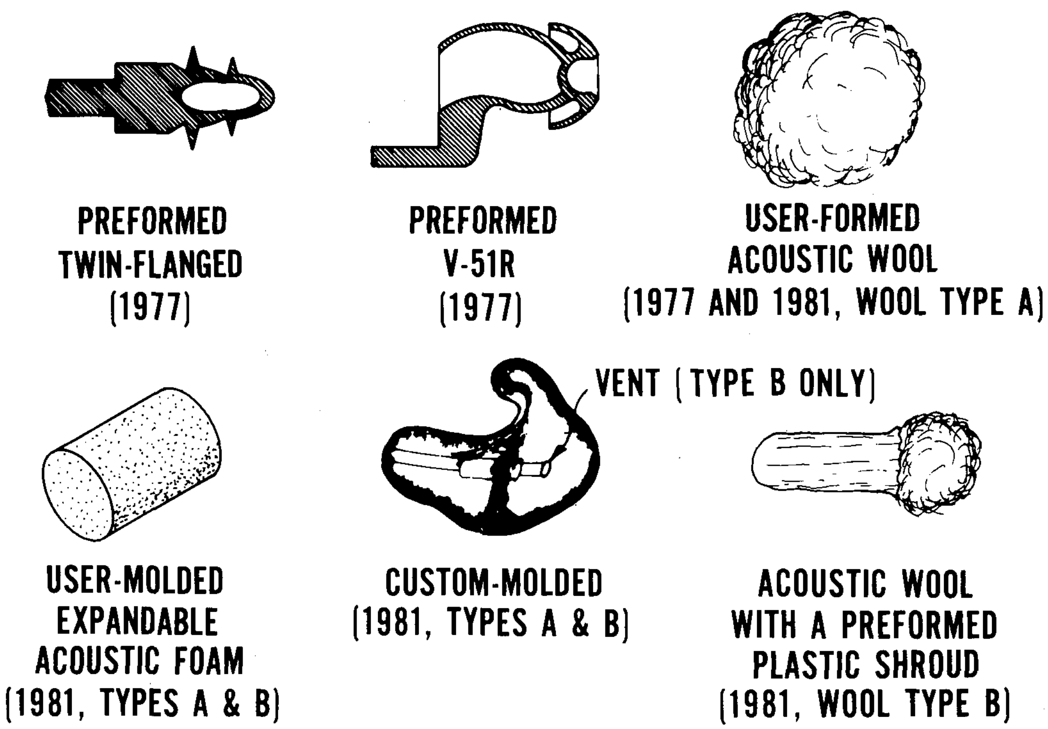

Figure 1 — Earplug types evaluated.

exposures were not in any way changed for purposes of this study, and workers were not exposed to levels of noise different from their normal working conditions.) Seven workers then were selected randomly from each of four groups, "high-active", "high-passive", "low-active", and "low-passive", for a total of 28 workers at each plant.(2)

Additional workers were similarly selected to replace those who chose not to participate, could not be included due to scheduling conflicts or illness, or did not meet audiometric criteria. Since previous audiograms were available for most employees at each of the plants, it was generally possible to use the following two audiometric criteria to aid in selection of subjects:

1. A hearing level (re: audiometric zero) not greater than 40 dB at any frequency in at least one ear.
2. A difference left and right ear hearing levels not greater than 20 dB at more than one test frequency.

The first criterion was to ensure that the hearing level plus attenuation would be less than the maximum output of the test system. The second criterion screened out persons who might not perform well in this binaural test in which the test signals are presented to both ears simultaneously. Since this study was designed to test hearing protection devices and not people, hearing threshold levels, rather than variables such as age and sex, were the primary basis for selection of subjects.

Thus, twenty-eight subjects were chosen at each of fifteen different industrial plants for a total of 420 subjects. At each plant, the 28 workers tested all used the same earplug type. The earplug types and the number of plants and workers corresponding to each type are shown in Table I.

At each plant, the twenty-eight workers each were tested five times over a period of five days. Over this period, the schedule usually called for each participating employee to be tested once per day for three days and twice on one day. The employees were scheduled randomly so they did not know when they were to be tested. They were only aware that they would be tested several times during the week.

Since no dependence was demonstrated between the factors "noise exposure" and "physical activity" and the amount of noise attenuation received, further discussion of these factors does not appear in this paper.

Equipment

An audiometric test van was specially instrumented to determine the real-ear noise attenuation of earplugs re:

TABLE I
Earplug Types and Sample Sizes

Earplug Types	Plants	Subjects
Preformed --		
Twin-flanged ('small' and 'regular' sizes)	1	28
V-51R (single-flanged, five sizes)	3	84
Acoustic Wool --		
Type A (cotton-like, user formed)	2	56
Type B (cotton-like in thin preformed plastic shroud)	1	28
Custom-molded --		
Type A (original impression is final mold)	2	56
Type B (final mold cast by manufacturer, vented)	2	56
Acoustic Foam --		
Type A (expandable, user-molded)	2	56
Type B (identical to Type A except for coloring and user's instructions)	2	56

ANSI S3.19-1974. This van was used in both 1977 and 1981 field investigations. The van was equipped with a dual test unit to permit testing two persons simultaneously. It contained a 5′ x 7′ test cell equipped with special circumaural headphone sets developed by the Pennsylvania State University Environmental Acoustics Laboratory.[10]

The headphone set consisted of a muff-type hearing protector fitted with earphone drivers. It could be worn with earplugs inserted without touching the earplugs or disturbing their fit. Testing with the headphones was binaural with parallel (in-phase) input to the headphone set. The two recording audiometer units were Grason-Stadler Model 1703's modified to allow insertion of an external noise signal and remote control operation of the audiometers. The audiometers controlled the amplitude of the signal to the headphone set and recorded the hearing levels. The signal to the audiometer passed through the output of a third octave filter set; thus, a narrow band output replaced the usual pure tone output of the audiometer. An electronic switching circuit interrupted the output, producing a "pulsing" signal of 300 milliseconds "on" and 500 milliseconds "off".

Test Procedures

The audiometric van was positioned as close as possible to a plant door to provide convenient access, but never in a

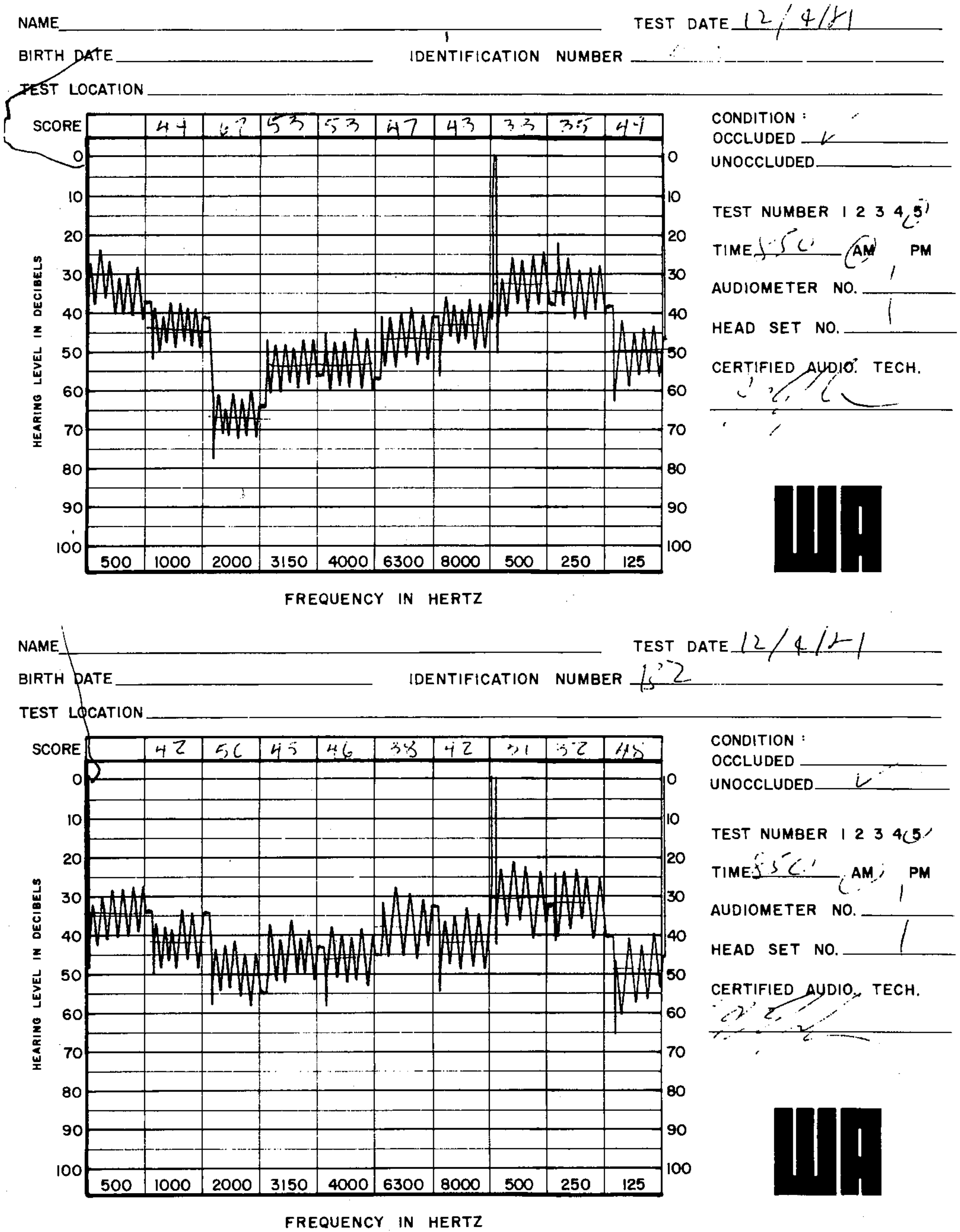

Figure 2 — Example audiograms from subjects with ears occluded (upper) and unoccluded (lower). Note: The test signals were presented binaurally; absolute calibrations were not performed and hearing level scale values are not referenced to audiometric zero.

location such that noises from the plant were discernible inside the van. Octave band recordings of sound pressure levels inside the test cell were made before and after each test session to ensure that ambient noise levels were sufficiently low so as not to exceed ANSI S3.19 permissible limits during testing.

Since only differences in hearing threshold levels were desired, absolute acoustic calibration of the audiometers was unnecessary. At each plant, hearing tests (biological calibrations) were performed using the same two audiometric technicians. These tests were performed at the start and end of each test day to ascertain that the instrumentation was operating properly.

Employees were accessed for testing in a candid fashion. When approached and informed that it was time for their test, each subject was shown an 8-1/2″ x 11″ cardboard sign with the statement "Time for Your Hearing Test. Please Do Not Touch Your Earplugs or Ears. Thanks.". The subject then was given this sign to hold with both hands as he or she walked with an escort to the test van. This procedure was followed to ensure that the fit of the earplugs was not adjusted.

The attenuation test procedure was administered first with the earplugs inserted (ears occluded), and then with earplugs removed (ears unoccluded). The first time the subjects were tested, they received the following verbal instructions (spoken slightly more loudly than usual because the workers' hearing threshold levels in the speech (or low) frequencies were somewhat higher due to their earplugs): "You will listen for a pulsing tone. As soon as you hear the tone, please press the button and hold it down until you no longer hear the tone; then release the button. When you again hear the tone, repeat the procedure." The person responsible for administering the test placed the headphone sets on each subject, extreme care being taken in positioning them, so that the earplugs were not disturbed. A 500 Hz test signal then was presented and the subjects were allowed to practice the task briefly to make certain they understood the procedure before recordings were made. Figure 2 shows typical data records for one test. The test signals were presented binaurally to be in accordance with ANSI S3.19. Each frequency shown in Figure 2 was presented, and a 30-second recording made after it was determined that the response was oscillating about threshold. The order of presentation for the third octave band test signals (denoted using the center frequencies) was 500, 1000, 2000, 3150, 4000, 6300, 8000, 500, 250, and 125 Hz. The first frequency was 500 Hz, which was repeated in order to demonstrate the reproducibility. Separate audiogram cards were used for occluded and unoccluded tests to avoid difficulties in interpretation caused by overlapping traces. Total time required for a complete test was about 15 minutes.

Testing never was begun until at least thirty minutes after the start of a work shift. This ensured that employees had been performing their regular duties, with earplugs inserted, prior to being tested.

If a worker was not wearing his hearing protectors effectively and prior to testing was exposed to noise sufficient to cause a temporary threshold shift (TTS) or temporary increase in hearing threshold levels, recovery from the TTS occurring during the testing period could have had a slight effect on the amounts of attenuation determined. Since the occluded threshold levels were determined first and could be increased due to the TTS slightly more than the unoccluded threshold levels, the attenuation values or differences between occluded and unoccluded threshold levels could have been slightly higher than the values found if TTS was not present. Thus, if this was the case, the attenuation values for that worker may be overestimated. Any resultant overestimation would in fact err on the "safe side" and therefore was not an important consideration in the study design.

Data Treatment

The analog audiograms corresponding to both the occluded and unoccluded cases were digitized, utilizing the midpoints of the pen oscillations at each frequency. By subtracting the respective data for the unoccluded case from that for the occluded, "uncorrected" attenuation values were obtained. The attenuation value could not be determined in less than one percent of the test cases due to hearing thresholds outside the output range of the audiometric test system.

To provide results comparable to the existing laboratory test results provided by the distributors of the earplugs, means and standard deviations of attenuation were calculated pooling all data (sample size equals number of subjects times number of tests). "Field" means and standard deviations of attenuation shown in Table II and Figures 3-4 in the RESULTS section then were "corrected" to yield the attenuation values in accordance with ANSI S3.19-1974. The procedure for accomplishing this was set forth in Appendix C of Reference 10.

"Laboratory" means and standard deviations of attenuation presented in Table II and Figures 3-4 in the RESULTS section are as reported by the earplug distributors and were obtained re ANSI S3.19-1974, with the exception of the results for the twin-flanged earplugs which were obtained re ANSI Z24.22-1957. The laboratory results shown for the V-51R earplugs are the average of results from the two distributors who provided these earplugs.[2]

Assuming a flat noise spectrum with equal octave band sound levels (or "pink noise", representative of the median spectral shape of industrial noise[11]), A-weighted noise reduction values were computed for each test of each worker by reducing the A-weighted octave band sound levels by the amounts of attenuation provided by the earplugs at each of the corresponding center frequencies and then computing the reduction in the overall A-weighted level. (The attenuation values for the 3150 and 4000 Hz frequencies were averaged and the average value was subtracted from the 4000 Hz octave band level; similarly, the average attenuation for the 6300 and 8000 Hz frequencies was subtracted from the 8000 Hz octave band level.) Computation of "field" noise reduction values included correction of attenuation at each test frequency by the method for adjusting mean attenuation set forth in Appendix C of Reference 10. "Laboratory" median

TABLE II
Attenuation Means and Standard Deviations in Decibels: Field and Laboratory Test Data for Eight Earplug Types

Earplug/Data	Test Frequency (Hz) 125	250	500	1000	2000	3150	4000	6300	8000
Twin-flanged									
Field -- Mean	4.5	3.4	2.0	4.4	14.3	19.1	16.1	9.9	9.0
S.D.	8.4	8.2	7.1	8.1	11.8	10.4	8.7	8.8	10.7
N	110	111	112	112	112	112	111	112	112
Lab -- Mean	21.0	25.0	25.0	27.0	32.0	41.0	44.0	40.0	37.0
S.D.	7.1	8.0	7.6	7.5	6.8	6.3	7.5	8.5	11.2
N	30	30	30	30	30	30	30	30	30
V-51R									
Field -- Mean	7.9	7.6	6.4	10.4	21.0	22.7	19.2	14.1	15.1
S.D.	10.6	9.2	9.5	9.9	11.9	9.5	8.7	10.0	10.3
N	332	332	333	333	333	332	332	331	332
Lab -- Mean	21.3	22.6	23.8	27.0	32.8	35.1	34.9	35.0	36.6
S.D.	4.0	3.4	3.2	2.8	2.6	4.0	3.5	6.2	4.4
N	30	30	30	30	30	30	30	30	30
Wool Type A									
Field -- Mean	2.8	3.8	4.5	68	16.2	16.6	14.5	18.0	21.3
S.D.	5.8	4.3	2.8	5.5	6.8	6.8	7.2	5.2	6.7
N	223	223	223	223	223	223	223	219	219
Lab -- Mean	10.0	13.0	16.0	20.0	31.0	36.0	37.0	38.0	34.0
S.D.	2.4	1.6	1.9	1.9	1.9	1.6	2.4	2.1	1.4
N	30	30	30	30	30	30	30	30	30
Wool Type B									
Field -- Mean	7.6	7.0	8.3	10.5	20.8	23.9	22.5	20.5	20.7
S.D.	7.3	6.6	7.3	7.7	10.1	9.8	8.4	8.1	7.6
N	112	112	112	112	112	112	112	112	112
Lab -- Mean	23.0	25.0	26.0	26.0	34.0	39.0	41.0	41.0	38.0
S.D.	3.6	2.8	2.5	3.0	3.0	2.2	2.8	3.2	3.6
N	30	30	30	30	30	30	30	30	30
Custom Type A									
Field -- Mean	9.2	8.9	8.6	10.8	23.1	27.4	27.0	20.0	17.7
S.D.	10.4	9.2	8.4	7.7	11.2	12.5	10.0	10.8	11.3
N	224	224	224	224	224	224	224	224	224
Lab -- Mean	9.3	12.9	14.4	18.6	28.5	33.0	34.9	29.3	27.3
S.D.	1.8	1.3	1.3	1.4	1.9	2.2	2.6	2.8	2.1
N	30	30	30	30	30	30	30	30	30
Custom Type B									
Field -- Mean	5.2	6.4	11.0	15.3	27.2	31.9	29.8	25.0	16.2
S.D.	7.8	5.9	6.0	6.8	7.2	6.5	7.5	6.7	6.6
N	224	224	224	224	224	220	220	220	220
Lab -- Mean	7.4	8.3	13.3	19.9	29.3	35.6	36.1	31.4	27.4
S.D.	3.8	3.9	2.2	2.6	3.0	2.6	2.6	3.0	3.5
N	30	30	30	30	30	30	30	30	30
Foam Type A									
Field -- Mean	15.0	15.0	16.1	18.2	28.3	34.9	33.2	28.8	26.5
S.D.	9.1	7.7	7.2	7.6	10.2	9.7	8.8	10.3	9.4
N	224	224	224	224	224	224	224	224	220
Lab -- Mean	29.6	31.3	34.1	34.0	35.5	40.8	41.9	39.9	39.3
S.D.	3.2	3.3	2.1	2.3	2.7	1.8	2.1	2.0	2.8
N	30	30	30	30	30	30	30	30	30
Foam Type B									
Field -- Mean	9.5	9.6	11.5	13.3	24.9	29.3	26.2	23.5	23.5
S.D.	9.8	8.8	9.2	9.1	12.0	12.1	9.5	10.4	9.7
N	224	224	224	224	224	220	224	220	216
Lab -- Mean	29.6	31.3	34.1	34.0	35.5	40.8	41.9	39.9	39.3
S.D.	3.2	3.3	2.1	2.3	2.7	1.8	2.1	2.0	2.8
N	30	30	30	30	30	30	30	30	30

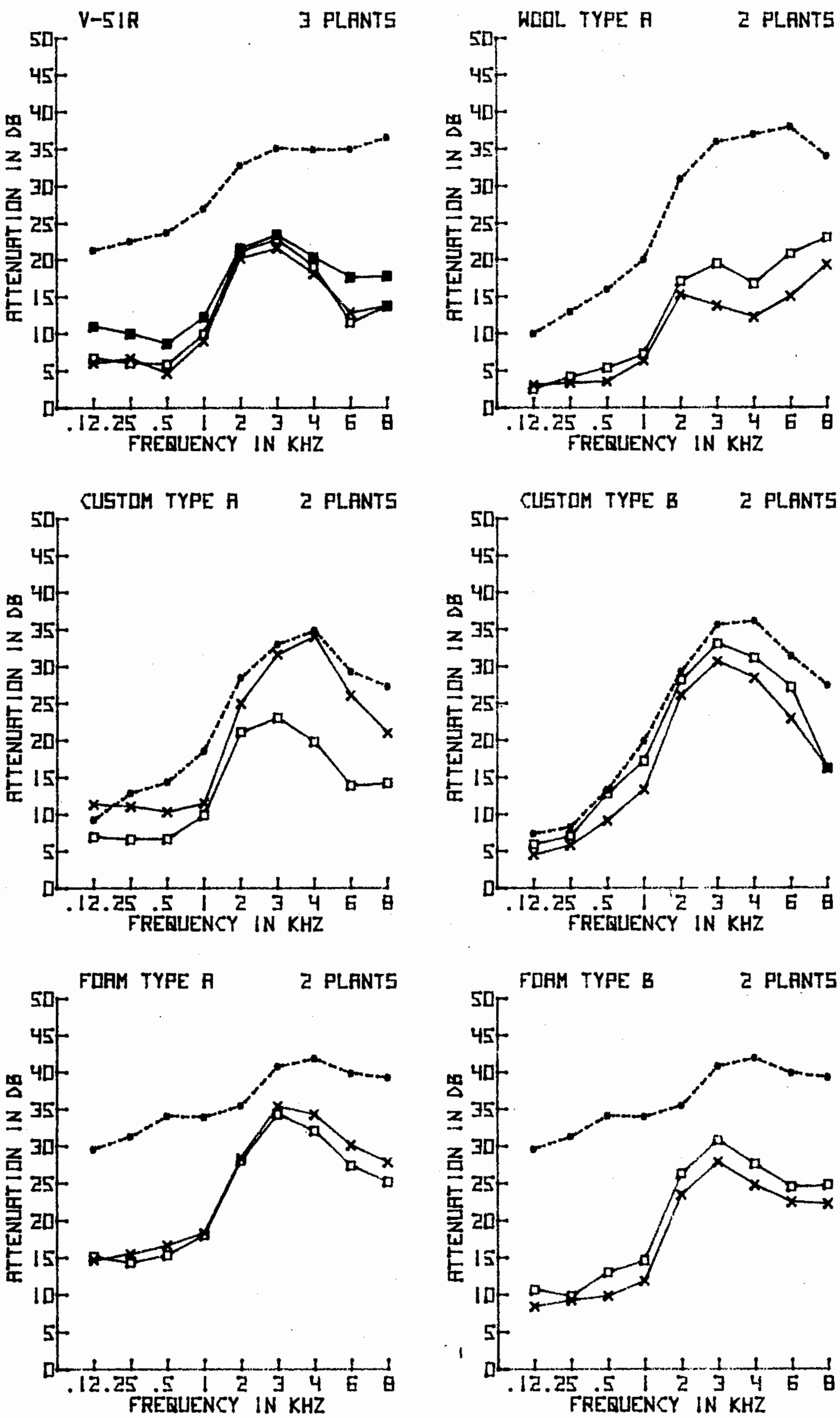

Figure 3 — Mean attenuation versus octave band center frequency for each plant of a particular earplug type tested at more than one plant (corresponding laboratory data provided by the earplug distributors are connected by dashed lines).

noise reduction values shown in Table III in the RESULTS section were estimated using the mean attenuation at each test frequency.

Results

Two-way analyses of variance indicated a statistically significant difference between the attenuation received in the first field test of all workers and in the four subsequent tests.[2,3] Although extreme care was taken to assure that the workers did not know exactly when they would be tested, the knowledge that they were to be tested apparently was enough incentive for them to wear the earplugs somewhat better than usual prior to the time of their first test. Beyond that time, apparently that initial incentive disappeared. As a result only the second through fifth tests were used in data analyses.

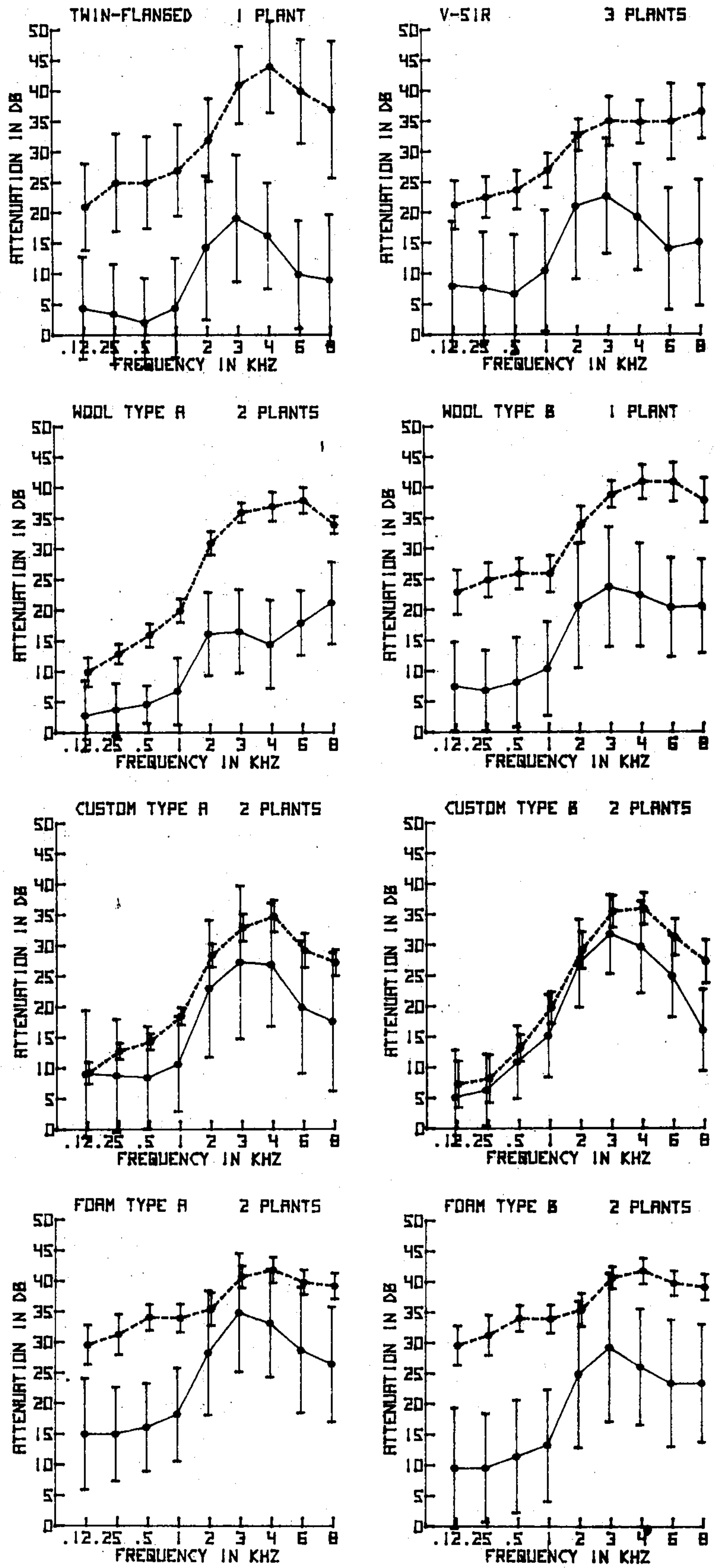

Figure 4 — Earplug attenuation versus octave band center frequency — field data (solid lines connect mean values) compared with laboratory data established by the earplug distributors (dashed lines connect mean values) — plus and minus one standard deviation shown about mean values.

Figure 3 shows mean attenuation values for workers at each plant for a particular earplug type that was tested at more than one plant. Also shown are the corresponding laboratory data provided by the earplug distributors. Clearly, the differences between plants for each earplug type are much smaller than the differences between field and laboratory results, with the exception of the results shown for three of the four plants at which custom-molded earplug types were tested. Differences in mean attenuation for the two custom-molded type A plants are large at 3150, 4000, 6300, and 8000 Hz. However, the differences between field and laboratory attenuation values are smaller for the custom-molded earplug types than for the other earplug types.

Figure 4 and Table II show the attenuation data for each of the earplug types included in the study. In Figure 4, the lower plot on each graph represents the mean and mean plus-or-minus one standard deviation for the field test data. For comparison, the upper plot is from laboratory data reported by the particular earplug distributor. In most cases these graphs reveal substantial differences in the magnitudes of attenuation values, even though the field data curves vary with frequency similarly to the curves for the corresponding earplug data established in the laboratory. Again, there does appear to be a much closer correspondence between the field and laboratory data for the custom-molded earplugs than for the other designs. With exception of the results shown for the twin-flanged earplugs, standard deviations from the field data are usually more than twice as large as those for the laboratory data.

In terms of A-weighted noise reduction, comparison of data in this study with laboratory data reported by the earplug distributors show that 50% of the workers tested were receiving less than one-half of the potential (or average) attenuation of the hearing protectors. Median noise reduction values for each earplug type are shown in Table III. The median noise reduction value from the field data versus that from the laboratory data is 13 versus 28 dB over all earplug types for all subjects tested, 7 versus 29 dB for the preformed types (twin-flanged and V-51R), 10 versus 26 dB for the acoustic wool types, 14 versus 20 dB for the custom-molded types, and 20 versus 36 dB for the acoustic foam types. From the field data, the 10% of the population noise reduction values for the acoustic wool, custom-molded, and acoustic foam earplug designs were all about 3 dB and for the preformed earplug designs were about 0 dB. Therefore, many of the workers received little or no protection using their earplugs.

Discussion

It is concluded that for any given earplug design there may well be large differences between the attenuation values as established in the laboratory and those actually being received in the industrial setting.

There are many reasons for the differences between field and laboratory results. In the case of pre-formed and user-formed earplug types, sizing, fit, and insertion are usually much less than optimum in the field, as indicated by the gross disparity between the field test results and the laboratory test results provided by the manufacturers.

For the custom-molded types, heavy reliance is placed upon the expertise of those who prepare the impression materials and form the final mold, since it is difficult for the user to wear this type improperly. The type A custom-molded protectors were fabricated by a company employee (a registered nurse in the case of the two plants of this study) who used the materials provided by the manufacturer to make a mold in each ear which was used for the final product. The "fit" of the protectors thus fabricated is dependent upon the technique of the person making the molds. This, it is thought, is the most likely cause for the large differences in data from the two plants using the custom-molded type A earplug. Such consistent differences were not observed in the data from the two plants with employees using the custom-molded type B earplugs. For this product, the impressions of a subject's external ear canals were taken first, then the impressions were sent to the manufacturer to fabricate the earplugs, apparently with more consistent results. It is important to note that, although the laboratory attenuation values for the custom-molded earplug types were smaller than those for the preformed and acoustic wool earplug types, the field attenuation values were larger.

The expandable foam earplugs, on the average, provided the greatest attenuation. However, they are usually not inserted fully, and are often not held in place during expansion to prevent outward slippage. The distributor's instructions for the type A foam earplugs specified that following insertion, each earplug be held in place for one minute; the distributor's instructions for the type B foam earplugs did not specify this time period. Although both distributors provided the same laboratory test results (established by the manufacturer who makes both foam types), the results obtained in the field were somewhat better for workers who used the type A foam earplugs. Although with long-term usage workers do not regularly read or necessarily follow the insertion instructions, it is possible that the time factor

TABLE III
Median A-Weighted Noise Reduction (Assuming "Pink Noise" Conditions)

Earplug Type	Field (dB)		Lab (dB)	
Twin-flanged	3		30	
V-51R	8		29	
Twin-flanged and V-51R		7		29
Acoustic Wool Type A	9		22	
Acoustic Wool Type B	11		30	
Acoustic Wool Types A and B		10		26
Custom-molded Type A	12		20	
Custom-molded Type B	15		19	
Custom-molded Types A and B		14		20
Acoustic Foam Type A	21		36	
Acoustic Foam Type B	17		36	
Acoustic Foam Types A and B		20		36

specified for installing the type A foam earplugs had some lasting effect, *i.e.*, perhaps more time was spent inserting the earplugs to lessen the need to spend time holding them in place.

In all cases, comfort and awareness of the hazard of hearing loss plays the major role in the incentive of the user to properly use hearing protectors. Regardless of the type of earplug used by a particular plant, a large portion of the workers received little or no attenuation. Allowance for a worker to obtain the type of earplug that is properly suited to his ear canals and that he is willing to wear properly is crucial.

In the majority of cases, workers received less than one-half of the potential attenuation of the earplugs. More time must be spent educating employees on the proper use of their hearing protection devices. Any of the hearing protection devices included in this study potentially can provide large amounts of attenuation, if proper usage and fit can be instituted and maintained. Time spent educating and monitoring employees is certainly the key aspect of a hearing conservation program.

These findings should be considered by those responsible for choosing earplugs for their employees. Serious underprotection from the established hazards of excessive noise exposure could result easily if one assumes that the users will be receiving the laboratory-established attenuation levels.

Acknowledgements

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References

1. **U.S. Department of Labor, Hearing Conservation Amendment (1910.95).** *Federal Register*, V46, N162, pp. 42633-42638 (August 21, 1981).
2. **Edwards, R.G., W.P. Hauser, N.A. Moiseev, A.B. Broderson, W.W. Green and B.L. Lempert:** *A Field Investigation of Noise Reduction Afforded by Insert-type Hearing Protectors.* HEW Publication No. (NIOSH) 79-115. Cincinnati, OH (1978).
3. **Edwards, R.G., A.B. Broderson, W.W. Green and B.L. Lempert:** *A Second Field Investigation of Noise Reduction Afforded by Insert-type Hearing Protectors.* NTIS No. 83-138768. National Institute for Occupational Safety and Health, Cincinnati, OH (1982).
4. **American National Standards Institute:** *American Standard Method for the Measurement of the Real-ear Attenuation of Ear Protectors at Threshold.* ANSI Z24.22-1957. Acoustical Society of America, New York, NY (1957).
5. **American National Standards Institute and Acoustical Society of America:** *Standard Method for the Measurement of Real-ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs.* ANSI S3.19-1974 and ASA STD 1-1975. Acoustical Society of America, New York, NY (1975).
6. **Padilla, M.:** Ear Plug Performance in Industrial Field Conditions. *S/V 10*:33-36 (May, 1976).
7. **Regan, D.E.:** Real-ear Attenuation of Personal Ear Protective Devices Worn in Industry. *Audiology and Hearing Education*, pp. 16-18, (December/January, 1977).
8. **Flugrath, J.M. and J.B. Turbeville, Jr.:** The Effectiveness of Earplugs. *S/V 6*:32-33 (May, 1972).
9. **Botsford, J.H.:** Ear Protectors — Their Characteristics and Uses. *S/V 6*:24-29 (November, 1972).
10. **Michael, P.L., R.L. Kerlin, G.R. Bienvenue, J.H. Prout and J.I. Shampan:** *A Real-ear Field Method for the Measurement of the Noise Attenuation of Insert-type Hearing Protectors.* HEW Publication No. (NIOSH) 76-181. Cincinnati, OH (1976).
11. **Kroes, P., R. Fleming and B. Lempert:** *List of Personal Hearing Protectors and Attenuation Data.* HEW Publication No. (NIOSH) 76-120. Cincinnati, OH (1975).

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