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THE EFFECTS OF EXPERIMENTER VERSUS SUBJECT FIT AND SUBJECT TRAINING ON HEARING PROTECTOR ATTENUATION

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ABSTRACT

THE EFFECTS OF EXPERIMENTER VERSUS SUBJECT FIT AND SUBJECT TRAINING ON HEARING PROTECTOR ATTENUATION

By

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In 1979, the Environmental Protection Agency ruled that all domestic hearing protection devices (HPDs) must bear a single number index of effect designated Noise Reduction Rating (NRR). The literature indicates the NRR is of questionable reliability and validity. This study investigated the effects of subject training and HPD fitting method upon NRR and real-ear attenuation at threshold.

Subjects were forty bilaterally normal-hearing listeners. Pre- and post-tests assessed the effects of a training program and attenuation measurements were made in general accord with ANSI S3.19-1974 at each of nine noise bands. NRRs were computed per EPA (1979).

Results showed that: (1) the training program provided significant information gain; (2) experimenter fit produced slightly (but not significantly) greater attenuation than subject fit; (3) training had no impact on mean attenuation; and (4) measured NRRs were considerably smaller than manufacturer's data.

To accomplish great things,
we must not only act,
but also dream,
not only plan,
but also believe.

-Anatole France

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INTRODUCTION

BACKGROUND

It is well known that excessive noise can damage the human auditory system. Such damage can occur in any of three ways (Melnick, 1978). A noise-induced temporary threshold shift (NITTS) is an observed change in hearing threshold level (HTL) which is reversible and recovers after a certain period of time following exposure. Recovery depends upon a variety of factors including the characteristics of the noise, the frequency of the measured NITTS and the amount of time between the termination of exposure and when threshold is measured. Noise-induced permanent threshold shift (NIPTS) occurs when excessive noise exposure is chronic over a period of years. The associated hearing loss does not reverse. The relation between NITTS and NIPTS varies greatly among individuals; consequently, there is no accurate way to predict who will be affected by intense noise or how much damage will occur. Acoustic trauma, a third type of auditory damage, is a loss of sensitivity following a single exposure to extremely intense sounds such as an explosion. The traumatic event produces destruction of hair cells in the organ of Corti and generally some permanent hearing loss results.

Damaging noise is prevalent in industrial environments. Protection from the harmful effects associated with intense noise ideally should focus on prevention. When appropriate administrative and engineering controls cannot sufficiently decrease noise to acceptable levels, however, personal hearing protection devices should be employed. Hearing protection devices can be classified into four general categories: helmets, ear canal caps, earmuffs and insert earplugs. There are over 200 different brands of devices commercially available, and it is reported that insert earplugs are the most popular (Smith and Borton, 1981). Hearing protection devices function to block the external auditory canal, thereby decreasing the sound pressure level (SPL) reaching the inner ear.

Several different methods for measuring hearing protection devices have been proposed and utilized (Nixon, 1982). These include:

(1) Real Ear Attenuation at Threshold;
(2) Loudness Balance;
(3) Temporary Threshold Shift;
(4) Aural Reflex;
(5) Subjective Comparison;
(6) Miniature Microphone;
(7) Masked Threshold;
(8) Hearing Loss for Speech; and
(9) Cadaver Measurements.

Each of these methods presents advantages and disadvantages.

Prior to 1979, the effectiveness of hearing protection devices was evaluated behaviorally by an absolute threshold shift procedure (Berger, 1980a) whereby unoccluded thresholds were subtracted from occluded thresholds. These attenuation values were utilized to numerically describe the amount of protection from noise the wearer could expect to receive. In September, 1979, the Environmental Protection Agency (EPA, 1979) specified that all domestic hearing protection devices must bear a label containing a single-number estimate of effectiveness. This estimate is designated "Noise Reduction Rating" (NRR).

The purpose of the NRR is to provide a simple basis for predicting protection in noisy environments and to allow comparison of the effectiveness of different protective devices. The NRR indicates the noise attenuation capability of a hearing protection device, weighted by an assumed noise spectrum and the statistical variations in band attenuation data obtained from a group of trained listeners (Juneau, 1982). For example, if a hearing protection device has an NRR of 25 dB, the average worker wearing the device should be able to expect that the SPL reaching the hearing mechanism is to be reduced by 25 dBA.

Enforcement of the EPA (1979) regulation specifically involves:

(1) label verification testing and reporting for each protection device in a manufacturer's product line;

(2) the monitoring of products by random selection for testing;

(3) audit testing of products by manufacturer's to insure that products comply with labeled values; and

(4) remedial orders if noncompliance occurs.

REVIEW OF THE LITERATURE

Federal Regulation of Noise

Federal laws governing occupational noise exposure and control began with the regulations issued under the authority of the Walsh-Healey Public Contracts Act Amendment of 1969. The Walsh-Healey Act specified that industrial noise must be controlled "to minimize fatigue and industrial accidents," provided a table of permissable noise exposure levels (90 dBA limit for 8-hours exposure), and specified the use of engineering and administrative controls to reduce hazardous noise levels. The Act was applicable to all industries with governmental contracts exceeding $10,000.

The Occupational Safety and Health Act was passed in 1970. This Act established the Occupational Safety and Health Administration (OSHA) and extended federal authority for industrial noise control to all industries involved in interstate commerce. The Act set standards for appropriate hearing conservation programs for employees when noise levels exceeded the permissable levels. An exposure limit was established at 90 dBA (slow) of steady state noise for 8-hours duration. The Act also created the National Institute for Occupational Safety and Health (NIOSH) which was authorized to "develop and establish recommended safety and health standards." In 1972, NIOSH published a criteria document which recommended a permissable noise exposure time-weighted average limit of 85 dBA for 8-hours of exposure.

EPA, 1979

As previously stated, the Environmental Protection Agency (EPA, 1979) specified that labels of all domestic hearing protection devices must bear an NRR. The behavioral test methods underlying the EPA's (1979) NRR are described in American National Standards Institute (ANSI) S3.19-1974 "Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs." ANSI S3.19-1974 specifies that for each device which is evaluated, ten trained, normal-hearing subjects shall be tested three times each with an unoccluded ear and with the hearing protection device fit by the experimenter or the subject. Although ANSI allows either experimenter or subject fit, EPA (1979) requires experimenter fit for determination of a devices NRR. Measurements are to be obtained in a laboratory setting in a diffuse (reverberant) sound field and test signals are to be third-octave bands of noise with center frequencies ranging from 125 Hz to 8000 Hz. Martin (1982) explains that 1/3-octave bands of noise

> ...represent a reasonable compromise between the need for frequency-specific attenuation data and the practical noise environment. The diffuse soundfield...ensures that sound is incident upon the protectors under test from all directions, as is usually the case in industry (p. 277).

Attenuation is determined by subtracting unoccluded audibility thresholds from occluded audibility thresholds. The NRR is then calculated from mean and standard deviation information generated from these values.

Table 1.1 shows a sample calculation of NRR (Michael and Bienvenue, 1980). Line 1 of the sample calculation is the assumed pink noise (equal SPL per octave) exposure level for octave band center frequencies 125-8000 Hz. Line 2 gives the adjustments for the "C"-weighted levels by which the pink noise octave band levels must be modified to yield a corresponding wide band level. The C-weighting network is a band-pass filter roughly equal to the inverse of the mean equal-loudness contour for normal ears at 70 phon. Line 3 is the algebraic difference between lines 1 and 2. These differences are summed logarithmically across frequency to yield a C-weighted, wide-band level. Line 4 gives the "A"-weighting adjustment values. The A-weighting network is a band-pass filter approximating the increase of the mean equal-loudness contour for normal ears at 40 phon. Line 5 gives the unprotected ear "A"-weighted levels which is calculated by subtracting the "A"-weighting adjustments from the assumed pink noise levels. Lines 6 and 7 give the mean and standard deviation values for a particular hearing protector as generated by the ANSI S3.19-1974 methodology. Line 8 gives the protected ear weighted levels. These values are obtained by subtracting the mean attenuation values from the unprotected ear "A"-weighted levels, then adding the doubled standard deviations. Thus, standard

Table 1.1. Sample calculation of the noise reduction rating (Michael and Bienvenue, 1980, p. 545).

	Octave Band Center Frequency in Hz						
	125	250	500	1000	2000	4000[a]	8000[b]
1. Assumed Pink Noise levels in dB	100	100	100	100	100	100	100
2. "C"-weighting adjustments in dB	0.2	0	0	0	-0.2	-0.8	-3.0
3. Unprotected ear "C"-weighted levels; line 1 - line 2 in dB	99.8	100	100	100	99.8	99.2	97.0
						Σ = 107.9 dB[c]	
4. "A"-weighting adjustments in dB	-16.1	-8.6	-3.2	0	+1.2	+1.0	-1.1
5. Unprotected ear "A"-weighted levels; line 1 - line 4 in dB	83.9	91.4	96.8	100	101.2	101	98.9
6. Mean attenuation in dB at frequency	12	17	25	33	34	42	25
7. Standard deviations in dB times 2	4	6	8	10	10	4	4
8. Protected ear weighted levels; line 5 - line 6 + line 7 in dB	75.9	80.4	79.8	77.0	77.2	63.0	77.9
						Σ = 86.1 dB[c]	
9. NRR = Σ line 3 values - Σ line 8 values - 3 dB. NRR = 107.9 - 86.1 - 3 = 18.8 dB.							

[a] Average of 3000 and 4000 Hz values

[b] Average of 6000 and 8000 Hz values

[c] Use logarithms to determine dB sums

deviations of measured group attenuation "derate" mean attenuation values, resulting in a nominally more conservative index of effect. The resultant protected ear weighted levels are then summated logarithmically. The NRR is calculated as the decibel summation of the protected ear weighted levels subtracted from the decibel summation of the unprotected "C"-weighted levels. Three decibels (for spectral uncertainty) is subtracted from this result, and the NRR for a given hearing protection device is obtained.

OSHA, 1981

In January, 1981, the Occupational Safety and Health Administration (OSHA) issued for public comment a hearing conservation amendment to its original occupational noise standard. The purpose of this amendment was "to prevent occupationally related cases of hearing impairment" (OSHA, 1981a, p. 4105). The regulation mandated a hearing conservation program for all employees exposed to a time-weighted average noise level of 85 dBA in an 8-hour duration. "Hearing conservation included noise exposure monitoring, audiometric testing, the use of hearing protective devices where necessary, and employee education" (OSHA, 1981a, p. 4079). OSHA (1981a) mandated the use of hearing protection devices for all employees exposed to 90 dBA or more of steady state noise during 8-hours of exposure where appropriate administrative and engineering controls are not able to reduce noise to acceptable levels. Further, hearing protection devices must be <u>provided</u> to all employees exposed to time-weighted average noise levels of 85 - 90 dBA, but only those employees exhibiting a significant threshold shift are required to wear them.

OSHA (1981a) specified that training programs be implemented for all employees exposed to 85 dBA or more of noise. Training programs are to be repeated annually and must address the following issues:

(1) The contents of the noise standard including the hearing conservation program;

(2) the effects of noise on hearing;

(3) specific machinery at the jobsite that could produce hazardous noise exposures;

(4) the role of engineering and administrative controls in the reduction of noise exposure;

(5) the contents of any noise control compliance plan in effect;

(6) the purpose of hearing protectors, the advantages, disadvantages, and attenuation of various types, and instructions on selection, fitting, use and care; and

(7) the purpose of audiometric testing, and an explanation of test procedures (p. 4164).

Finally, OSHA (1981a) mandated the use of the EPA (1979) regulation. Although several provisions of the original amendment (OSHA, 1981a) were not implemented, the bulk of the hearing conservation amendment was put into effect in August, 1981 (OSHA, 1981b). A final rule was issued by OSHA in March, 1983 (OSHA, 1983).

Interlaboratory Differences in Measured Attenuation

Berger, Kerivan and Mintz (1982) reported results found in an EPA funded inter-laboratory comparison. Eight

U.S. test laboratories were required to obtain attenuation data (re: EPA, 1979 and ANSI S3.19-1974) on four types of hearing protection devices. The NRR values were also calculated. The results indicated differences in mean and standard deviations among laboratories, probably attributable to differences in hearing protector fitting, subject selection, subject training and data reduction techniques.

Although not stated in this report, several other explanations for the inter-laboratory differences are possible. These include:

(1) departures from specified acoustical properties (spatial, spectral, and temporal) of signal sources and test environments;

(2) variations within acoustical specifications of signal sources and test environments;

(3) differences in the accuracy and precision of signal sources and test environments;

(4) variations in acoustical factors not currently covered by the EPA and ANSI documents;

(5) variations in subjects' threshold criteria and training; and/or

(6) variations in psychophysical measurement methods affecting the precision of attenuation measurements (e.g., step size).

Berger, Kerivan and Mintz concluded that:

> The results...do not cast aspersions on the NRR per se, but rather on the data from which the NRR is computed. The results do show, however, that application of any one set of laboratory data to a real world environment for the purposes of predicting an estimated protected noise exposure is a tenuous proposition at best... optimal attenuation values are of little use to designers, purchasers, or users who need some indication of the protection that hearing protection devices can normally be expected to provide (p. 18).

Forshaw (1982) states several explanations for why variations occur from laboratory to laboratory. First, the standards (ANSI S3.19-1974 and EPA, 1979) are not sufficiently explicit on the selection of subjects and on the fitting procedures of the hearing protection devices for testing. Second, it is stated that there are sources of variance inherent in the real-ear threshold method of measurement. Third, the attenuation of protectors depends on factors such as size and shape of the external auditory canal and of the contours of the circumaural region of the head. Fourth, inter-subject differences may be significant from laboratory to laboratory when only ten subjects are used. Finally, shifts in a subject's attention span and his/her signal detection criterion may be a source of error because of the difficult listening task employed.

Laboratory versus Field Data

The validity of the NRR is open to question. Although the NRR is intended to describe the overall attenuation characteristics of a protection device, measurements are obtained under optimal conditions. It is obvious that industrial field environments differ significantly from laboratory environments. Therefore, laboratory measurements of hearing protection devices may not accurately reflect effectiveness of the device in the industrial field setting. Several studies have supported this contention.

Padilla (1976) compared the attenuation characteristics of earplugs in controlled laboratory environments and in uncontrolled industrial environments. Subjects for this study were industrial workers who routinely performed noisy tasks and who were required to wear hearing protection devices. The subjects were divided into two groups: group A subjects were brought into the laboratory for testing; group B subjects were tested in the field. Results indicated that (1) some individuals were adequately protected but many were not; (2) overall mean attenuation for the field testing was only 12 dB at 500 Hz (pure tone signal simultaneously directed to both ears); (3) individually fitted earplugs were more effective than pre-sized earplugs; and (4) the degree of protection is influenced by the fitting technique. Padilla stated:

> ...when the subjects know that their earplugs are going to be tested and that the test is only going to take a few minutes, they are apparently further motivated and a better effort is made to obtain proper earplug placement. This may indicate that perhaps other types of motivation, enforcement, etc. need to be investigated (p. 35).

Padilla concluded that laboratory data do not accurately represent field performance and that a significant number of employees were unprotected from hazardous noise in industrial settings.

Regan (1977) obtained attenuation data for earplugs on 32 subjects employed by a steel stamping company. This study sought to determine whether manufacturers' attenuation results accurately reflected the actual attenuation provided by hearing protection devices in industrial work environments. The study also compared attenuation values between various types of protection devices. All subjects routinely used hearing protection devices. Four types of devices were used: (1) malleable, soft sponge inserts, (2) non-malleable rubber inserts, (3) custom-fitted earplugs, and (4) earmuffs. Data were collected by escorting subjects directly from their work stations to an audiometric test van near the plant. Escorts were provided to insure that no manipulation of the hearing protection device took place. Subjects were tested four times each during a two-week period utilizing the test method described in an earlier version of ANSI S3.19-1974 (ANSI Z24-22-1957). Results indicated that the attenuation provided to these industrial workers was significantly less than that specified by the manufacturers. Results further indicated that custom-fitted earplugs offered the least amount of attenuation and malleable sponge inserts offered the greatest attenuation. Regan concluded that these hearing protection devices provided an inefficient means of protecting employees from hazardous noise.

Michael, et al. (1976, as cited in Edwards, et al., 1978 and in Michael and Bienvenue, 1980) developed a field test method and a special headphone system for measuring attenuation characteristics of hearing protection devices. The field test method was designed to document the variability of hearing protector performance in the industrial environment; it was not designed to replace the ANSI S3.19-1974 method. The study provided a means of correcting attenuation measurements made in the field to values that would have been obtained in the laboratory.

Edwards, et al. (1978) studied the attenuation characteristics of three types of earplugs on 168 workers from six industrial sites. Subjects were tested five times each over a period of five days. Subjects were randomly selected for testing from their work sites and escorted to an audiometric test van near the plant. This study utilized the field test method described by Michael, et al. (1976) and subject fit of the hearing protection devices. It was found that on the average, industrial employees received only 33 - 54% of the maximum protection afforded by the devices. Results further indicated that when the attenuation corrections suggested by Michael, et al. (1976) were employed, field results more closely compared to laboratory results. These researchers recommended that: (1) additional testing of industrial employees using other types of hearing protection devices is needed; (2) additional research is needed to determine why hearing protection devices are not correctly attenuating noise; and (3) attenuation values provided by manufacturer's should be decreased by 60% to reflect realistic values for protection in industrial work settings.

Alberti, et al. (1979) evaluated the attenuation characteristics of three types of earplugs and a group of assorted earmuffs on 88 industrial workers. These subjects were required to fit the protector to themselves. Open and occluded thresholds were obtained using 1/3-octave bands of noise at center frequencies ranging from 125 - 6000 Hz. Testing was conducted in a free-field sound proof booth utilizing a psychophysical method of limits. Mean attenuation for each group of hearing protectors was computed by subtracting unoccluded thresholds from occluded thresholds.

Results indicated that attenuation increased with frequency for each type of device through 3000 Hz. Above 3000 Hz, some dropoff in attenuation was noted. At 125 and 250 Hz, the earplugs provided greater attenuation, however, above 250 Hz, the earmuffs provided significantly more attenuation than the earplugs. Custom molded earplugs provided considerably less attenuation across all frequencies. Large standard deviations were also found. Attenuation values were found to be less than values given by the manufacturers of the protection devices.

These results are consistent with those of similar studies indicating that attenuation of hearing protection devices in industry is considerably lower than manufacturer's-laboratory data would suggest. The reasons cited for these differences relate to fit of the devices.

Berger (1982) reports results of a similar study. Sixty-five randomly selected, untrained persons served as subjects. Subjects were screened otoscopically and administered a battery of four tests: These were

(1) pure tone unoccluded thresholds under earphones;

(2) 1/3-octave band unoccluded thresholds in a diffuse soundfield;

(3) 1/3-octave band occluded (subject fit) thresholds in a diffuse soundfield; and

(4) 1/3-octave band occluded (experimenter fit) threshold measures in a diffuse soundfield.

Test conditions (2), (3), and (4) were conducted in accordance with ANSI S3.19-1974 with the exception that subjects were tested only once. Testing was conducted in the order outlined above. An insert type protector was used.

Results indicated significantly poorer attenuation below 2000 Hz of the subject fit group. Comparison was made of the untrained experimenter fit group and ten trained subjects with experimenter fit of the device. Attenuation results were similar. Berger also compared two previous field studies, manufacturers' data, and data from the subject fit group of this study. Subject fit data were very similar to the data from the two in-field studies. Manufacturers' label attenuation results were significantly better than these three groups.

It can be concluded from these results that laboratory test methods utilizing subject fit of hearing protection devices may yield attenuation values which are in better agreement with attenuation values obtained in the field.

Abel, Alberti and Riko (1982) studied the attenuation of six types of earplugs and four types of earmuffs on 347 industrial employees. Subjects were required to fit their own protectors without instruction. One-third octave bands of noise were employed and testing was conducted in a sound treated booth. The psychophysical method of limits was used for all threshold estimates.

Results indicated a wide variation in attenuation values within and between hearing protector types. These attenuation values were significantly less than the manufacturers specified values. The primary reason cited for these differences relates to fit of the protector. In the industrial field environment, hearing protection devices are often improperly worn, and therefore may not provide sufficient protection from harmful noise.

Martin (1982) compared attenuation data from experimenter fit and subject fit conditions for a pre-molded plastic earplug. The number of subjects and exact test conditions were not specified; it was stated that a real-ear threshold method similar to the ANSI standard was employed. Table 1.2 shows the mean and standard deviation values for these test conditions.

Martin found that the experimenter fit situation results in significantly higher mean attenuation values and significantly lower standard deviation values then the subject fit group. He concluded that subject fit produces attenuation measurements which more closely approximate real world performance than does experimenter fit.

Berger (1983) reviewed data from ten studies published since 1975. Table 1.3 summarizes his findings for 1551

Table 1.2. Mean and standard deviation values of attenuation of earplugs, in decibels. From Martin (1982).

		Test Frequency in Hertz							
		250	500	1k	2k	3.1k	4k	6.3k	8k
Experimenter Fit	$\bar{X}$	25.1	25.8	29.1	34.1	38.6	34.7	32.3	30.9
	SD	4.3	4.9	3.7	4.3	5.6	5.7	6.0	5.8
Subject Fit	$\bar{X}$	16.9	16.4	18.8	24.0	30.0	28.4	28.1	29.7
	SD	9.3	12.1	8.4	7.8	9.9	8.1	11.3	10.5

Table 1.3. Summary information from 10 real-world studies. From Berger (1983).

Device	Test Type[a]	No. of Subjects	NRR_{84}
Foam Plug	1	58	19
(EAR and Decidamp)	3	24	9
	3	55	9
	1	56	5
	1	56	12
	1	31	9
Custom Molded	1	7	7
	1	6	4
	1	230	8[b]
	3	48	3
	1	56	8
	1	44	4
Willson EP100	1	22	0
	1	28	-2
	3	45	10
V-51R	1	9	7[b]
	1	183	-1[b]
	1	84	1
	3	20	2
MSA Accu-Fit	1	13	2[b]
Norton Com-Fit	3	18	7
Bilsom Fiberglass (down)	1	56	3
(down)	1	28	4
(POP)	1	28	4
(soft)	1	36	1
David Clark	3	17	15
Safety Supply # 258	3	15	12
Hellberg MK-IV	3	58	11
MSA MK IV	3	47	11
	2	15	4
Welsh 4530	1	5	20
Earmuffs[c]	2	101	14[b]
AO 1720	2	11	7
Glendale 900	2	10	10
Bilsom UF-1	1	31	13

Total Subjects = 1551

---

[a] Test types are: 1. Real-ear attenuation at threshold with employees pulled from work stations; 2. Dosimeter mics inside and outside earmuff on employees in work place; 3. Real-ear attenuation at threshold with employees reporting to outside test clinic and using their HPDs as normally worn.

[b] NRRs estimated from measured dBA noise reduction or from attenuation data at only 500 or 1000 Hz.

[c] No model was specified since many different models were used.

total subjects, 50 different industrial sites, and several types of hearing protection devices (Berger, 1983, p. 13). The designation NRR_{84} indicates NRR calculations based upon a single standard deviation correction factor, which suggests that 84% of a normal population would be expected to produce NRR values equal to or larger than the data shown. Berger contends that this is a more valid estimate than the EPA procedure which employs a correction factor of two standard deviations to describe expectations for 98% of the normal population. As is evident in Table 1.3, the NRR_{84} values range from 0-20 dB indicating a very wide range of protection in the industrial environment.

Table 1.4 (Berger, 1983, p. 14) compares the field NRR_{84} to the manufacturer listed NRR_{98} for the same 1551 subjects. These data clearly indicate that employees are receiving significantly less protection in the industrial field environment than manufacturers' (laboratory) data would suggest.

Berger concluded that the NRR can be a practical and suitable estimate of noise reduction if some changes are made. He suggests that 10 dB be subtracted from labeled NRRs before being subtracted from C-weighted sound levels and that improved motivation, training and supervision take place in the field to insure proper use of hearing protection.

The above research indicates that laboratory test results relate poorly to field test results. Berger (1980b) cited several observations related to the issue of laboratory

Table 1.4. Summary of labeled vs. real-world performance. From Berger (1983).

Device	No. of Subjects	NRR_{98}	NRR_{84}	Δ
Foam Plug	280	29	11	18
Custom Molded	391	14	6	8
Willson EP100	95	15	3	12
V-51R	296	23	2	21
MSA Accu-Fit	13	14	2	12
Norton Com-Fit	18	26	7	19
Bilsom Fiberglass	148	22	3	19
EARPLUGS (AVERAGE)	1241	20	5	15
David Clark	17	23	15	8
Safety Supply #258	15	22	12	10
Hellbert MK-IV	58	23	11	12
MSA MK IV	62	23	8	15
Welsh 4530	5	25	20	5
Genrl. Muffs	101	22	14	8
AO 1720	11	25	7	18
Gelndale 900	10	22	10	12
Bilsom UF-1	31	22	13	9
EARMUFFS (AVERAGE)	310	23	12	11
GRAND AVERAGE	1551	22	9	13

versus real-world performance of hearing protection devices:

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

Sources of Variation in Laboratory and Field Data

It has been established that laboratory performance of hearing protection devices differs significantly from real-world performance. Several explanations for this difference are possible. All relate to the required NRR measurement technique.

First, the measurement method (EPA, 1979; ANSI S3.19-1974) specifies that all measurements be obtained in a diffuse (reverberant) sound field. Such a controlled acoustic environment produces optimally stable results. Industrial environments almost certainly do not conform to such a field; thus there may be interactions among acoustic fields, bodies, and hearing protection devices themselves. This is a source of variance which is expected to have an impact on the effectiveness of hearing protection devices in industrial environments. Related to this issue is the mobility of the subject. NRR test subjects must be seated quietly and are immobile for relatively long periods of time; industrial workers generally move about during a work day. In the field, workers will perspire and engage in various jaw motions (i.e., talking, chewing, etc.) which may influence the fit of hearing protectors. Consequently, industrial workers may, without realizing it, displace or inappropriately adjust the hearing protection device, thereby decreasing its attenuation characteristics.

Related to this issue are possible changes in the threshold criteria of workers tested in field settings. Industrial workers are not trained listeners and it is expected that trained laboratory subjects would exhibit more stable results during testing. Published reports of field tests tend not to provide the control condition data necessary to allow assessment of this effect.

A second explanation relates to psychophysical method of measurement. ANSI S3.19-1974 does not specify the psychophysical method to be used for testing hearing protection devices. Different psychophysical measurement methods produce different variances (Gescheider, 1976). For example, the method of adjustment generally produces smaller standard errors of measurement than other psychophysical methods. Because a related index of dispersion is used in the computation of the NRR, different psychophysical methods of measurement would be expected to produce different estimates of NRR.

The laboratory that provides the majority of NRR testing (Pennsylvania State University) employs a method of adjustment; published reports of field tests most often indicate use of a modified method of limits. Other psychophysical method variables influencing outcomes (both in terms of precision and variance) include attenuation step size, the direction of signal level change (increasing or decreasing level), and the number of threshold crossings used to estimate threshold for a given frequency or noise band.

Humes (1983) obtained attenuation values of ten hearing protection devices (5 earmuffs, 5 earplugs) utilizing four psychophysical measurement methods. Ten normal hearing young adults served as subjects. Each subject was tested for all ten protection devices and each of the four psychophysical procedures. One-third octave bands of noise were presented in a diffuse soundfield in accordance with ANSI S3.19-1974. The four psychophysical procedures utilized were:

(1) the real-ear threshold procedure described in ANSI S3.19-1974 utilizing a transformed up-down method (Levitt, 1971);

(2) the magnitude-estimation procedure for loudness (Stevens, 1975) which produced unprotected and protected loudness growth functions;

(3) the reaction-time paradigm whereby protected and unprotected reaction-time intensity functions were compared; and

(4) the masked bone-conduction threshold procedure whereby the mean of the unprotected masked thresholds were subtracted from the mean of the protected masked threshold.

Procedures (2), (3), and (4) used 1/3 octave bands of noise having intensity levels ranging from 50 - 90 dB SPL to evaluate the protection devices. This allowed for the assessment of attenuation linearity of hearing protection devices.

Attenuation results were computed for each subject and for each device across each psychophysical procedure. Results for noise levels ranging from 50 - 90 dB SPL showed that attenuation was linear over this range. Linearity of hearing protection devices could not be assessed at levels above 90 dB SPL, and it was suggested that a method be devised to do this as industrial noise levels often exceed this level and protection at these levels need to be determined.

Humes stated that the preferred method of determining attenuation characteristics of hearing protection devices is the real-ear method. The magnitude estimation and reaction-time procedures tended to underestimate attenuation when compared to other procedures. The reaction-time paradigm was found to be the most difficult to implement and the most time consuming and therefore not recommended. It was recommended that the masked bone conduction technique be incorporated into the ANSI standard to assess attenuation at high intensity levels.

Attenuation results from this study were compared to data from other studies. It was found that manufacturers' attenuation data were considerably higher than attenuation data obtained from this study, regardless of the psychophysical procedure used. Humes concluded that "...manufacturer's specifications of attenuation characteristics are often optimal as opposed to typical characteristics" (p. 310).

The EPA (1979) specifies that NRR measurements are to be made with the device fit by the experimenter according to the manufacturers specifications. It has been suggested that experimenter fit relates poorly to subject fit (Juneau, 1982; Smith and Borton, 1981; Berger, 1980c). This may be the single most important reason why attenuation data obtained in the laboratory do not compare to attenuation data obtained in industrial field environments. Smith, et al. (1980) as cited in Smith and Borton, 1981) had 100 adult subjects choose the 'best fitting' earplugs for both ears. Results indicated that 68% of the subjects chose earplugs which were too small. Smith, et al. concluded that industrial employees may have the same problem when fitting themselves with ear protection. Smith and Borton (1981) state that little research has accurately addressed this issue. The laboratory test situation requires careful fit and adjustment of the hearing protection device and for this reason, optimal attenuation is obtained. This may not be the case in industrial work environments. Because of poor comfort, motivation or training, hearing protection devices may be inappropriately fit, thus decreasing their effectiveness (Berger, 1980c). Another cause of poor fit may be due to readjustment of the protection device throughout the duration of the work day. As stated, jaw movement can displace the device causing poor fit and protection.

A final issue with regard to experimenter versus subject fit is interaction with the type of protector. Because of the ability to visually observe placement, experimenters would be expected to accomplish more consistent positioning than subjects of earmuffs. Because of the ability to tactually observe placement, subjects (especially trained or experienced ones) would be expected to accomplish more consistent positioning of insert protectors.

Closely associated with the issue of experimenter versus subject fit is the issue of the effect of training of subjects when obtaining NRR data. Optimal laboratory data are obtained through the training of subjects. This is done to minimize response errors and is accomplished through the use of a response consistency criterion. Additionally, the NRR measurement technique utilizes trained and motivated subjects who are knowledgeable about the purpose and function of hearing protection devices. The issue is between the goals of stable (reliable) measurements and accurate (predictively valid) measurements. Laboratory methods, with their attempts to minimize variations from sources other than the hearing protector, approximate the former through procedural control. In so doing, they may accomplish reliability at the expense of validity.

Tobias (1982) summarized many of the issues raised above:

> Manufacturers, who are paying laboratories to run these tests for them, clearly should prefer measurers who come out with the best results--

> the better the measured attenuation two standard deviations below the mean, the better their hearing protector's Noise Reduction Rating. Anything that improves the mean such as selecting only the best subjects and making the best possible fittings of the protectors, and anything that decreases the size of the standard deviation, such as homogenizing the population of test subjects, will lead to good scores. Manufacturers should be pleased. But the ultimate users probably should not. Those scores no longer serve the purpose that the Environmental Protection Agency must have intended. When variability is artificially decreased, one no longer has a reasonable basis for judging how well a given device will work on the person at the second percentile among wearers of that device. These labs are doing everything strictly according to the standard. They are not cheating. They are not changing the rules. Yet when they publish data, they show ratings at the mean that are often very close to the ratings one or two standard deviations below the mean. By compressing the range of normal variations, they give attenuation values that say nearly nothing about real-world variability. As a result, one begins to believe that their data are no more informative than if they had been collected on a single subject...Measurers of hearing protectors need to continue to evaluate and re-evaluate test procedures, to modify them, to interpret them, and to ignore them at the proper times. The influence of these procedures and their variations on economics, on safety, and on health are potentially enormous (p. 172-173).

STATEMENT OF THE PROBLEM

Several studies indicate substantial differences between laboratory attenuation measurement technique results and the actual field tested attenuation results. Such differences, in turn will be reflected in NRR results. These studies indicate that hearing protection devices utilized in industrial work environments do not always afford the maximum protection indicated by the manufacturers of these devices. Berger (1980b) stated that existing test methods for hearing protection device performance can be utilized with modifications related to selection, fitting, and training of subjects.

This study sought to determine whether the variables of hearing protector fit and subject training affect attenuation and NRR data obtained in the laboratory testing situation. The following questions were asked:

(1) Is information gain significantly affected by the presence of a training program?

(2) Do real-ear attenuation values differ significantly as a function of experimenter fitting versus subject fitting of hearing protection devices?

(3) Do real-ear attenuation values differ significantly as a function of trained versus untrained listeners?

(4) Do real-ear attenuation values differ significantly as a function of the interaction between fitting method and subject training?

(5) Do real-ear attenuation values differ significantly as a function of test band?

(6) What is the correlation between information gain and real-ear attenuation as a function of fitting method and subject training?

(7) Do NRR estimates differ as a function of experimenter fitting versus subject fitting of hearing protection devices?

(8) Do NRR estimates differ as a function of trained versus untrained listeners?

CHAPTER II

METHODS

INTRODUCTION

In September, 1979, the Environmental Protection Agency ruled that all domestic hearing protection devices must bear a label containing the devices Noise Reduction Rating (NRR). The NRR indicates the noise attenuation capability of a hearing protection device, weighted by an assumed noise spectrum and the statistical variations in band attenuation data obtained from a group of trained listeners. Several studies (Padilla, 1976; Regan, 1977; Edwards, _et al_. 1978; Alberti, _et al_. 1979; Abel, Alberti, and Riko, 1982; Berger, 1983) indicate that attenuation data (which were used to compute the NRR) generated in controlled laboratory settings do not accurately reflect effectiveness of protection devices in the industrial field setting. It has been suggested that the NRR underestimates the actual protection provided in industrial environments. This study sought to determine whether the variables of hearing protector fit and subject training affect attenuation and NRR data obtained in the laboratory testing situation.

SUBJECTS

Subjects were forty adult listeners (20 females; 20

males) with normal hearing bilaterally. Subjects were initially naive about hearing protection devices (fit, types, usage). All subjects completed a case history form (Appendix A) and underwent otoscopic, audiometric and impedance testing. Subjects reported no history of otologic surgery, familial history of hearing loss, current upper respiratory infections, vertigo, tinnitus or hearing loss and were free of excess cerumen. Pure tone air and bone conduction hearing threshold levels (HTLs) were no poorer than 10 dB at test frequencies between 250 and 4000 Hz and no poorer than 15 dB at 8000 Hz. Subjects exhibited Type A tympanograms (Jerger, 1970), acoustic reflex thresholds within a normal sound pressure level (SPL) range of 70-100 dB HTL and 60-90 dB SL at 500 Hz, 1000 Hz and 2000 Hz, and absence of acoustic reflex decay at 500 Hz and 1000 Hz bilaterally (i.e., not more than 50% reduction in response amplitude during a 10-second period). Audiological and otological normalcy was confirmed within three days of experimental testing and recorded on the screening form presented in Appendix A. The audiometer and impedance bridge met relevant requirements of ANSI S3.6-1969 "American National Standard Specifications for Audiometers."

Subjects were randomly assigned to one of four groups. Group A consisted of ten subjects with hearing protection devices fit by the experimenter (re: ANSI S3.19-1974 "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs").

Group A subjects also participated in a training program (see below). Group B consisted of ten subjects with hearing protection devices fit by the subjects. These subjects also participated in the training program. Group C consisted of ten untrained listeners with hearing protectors fit by the experimenter. Group D consisted of ten untrained subjects with hearing protectors fit by the subjects. Groups C and D did not receive the training program.

STIMULUS MATERIALS

Hearing Protection Devices

The hearing protection devices used for this study were the Bilsom "Propp-o-Plast" disposable insert-type plugs. These devices are composed of a cotton-like material covered by a polyethylene film wrapper. This earplug is given an NRR of 20 decibels.

Training Program

Twenty subjects (Groups A and B) participated in a training program. This consisted of a commercially available (Bilsom International) multi-media education program. A videotape program was presented emphasizing the following information and affective topics:

(1) the hearing mechanism and how it operates;
(2) the effects of noise on the hearing mechanism;
(3) the consequences of noise-induced hearing loss; and
(4) hearing protection devices - how and why they work.

Subjects were given the opportunity to ask questions regarding the information presented and given practice in fitting the hearing protection devices. Subjects participated in this training program on the day of data collection.

All forty subjects were given a 40 item, multiple choice (5 item) pre-test and a 20 item, multiple choice post-test. The pre-test consisted of 20 content items designed to assess the informational and affective effects of the training program. It also consisted of 20 distractor items (anatomy, physiology and pathology of the eye). The post-test consisted of 20 content items. Alternate forms of the test were administered at the time of audiometric screening and again directly following data acquisition. Copies of the pre- and post-tests and the correct answers may be found in Appendix C.

Signal Generation

The signals used in this study were narrow bands of noise with the following center frequencies: 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. These noise bands were numbered from 1 - 9.

The original signal source (Bruel & Kjaer Model 1024) was operated in a sine-band mode, then band-pass filtered (Krohn-Hite Model 3550) at a rejection rate of 24 dB per octave. Band 1 was generated using a 30 Hz wide band; band 2 was generated using a 100 Hz wide band and bands 3 - 9 were generated using a 300 Hz wide band. Upper and lower cut-off frequencies were calculated from equations given in ANSI S1.11-1966 "Specification for Octave, Half-Octave, and Third-Octave Band Filter Sets." The equations are as follows:

$f_L = 0.8909 \times f_C$

$f_H = 1.1225 \times f_C$

where f_L = low cut-off frequency (Hz)

f_H = high cut-off frequency (Hz)

f_C = center frequency of band (Hz)

The output of the filter was routed through a selector switch to channel 2 of a four-track, reel-to-reel tape recorder (Teac Model A-2340 SX) operated at 7.5 inches per second and using a 1.5 mil polyester tape (Ampex Model 406). The other input to the selector switch was a 1000 Hz sinusoidal level calibration tone produced by a function generator (Wavetek Model 185). Channel 4 of the tape recorder was driven by a microphone (Audio-Technica Model ATM41).

Level calibration tones were recorded for 60-seconds on channels 2 and 4. For each of the nine noise bands, a 10-second level calibration tone was recorded on channel 2, followed by 45-seconds of stimuli. Appropriate voice labels announcing each band were placed on recorder channel 4 just prior to the beginning of the band on channel 2.

Similarly, 60-second bands of white noise were generated with a sine-random generator (Bruel & Kjaer Model 1024) and recorded on tape channel 2. These bands were recorded without the band-pass filter.

Stimuli were then replayed and VU level differences between level calibration tones and noise bands were noted for each band. The output of recorder channel 2 was routed to the input of channel 1. Stimuli were re-recorded with input gain settings selected to minimize VU level differences between level calibration tones and noise bands. Final level differences between noise bands and calibration tones were less than 1 VU.

Thus the final stimulus tape consisted of (1) a 60-second, 1000 Hz level calibration tone on channels 1 and 4; (2) a 60-second band of white noise on channel 1; (3-12) a 10-second calibration tone and a 45-second noise band on channel 1, preceeded by a voice label on channel 4; and (13) an additional 60-second band of white noise on channel 1. Leader tape separated successive stimuli.

The spectra of the noise bands were verified as follows. The output of the tape recorder was routed to a narrow-band analyzer (Bruel & Kjaer Model 2107), then to a graphic level recorder (Bruel & Kjaer Model 2305). Each stimulus band was analyzed in terms of center frequency, high and low cut-off frequency and amplitude at 1 octave above and below the center frequency. Results are given in Table 2.1. Measured bandwidths were somewhat narrower than those specified by ANSI S1.11-1966 for noise bands centered at 3150, 4000, 6300, and 8000 Hz.

EXPERIMENTAL APPARATUS

Environment

The test chamber used in this study was an IAC reverberation

Table 2.1. Values of noise band spectra analysis.

Band	f_L*	f_C*	f_H*	BW*	Attenuation 1 octave above f_C	Attenuation 1 octave below f_C
1	115	125	140	30	58.5 dB	59.0 dB
2	230	250	280	100	53.0 dB	56.0 dB
3	445	500	560	300	55.0 dB	45.0 dB
4	900	1000	1100	300	45.0 dB	58.0 dB
5	1800	2000	2200	300	65.0 dB	45.0 dB
6	2800	3150	3500	300	52.0 dB	57.5 dB
7	3600	4000	4400	300	60.0 dB	60.0 dB
8	5600	6300	7000	300	59.0 dB	55.0 dB
9	7000	8000	9000	300	55.0 dB	58.5 dB

*in Hertz

chamber equiped with a smaller test capsule customized to accomodate the acoustical requirements of ANSI S3.19-1974. The test capsule was a hexagonal shaped room with a steel floor and masonite-covered walls and ceiling. Figure 2.1 presents a diagramatic view of the test capsule and its contents.

Signal Presentation System

Figure 2.2 presents a block diagram of the stimulus presentation system used in this experiment. The noise bands and voice labels were reproduced by a tape recorder (Teac Model A-2340 SX) on channels 1 and 4, respectively. The voice label channel was routed to an amplifier-speaker combination (Ampex Model AA620) to allow monitoring of stimuli by the experimenter. Test signals were reproduced, split, and then routed to an electronic switch (Coulbourn Model S84-04), and to a contour-following integrator (Coulbourn Model S76-01) and a bipolar comparator (Coulbourn S21-06). The integrator-comparator subsystem controlled the logic system discussed below. The output of the electronic switch was routed to an amplifier (Coulbourn Model S82-24). The electronic switch was activated by a pair of timers (controlled by the logic system) which gated the signal on for 500 msec and off for 500 msec with exponential rise and fall times of 50 msec. The signal was then routed to the external signal input of a Bekesy audiometer (Grason-Stadler Model E800). Internally, the Bekesy audiometer pre-amplified the signal, then passed it through a recording attenuator

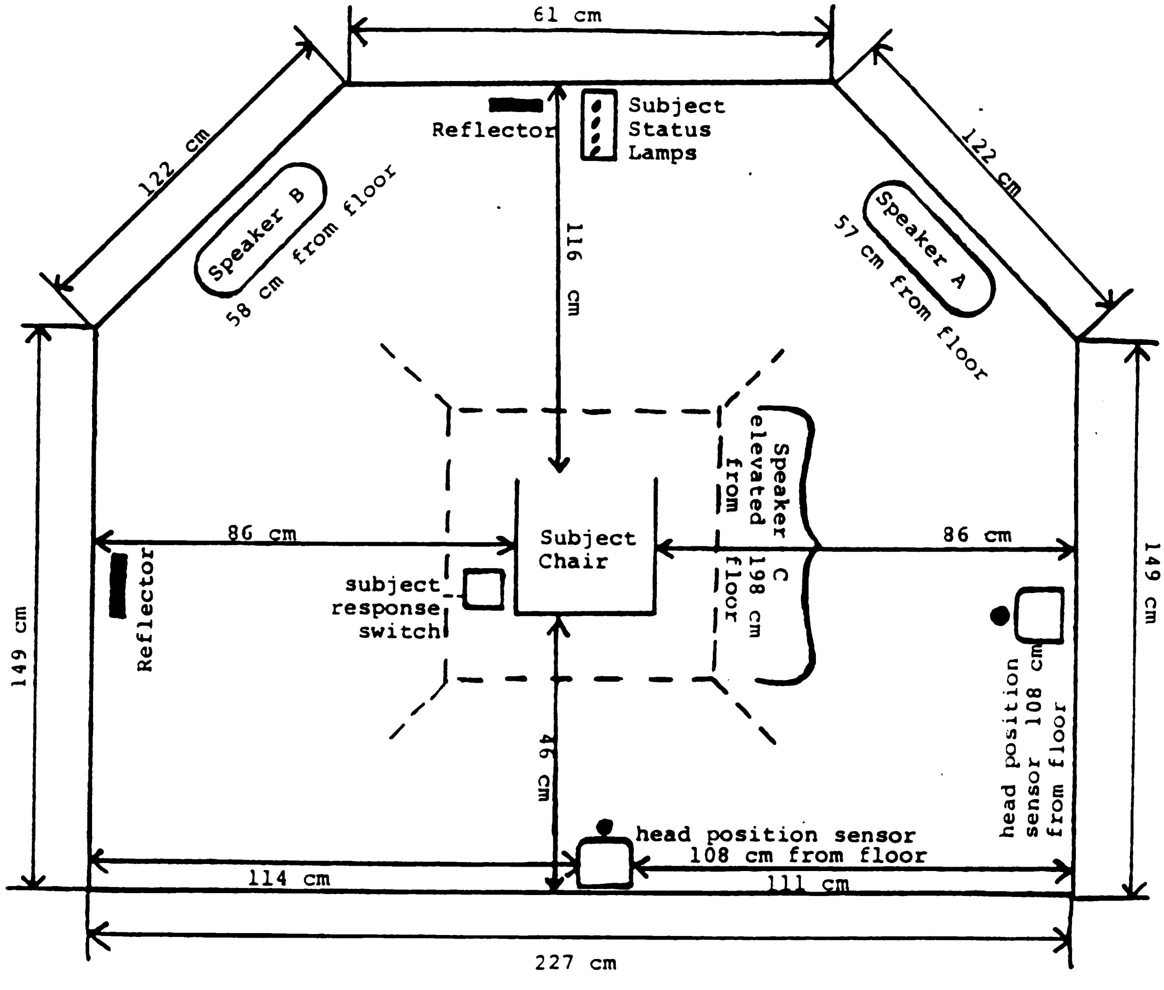

Figure 2.1. Schematic view of the test capsule.

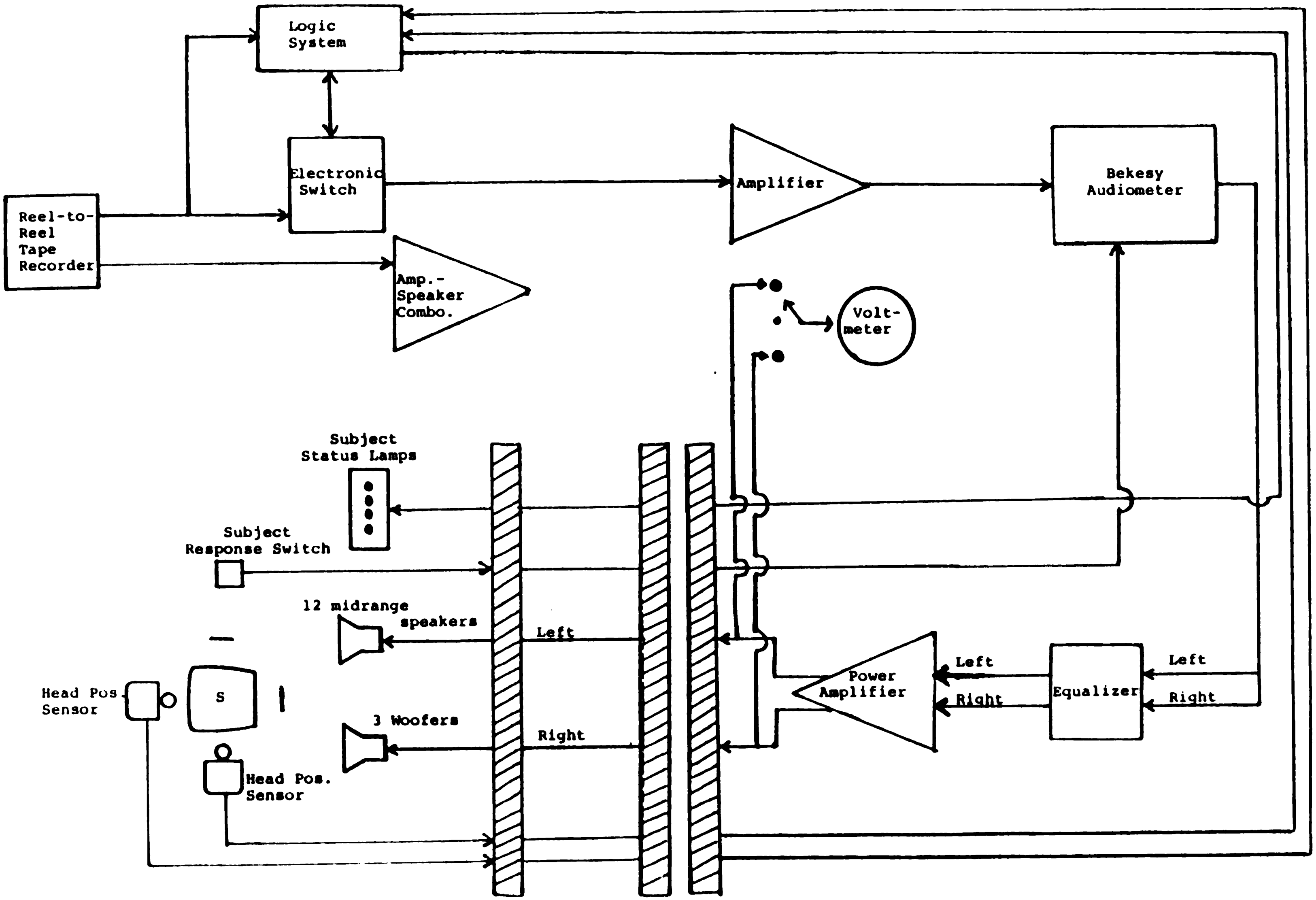

Figure 2.2. Block diagram of stimulus presentation system.

controlled by a subject-operated switch, a step attenuator controlled by the experimenter, and an output amplifier. The output of the audiometer was split, then routed to the right and left channels of an equalizer (Radio Shack Model 31-2000). The right channel of the equalizer was low-pass filtered at 1.0 kHz and routed to the right input channel of a power amplifier (McIntosh Model MC 2205). The left equalizer channel was high-pass filtered at 1.0 kHz and routed to the left input channel of the power amplifier. From this point, the left channel was routed to speaker array # 1 and the right channel to speaker array # 2. Secondary outputs from the two channels of the power amplifier allowed measurement of the voltage driving each loudspeaker array (Bruel & Kjaer Model 2409).

Speaker array # 1 consisted of twelve, 11-cm midrange speakers (Radio Shack Model 40-1282B, 50 watts, 8 ohms). Speaker array # 2 consisted of three, 38-cm woofers (Radio Shack Model 40-1315A, 100 watts, 8 ohms). These speaker arrays were organized in three panels, 91-cm on a side. Each panel consisted of one woofer and four midrange speakers. One panel was suspended above the subject at an elevation of 198 cm above the floor. The other two panels were mounted on legs which elevated the lower edge of the panel 57 cm from the floor. These panels were oriented at approximately 45° azimuth relative to the subject. The wiring diagram of the speaker arrays is found in Appendix D.

Logic System

Figure 2.3 illustrates the logic system used in this study. To semi-automate signal control, communication with the subject and response acquisition, one output from recorder channel 1 activated a contour-following integrator subsystem (Coulbourn Model S76-01). The integrator summated test signal energy over 20 msec and produced a dc output proportional to the summated input. This signal was routed to a bipolar comparator (Coulbourn Model S21-06) which functioned as a one-bit analog-to-digital converter. The complimentary output of the comparator was true if the input to the device was below a threshold voltage selected to index the presence of a test signal on the tape.

When the signal was absent or below threshold, the signal "off" timers forced the electronic switch open (off). Other components of the logic system made it possible to hold the test signal off when the subject was out of position or when the system was turned off by means of an experimenter control switch.

Subject head position was sensed by a pair of infrared photo cell alarm devices (Radio Shack Model 49-201) positioned inside the test capsule. One alarm sensed subject head position in an anterior-posterior plane, the other in a sagittal plane. This subsystem allowed no more than 18 cm (± 9 cm) of head movement from side-to-side and no more than 20 cm (± 10 cm) of movement from front-to-back.

The logic system also controlled a set of lamps located

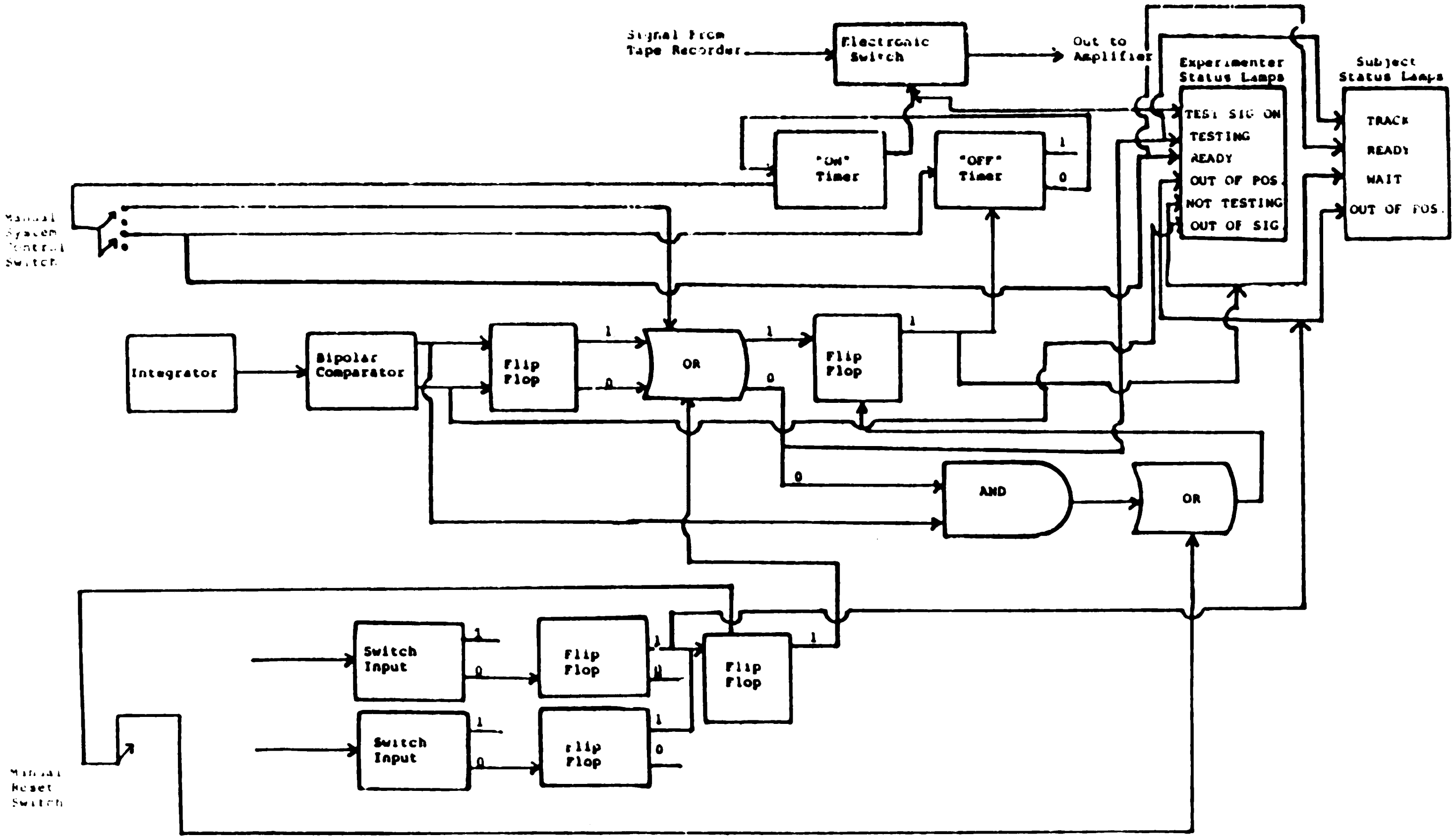

Figure 2.3. Block diagram of logic system.

inside the test capsule. These lamps were used to tell the subject to 'get ready;' 'wait;' or 'track' a test signal. A fourth lamp alerted the subject if he/she was 'out of position.' A similar set of lamps located outside the test chamber informed the experimenter of the status of the system.

Response Acquisition System

The response acquisition system consisted of the status lamps noted above and a Bekesy recording audiometer controlled by a subject response switch. When the switch was depressed, the recording attenuator reduced the signal level at a rate of 5 dB per second; when the switch was released, the signal level increased at the same rate.

For all noise band threshold measurements, the audiometer was configured with the calibration cam set in the SPL channel, then disengaged from the plotter drive at the 1000 Hz position of the cam.

System Calibration

Temporal Parameters.

The temporal parameters of the test signals (on-time, inter-stimulus interval, rise-fall time) were verified through measurements with a storage oscilloscope (Tektronix Model T912) of the electrical signal presented to the Bekesy audiometer. Measured signal duration was 500 msec with a rise-fall time of 50 msec. Interstimulus interval was 500 msec. It was assumed that other components of the signal presentation system had negligible effects upon the temporal features of the signal.

Attenuator Linearity. Attenuator linearity was assessed acoustically. A free-field microphone (Bruel & Kjaer Model 4145) was placed on a tripod and placed inside the test capsule at a position comparable to the center of the head of a subject. The microphone signal was pre-amplified (Bruel & Kjaer Model 2619 and 2804), then routed to a measurement amplifier (Bruel & Kjaer Model 2607). Microphone sensitivity was calibrated with a level calibrator (GenRad Model 1986). Results (see Table 2.2) were within the specifications of ANSI S3.6-1969.

Harmonic Distortion. ANSI S3.19-1974 specifies that the entire system produce less than 5% total harmonic distortion measured at the position of the subjects head. Harmonic distortion could not be measured because of laboratory equipment constraints.

Signal Level. Each of the test stimuli was reproduced in a steady-state mode (the electronic switch was held on) for signal level calibration. The recording attenuator of the Bekesy audiometer was set at the 100-dB position. The +20-dB pad was engaged at various frequencies. Figure 2.4 presents the block diagram of the instrumentation used for these measurements. A pressure microphone (Bruel & Kjaer Model 4144) was placed in the test capsule at the center head position. The microphone was routed to a pre-amplifier

Table 2.2. Acoustical attenuator linearity measurement results.

Signal	Attenuator Position	Measured Value
White Noise	100 dB	88.0 dB
	90 dB	78.0 dB
	80 dB	68.0 dB
	70 dB	58.0 dB
	60 dB	49.5 dB
125 Hz	100 dB	90.0 dB
	90 dB	80.0 dB
	80 dB	70.0 dB
	70 dB	61.0 dB
	60 dB	51.0 dB
250 Hz	100 dB	100.0 dB
	90 dB	91.0 dB
	80 dB	81.0 dB
	70 dB	71.0 dB
	60 dB	61.0 dB
	50 dB	51.0 dB
500 Hz	100 dB	96.0 dB
	90 dB	86.5 dB
	80 dB	76.0 dB
	70 dB	66.0 dB
	60 dB	56.5 dB
1000 Hz	100 dB	85.5 dB
	90 dB	75.5 dB
	80 dB	66.5 dB
	70 dB	56.0 dB
	60 dB	48.0 dB
2000 Hz	100 dB	87.5 dB
	90 dB	78.0 dB
	80 dB	68.0 dB
	70 dB	58.0 dB
	60 dB	49.0 dB
3150 Hz	100 dB	83.0 dB
	90 dB	73.0 dB
	80 dB	63.0 dB
	70 dB	54.0 dB

Table 2.2 Continued.

Signal	Attenuator Position	Measured Value
4000 Hz	100 dB	83.0 dB
	90 dB	73.0 dB
	80 dB	64.0 dB
	70 dB	54.0 dB
6300 Hz	100 dB	74.0 dB
	90 dB	65.0 dB
	80 dB	55.5 dB
8000 Hz	100 dB	75.0 dB
	90 dB	65.0 dB
	80 dB	56.0 dB
	70 dB	48.0 dB

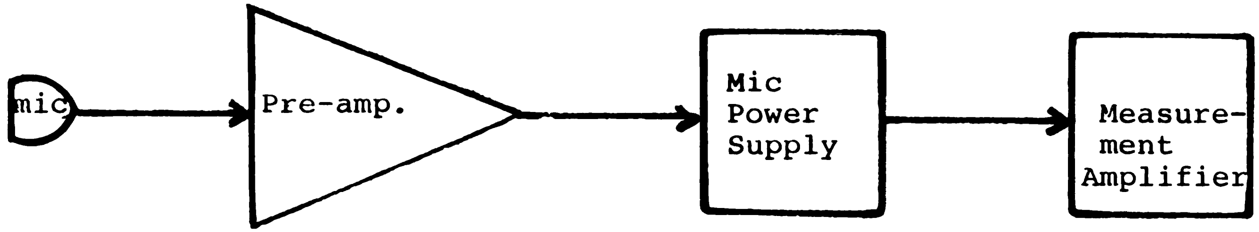

Figure 2.4. Block diagram of instrumentation for signal level measurements.

(Bruel & Kjaer Model 2619) and powered by a microphone power supply (Bruel & Kjaer Model 2804). The output was routed to a measurement amplifier (Bruel & Kjaer Model 2607). The microphone was calibrated with a level calibrator (Gen-Rad Model 1986). Additionally, speaker voltages were measured with an electronic voltmeter (Bruel & Kjaer Model 2409) for the right and left channels for each of the test bands.

Levels were measured for each of the nine test bands and overall levels were measured for the white noise signal. Voltages were also recorded. Table 2.3 presents the results of these measurements.

Reverberation Time. Reverberation time of the test capsule was also measured. Reverberation time, T_{60}, is defined as "the time that would be required for the mean square sound pressure level, originally in a steady-state, to fall 60 dB after the source has stopped (ANSI S3.19-1974, p. 2). ANSI S3.19-1974 specifies that the reverberation time in the capsule (without the subject present) shall be between 500 and 1600 msec for each test band. Appendix E describes the instrumentation, methods and results of reverberation time measurements. The chamber was marginally below specifications (between 300 and 460 msec) of ANSI S3.19-1974 for this parameter at all frequencies. It was assumed that this would not affect the results of this study.

Spatial Uniformity of Acoustic Field. The test chamber was also calibrated in terms of the spatial uniformity of the acoustic field in relation to the subjects head. ANSI

Table 2.3 Signal level measurement results.

Signal	Voltage: Right Channel	Voltage: Left Channel	Octave Band Levels
White Noise	500 mvolts	500 mvolts	88.0 dB
125 Hz	1600 mvolts	30 mvolts	90.0 dB
250 Hz	2500 mvolts	30 mvolts	100.0 dB
500 Hz	1600 mvolts	50 mvolts	97.0 dB
1000 Hz	400 mvolts	140 mvolts	86.0 dB
2000 Hz	85 mvolts	450 mvolts	81.0 dB
3150 Hz*	300 mvolts	10,500 mvolts	103.0 dB
4000 Hz*	650 mvolts	15,000 mvolts	102.0 dB
6300 Hz*	760 mvolts	12,500 mvolts	97.0 dB
8000 Hz*	540 mvolts	15,000 mvolts	94.0 dB
White Noise	540 mvolts	1,000 mvolts	89.0 dB

*20 dB pad engaged.

S3.19-1974 specifies that the SPL measured at six positions relative to the center of a subjects head (± 10 cm in the front-back dimension and ± 15 cm in the up-down and right-left dimensions) shall remain within a range of 6 dB for all test bands. Further, the difference in SPL between the right-left positions shall not exceed 2 dB.

Appendix F describes the instrumentation, methods and results of spatial uniformity measurements. The chamber and signal presentation system conformed to the specifications of ANSI S3.19-1974 for this parameter.

Ambient Noise. ANSI S3.19-1974 specifies that the ambient noise in the test capsule (with test instrumentation on and no test signal present) shall not exceed specified levels. Because of laboratory equipment constraints, ambient noise levels could not be measured for individual octave bands. The overall ambient noise was measured in the test capsule using the instrumentation described in the spatial uniformity of the acoustic field section and using dBA, dBC and linear metering characteristics on the measurement amplifier. The following ambient noise levels were obtained:

(1) 33.0 dBA

(2) 43.5 dBC

(3) 44.0 dB linear

A low amplitude, low frequency hum was noted in the test capsule and although these levels appear high, the character of the hum was such that it did not interfere with preliminary testing. The source of this hum was assumed to be the power amplifier. This was confirmed when ambient noise measurements were repeated with the power amplifier turned off. The following results were obtained:

(1) 24.5 dBA

(2) 33.0 dBC

(3) 37.0 dB linear

EXPERIMENTAL PROCEDURES

Subject Screening

Subjects were required to read a statement of purpose and sign an informed consent release form (Appendix A). All subjects completed a case history form and underwent otoscopic, audiometric and impedance screening. The equipment used for subject screening was an audiometer (Tracoustics Program III) and a middle ear analyzer (Grason Stadler Model 1723). Subjects were screened in an IAC sound treated chamber in accordance with ANSI S3.6-1969. Subjects who met criteria (Appendix A) were given the pre-test and scheduled for data collection. Subjects reported no exposure to excessive noise for at least one hour prior to screening.

Running Calibration

The signal presentation system was calibrated for level each time the system was used (i.e., for each subject). This was accomplished electronically by (1) driving the system with tape-recorded level calibration signals (1000 Hz tone and white noise), (2) setting intermediate voltage amplifiers, the equalizer, and the audiometer attenuator to their preset positions, and (3) adjusting the level controls of the power amplifier to yield criterion voltages at the outputs of the amplifier with the loudspeakers in circuit. Voltage was monitored with a voltmeter (Bruel & Kjaer Model 2409) and a routing switch that allowed connection to either (or neither) of the power amplifier outputs. System presets were as follows: tape recorder output level - 0 VU; signal line amplifier output level - -4 VU; audiometer input level - -3 VU; and audiometer recording attenuation pen at 100 dB.

Data Collection Procedures

Test procedures followed those prescribed by ANSI S3.19-1974. Four groups of ten subjects each were tested. Group A consisted of ten subjects (five females; five males) who participated in the training program and experimenter fit of the hearing protection devices. Group B subjects consisted of ten subjects (five females; five males). This group also participated in the training program, but used subject fit of the protectors. Group C (five females; five males) did not participate in the training program and were fit by the experimenter. Group D (five females; five males) did not participate in the training program and used a subject fit strategy.

Subjects reported no exposure to excessive noise 24 hours prior to data collection. Subjects were given instructions (written and verbal) and permitted to ask questions. Subjects were seated in the soundfield using the head position sensing system. No signals were present for five minutes prior to testing. A brief training session consisting of two, one-minute threshold tracings using white noise were completed. Any subject who presented an average excursion size greater than 15 dB was dismissed. Groups A and C were fit with the protection device by the experimenter in accordance with manufacturer's instructions and ANSI S3.19-1974. Subjects were instructed not to manipulate the protector in any way. Groups B and D (subject fit) were given the manufacturer's directions and instructed to fit the device. They were allowed to manipulate the device in order to obtain a good seal prior to testing. A white noise was presented at approximately 60 dB SL for purposes of manipulation. Once the hearing protection device had been manipulated and attenuation found satisfactory to the subject, further manipulation was not allowed.

The first measurement obtained following the brief training session was an unoccluded measurement. The order of occluded and unoccluded measurments were alternated. Three separate trials of each measure (open and occluded) were obtained at each of the nine test bands. The test bands were also randomized. Rest periods were provided to the subjects. The psychophysical method of adjustment was used for all trials. Each separate occluded trial included a refit of the hearing protector using a new pair of protectors. After the fitting of hearing protection devices (experimenter and subject), subjects were asked to engage in vigorous jaw motions to insure proper fit. The run protocol used in this study is found in Appendix B.

DATA REDUCTION

Form and Volume of Subject Data

Following data collection, there were 40 pre- and post-tests. These were scored and tallied as percentage correct scores. Two thousand one hundred and sixty fixed frequency Bekesy tracings were also obtained. These included three trials for each subject for unoccluded and occluded thresholds at each of the nine test bands.

Pre- and Post-Test Scores

Raw data gathered from the pre- and post-tests were in the form of percent-correct responses. Pre-tests were scored such that distractor items were ignored. Information gain (the signed difference score between post-test and pre-test results) was computed for each subject.

Attenuation Data

Raw data were in the form of 45-second fixed frequency Bekesy tracings. Thresholds were defined as the mean of the mid-point of the last ten excursions. Attenuation was computed by subtracting the mean threshold for each occluded condition from the mean threshold for each unoccluded condition.

Noise Reduction Ratings (NRRs)

Finally, Noise Reduction Ratings (NRRs) were computed for each subject group. These were summarized in tabular form and compared to each other and the manufacturer's listed NRR for the hearing protection devices.

CHAPTER III

RESULTS

INTRODUCTION

In September, 1979, the Environmental Protection Agency ruled that all domestic hearing protection devices must bear a label containing the devices Noise Reduction Rating (NRR). Studies have indicated that the laboratory-generated NRR relates poorly to industrial field generated NRR values. It has been suggested that the NRR underestimates the actual protection provided in industrial environments.

This study sought to determine whether the method of fitting hearing protectors (experimenter vs. subject) and subject training (present vs. absent) affect attenuation and NRR data obtained in a laboratory testing situation. Additionally, the study sought to assess the effect of a particular mediated training package upon knowledge of basic auditory function and noise-induced hearing loss among initially naive subjects.

Forty normal hearing adult listeners (20 females; 20 males) served as subjects. Subjects were randomly assigned to one of four groups. Group A consisted of ten subjects who participated in a commercial training program and whose hearing protectors were fit by the experimenter. Group B consisted of ten subjects who participated in the training program and who fitted their own hearing protectors. Group C consisted of ten subjects who did not participate in the training program and who utilized an experimenter fit strategy. Group D consisted of ten subjects who utilized a subject fit strategy. Group D subjects did not participate in the training program.

All forty subjects were given a 40 question pre-test and a 20 question post-test designed to assess the informational and affective effects of the training program. Alternate forms of the tests were administered at the time of audiometric screening and again directly following acquisition of real-ear attenuation thresholds. Attenuation data was gathered in accordance with ANSI S3.19-1974 "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs."

DATA REDUCTION AND ANALYSIS

STATISTICAL PROCEDURES

The following descriptive statistics were used:

(1) mean
(2) variance
(3) standard deviation
(4) range
(5) standard error of the mean
(6) confidence interval of the mean
(7) skewness
(8) kurtosis

(9) Pearson product-moment correlation coefficient
(10) mean absolute deviation

Computation of these statistics was accomplished by hand and by ELF (Econometric Linear Forecasting), an Apple II computer program published by the Winchendon Group of Alexandria, Virginia.

The analyses of variance (ANOVAs) were computed using the ELF and ANOVA computer programs. The ANOVA is an Apple II computer program published by Human Systems Dynamics of Northridge California. These programs provide normal ANOVA summary tables, plus estimates of the exact probability of occurence of observed F-ratios assuming the null hypothesis is true.

Other statistical procedures included the Fisher r - Z, Z - r transform, omega^2, and eta^2 (Hays, 1973). These computations were made as indicated by the outcome of the ANOVAs. The significance criterion for all inferential statistics was $P_\alpha < .05$.

The NRRs were computed by a computer program written by M.R. Chial, Ph.D. This program followed the EPA NRR method and was run on the Apple IIe computer (see Appendix G for source code).

INFORMATION GAIN

Informational tests were scored in terms of percent correct. Information gain was computed as the difference between the pre- and post-test scores for each subject.

Appendix H contains the pre-test, post-test and information gain scores for each subject. Only the content items on the pre-test were scored and used for analysis. The distractor items were disregarded.

Description of Outcomes

Table 3.1 presents means, standard deviations, and standard errors of the mean for pre-test scores, post-test scores, and information gain scores obtained from all four groups of subjects. Figures 3.1 and 3.2 graphically present the same information. Appendix I presents additional summary information for these data.

Mean pre-test scores ranged from 65.5% (Group B-trained) to 71.5% (Group D-untrained) across groups, with a grand mean of 67.5%. This suggests that the four groups did not differ appreciably in pre-experimental knowledge of hearing, hearing loss and hearing protection. Mean post-test scores ranged from 62.0% (Group C-untrained) to 82% (Group A-trained). Mean information gain was 15.5% and 12.0% for the two trained groups, and -4.0% and -1.5% for the two untrained groups. Thus, training appeared to increase the difference between post-test and pre-test performance. Standard deviations for all three measures were moderate across groups.

Pearson product-moment correlation coefficients were computed to assess the degree of relationship among (1) pre- and post-test scores, (2) pre-test scores and information gain scores, and (3) post-test scores and information gain

Table 3.1. Means, standard deviations and standard errors of the mean for pre-test, post-test, and information gain scores (percent correct) across groups.

	Pre-Test	Post-Test	Information Gain
Group A (experimenter fit; training)			
Mean	67.0	82.5	15.5
Standard Deviation	16.0	12.5	23.7
Standard Error of the Mean	5.07	3.96	7.51
Group B (subject fit; training)			
Mean	65.5	77.5	12.0
Standard Deviation	15.5	13.7	14.0
Standard Error of the Mean	4.91	4.36	4.42
Group C (experimenter fit; no training)			
Mean	66.0	62.0	-4.0
Standard Deviation	13.3	10.4	15.9
Standard Error of the Mean	4.20	3.27	5.04
Group D (subject fit; no training)			
Mean	71.5	70.0	-1.5
Standard Deviation	10.6	8.2	13.6
Standard Error of the Mean	3.34	2.58	4.28
Groups A - D			
Mean	67.5	73.0	5.5
Standard Deviation	13.7	13.5	18.7
Standard Error of the Mean	2.16	2.13	2.95

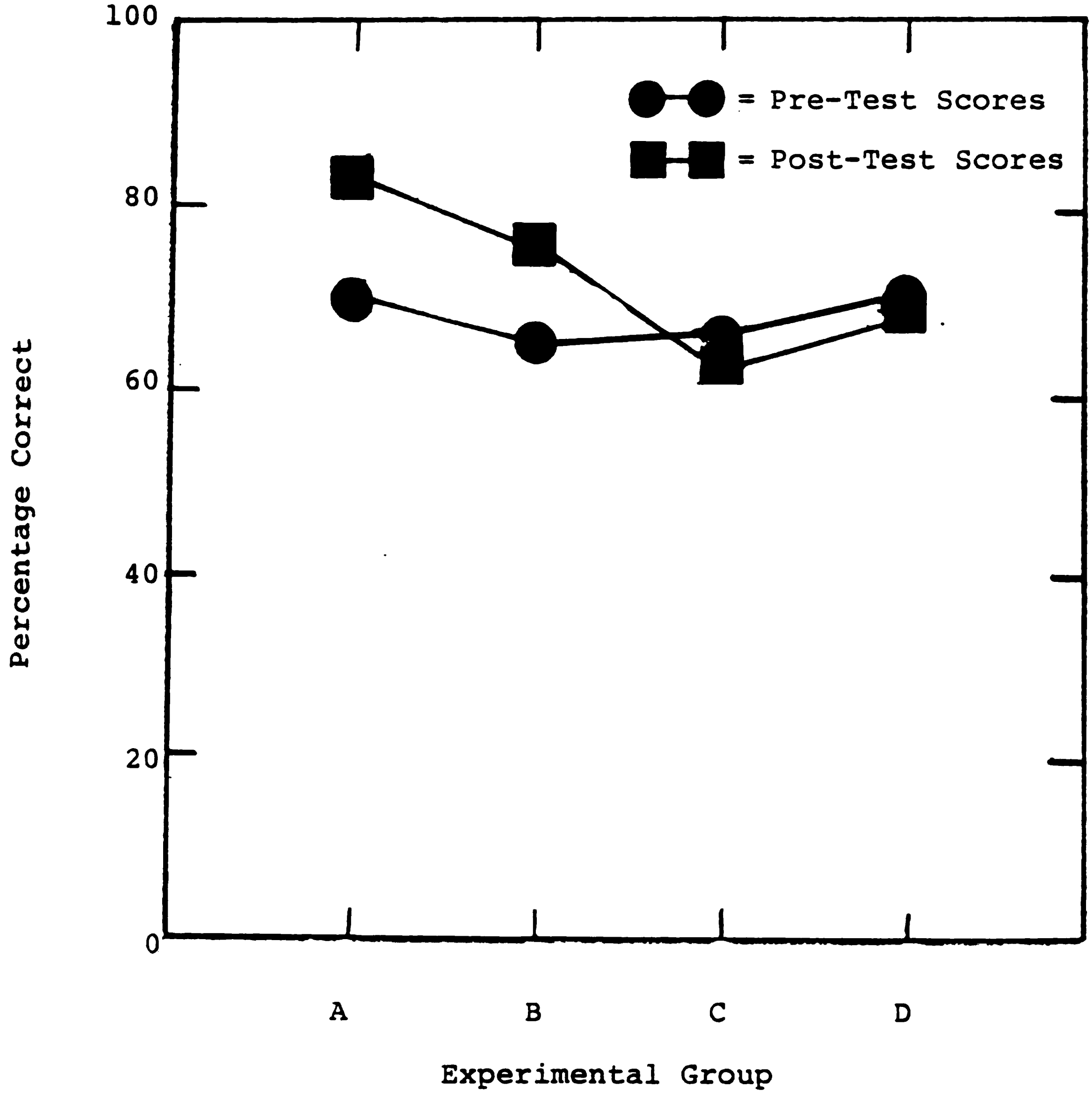

Figure 3.1. Pre-test and post-test means for all groups. (Group A=experimenter fit and training; Group B=subject fit and training; Group C = experimenter fit and no training; Group D = subject fit and no training.)

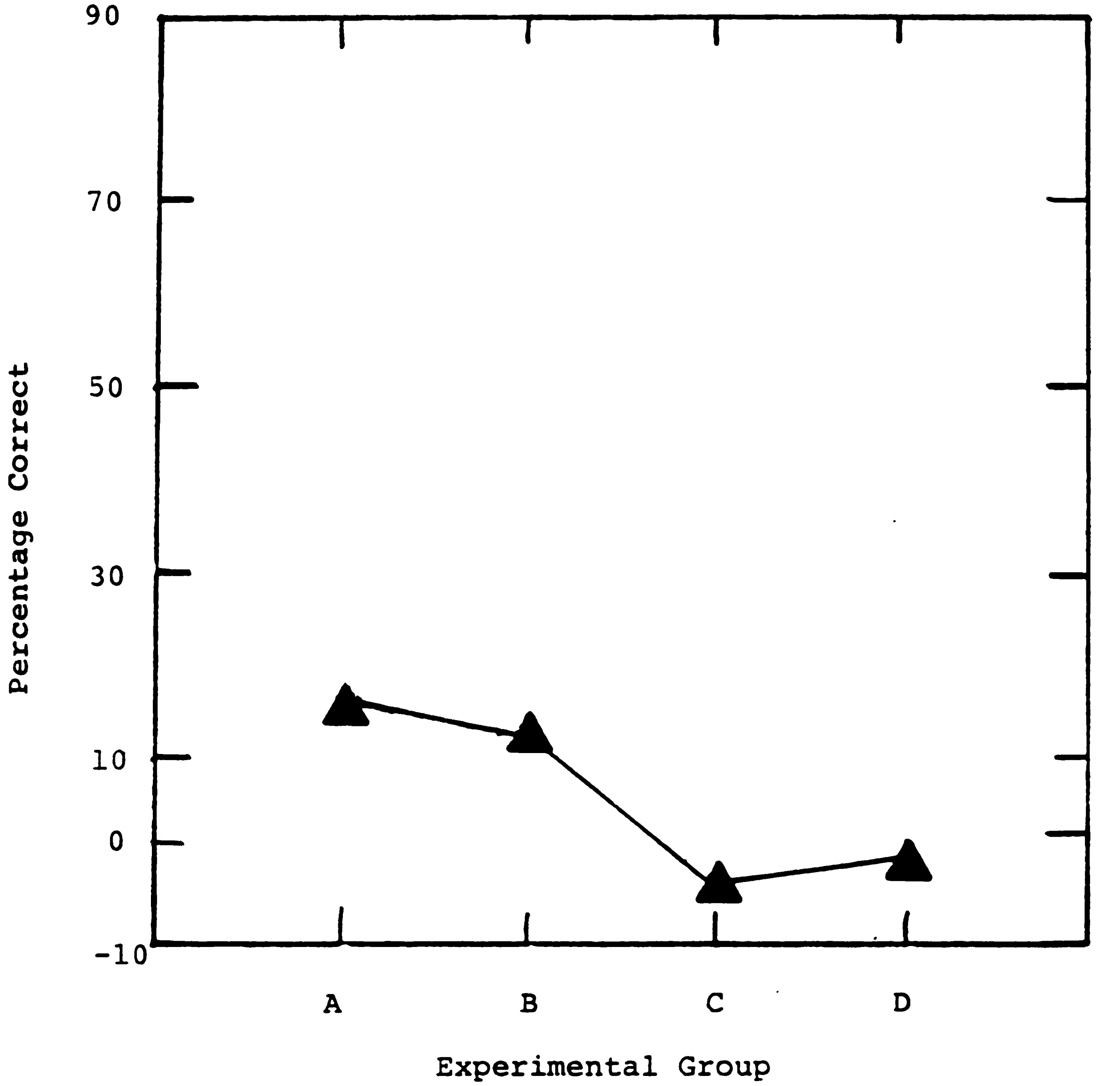

Figure 3.2. Information gain means for all groups. (Group A=experimenter fit and training; Group B= subject fit and training; Group C=experimenter fit and no training; Group D=subject fit and no training.)

scores. Table 3.2 summarizes these results. As can be seen when viewing Table 3.2, the correlation between pre-test and post-test scores was statistically significant for Group B and for Groups A - D. Statistically significant correlations were also obtained for Groups A, C and D and Groups A - D for the post-test to information gain relation.

Analysis of Outcomes

An analysis of variance (ANOVA) was performed on pre-test scores to assess potential bias in the assignment of subjects to experimental groups. Table 3.3 reports an F-ratio of .38 indicating no statistically significant differences among groups.

Table 3.4 reports a two-way ANOVA where information gain (the difference between post-test and pre-test scores) was the dependent variable. Hearing protection device fit and training were the independent variables. F-ratios were .01 for fit, .3 for the fit-training interaction and 9.1 for training. Strength of statistical association (ω^2) was computed for the effect of training. The resulting ω^2 value was .17, indicating 17% of the total variance in information gain is accounted for by training.

REAL-EAR ATTENUATION DATA

Attenuation data initially were in the form of 2160, 30-second fixed-frequency Bekesy tracings. Threshold was defined as the mean of the midpoints of the last ten excursions. Attenuation was computed by subtracting the mean

Table 3.2. Correlation coefficients relating pre-test, post-test and infromation gain scores for four groups of subjects. Groups A and B received training; Groups C and D did not.

	A	B	C	D	A - D
Pre-Post Test	-.37	.55	.11	-.03	.56
Pre-Information Gain	-.87	-.57	-.77	-.79	-.69
Post-Information Gain	.78	.37	.56	.63	.68

df = 9 for Groups A, B, C, and D
Significance criterion for $P_\alpha \leq .10$: $r \geq .52$

df = 39 for Groups A - D
Significance criterion for $P_\alpha \leq .10$: $R \geq .26$

Table 3.3. Results of ANOVA of pre-test scores.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Between	225	3	75	.38	---	---
Within	7075	36	196.528			
Total	7300	39				

Table 3.4. Results of two-way ANOVA of information gain scores.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	ω^2
Fit	2.5	1	2.5	.01	---
Training	2722.5	1	2722.5	*9.1	.17
Interaction	90.0	1	90.0	.3	---
Residual	10775.0	36	299.31		
Total	13590.0	39			

*significant at or beyond $P_\alpha = .05$

threshold for each occluded condition from the mean threshold for each unoccluded condition. Individual subject attenuation data (means and standard deviations across trials) are presented in Appendix J.

Reliability of Data Reduction

Reliability of data reduction was assessed as follows. Four subjects (10%) were selected at random from the larger group of forty listeners. Threshold tracings from these subjects were independently re-analyzed by an experienced audiologist who determined mean attenuation across three trials at each noise band. These results were compared to those produced by the experimenter (see Appendix K). The worst-case difference in measured attenuation was less than 2 dB. Mean absolute deviations (subsummed across test bands within subjects) ranged from 0.2 dB to 0.6 dB. Correlation coefficients (r) were computed to index the consistency of measured attenuation across test bands. For each of the four subjects so considered, correlations were $r = .99$. Thus it appears that data reduction methods were highly reliable.

Description of Outcomes

Table 3.5 presents the group attenuation data (means, standard deviations and standard errors of the mean) across subjects. Figures 3.3 - 3.6 display these results graphically. Table 3.6 presents the group attenuation data (means, standard deviations and standard errors of the mean) across trials and subjects. This is the descriptive statistical method

Table 3.5. Attenuation data across subjects (10 subjects per group).

	Frequency								
Measure	125	250	500	1000	2000	3150	4000	6300	8000
Group A (experimenter fit; training)									
Mean	8.1	8.2	14.2	16.7	25.3	30.2	32.9	34.6	33.0
Standard Deviation	3.1	2.5	1.9	2.3	3.2	2.5	2.4	3.6	3.5
Standard Error of the Mean	1.03	.83	.63	.77	1.06	.83	.80	1.20	1.16
Group B (subject fit; training)									
Mean	7.6	7.3	11.6	12.3	20.9	26.4	27.7	30.0	29.6
Standard Deviation	6.5	5.6	6.1	6.1	8.4	7.0	6.9	9.6	8.7
Standard Error of the Mean	2.16	1.86	2.03	2.03	2.80	2.33	2.30	3.20	2.90
Group C (experimenter fit; no training)									
Mean	10.4	10.5	14.4	17.9	25.2	31.4	32.6	33.8	32.8
Standard Deviation	4.9	4.4	4.3	5.6	3.2	4.7	4.3	3.9	4.9
Standard Error of the Mean	1.63	1.46	1.43	1.86	1.06	1.56	1.43	1.30	1.63
Group D (subject fit; no training)									
Mean	10.9	9.2	14.1	14.9	24.1	30.1	30.1	33.5	33.3
Standard Deviation	4.5	4.7	5.9	5.7	5.1	7.0	6.4	4.8	4.9
Standard Error of the Mean	1.50	1.56	1.96	1.90	1.70	2.33	2.13	1.60	1.63

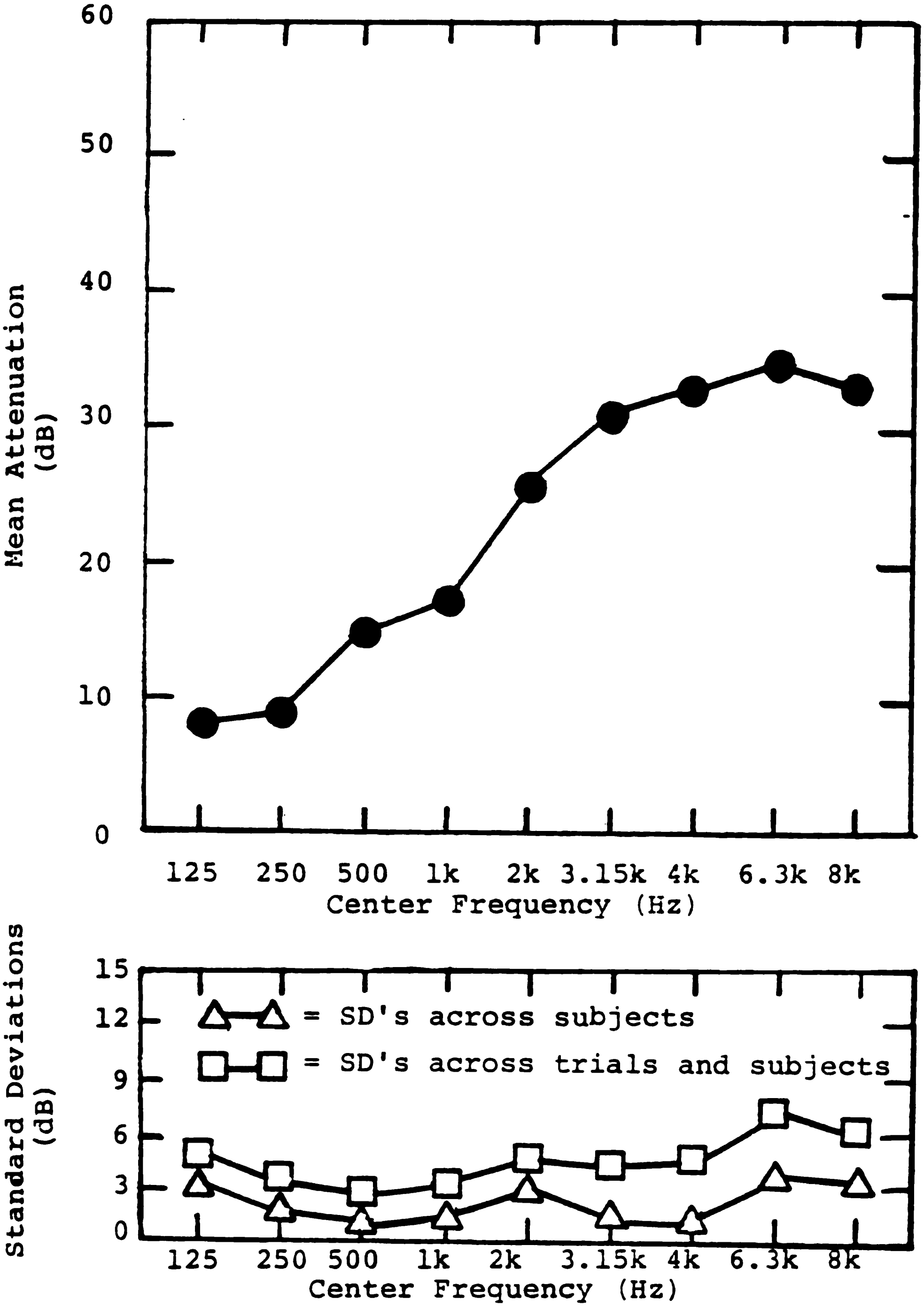

Figure 3.3. Means and standard deviations of attenuation data across ten subjects -- Group A (experimenter fit and training).

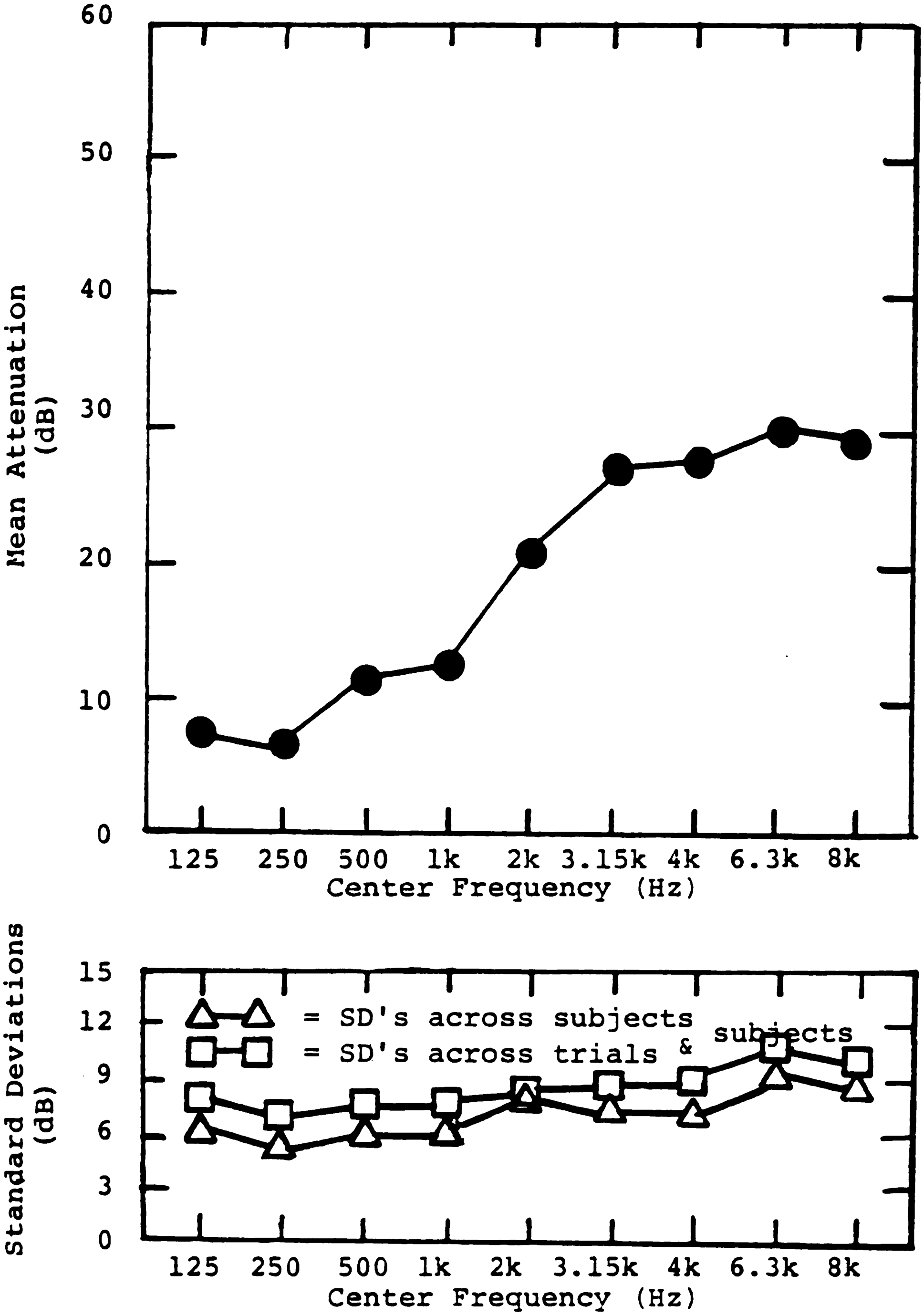

Figure 3.4. Means and standard deviations of attenuation data across ten subjects -- Group B (subject fit and training).

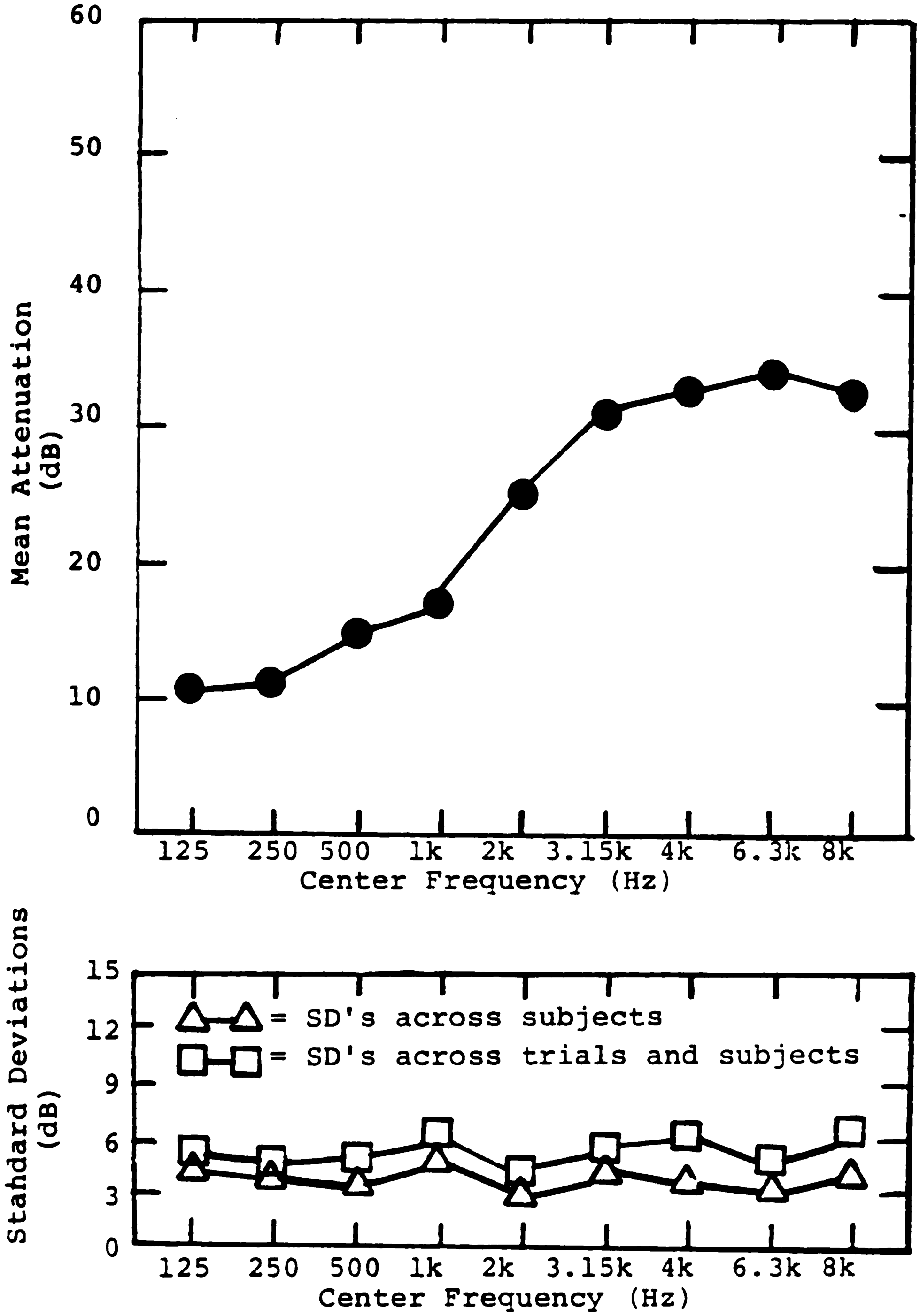

Figure 3.5. Means and standard deviations of attenuation data across ten subjects -- Group C (experimenter fit and no training).

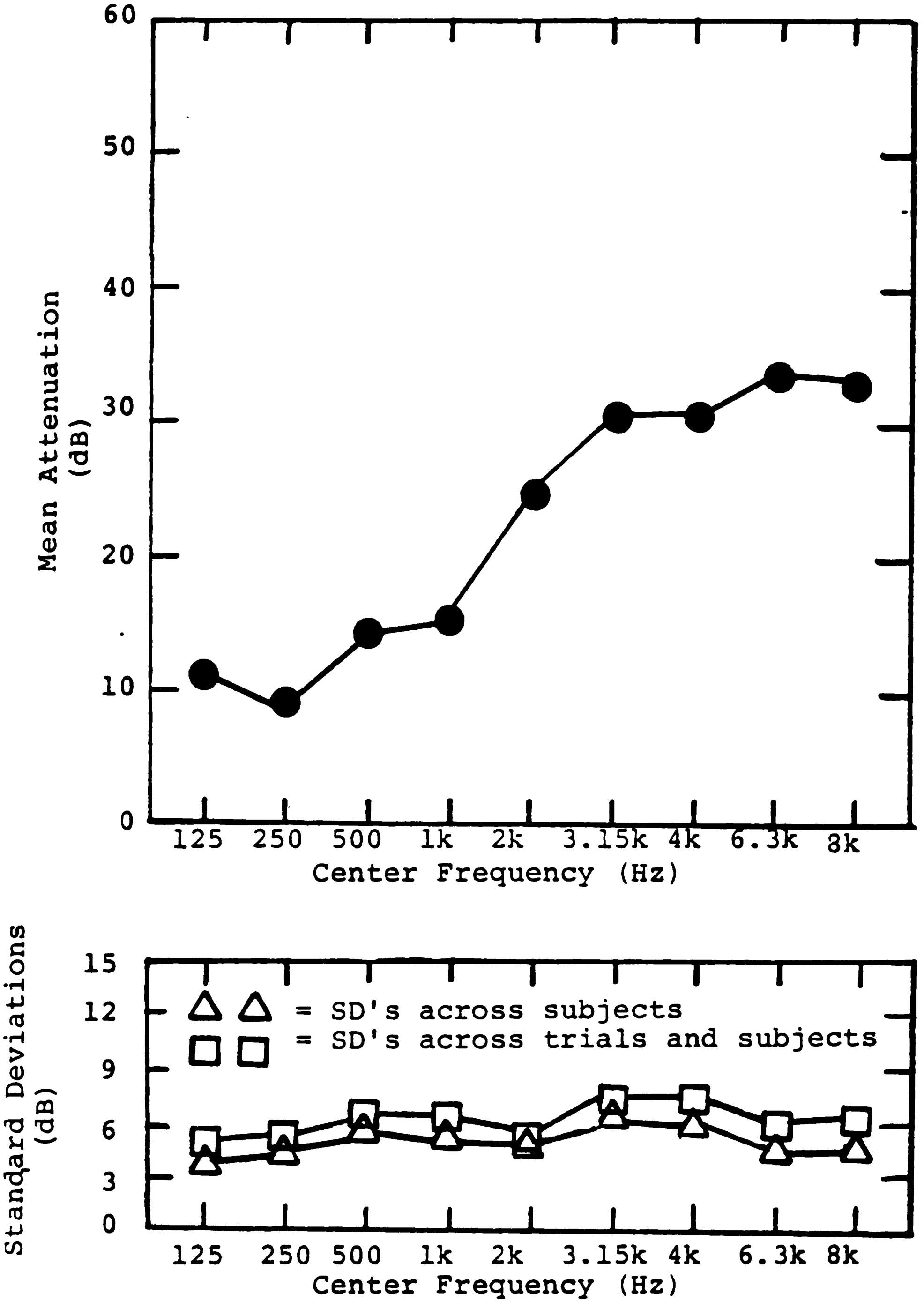

Figure 3.6. Means and standard deviations of attenuation data across ten subjects -- Group D (subject fit and no training).

Table 3.6. Attenuation data across subjects and trials (10 subjects per group; 3 trials).

	Frequency								
Measure	125	250	500	1000	2000	3150	4000	6300	8000
Group A (experimenter fit; training)									
Mean	8.1	8.2	14.2	16.7	25.3	30.2	32.9	34.6	33.0
Standard Deviation	4.6	3.9	2.9	3.7	4.9	4.8	5.0	7.4	6.3
Standard Error of the Mean	1.53	1.30	.97	1.23	1.63	1.60	1.66	2.46	2.10
Group B (subject fit; training)									
Mean	7.6	7.3	11.6	12.3	20.9	26.4	27.7	30.0	29.6
Standard Deviation	7.2	6.5	6.7	6.4	8.7	8.9	9.0	10.3	9.7
Standard Error of the Mean	2.40	2.16	2.23	2.13	2.90	2.96	3.00	3.43	3.23
Group C (experimenter fit; no training)									
Mean	10.4	10.5	14.4	17.9	25.2	31.4	32.6	33.8	32.8
Standard Deviation	5.8	5.0	5.3	6.5	5.1	6.0	6.6	5.5	6.4
Standard Error of the Mean	1.90	1.66	1.76	2.16	1.70	2.00	2.20	1.83	2.13
Group D (subject fit; no training)									
Mean	10.9	9.2	14.1	14.9	24.1	30.1	30.1	33.5	33.3
Standard Deviation	5.7	5.9	6.7	6.7	5.9	7.5	7.6	6.1	6.3
Standard Error of the Mean	1.90	1.96	2.23	2.23	1.96	2.50	2.53	2.03	2.10

defined in ANSI S3.19-1974 where results are described based upon 30 observations (i.e., 10 subjects, 3 trials). Figures 3.3 - 3.6 also display these standard deviation results graphically. Table 3.7 shows the descriptive statistics on attenuation data for groups collapsed across fit and training for Groups A and C (experimenter fit), Groups B and D (subject fit), Groups A and B (training) and Groups C and D (no training). Appendix L presents additional summary information for these data.

The experimenter fit groups (A and C) displayed greater mean attenuation at all frequencies except 125 Hz than did the subject fit groups (B and D). The experimenter fit groups also displayed lower standard deviations and standard errors of the mean than did the subject fit groups. This result was consistent across all frequencies. The trained groups (A and B) showed greater mean attenuation results across all frequencies than did the untrained groups. The trained groups also showed lower standard deviation results at all frequencies except at 250 Hz, 2000 Hz and 3150 Hz. The standard errors of the means revealed no pattern of difference between the trained and untrained groups.

Reliability of Subject and Group Data

Reliability was assessed in several ways. At the level of the individual subject, reliability was assessed using the Pearson product-moment correlation coefficient computed to index consistency of measured attenuation for each test band in Trials 1 and 2, Trials 2 and 3 and Trials 1 and 3. Tables

Table 3.7. Attenuation data across subjects.

Measure	Frequency 125	250	500	1000	2000	3150	4000	6300	8000
Groups A and C (Experimenter Fit)									
Mean	9.2	9.4	14.3	17.3	25.3	30.8	32.8	34.2	32.9
Standard Deviation	4.2	3.7	3.3	4.3	3.2	3.7	3.4	3.7	4.2
Standard Error of the Mean	.94	.84	.74	.96	.71	.84	.77	.83	.94
Groups B and D (Subject Fit)									
Mean	9.3	8.3	12.9	13.6	22.6	28.3	28.9	31.8	31.5
Standard Deviation	5.7	5.2	6.0	5.9	7.0	7.1	6.6	7.7	7.1
Standard Error of the Mean	1.28	1.16	1.34	1.32	1.56	1.56	1.49	1.72	1.60
Groups A and B (Training)									
Mean	10.6	9.9	14.3	16.4	24.7	30.8	31.4	33.7	33.1
Standard Deviation	4.6	4.5	5.1	5.8	4.2	5.9	5.5	4.3	4.8
Standard Error of the Mean	1.03	1.02	1.13	1.29	.95	1.32	1.23	.97	1.08
Groups C and D (No Training)									
Mean	7.9	7.8	12.9	14.6	23.1	28.3	30.3	32.3	31.3
Standard Deviation	5.0	4.3	4.6	5.0	6.6	5.5	5.8	7.5	6.7
Standard Error of the Mean	1.12	.96	1.04	1.12	1.47	1.23	1.29	1.68	1.50
Groups A - D (All Groups)									
Mean	9.2	8.8	13.6	15.5	23.9	29.6	30.8	33.0	32.2
Standard Deviation	5.0	4.5	4.8	5.4	5.5	5.7	5.6	6.1	5.8
Standard Error of the Mean	.780	.710	.765	.858	.875	.909	.883	.962	.922

3.8 - 3.11 show these results for individual subjects within groups. These data were then averaged using the Fisher r - Z transform (1) across trial pairs within subjects and (2) across subjects within groups. Reliability across trial-pairs and subjects were .90 for Group A, .85 for Group B, .88 for Group C and .88 for Group D.

Statistically significant correlations ($P_\alpha \leq .10$) were those which exceeded .55. Based on this, all subjects except one exhibited reliable results. All four groups of subjects showed very high correlations indicating very dependable relations.

At the group level, the indices of reliability were the standard deviations, standard errors of the mean and Pearson product-moment correlation coefficients (for each group and for each noise band). Standard deviations and standard errors of the mean were moderate suggesting reasonable stability in attenuation across trials within groups. The opposite result was obtained when reliability was assessed using Pearson product-moment correlation coefficients.

Tables 3.12 - 3.15 present correlation coefficients for each group and each noise band. These data were then averaged using the Fisher r - Z transform (1) across trial pairs for each noise band and (2) across noise bands for each group. Reliability across noise bands for each group was .01 for Group A, .68 for Group B, .40 for Group C and .57 for Group D.

Statistically significant correlations ($P_\alpha \leq .10$) were those exceeding .55. Only Groups B and D (subject fit)

Table 3.8. Reliability of individual subject data -- Group A (Experimenter fit and training).

Subject	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
1	.80	.92	.70	.83
2	.94	.84	.82	.87
3	.85	.91	.78	.85
4	.98	.87	.90	.93
5	.93	.88	.94	.92
6	.93	.91	.96	.93
7	.77	.87	.96	.89
8	.90	.82	.89	.87
9	.95	.95	.89	.93
10	.92	.91	.96	.93
Mean	.90	.89	.88	.90

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.9. Reliability of individual subject data -- Group B (Subject fit and training).

Subject	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
1	.36	-.46	-.20	-.34
2	.84	.94	.89	.89
3	.93	.91	.93	.92
4	.92	.99	.92	.96
5	.88	.86	.92	.89
6	.98	.98	.98	.98
7	.88	.91	.71	.85
8	.93	.90	.97	.94
9	.98	.97	.97	.82
10	.81	.98	.83	.91
Mean	.85	.80	.79	.85

df = 8

significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.10. Reliability of individual subject data -- Group C (Experimenter fit and no training).

Subject	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
1	.97	.98	.94	.96
2	.53	.86	.74	.73
3	.96	.84	.86	.90
4	.81	.80	.89	.83
5	.44	.91	.85	.79
6	.95	.97	.96	.96
7	.88	.92	.86	.88
8	.95	.95	.95	.95
9	.94	.88	.89	.90
10	.93	.89	.94	.92
Mean	.84	.90	.89	.88

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.11. Reliability of individual subject data -- Group D (Subject fit and no training).

Subject	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
1	.92	.97	.96	.95
2	.96	.92	.95	.94
3	.95	.95	.96	.95
4	.93	.72	.82	.84
5	.97	.94	.94	.95
6	.77	.75	.64	.72
7	.97	.98	.96	.97
8	.72	.71	.87	.78
9	.94	.96	.95	.95
10	.80	.74	.83	.79
Mean	.89	.86	.89	.88

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.12. Reliability across trials and noise bands for Group A (experimenter fit and training).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.22	.26	-.08	.13
250	.21	.23	-.18	.09
500	-.02	.21	.38	.19
1000	.03	.30	-.22	.04
2000	-.44	.07	.66	.09
3150	-.25	-.12	-.04	-.14
4000	-.15	-.56	.13	-.19
6300	.44	-.44	-.25	-.08
8000	-.30	.14	.14	-.007
Mean	-.03	.01	.06	.01

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.13. Reliability across trials and noise bands for Group B (subject fit and training).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.81	.67	.49	.67
250	.41	.86	.37	.55
500	.82	.88	.80	.83
1000	.77	.93	.69	.80
2000	.84	.95	.86	.88
3150	.21	.85	.27	.44
4000	.67	.20	.81	.56
6300	.78	.95	.63	.79
8000	.47	.81	.59	.62
Mean	.64	.79	.61	.68

df = 8
significance criterion for $P_\alpha \leq .10$: r .55

Table 3.14. Reliability across trials and noise bands for Group C (experimenter fit and no training).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.57	.81	.43	.60
250	.85	.43	.69	.66
500	.70	-.007	.52	.40
1000	.59	.50	.57	.55
2000	-.27	-.30	.58	.003
3150	.57	.46	.40	.48
4000	-.02	.19	.26	.14
6300	.20	.33	.65	.39
8000	.15	.48	.45	.36
Mean	.37	.32	.51	.40

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.15. Reliability across trials and noise bands for Group D (subject fit and no training).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.45	.63	.17	.42
250	.59	.59	.42	.53
500	.78	.73	.57	.69
1000	.71	.46	.61	.59
2000	.63	.56	.77	.65
3150	.68	.87	.87	.81
4000	.79	.60	.56	.65
6300	.34	.59	.32	.42
8000	.33	.54	.21	.36
Mean	.59	.62	.50	.57

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

exceeded this criterion across noise bands and trial pairs. Groups A and C (experimenter fit) did not. Thus it appears that the experimenter fit strategy produced less reliable results across trials and noise bands than did the subject fit strategy.

To determine whether training or fit affected reliability, correlation coefficients were further averaged across group pairs, trial pairs and noise bands. Significant correlations were those which exceeded .38 at the $P_\alpha \leq .10$ significance level. Table 3.16 presents the reliability results across trials and noise bands for the experimenter fit groups (A and C). The reliability across noise bands and within trial pairs for the experimenter fit groups was .24, indicating less than significant reliability. For the intra-noise band, inter-trial conditions, significant reliability was only found at 125 Hz, 250 Hz and 1000 Hz.

Table 3.17 presents correlations for the subject fit groups (B and D). All of the inter-trial, intra-noise band and inter-noise band, intra-trial conditions achieved significant correlation coefficients. Thus, it appears that the subject fit groups were reliable across trials and noise band.

Tables 3.18 and 3.19 present correlations for the training groups (A and B) and the no training groups (C and D), respectively. Most of the inter-trial, intra-noise band correlation coefficients and all of the intra-trial, inter-noise band correlation coefficients were significant. For the most part then, the training and no training groups were reliable across trials and noise bands.

Table 3.16. Reliability across trials and noise bands for Groups A and C (experimenter fit).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.46	.54	.25	.42
250	.66	.36	.41	.47
500	.57	.04	.44	.35
1000	.47	.45	.41	.44
2000	-.33	-.16	.60	.04
3150	.20	.20	.24	.21
4000	-.07	-.11	.21	.01
6300	.30	-.15	-.07	.03
8000	-.11	.29	.27	.15
Mean	.24	.16	.31	.24

df = 18
significance criterion for $P_\alpha \leq .10$: $r \geq .38$

Table 3.17. Reliability across trials and noise bands for Groups B and D (subject fit).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.64	.69	.38	.57
250	.48	.71	.42	.54
500	.67	.82	.57	.69
1000	.69	.65	.62	.65
2000	.74	.81	.76	.77
3150	.37	.87	.40	.55
4000	.73	.24	.52	.51
6300	.57	.63	.80	.67
8000	.44	.73	.51	.56
Mean	.59	.68	.55	.61

df = 18
significance criterion for $P_\alpha \leq .10$: $r \geq .38$

Table 3.18. Reliability across trials and noise bands for Groups A and B (training).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.61	.54	.34	.50
250	.37	.64	.23	.41
500	.65	.80	.71	.72
1000	.64	.77	.57	.66
2000	.52	.80	.78	.70
3150	.02	.73	.11	.29
4000	.36	.11	.63	.37
6300	.67	.59	.33	.53
8000	.24	.60	.50	.45
Mean	.45	.62	.46	.51

df = 18
significant criterion for $P_\alpha \leq .10$: $r \geq .38$

Table 3.19. Reliability across trials and noise bands for Groups C and D (no training).

Frequency	$T_1 - T_2$	$T_2 - T_3$	$T_1 - T_3$	Mean
125	.46	.69	.20	.45
250	.73	.50	.49	.57
500	.65	.49	.48	.54
1000	.67	.48	.57	.57
2000	.32	.14	.64	.37
3150	.58	.65	.65	.63
4000	.46	.34	.37	.39
6300	.20	.41	.44	.35
8000	.22	.50	.34	.35
Mean	.48	.47	.46	.47

df = 18
significant criterion for $P_\alpha \leq .10$: $r \geq .38$

Based upon the results presented in Tables 3.16 - 3.19, it can be concluded that:

(1) experimenter fit of hearing protection devices yield unreliable results across trials and noise bands;

(2) subject fit of hearing protection devices yield reliable results; and

(3) the presence of a training program did not affect the reliability.

Relation Between Information Gain and Real-Ear Attenuation

Relations between information gain and mean attenuation for three test bands (125 Hz, 1000 Hz, and 8000 Hz) was assessed for each group using Pearson product-moment correlation coefficients. Table 3.20 presents these results.

Significant correlations ($P_\alpha \leq .10$) were those which exceeded .55. Based on this, it appears that there is no statistically significant relationship between information gain and attenuation at 125 Hz, 1000 Hz, and 8000 Hz for any of the experimental groups.

Analysis of Outcomes

A three-way ANOVA was performed on the attenuation data where the factors were frequency, hearing protector fit (experimenter vs. subject) and subject training (present vs. absent). The significance criterion for this ANOVA was .05.

Table 3.21 summarizes results of this ANOVA. The two

Table 3.20. Relation between information gain and real-ear attenuation for all groups.

	Center Frequency (Hz) 125	1000	8000
Group A (experimenter fit and training)	-.07	.05	-.35
Group B (subject fit and training)	-.38	-.47	-.40
Group C (experimenter fit and no training)	-.32	.18	.09
Group D (subject fit and no training)	.32	.04	.09

df = 8
significance criterion for $P_\alpha \leq .10$: $r \geq .55$

Table 3.21. Results of three-way ANOVA of attenuation data.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	eta^2
Between						
Fit (exp. vs. subject)	412.035	1	412.035	2.462	.121	---
Training (pres. vs. absent)	293.655	1	293.655	1.754	.190	---
Fit-by-Training	119.416	1	119.416	.713	----	---
Error	6023.752	36	167.326	-----	----	---
Within						
Test band	32515.310	8	4064.413	*362.319	<.001	.87
Fit-by-band	127.283	8	15.910	1.418	.187	---
Training-by-band	24.479	8	3.059	.272	----	---
Fit-by-training-by-band	44.500	8	5.562	.495	----	---
Error	3230.715	288	11.217	-----	----	---
Total	42791.149	359				

*Significant at or beyond $P_\alpha = .05$

main effects of fit and training approached but did not achieve significance. Similarly, the fit-by-training interaction did not significantly influence mean attenuation.

As anticipated, the main effect of test band was significant. The strength of association (eta^2) for the main effect of test band was .87. Thus nearly 90% of total variation in attenuation can be attributed to the frequency of the test band.

Because the main effect of test band accounted for such a large proportion of the variance in attenuation, and because the present study was motivated by an interest in the effects of fit and training, nine additional ANOVAs were performed, one for each test band. Each of these analyses was a two-way, randomized-blocks, fixed-effects ANOVA. Results are given in Tables 3.22 - 3.30. The main effect of hearing protection device fit was significant at only two frequencies (1000 Hz and 4000 Hz). In addition, the effect of fit approached significance at the test frequencies of 2000 Hz, 3150 Hz and 6300 Hz. The strength of association (eta^2) of the fit effect for 1000 Hz and 4000 Hz was .09 indicating that only 9% of total variation in attenuation can be attributed to the factor of fit. The main effect of training and the interaction effect of fit and training were found not to be significant at any test frequency. It is believed that the significance of fit at the two frequencies was obscurred in the three-way ANOVA by the strength of effect associated with test band (87%).

Table 3.22. Results of two-way ANOVA of attenuation data - 125 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	.008	1	.008	.000	---	--
Training	77.284	1	77.284	3.160	.08	--
Interaction	2.303	1	2.303	.094	---	--
Residual	880.381	36	24.555			
Total	959.978	39				

*significant at or beyond $P_\alpha = .05$

Table 3.23. Results of two-way ANOVA of attenuation data - 250 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	$\acute{\omega}^2$
Fit	11.448	1	11.448	.563	---	--
Training	43.680	1	43.680	2.150	.147	--
Interaction	.529	1	.529	.026	---	--
Residual	731.271	36	20.313			
Total	786.930	39				

*significant at or beyond $P_\alpha = .05$

Table 3.24. Results of two-way ANOVA of attenuation data - 500 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	21.315	1	21.315	.891	---	--
Training	17.955	1	17.955	.751	---	--
Interaction	13.456	1	13.456	.562	---	--
Residual	860.495	36	23.902			
Total	913.223	39				

*significant at or beyond P_α = .05

Table 3.25. Results of two-way ANOVA of attenuation data - 1000 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	135.423	1	135.423	*4.998	.029	.09
Training	33.488	1	33.488	1.236	.273	--
Interaction	4.761	1	4.761	.175	---	--
Residual	975.289	36	27.091			
Total	1148.963	39				

*significant at or beyond $P_\alpha = .05$

Table 3.26. Results of two-way ANOVA of attenuation data - 2000 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	73.712	1	73.712	2.485	.120	--
Training	25.760	1	25.760	.868	---	--
Interaction	27.060	1	27.060	.912	---	--
Residual	1067.676	36	29.657			
Total	1194.209	39				

*significant at or beyond P_α = .05

Table 3.27. Results of two-way ANOVA of attenuation data - 3150 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	65.024	1	65.024	2.034	.159	---
Training	59.049	1	59.049	1.847	.179	---
Interaction	13.923	1	13.923	.435	---	---
Residual	1150.741	36	31.965			
Total	1288.739	39				

*significant at or beyond $P_\alpha = .05$

Table 3.28. Results of two-way ANOVA of attenuation data - 4000 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	150.156	1	150.156	*5.219	.026	.09
Training	10.506	1	10.506	.365	---	---
Interaction	18.906	1	18.906	.657	---	---
Residual	1035.644	36	28.767			
Total	1215.213	39				

*significant at or beyond $P_\alpha = .05$

Table 3.29. Results of two-way ANOVA of attenuation data - 6300 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	60.025	1	60.025	1.640	.206	---
Training	19.599	1	19.599	.535	---	---
Interaction	45.369	1	45.369	1.239	.272	---
Residual	1317.241	36	36.590			
Total		39				

*significant at or beyond P_α = .05

Table 3.30. Results of two-way ANOVA of attenuation data - 8000 Hz.

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	P_{α_F}	ω^2
Fit	22.201	1	22.201	.646	---	---
Training	30.975	1	30.975	.901	---	---
Interaction	37.635	1	37.635	1.095	.302	---
Residual	1236.525	36	34.347			
Total	1327.338	39				

*significant at or beyond P_α = .05

Summary

To summarize:

(1) Data reduction techniques of real-ear attenuation data were highly reliable.

(2) Reliability across trial pairs, within subjects was high and statistically significant for all but one subject.

(3) Reliability across trial pairs, within noise bands was statistically significant for the subject fit groups, but not the experimenter fit groups.

(4) Reliability across trial pairs, within noise bands was statistically significant for both the trained and untrained groups.

(5) The relation between information gain and real-ear attenuation was not statistically significant.

(6) The main effect of test band was statistically significant.

(7) The main effect of hearing protector fit was significant for 1000 Hz and 4000 Hz. At these bands, experimenter fit produced greater mean attenuation than subject fit.

(8) The main effect of subject training was not statistically significant. None of the two-way interactions among fit, training and test band were significant, nor was the three-way interaction.

NOISE REDUCTION RATINGS (NRRs)

NRR values were computed by means of a computer program (Appendix G) which duplicated the procedures described by the Environmental Protection Agency (EPA, 1979). Table 3.31 presents NRRs for each subject group and for several combinations of groups. At the group level, NRRs were calculated using the definition of standard deviation specified in ANSI S3.19-1974 (N = 3 trials x number of subjects). At the group level, and for the combined groups, NRR was calculated using the more traditional definition for standard deviation (N = number of subjects). In all cases, mean attenuation was calculated across trials and across subjects.

The NRR for the Bilsom Propp-o-Plast device is 22.1 dB (labeled as 20 dB).* The NRRs computed from the present data were appreciably smaller than the labeled NRR. NRR results showed that Group B (subject fit and training) and Group D (subject fit and no training) yielded the lowest NRRs (.9 and 5.1 dB, respectively). For the experimenter fit groups, the training group (A) yielded a higher NRR (11.8 dB) than the no training group (B-NRR 8.2 dB). It appears, then, that fit influenced NRRs, but training probably did not.

When NRRs were computed on the basis of only fit or training (N = 20), the experimenter fit groups (A and C) and the training groups (A and B) yielded slightly larger

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*These numbers are based upon data generated by Paul Michael, Ph.D. at Pennsylvania State University and are offered by Bilsom per the EPA regulation.

Table 3.31. NRR results.

Group(s)	NRR	(ANSI) NRR
Group A (experimenter fit and training)	11.8	9.0
Group B (subject fit and training)	.9	-.2
Group C (experimenter fit and no training)	8.2	8.2
Group D (subject fit and no training)	5.1	3.2
Groups A and C (experimenter fit)	9.6	---
Groups B and D (subject fit)	3.1	---
Groups A and B (training)	6.6	---
Groups C and D (no training)	5.3	---
Groups A - D	6.0	---

NRRs (9.6 and 6.6 dB, respectively) than the subject fit groups (B and D) or the no training groups (C and D - 3.1 and 5.3 dB, respectively). The NRR for all 40 subjects was 6.0 dB.

CHAPTER IV

DISCUSSION

INTRODUCTION

The purpose of this study was to determine whether the variables of hearing protector fitting (experimenter versus subject) and subject training (present versus absent) affect attenuation and NRR data obtained in a laboratory testing situation. The following questions were asked:

(1) Is information gain significantly affected by the presence of a training program?

(2) Do real-ear attenuation values differ significantly as a function of experimenter fitting versus subject fitting of hearing protection devices?

(3) Do real-ear attenuation values differ significantly as a function of trained versus untrained listeners?

(4) Do real-ear attenuation values differ significantly as a function of the interaction between fitting method and subject training?

(5) Do real-ear attenuation values differ significantly as a function of test band?

(6) What is the correlation between information gain and real-ear attenuation as a function of fitting method and subject training?

(7) Do NRR estimates differ as a function of experimenter fitting versus subject fitting of hearing protection devices?

(8) Do NRR estimates differ as a function of trained versus untrained listeners?

INFORMATION GAIN

The two subject groups (A and B) exposed to the Bilsom training films "Nice To Hear" and "SOS" exhibited significant information gain when tested in a pre-test - post-test paradigm. For this reason, and because the two groups (C and D) not so exposed produced negative information gain, it is reasoned that the Bilsom films cause at least a short-term increase in subject information about hearing, industrial noise, and hearing conservation.

OSHA (1983) acknowledges the potential value of employee training in these areas through the requirement of annual instruction (OSHA, 1983, p. 9739). Although the Bilsom materials produce information gain, and although they have been found by others to contribute significantly to the overall effectiveness of hearing conservation programs (Karmy and Martin, 1982), the present findings suggest a lack of effect upon real-ear attenuation and derived NRR values. This lack of impact is evidenced by (1) the small correlations between information gain and real-ear attenuation and (2) the non-significant ANOVA main-effect of training upon real-ear attenuation.

The Bilsom films devote little attention to the method by which hearing protectors should be fitted by users, probably because the details of those methods vary with protector type and because the film producers chose not to assume the use of any particular protector by the viewer. Further, the training tests designed to assess information gain did not include items relating to the details of fitting protectors.

In addition to viewing films, the trained subjects in Groups A and B were given instruction in the use of the particular insert protector used in the study; Groups C and D received only the information printed on the protector package. Possibly, the additional instruction offered by the experimenter was ineffective. Alternatively, the information on the protector package was just as effective (or ineffective) as that provided by the experimenter. In any event, it appears that special measures are necessary to instruct wearers of insert hearing protectors in the correct fitting of those devices.

REAL-EAR ATTENUATION AND NOISE REDUCTION RATINGS (NRRs)

As noted in Chapter III, reliability was assessed at the level of the individual subject and at the group level. Reliability at the level of the individual subject (Tables 3.8 - 3.11) was significant for all but one subject. This indicates that subjects were consistent in their threshold criteria across trials and across noise bands. This was not fully the case at the group level (Tables 3.12 - 3.19) where reliability was assessed across trials and across subjects, within noise bands. Only the subject-fit groups, B and D (trained and untrained, respectively) exhibited reliable results. This suggests that when subjects fit the devices themselves, they were consistent across trials. In other words, they probably developed some internalized criterion for correct fit of the protectors. When the experimenter fit the devices from trial to trial, reliability was poorer, suggesting a less consistent criterion for fit across trials. This difference may occur because subjects are able to tactually observe placement of insert protectors and experimenters can only visually observe placement.

When correlation coefficients were further averaged across group pairs, trial pairs and noise bands (Tables 3.16 0 3.19), the subject fit groups (B and D), the trained groups (A and B) and the untrained groups (C and D) achieved significance. This supports the contention that the subject fit strategy produced greater reliability than the experimenter fit strategy, regardless of training.

The outcomes of the analysis of attenuation data revealed several issues. To aid in this discussion, Table 4.1 reviews the information on means, standard deviations and standard errors of the mean for the four experimental groups. Table 4.1 also presents the labeled means and standard deviations for the Bilsom Propp-o-Plast protector. These data were generated by Paul L. Michael, Ph.D. at the Pennsylvania State University in accord with ANSI S3.19-1974.

Table 4.1. Attenuation data from this study and from Michael's data.

Measure	Frequency 125	250	500	1000	2000	3150	4000	6300	8000
Group A (experimenter fit; training)									
Mean	8.1	8.2	14.2	16.7	25.3	30.2	32.9	34.6	33.0
Standard Deviation	3.1	2.5	1.9	2.3	3.2	2.5	2.4	3.6	3.5
Standard Error of the Mean	1.03	.83	.63	.77	1.06	.83	.80	1.20	1.16
Group B (subject fit; training)									
Mean	7.6	7.3	11.6	12.3	20.9	26.4	27.7	30.0	29.6
Standard Deviation	6.5	5.6	6.1	6.1	8.4	7.0	6.9	9.6	8.7
Standard Error of the Mean	2.16	1.86	2.03	2.03	2.80	2.33	2.30	3.20	2.90
Group C (experimenter fit; no training)									
Mean	10.4	10.5	14.4	17.9	25.2	31.4	32.6	33.8	32.8
Standard Deviation	4.9	4.4	4.3	5.6	3.2	4.7	4.3	3.9	4.9
Standard Error of the Mean	1.63	1.46	1.43	1.86	1.06	1.56	1.43	1.30	1.63
Group D (subject fit; no training)									
Mean	10.9	9.2	14.1	14.9	24.1	30.1	30.1	33.5	33.3
Standard Deviation	4.5	4.7	5.9	5.7	5.1	7.0	6.4	4.8	4.9
Standard Error of the Mean	1.50	1.56	1.96	1.90	1.70	2.33	2.13	1.60	1.63
Michael's Data									
Mean	22.6	24.5	26.2	26.2	34.0	39.2	40.5	41.3	38.3
Standard Deviation	3.6	2.8	2.5	3.0	3.0	2.2	2.8	3.2	3.6

Evident from the results of this study is that attenuation across frequencies tended to increase as frequency increased except at 8000 Hz where a small drop in attenuation was noted. Michael's data show the same trend. This was further confirmed by a three-way ANOVA which showed that the main effect of test band was statistically significant. Indeed, 87% of the total variation in attenuation was attributed to test band frequency.

Table 4.2 presents means and standard deviations for the EAR insert hearing protector for comparison to a similar type of hearing protector (Abel, Alberti and Riko, 1982). These results represent an average of 347 subjects tested following a subject fit strategy. Although these data were gathered with different procedures and used a different protector, the effect of frequency upon attenuation was similar to the present data: frequency increases, then drops off slightly at the higher frequencies.

Results from the present study indicated that the experimenter fit groups (A and C) and the groups which received training(A and B) showed slightly greater mean attenuation and slightly smaller standard deviations than the subject fit groups (B and D) or the untrained groups (C and D). These effects were not statistically significant except for fit at 1000 and 4000 Hz. Martin (1982) compared attenuation on a pre-molded insert earplug in terms of experimenter fit versus subject fit. He found that the experimenter fit condition yielded higher mean attenuation and lower standard

Table 4.2. Attenuation results for the EAR hearing protection device (From Abel, Alberti and Riko, 1982, p. 320).

	Frequency							
Measure	125	250	500	1000	2000	3000	4000	6000
Mean	12.8	14.2	14.5	18.0	24.5	27.1	25.2	21.8
Standard Deviation	8.3	10.0	8.7	7.7	7.5	8.0	8.5	9.2

deviations than the subject fit group (see Table 1.2). It is not known whether these differences were statistically significant. Martin (1982, p. 275) stated

> This...does illustrate the need for rigorously defined fitting procedures in standard methods and, more importantly, the need for general agreement as to which type of fitting procedure should be specified.

Closely associated with the attenuation results are NRRs. The published NRR for the Bilsom Propp-o-Plast device is 22.1 dB. The means and standard deviations used to compute this NRR are presented in Table 4.1 (Michael's data). NRRs obtained in this study were considerably smaller than those reported by the manufacturer of this device. As with the attenuation data, somewhat larger NRRs were obtained for the experimenter fit and training strategies. Because the NRRs were based upon the attenuation values, and because attenuation did not differ significantly as a function of fit or training, it was reasoned that NRR differences were not statistically significant.

RELATION OF OUTCOMES TO PRIOR RESEARCH

Berger, Kerivan and Mintz (1982) demonstrated differences in measured attenuation and NRRs for insert protectors tested by eight laboratories. These differences persist despite nominal conformity with the ANSI S3.19-1974 and EPA (1979) methods. Berger, Kerivan and Mintz (1982) attributed inter-laboratory differences to hearing protector fitting, subject selection, subject training, and data reduction techniques, but did not report details of methodological differences among laboratories.

Forshaw (1982) cited several reasons for variations in attenuation measurements from laboratory to laboratory. He stated that the ANSI and EPA methods are not sufficiently explicit on the selection and training of subjects or on fitting procedures. He further stated that differences may be significant from laboratory to laboratory when only ten subjects are used for testing. Because of the difficult listening task and the length of the testing (approximately 2.5 hours in the present experiment), changes in signal detection criteria may be a source of variance. Many of the subjects used in this study stated that the listening task was difficult and fatiguing. This may explain why standard deviations were higher than expected and why mean attenuation and NRRs were lower than expected. Although frequent rest periods were provided, it is felt that subject fatigue affected results.

Neither the ANSI or EPA test methods provide detailed guidelines for subject selection or training. The ANSI document specifies only that subjects exhibit normal hearing bilaterally. Because more specific requirements are not provided, laboratories may differ in the rigor with which they select and motivate subjects. Paid subjects may be better practiced and better motivated than unpaid subjects; this in turn may influence the outcomes of experimental testing.

Few guidelines are present in these standards with regard to subject training. ANSI specifies that trained subjects are to be used. Presumably, training refers to threshold tracking, but no information is offered as to the amount of training that should be provided. The ANSI document specifies only that

> ...no listeners shall be selected as a subject for these tests whose variability for the open threshold of audibility...is such that a range on three successive open threshold measurements at any test band between the 250 and 4000 Hz bands is greater than 6 dB (p. 4).

Using this criterion for unoccluded thresholds, five of the forty subjects used in this study would have been rejected. One of these came from Group A (experimenter fit and training), one came from Group C (experimenter fit and no training), and three came from Group B (subject fit and training). Because of this distribution, it is felt that the increased variability of these subjects probably did not affect the attenuation results in terms of the experimental factor of fit.

Differences among laboratories should be expected, and indeed have been found in the presence of such ambiguities. Tobias (1982, p. 171) stated:

> Neither the American standard nor the EPA computational procedures says anything substantive about how to select the human subjects for testing or about how to fit the hearing protectors to the subjects' ears. Again, measurers are making choices. Some choose their subjects more or less randomly, from the belief that only with that sort of selection can the variability values give a reasonable approximation to the ways in which the protector will work away from the laboratory. Others, suggesting that the increased variability one gets with a heterogeneous group of subjects lead to unreliable

> results -- that is, the results are not precisely repeatable -- began to collect experienced listeners for their tests of hearing protectors.

Assuming validity of Tobias' statements, and because subjects used in this study were not "professional" listeners, it is reasoned that the results obtained here give a "reasonable approximation to the ways in which the protector will work away from the laboratory" (Tobias, 1982, p. 171). This is further supported by the observation that the attenuation and NRR results obtained in this study closely parallel those found by others in field tests (see Tables 1.3 and 1.4). Work reported by Padilla, 1976, Regan, 1977, Edwards, <u>et al</u>., 1978, and Alberti, <u>et al</u>., 1979 indicated that attenuation results obtained in the industrial field are considerably lower than laboratory results primarily because better results tend to be found when devices are fit by experimenters and because in-field studies utilize a subject fit strategy.

In addition to differences in subject selection and training, factors related to hearing protector fit may serve to explain the present outcomes. These factors include:

(1) the experimenter did not optimally fit the devices and the package label instructions for fitting were insufficient or not followed properly; or

(2) both methods were equally effective and published data are erroneously large; or

(3) proper fit was not possible for reasons of device design.

Several observations are possible with regard to device design and the interaction of such design with subject variables. In the present study, equal numbers of males and females were used in each group. Although subject sex is typically not reported in published studies of hearing protector effects, and although the EPA and ANSI procedures are silent on this issue, it is known that males and females differ in ear canal dimensions. It is possible that subjects with relatively large or small canals were not adequately protected by the devices used here. Second, it was noted that several of the protectors could not be used because the polyethelene cover separated from the cotton-like filling when the protectors were removed from the dispensing package. It is possible that similar separation occured after the devices were inserted, thus reducing the effectiveness of the seal between the outer surface of the protector and the canal wall.

Other reasons which may explain why the attenuation measurements and NRRs obtained in this study were lower than published results relate to variations from acoustical specifications of the test environment. The test chamber used in this study had:

(1) slightly shorter reverberation times than specified by ANSI S3.19-1974;

(2) higher overall ambient noise levels than specified by ANSI S3.19-1974; and

(3) undetermined levels of total harmonic distortion.

ANSI S3.19-1974 specifies a reverberant sound field primarily to simulate the diffuse characteristics of industrial sound fields. Reverberation times are to be between 500 and 1600 msec for each test band. Measured reverberation times of the test chamber used in this study were marginally below criteria, ranging from 300 - 460 msec. Because of the departure from specifications was minor, it is reasoned that the shorter reverberation times measured in the laboratory had a minimal effect on measured attenuation.

Total harmonic distortion could not be measured because of instrumental limitations. If appreciable harmonic distortion had been present in the system, it is expected that the unoccluded thresholds would have been better (lower) than they were. Therefore, it is unlikely that harmonic distortion had an effect.

As stated in Chapter II, ambient noise levels could not be measured at individual noise bands. Overall ambient noise was measured in the test chamber using linear, A-weighted and C-weighted characteristics. To determine the possible effects of increased ambient noise level on measured attenuation, the maximum permissible ambient levels for individual octave bands specified in ANSI S3.19-1974 were converted to A- and C-weighted levels and then compared to the ambient levels of the test chamber used in this study. As noted in Table 4.3, the differences in maximum permissable levels specified by ANSI S3.19-1974 and the measured levels from the test chamber were 4 dBA, 15.0 dBC and 11.5 dB linear. If it is assumed that the effect of ambient noise upon unoccluded

Table 4.3. Converted ambient noise levels.

	dBA	dBC	Linear
Ambient noise levels obtained in test chamber	33.0	43.5	44.0
Maximum permissable ambient noise levels per ANSI S3.19-1974	29.0	28.5	31.5
Difference	4.0	15.0	12.5

threshold is linear with respect to level and frequency, and further that ambient noise would not affect threshold standard deviations, then NRRs can be re-computed by adding a constant to the attenuation measured at each noise band. This was done for Group A (experimenter fit and training) and new NRRs were computed. Adjusted NRRs were 15.8 dB for the "corrected" dBA levels, 28.0 dB for the "corrected" dBC levels, and 24.3 dB for the "corrected" linear levels. The NRR originally computed for this experimental group was 11.8 dB, while the labeled NRR for the device was 20.0 dB. While it cannot be known with certainty whether the increased ambient noise in the test chamber adversely affected results, it is probable that lower ambient noise levels would have produced greater mean attenuations and NRRs.

The ANSI S3.19-1974 document requires fairly strict controls on the acoustic field used for testing hearing protection devices in the hope of producing stable results. Industrial environments almost certainly do not conform to such optimal control, and there may be interactions among acoustic fields, bodies and hearing protection devices. These sources of variance are expected to impact the effectiveness of hearing protection devices in real environments. Although the test chamber used in this study was not completely within specifications for all parameters, and although these limitations seem to have produced less than optimal results, it appears the test environment may have been more like an industrial field environment.

This study was not designed to investigate the effects of inter-trial differences upon measured attenuation, but instead followed the requirement of ANSI S3.19-1974 that data be averaged across three trials (within-trial dispersion was not measured). As an *ad hoc* analysis, raw attenuation data (Appendix J) were studied to determine the number of subjects who gave maximum attenuation values during the last trial. Tallies are shown in Table 4.4. With only a few exceptions, at least a third of the subjects in each group and at each test band produced greater attenuation results in Trial 3. Group B (subject fit and training) yielded the greatest count across test bands; Group D (subject fit and no training) gave an intermediate count; and Groups A (experimenter fit and training) and C (experimenter fit and no training) produced the smallest counts. Instances of greater attenuation for Trial 3 were similar (about 15 subjects across four groups) for the nine test bands, the exception being the 250 Hz band which yielded a count of 25.

This learning effect is more potent in the subject fit groups than in the experimenter fit groups. The factor of training seems to have little impact upon the trend toward greater attenuation in Trial 3, however.

Had the Trial 3 data been used instead of the mean across trials, the factor of fit may have been significant at more than two test bands. Further, the learning effect may (in part) explain why the present attenuations and NRRs

Table 4.4. *Ad hoc* analysis of Trial 3 attenuation data. (Numbers are the numbers of subjects per group which exhibited greater attenuation at Trial 3).

	Frequency									
	125	250	500	1000	2000	3150	4000	6300	8000	$\bar{X}$
Group A*	6	6	3	2	6	4	3	3	1	3.8
Group B*	3	5	2	4	1	4	4	5	5	8.1
Group C*	2	6	4	4	3	4	2	4	5	3.8
Group D*	6	8	4	4	4	4	6	2	4	4.7
Total	17	25	13	14	14	16	15	14	15	15.9

*Group A = experimenter fit and training; Group B = subject fit and training; Group C = experimenter fit and no training; Group D = subject fit and no training.

were lower than those reported by Michael. Regardless, the possibility of a learning effect in subjects who otherwise satisfy response stability requirements suggests the need for study of short-term learning effects.

It is apparent that there exists a wide range of variation in attenuation and NRRs generated among laboratories and industrial fields and a variety of explanations for these differences. It is felt that the ANSI and EPA testing methods should be expanded to include better ways of similating industrial field settings. It is felt that more research is needed to determine why inter-laboratory differences exist, what specifically the differences are, and ways to resolve the differences. If this is not done, users of the devices cannot really know what protection can be expected from a particular device and consequently may be underprotected.

FINDINGS

This study sought to determine whether the variables of hearing protector fit and subject training affect attenuation and NRR data obtained in the laboratory testing situation. Based on the results and analysis of the results, the present study found as follows:

(1) Information gain was significantly increased by a training program.

(2) Reliability at the individual subject level was high and statistically significant for all but one subject.

(3) Reliability at the group level was statistically significant for the subject fit groups and for trained and untrained groups, but not for the experimenter fit groups.

(4) Real-ear attenuation values differed significantly as a function of test band in patterns similar to what has been reported elsewhere.

(5) Real-ear attenuation values and NRR estimates obtained for the Bilsom Propp-o-Plast device were considerably lower than the manufacturer's labeled attenuation values and NRR estimate. At least in part, this was due to inter-trial learning effects and problems of ambient noise.

(6) Real-ear attenuation values differed significantly as a function of fit only at 1000 Hz and 4000 Hz and approached significance at 2000 Hz, 3150 Hz, and 6300 Hz.

(7) Real-ear attenuation values did not differ significantly as a function of the presence or absense of subject training.

(8) Real-ear attenuation values did not differ significantly as a function of the interaction between fitting method and subject training.

(9) The correlation between information gain and real-ear attenuation was not significant as a function of fitting method or subject training.

(10) NRR estimates appeared to differ as a function of

experimenter vs. subject fit slightly. Increased NRR estimates were found for the experimenter fit strategy.

IMPLICATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The results and outcomes of this study (as well as others reviewed herein) present some important implications for the industrial sector. Several issues about laboratory testing of hearing protection devices, in general, remain unresolved and deserve further attention. Several issues about the data generated from this study remain unresolved as well.

It has been demonstrated that differences among laboratories and industrial field environments exist with regard to measured attenuation and NRRs. Industries using hearing protection devices should be aware that these differences exist and that the protection devices they are purchasing and using may reflect inaccurate protection values. Further research should focus on the test methods used for measuring hearing protection devices. There is a need for an "objective" test method to account for human subject effects related to variances associated with fit and training and also those variances associated with laboratory versus field effects.

In particular, future research should focus upon subject selection and training procedures and upon laboratory fitting practices. An appropriate goal for such work is to identify a balance between (1) the problem of stability in measured attenuation, and (2) the problem of validity in predicting effectiveness in the field. One approach to this goal would be to employ subject fit methods and to study patterns of change in measured attenuation across trials (i.e., as initially naive listeners become more practiced through experience). The resulting "learning curve" may allow more accurate prediction of protector effects in real-world situations. It is expected that inter-trial effects will vary for different types of protectors.

Similarly, the long-term effects of subject training should be investigated. It is expected that "professional" subjects will develop threshold criteria and self-fit strategies which differ appreciably from those of less experienced subjects and from those of workers in field environments.

The effects of sex on measured attenuation and NRRs obtained in the laboratory should be investigated. Although industrial environments typically involve more males than females, women are present in the work force. It would be appropriate to address these issues and their effects on hearing protection device testing methods and performance.

Industry assessments of hearing conservation program and monitoring audiometry are indeed important. Because NRR estimates are variable across laboratories and, perhaps, invalid, further research is needed to determine these effects on hearing conservation programs.

CONCLUSIONS

In addition to the findings and implications discussed above, several conclusions can be stated:

(1) This study demonstrated that two of Bilsom, International's training films ("Nice To Hear" and "SOS") provide a significant amount of short-term information gain regarding hearing, industrial noise and hearing conservation. Although these training films do not appear to affect the outcome of attenuation measurements and NRRs, it is felt that these and similar training materials would provide substantial information to industrial employees and would be appropriate for use in hearing conservation programs.

(2) It was shown that subjects exposed to the training program and those who had hearing protection devices fitted by the experimenter demonstrated slightly greater mean attenuation values and lower standard deviations; these were statistically significant for only two frequencies. Based on this outcome and previous research, it is concluded that experimenter fit strategies employed in laboratory test environments yield greater attenuation and NRR results than do subject fit strategies.

(3) This study supported the previous, somewhat discouraging finding that different laboratories produce different NRR estimates, despite

considerable effort to manage test signals, the test environment, subject selection, subject training, hearing protection device fitting method and psychophysical method. Although there are two standards which specify methods for the measurement of hearing protection devices, differences are still found when nominally similar methods are followed.

(4) Further study is indicated to determine why inter-laboratory differences exist, the magnitudes and ranges of those differences, and ways to resolve them.

(5) In its present form, the ANSI S3.19-1974 test method produces highly variable results (a) among laboratories and (b) between laboratory and industrial field settings. The method, therefore, requires further study and refinement to reduce this variability.

CHAPTER V

SUMMARY AND CONCLUSIONS

INTRODUCTION

It is well known that excessive noise can damage the human auditory system; excessive noise can cause other sorts of problems as well. Damaging noise is prevalent in industrial environments and protection from the harmful effects of industrial noise should focus on prevention. When appropriate engineering and administrative controls cannot sufficiently decrease noise to acceptable levels, hearing protection devices are often employed.

Prior to 1979, the effectiveness of hearing protection devices were evaluated behaviorally by an absolute threshold shift procedure. In September, 1979, the Environmental Protection Agency (EPA, 1979) ruled that all domestic hearing protection devices must bear a label containing a single-number estimate of effectiveness designated Noise Reduction Rating (NRR). The NRR indicates the noise attenuation capability of a hearing protection device, weighted by an assumed noise spectrum and the statistical variations in band attenuation data obtained from a group of ten listeners (Juneau, 1982). The behavioral test methods underlying the NRR are described in American National Standards Institute

(ANSI) S3.19-1974 "Measurement of Real-Ear Protection of Hearing Protectors and the Physical Attenuation of Earmuffs." The EPA also requires an experimenter fit strategy for determination of a devices NRR.

A review of the literature indicates that the validity of the NRR is open to question. Because the NRR is obtained under optimal laboratory conditions, these may not accurately reflect effectiveness of the device in the industrial field setting where the device is used. Several studies (Padilla, 1976; Regan, 1977; Edwards, *et al.*, 1978; Alberti, *et al.*, 1979; Abel, Alberti, and Riko, 1982; Berger, 1983) have shown that attenuation data (used to compute the NRR) generated in controlled laboratory settings do not accurately reflect effectiveness of protection devices in the industrial field setting. Other studies (Berger, Kerivan and Mintz, 1982; Forshaw, 1982) have indicated that there are inter-laboratory differences among laboratories which conduct NRR tests. Reasons cited for these inter-laboratory and laboratory-field differences include subject selection and training, fit of the device, data reduction techniques and variations in acoustical parameters. This study was designed to assess the effects of hearing protector fit and subject training on attenuation and NRR data obtained in a laboratory testing situation.

METHODS

Subjects for this study were forty adult listeners

(20 females; 20 males) who exhibited otoscopic, audiometric and otologic normalcy. Subjects were randomly assigned to one of four groups consisting of ten subjects each. Two experimental groups (A and B) viewed a commercially available (Bilsom International) multi-media education program designed to emphasize several informational and affective topics related to hearing, industrial noise and hearing conservation. Groups C and D did not receive the training program. Two groups (A and C) had hearing protection devices fit by the experimenter, and the remaining two groups (B and D) utilized a subject fit strategy.

All 40 subjects were administered a 40 question pre-test and a 20 question post-test. These tests were designed to assess the informational and affective effects of the training program. Information gain scores were obtained as the difference between the post-test and pre-test scores.

The hearing protection device used for all measurements was the Bilsom "Propp-o-Plast" disposable, insert type plug. Real-ear attenuation at threshold measurements were taken in accord with ANSI S3.19-1974; three trials each of unoccluded and occluded measures were taken at each of nine frequencies (125 - 8000 Hz, 1/3-octave bands of noise). Attenuation for a given test band was computed as the difference between occluded and unoccluded threshold measures across trials. NRRs were also computed for the experimental groups.

RESULTS

With regard to information gain, results showed that training increased the difference between post-test and pre-test performance. Higher mean information gain scores were found for the groups which received the training program (A and B). A two-way analysis of variance (ANOVA) performed on information gain with the main effects of hearing protection device fit and subject training showed that the effect of subject training was statistically significant.

Reliability of measured attenuation was assessed across trials at the level of the individual subject (across noise bands) and at the group level (across subjects). These results showed that at the subject level, all subjects but one demonstrated reliability that was high and statistically significant. At the group level, reliability across noise bands and groups was statistically significant for the subject fit groups (B and D), the trained groups (A and B) and the untrained groups (C and D). The experimenter fit groups (A and C) did not demonstrate statistically significant reliability.

Mean attenuation results showed greater attenuation and lower standard deviations for the experimenter fit groups (A and C) and for the trained subjects (Groups A and B). The relation between information gain and attenuation was assessed and found not to be statistically significant. A three-way ANOVA showed that the main effect of test band was statistically significant, but that the main effects of hearing protector fit and subject training were not.

Subsequent analyses revealed statistically significant results for the main effect of fit at the frequencies 1000 and 4000 Hz and approached significance at 2000, 3150, and 8000 Hz.

Noise reduction ratings (NRRs) for the experimenter fit groups (A and C) and for the training groups (A and B) were greater than those computed for the subject fit groups (B and D) or the no training groups (C and D). These NRRs were compared to the labeled NRR for the device tested and were considerably lower than the labeled-manufacturer's data.

CONCLUSIONS

Based on the results and analysis of the results, the following conclusions are offered:

(1) This study demonstrated that two of Bilsom, International's training films ("Nice To Hear" and "SOS") provide a significant amount of short-term information gain regarding hearing, industrial noise and hearing conservation. Although these training films do not appear to affect the outcome of attenuation measurements and NRRs, it is felt that these and similar training materials would provide substantial information to industrial employees and would be appropriate for use in hearing conservation programs.

(2) It was shown that subjects exposed to the training program and those who had hearing protection devices fitted by the experimenter demonstrated

slightly greater mean attenuation values and lower standard deviations; these were statistically significant for only two frequencies. Based on this outcome and previous research, it is concluded that experimenter fit strategies employed in laboratory test environments yield greater attenuation and NRR results than do subject fit strategies

(3) This study supported the previous, somewhat discouraging finding that different laboratories produce different NRR estimates, despite considerable effort to manage test signals, the test environment, subject selection, subject training, hearing protection device fitting method and psychophysical method. Although there are two standards which specify methods for the measurement of hearing protection devices, differences are still found when nominally similar methods are followed.

(4) Further study is indicated to determine why inter-laboratory differences exist, the magnitudes and ranges of those differences, and ways to resolve them.

(5) In its present form, the ANSI S3.19-1974 test method produces highly variable results (a) among laboratories and (b) between laboratory and industrial field settings. The method, therefore,

requires further study and refinement to reduce this variability.

APPENDICES

APPENDIX A

SUBJECT SCREENING FORMS

STATEMENT OF PURPOSE

The experiment which you are about to participate in relates to the use of hearing protection devices commonly used in industrial settings. The purpose of this experiment is to determine differences in hearing protection device measurements.

INFORMED CONSENT RELEASE

1) I,____________________________, freely and voluntarily consent to serve as a subject in a scientific study of hearing protection device performance conducted by Kimberly A. Payne, B.A. working under the supervision of Michael R. Chial, Ph.D.

2) I understand that the purpose of the study is to determine differences in hearing protection device measurements, which may be of future usefulness to professionals involved in hearing protection. I also understand that the procedures involved are experimental and that the results of this study will not be of any direct personal benefit to me.

3) I understand that I will not be exposed to any experimental conditions which constitute a threat to hearing, nor to physical or psychological well being.

4) I understand that the data gathered for this study are confidential, that no information uniquely identified with me will be made available to other persons or agencies, and that any publication of the results of this study will maintain anonymity.

5) I engage in this study freely, without payment to me or from me, and without implication of personal benefit. I understand that I may cease participation in the study at any time.

6) I have had the opportunity to ask questions about the nature and purpose of the study and I have been provided with a copy of this written informed consent form. I understand that upon completion of the study, and at my request, I can obtain additional explanation about the study.

SIGNED:____________________________ DATE:______________________

SUBJECT CASE HISTORY

1) Age:
   Sex:

2) Do you have a history of familial hearing loss. If so, state relation and age of person.

3) Have you ever had ear surgery? If so, what type and when?

4) Do you have or have you ever had hearing loss, vertigo, or tinnitus? If so, please explain.

5) Do you currently have a cold, ear infection or upper respiratory infection?

6) Have you ever worked in a noisy industrial setting? If so, when and for how long? Were you required to wear hearing protection devices?

7) Have you ever taken the following drugs?
   - kanamycin
   - gentamycin
   - streptomycin
   - dihydrostreptomycin

8) Have you ever been treated for severe burns or a severe infection (i.e., meningitis, encephalitis, etc.)?

9) Have you taken any drugs in the last 72 hours (excluding coffee and aspirin)? List all.

CRITERIA FOR AUDIOLOGICAL AND OTOLOGICAL NORMALCY

1) Normal bilateral otoscopy. No excess cerumen.

2) Pure tone air and bone conduction thresholds (dB HTL) no greater than 10 dB (re: ANSI S3.6-1969) at test frequencies between 250 Hz and 6000 Hz and no greater than 15 dB at 8000 Hz.

3) Type A tympanograms bilaterally. Acoustic reflex thresholds within a normal level of 70-90 HTL and 60-90 SL at 500 Hz, 1000 Hz and 2000 Hz.

4) Absence of acoustic reflex decay at 500 Hz and 1000 Hz, bilaterally.

5) No reported history of otologic surgery, familial hearing loss, or current URI's, vertigo, tinnitus or hearing loss.

6) Confirming data shall be obtained within 2 days of experimental testing.

SUBJECT SCREENING FORM

SUBJECT NAME________________________SCREENING DATE__________

AGE_______________PHONE___________________SEX_______________

EXAMINER_______________________AUDIOMETER___________________

AIR AND BONE CONDUCTION THRESHOLDS: dB HTL

		250	500	1000	2000	4000	8000
AC	Right Ear	___	___	____	____	____	____
	Left Ear	___	___	____	____	____	____
BC	Right Ear	___	___	____	____	____	
	Left Ear	___	___	____	____	____	

OTOSCOPIC EXAMINATION_______________________________________

TYMPANOMETRIC RESULTS: SEE ATTACHED TYMPANOGRAM

BRIDGE____________________________

ACOUSTIC REFLEX THRESHOLDS:

	500	1000	2000
Right Ear	___	____	____
Left Ear	___	____	____

ACOUSTIC REFLEX DECAY:

	500	1000
Right Ear	___	____
Left Ear	___	____

STATEMENT OF PURPOSE READ___________________________________

INFORMED CONSENT RELEASE FORM SIGNED________________________

TRAINING PROGRAM COMPLETED__________________________________

PRE-TEST ADMINISTERED_______________________________________

SUBJECT INSTRUCTIONS

You will be listening to different sets of noises at different pitches. These sounds will be very faint. As soon as you hear the noises, press the button. As soon as the noises go away, release the button. You must listen very carefully. Please keep your eyes focused on the lighted box in front of you. Your instructions will be on this box. Keep your head and eyes facing this box. If the clear light goes on, this indicates that your head is out of position. Place your head back into position until the clear light goes off, and the test will continue. There is an intercom system in this lab, so you may communicate with the experimenter. Do you have any questions?

APPENDIX B

RUN PROTOCOL

RUN PROTOCOL

SUBJECT #: ______ ______ GROUP: A B C D

SUBJECT CODE ________ SUBJECT NAME ________________ PHONE ____________

SCREENING DATE ____________________ TESTING DATE ________________

STATEMENT OF PURPOSE READ ________________________________

INFORMED CONSENT RELEASE FORM SIGNED ________________________

CALIBRATION: (1000 Hz pure tone)

TAPE RECORDER OUTPUT LEVEL (0 VU) ________________________

LINE AMPLIFIER OUTPUT LEVEL (-4 VU) ________________________

AUDIOMETER INPUT LEVEL (-3 VU) ________________________

AUDIOMETER RECORDING ATTENUATOR PEN SET (100 dB) ________________

POWER AMPLIFIER OUTPUT VOLTAGES (white noise) RIGHT 500 mvolts ______

LEFT 500 mvolts ______

SUBJECT REPORTED NO EXPOSURE TO EXCESSIVE NOISE IN LAST 24 HOURS ____

SUBJECT ACCLAMATED TO TEST ENVIRONMENT FOR 5 MINUTES ____________

RESPONSE TRAINING SESSION COMPLETED ________________________

EXCURSION WIDTH ON TRAINING SESSION ________________________

SUBJECT DISMISSED? ________________________________

UNOCCLUDED WHITE NOISE THRESHOLD ________________________

TRAINING PROGRAM ADMINISTERED ________________________

PRE-TEST ADMINISTERED ____________________ FORM ____________

PRE-TEST SCORE ________________________________

POST-TEST ADMINISTERED ____________________ FORM ____________

POST-TEST SCORE ________________________________

HEARING PROTECTOR DEVICE FIT:

EXPERIMENTER FIT ________________ SUBJECT FIT ____________

DEVICE MANIPULATED ____________

Table 1. Random Schedule of Test Signal Presentation.

Measure	Randomization Schedule
Unoccluded Trial 1	___ ___ ___ ___ ___ ___ ___ ___ ___
Occluded Trial 1	___ ___ ___ ___ ___ ___ ___ ___ ___
Unoccluded Trial 2	___ ___ ___ ___ ___ ___ ___ ___ ___
Occluded Trial 2	___ ___ ___ ___ ___ ___ ___ ___ ___
Unoccluded Trial 3	___ ___ ___ ___ ___ ___ ___ ___ ___
Occluded Trial 3	___ ___ ___ ___ ___ ___ ___ ___ ___

Table 2. Threshold Data.

				Test Frequency					
Measure	125	250	500	1000	2000	3150	4000	6300	8000
Unoccluded Trial 1									
Occluded Trial 1									
Unoccluded Trial 2									
Occluded Trial 2									
Unoccluded Trial 3									
Occluded Trial 3									
$\bar{X}$ Unoccluded									
SD									
$\bar{X}$ Occluded									
SD									

Table 3. Attenuation Data.

				Test Frequency					
Measure	125	250	500	1000	2000	3150	4000	6300	8000
Trial 1									
Trial 2									
Trial 3									
$\bar{X}$									
SD									

DATA FILED IN SUBJECTS FOLDER________________________________

APPENDIX C

TRAINING TESTS

PRE-TEST
FORM A

1) Tears are caused by:
   - a) irritation to the eye
   - b) anxiety or emotion
   - c) infection
   - d) all of the above
   - e) none of the above

2) Cataracts affect:
   - a) the iris
   - b) the retina
   - c) the conjunctiva
   - d) the lens
   - e) none of the above

3) The lacrimal apparatus is responsible for:
   - a) cleansing and lubrication
   - b) production of visual purple
   - c) production of vitreous fluid
   - d) focusing
   - e) none of the above

4) Earplugs should be inserted in the ear by:
   - a) reaching under the chin, pulling the ear down and back and inserting the plug
   - b) reaching behind the head, pulling the ear back, and inserting the plug
   - c) reaching over the head, pulling the ear up and back and inserting the plug
   - d) reaching in front of the head, pulling the ear forward, and inserting the plug
   - e) none of the above

FORM A

5) A person with a permanent hearing loss:

- a) will generally have problems with both loudness and clarity of sounds
- b) will only have problems with loudness of sounds
- c) will only have problems with clarity of sounds
- d) generally will not have problems unless the hearing loss is profound
- e) none of the above

6) Sound is composed of:

- a) time and mass
- b) minutes and weight
- c) frequency and intensity
- d) hearing loss
- e) none of the above

7) Which of the following would be the least intense?

- a) rustle of a leaf
- b) jet aircraft
- c) drill press
- d) traffic
- e) none of the above

8) Correction of visual impairment may involve:

- a) corrective lenses
- b) surgery
- c) medication
- d) all of the above
- e) none of the above

9) With regard to hearing protection devices:

   a) earplugs are the best type

   b) earmuffs are the best type

   c) earplugs are best used in recreational settings but earmuffs are best used in industrial settings

   d) a wide variety of hearing protectors exist

   e) none of the above

10) Nystagmus is associated with:

   a) vision only

   b) balance only

   c) vision and balance

   d) vision, balance and hearing

   e) none of the above

11) Which of the following statements is true?

   a) all industrial work settings have excessive noise

   b) only industrial work settings in Chicago, New York and Los Angeles have excessive noise

   c) each and every industrial work setting must be measured for excessive noise levels

   d) employees of industrial work settings must provide their own hearing protection

   e) none of the above

12) The hearing cells are located in the:

   a) ear canal

   b) cochlea

   c) eardrum

   d) middle ear

   e) none of the above

FORM A

13) Which of the following statements is true?

a) the cornea exists in the outer layer of the eye

b) the cornea exists in the middle layer of the eye

c) the iris exists in the outer layer of the eye

d) the retina exists in the middle layer of the eye

e) none of the above

14) The retina:

a) translates light waves into neural impulses

b) gives color to the eye

c) is associated with the pupil

d) produces tears

e) none of the above

15) Hearing loss could affect:

a) a persons family life

b) a persons social life

c) a persons professional life

d) all of the above

e) none of the above

16) Which of the following statements is false?

a) hearing protection devices prevent hearing loss

b) noisy machinery can be provided with sound insulating enclosures

c) hearing loss from noise exposure is permanent

d) many types of hearing protection devices exist

e) none of the above

FORM A

17) Soundwaves first reach:

- a) the brain
- b) the cochlea
- c) the eardrum
- d) the middle ear
- e) none of the above

18) Blindness may cause:

- a) digestive disorders
- b) feelings of loss and anxiety
- c) loss of balance
- d) all of the above
- e) none of the above

19) The sense organ associated with vision is:

- a) the mouth
- b) the eye
- c) the ear
- d) the brain
- e) none of the above

20) The 3 bones of the ear are located in the:

- a) outer ear
- b) middle ear
- c) inner ear
- d) eardrum
- e) none of the above

FORM A

21) Hearing loss is measured:

a) in a loss of decibels

b) in errors of understanding speech

c) as a %

d) in all of the above

e) none of the above

22) Which of the following statements is false?

a) excessive noise may increase a persons blood pressure

b) excessive noise may cause irritability

c) excessive noise causes hearing loss

d) excessive noise may cause digestive disorders

e) none of the above

23) The photosensitive system of the retina is/are:

a) the lacrimal apparatus

b) the conjunctiva

c) the cornea

d) the rods and cones

e) none of the above

24) Which of the following statements is true?

a) the rods are sensitive to bright light

b) the rods are sensitive to dim light

c) the cones are sensitive to dim light

d) the cones are equally sensitive to bright and dim light

e) none of the above

FORM A

25) The purpose of a hearing protection device is:

- a) to decrease the level of sound reaching the inner ear
- b) to restore damaged hearing cells
- c) to prevent ear infections
- d) to improve a persons hearing
- e) none of the above

26) The ability to communicate is dependent upon:

- a) hearing alone
- b) speech alone
- c) hearing and speech
- d) high IQ
- e) none of the above

27) Myopia is synonomous with:

- a) conjunctivitis
- b) farsightedness
- c) cataracts
- d) astigmatism
- e) none of the above

28) An effective hearing protector is:

- a) one which is comfortable
- b) one which is comfortable and is fit properly
- c) one which is disposable
- d) one which lasts a long time
- e) none of the above

FORM A

29) The portion of the eye which gives color is:

a) the retina

b) the iris

c) the conjunctiva

d) the cornea

e) none of the above

30) Which of the following statements is true?

a) hearing conservation programs consist only of training programs

b) hearing conservation programs are required by federal law

c) hearing conservation programs consist only of hearing protection device utilization

d) hearing conservation programs are not required by federal law

e) none of the above

31) Harmful noise may be found in/on:

a) golf courses

b) steel stamping plants

c) churches or synagogues

d) grocery stores

e) none of the above

32) Each eye contains _______ million rods:

a) 1

b) 10

c) 20

d) 130

e) none of the above

33) The organ of hearing is/are the:

a) cochlea

b) ossicles

c) eardrum

d) middle ear

e) none of the above

34) Which of the following is true?

a) sight is more important than taste

b) sight is more important than hearing

c) hearing is more important than taste

d) taste is more important than hearing

e) none of the above

35) Each eye contains ______ million cones:

a) 6

B) 8

c) 10

d) 100

e) none of the above

36) Conjunctivitis is:

a) progressive blindness

b) acute blindness

c) inflammation of the conjunctiva

d) inflammation of the cornea

e) none of the above

FORM A

37) The darkened portion at the center of the eye is the:

a) cornea

b) retina

c) iris

d) lens

e) none of the above

38) The humors of the eye refer to:

a) the lens

b) the rods and cones

c) the fluids of the eye

d) the iris

e) none of the above

39) Which of the following statements is false?

a) hearing cells send signals to the brain

b) damaged hearing cells are easily repaired or restored

c) each hearing cell reacts to a different frequency or pitch

d) hearing cells react to sound waves

e) none of the above

40) The principle organ of sight is:

a) the lens

b) the cornea

c) the retina

d) the conjunctiva

e) none of the above

PRE-TEST
FORM B

1) Cataracts affect:

   a) the iris

   b) the retina

   c) the conjunctiva

   d) the lens

   e) none of the above

2) Which of the following statements is true?

   a) a person with a hearing loss does not need to wear hearing protectors

   b) persons over the age of 50 do not need to wear hearing protectors

   c) persons who have normal hearing do not need to wear hearing protectors

   d) once a person has gotten used to noise, hearing protectors are no longer needed

   e) none of the above

3) The portion of the eye which gives color is:

   a) the retina

   b) the iris

   c) the conjunctiva

   d) the cornea

   e) none of the above

4) Nystagmus is associated with:

   a) vision only

   b) balance only

   c) vision and balance

   d) vision, balance and hearing

   e) none of the above

FORM B

5) Hearing loss from noise exposure:

a) is intermittent

b) is always temporary

c) is usually progressive

d) is aggrevated by ear infections

e) none of the above

6) Each eye contains ______ million cones:

a) 6

b) 8

c) 10

d) 100

e) none of the above

7) Which of the following statements is true?

a) the cornea exists in the outer layer of the eye

b) the cornea exists in the middle layer of the eye

c) the iris exists in the outer layer of the eye

d) the retina exists in the middle layer of the eye

e) none of the above

8) The darkened portion at the center of the eye is the:

a) cornea

b) retina

c) iris

d) lens

e) none of the above

FORM B

9) The humors of the eye refer to:

a) the lens

b) the rods and cones

c) the fluids of the eye

d) the iris

e) none of the above

10) Noise may best be defined as:

a) unwanted sound

b) pleasant sound

c) soundwaves

d) pressure waves

e) none of the above

11) Hearing protection devices:

a) should rarely be worn

b) should be worn wherever excessive noise is found (industrial and recreational settings)

c) should not be worn until a hearing loss exists

d) should only be worn in industrial field environments

e) none of the above

12) Persons working in noisy industrial settings may:

a) get used to excessive noise and consequently not acquire a hearing loss

b) not utilize earmuffs because earplugs are known to work better

c) choose to wear or not to wear hearing protection devices

d) experience adverse effects from noise exposure other than hearing loss

e) none of the above

FORM B

13) Myopia is synonomous with:

- a) conjunctivitis
- b) farsightedness
- c) cataracts
- d) astigmatism
- e) none of the above

14) Which of the following statements is true?

- a) hearing cells can be destroyed by noise and once destroyed cannot be restored
- b) hearing cells are not destroyed by noise
- c) hearing cells may be destroyed from noise exposure but can be restored with a hearing aid
- d) current surgical techniques can restore damaged hearing cells
- e) none of the above

15) Which of the following is true:

- a) sight is more important than taste
- b) sight is more important than hearing
- c) hearing is more important than taste
- d) taste is more important than hearing
- e) none of the above

16) Tears are caused by:

- a) irritation to the eye
- b) anxiety or emotion
- c) infection
- d) all of the above
- e) none of the above

FORM B

17) Hearing conservation programs consist of:

- a) noise level measurements
- b) regular hearing tests
- c) use of hearing protection devices
- d) all of the above
- e) none of the above

18) The lacrimal apparatus is responsible for:

- a) cleansing and lubrication
- b) production of visual purple
- c) production of vitreous fluid
- d) focusing
- e) none of the above

19) Excessive noise may:

- a) cause hearing loss
- b) cause insomnia
- c) cause anxiety
- d) cause all of the above
- e) none of the above

20) Hearing damage from noise exposure is:

- a) cured with surgery
- b) cured with a hearing aid
- c) cured with rehabilitation
- d) cured with hearing protection devices
- e) none of the above

FORM B

21) Correction of visual impairment may involve:

a) corrective lenses

b) surgery

c) medication

d) all of the above

e) none of the above

22) The sense organ associated with vision is:

a) the mouth

b) the eye

c) the ear

d) the brain

e) none of the above

23) Industrial work environments typically:

a) are quiet places

b) have few sources of excessive noise

c) have many sources of excessive noise

d) have sound treated work stations

e) none of the above

24) The ability to hear is important:

a) for communication

b) for enjoyment of our environment

c) to alert or warn us of danger

d) all of the above

e) none of the above

FORM B

25) Of the following which environment is most likely not to contain excessive noise levels?

   a) nightclubs

   b) rifle ranges

   c) steel stamping plants

   d) airports

   e) none of the above

26) Blindness may cause:

   a) digestive disorders

   b) feelings of loss and anxiety

   c) loss of balance

   d) all of the above

   e) none of the above

27) After earplugs are inserted, you should:

   a) do chewing motions to make sure they are in place

   b) be careful not to move your jaw anymore than necessary

   c) talk and chew normally

   d) avoid adjusting them in any way

   e) none of the above

28) The principle organ of sight is:

   a) the lens

   b) the cornea

   c) the retina

   d) the conjunctiva

   e) none of the above

FORM B

29) The cochlea is located in:

- a) the outer ear
- b) the middle ear
- c) the inner ear
- d) the eardrum
- e) none of the above

30) Which of the following statements is true:

- a) the rods are sensitive to bright light
- b) the rods are sensitive to dim light
- c) the cones are sensitive to dim light
- d) the cones are equally sensitive to bright and dim light
- e) none of the above

31) The retina:

- a) translates light waves into neural impulses
- b) gives color to the eye
- c) is associated with the pupil
- d) produces tears
- e) none of the above

32) Conjunctivitis is:

- a) progressive blindness
- b) acute blindness
- c) inflammation of the conjunctiva
- d) inflammation of the cornea
- e) none of the above

FORM B

33) Which of the following is not a consideration in choosing hearing protection?

a) comfort

b) attenuation

c) hygiene

d) type of device

e) none of the above

34) Which of the following is false?

a) hearing loss generally has effects on personality

b) hearing loss may cause loss of self confidence

c) hearing loss may cause insecurity

d) hearing loss may cause anxiety

e) none of the above

35) The human ear:

a) can block out damageable noise

b) reacts equally to all sounds

c) is unaffected by excessive noise

d) transforms sound waves into auditory impressions or messages

e) none of the above

36) There are approximately ______ hearing cells in each ear:

a) 1 million

b) 350

c) 10,000

d) 30,000

e) none of the above

37) Which of the following is true?

- a) earplugs provide the best protection from harmful noise
- b) earmuffs provide the worst protection from harmful noise
- c) earmuffs plus earplugs provide the best protection from harmful noise
- d) earmuffs provide the best protection from harmful noise
- e) none of the above

38) Each eye contains ______ million rods

- a) 1
- b) 10
- c) 20
- d) 130
- e) none of the above

39) The simplest way to protect people from excessive industrial noise is:

- a) to provide them with rehabilitation
- b) to provide them with hearing protection devices
- c) to provide them with a hearing aid
- d) to fire them
- e) none of the above

40) The photosensitive system of the retina is/are:

- a) the lacrimal apparatus
- b) the conjunctiva
- c) the cornea
- d) the rods and cones
- e) none of the above

POST-TEST
FORM A

1) Which of the following is false?

   a) hearing loss generally has effects on a personality

   b) hearing loss may cause loss of self confidence

   c) hearing loss may cause insecurity

   d) hearing loss may cause anxiety

   e) none of the above

2) Hearing damage from noise exposure is:

   a) cured with surgery

   b) cured with a hearing aid

   c) cured with rehabilitation

   d) cured with hearing protection devices

   e) none of the above

3) Which of the following is true?

   a) earplugs provide the best protection from harmful noise

   b) earmuffs provide the worst protection from harmful noise

   c) earmuffs plus earplugs provide the best protection from harmful noise

   d) earmuffs provide the best protection from harmful noise

   e) none of the above

4) Which of the following is not a consideration in choosing hearing protection?

   a) comfort

   b) attenuation

   c) hygiene

   d) type of device

   e) none of the above

FORM A

5) The simplest way to protect people from excessive industrial noise is:

   a) to provide them with rehabilitation

   b) to provide them with hearing protection devices

   c) to provide them with a hearing aid

   d) to fire them

   e) none of the above

6) Which of the following statements is true:

   a) hearing cells can be destroyed by noise and once destroyed cannot be restored

   b) hearing cells are not destroyed by excessive noise

   c) hearing cells may be destroyed from noise exposure but can be restored with a hearing aid

   d) current surgical techniques can restore damaged hearing cells

   e) none of the above

7) The cochlea is located in:

   a) the outer ear

   b) the middle ear

   c) the inner ear

   d) the eardrum

   e) none of the above

8) Hearing conservation programs consist of:

   a) noise level measurements

   b) regular hearing tests

   c) use of hearing protection devices

   d) all of the above

   e) none of the above

FORM A

9) After earplugs are inserted, you should:

- a) do chewing motions to make sure they are in place
- b) be careful not to move the jaw anymore than necessary
- c) talk and chew normally
- d) avoid adjusting them in any way
- e) none of the above

10) Which of the following statements is true?

- a) a person with a hearing loss does not need to wear hearing protectors
- b) persons over the age of 50 do not need to wear hearing protectors
- c) persons who have normal hearing do not need to wear hearing protectors
- d) once a person has gotten used to noise, hearing protectors are no longer needed
- e) none of the above

11) Excessive noise may:

- a) cause hearing loss
- b) cause insomnia
- c) cause anxiety
- d) cause all of the above
- e) none of the above

12) Noise may best be defined as:

- a) unwanted sound
- b) pleasant sound
- c) soundwaves
- d) pressure waves
- e) none of the above

FORM A

13) Of the following, which environment is most likely not to contain excessive noise levels:

   a) nightclubs

   b) rifle ranges

   c) steel stamping plants

   d) airports

   e) none of the above

14) Hearing loss from noise exposure:

   a) is intermittent

   b) is always temporary

   c) is usually progressive

   d) is aggrevated by ear infections

   e) none of the above

15) There are approximately ______hearing cells in each ear:

   a) 1 million

   b) 350

   c) 10,000

   d) 30,000

   e) none of the above

16) Hearing protection devices:

   a) should rarely be worn

   b) should be worn wherever excessive noise is found (industrial and recreational)

   c) should not be worn until a hearing loss exists

   d) should only be worn in industrial field environments

   e) none of the above

FORM A

17) The human ear:

a) can block out damageable noise

b) reacts equally to all sounds

c) is unaffected by excessive noise

d) transforms sound waves into auditory impressions or messages

e) none of the above

18) Persons working in noisy industrial settings may:

a) get used to excessive noise and consequently not acquire a hearing loss

b) not utilize earmuffs because earplugs are known to work better

c) choose to wear or not to wear hearing protection devices

d) may experience adverse effects from noise exposure other than hearing loss

e) none of the above

19) The ability to hear is important:

a) for communication

b) for enjoyment of our environment

c) to alert or warn us of danger

d) all of the above

e) none of the above

20) Industrial work environments typically:

a) are quiet places

b) have few sources of excessive noise

c) have many sources of excessive noise

d) have sound treated work stations

e) none of the above

POST-TEST
FORM B

1) With regard to hearing protection devices:

   a) earplugs are the best type

   b) earmuffs are the best type

   c) earplugs are best used in recreational settings but earmuffs are best used in industrial settings

   d) a wide variety of hearing protectors exist

   e) none of the above

2) The organ of hearing is/are the:

   a) cochlea

   b) ossicles

   c) eardrum

   d) middle ear

   e) none of the above

3) An effective hearing protector is:

   a) one which is comfortable

   b) one which is comfortable and is fit properly

   c) one which is disposable

   d) one which lasts a long time

   e) none of the above

4) Which of the following is false?

   a) hearing protection devices prevent hearing loss

   b) noisy machinery can be provided with sound insulating enclosures

   c) hearing loss from noise exposure is permanent

   d) many types of hearing protection devices exist

   e) none of the above

FORM B

5) Which of the following would be the least intense?

- a) rustle of a leaf
- b) jet aircraft
- c) drill press
- d) traffic
- e) none of the above

6) Sound is composed of:

- a) time and mass
- b) minutes and weight
- c) frequency and intensity
- d) hearing loss
- e) none of the above

7) Which of the following statements is true?

- a) all industrial work settings have excessive noise
- b) only industrial work settings in Chicago, New York and Los Angeles have excessive noise
- c) each and every industrial work setting must be measured for excessive noise levels
- d) employees of industrial work settings must provide their own hearing protection
- e) none of the above

8) The 3 bones of the ear are located in the

- a) outer ear
- b) middle ear
- c) inner ear
- d) eardrum
- e) none of the above

FORM B

9) Which of the following statements is false?

a) hearing cells send signals to the brain

b) damaged hearing cells are easily repaired or restored

c) each hearing cell reacts to a different frequency or pitch

d) hearing cells react to soundwaves

e) none of the above

10) Hearing loss could affect:

a) a persons family life

b) a persons social life

c) a persons professional life

d) all of the above

e) none of the above

11) Soundwaves first reach:

a) the brain

b) the cochlea

c) the eardrum

d) the middle ear

e) none of the above

12) Which of the following statements is false?

a) excessive noise may increase a persons blood pressure

b) excessive noise may cause irritability

c) excessive noise causes hearing loss

d) excessive noise may cause digestive disorders

e) none of the above

FORM B

13) Which of the following statements is true?

- a) hearing conservation programs consist only of training programs
- b) hearing conservation programs are required by federal law
- c) hearing conservation programs consist only of hearing protection device utilization
- d) hearing conservation programs are not required by federal law
- e) none of the above

14) Harmful noise may be found in/on:

- a) golf courses
- b) steel stamping plants
- c) churches or synagogues
- d) grocery stores
- e) none of the above

15) The purpose of a hearing protection device is:

- a) to decrease the level of sound reaching the inner ear
- b) to restore damaged hearing cells
- c) to prevent ear infections
- d) to improve a persons hearing
- e) none of the above

16) The ability to communicate is dependent upon:

- a) hearing alone
- b) speech alone
- c) hearing and speech
- d) high IQ
- e) none of the above

FORM B

17) A person with a permanent hearing loss:

a) will generally have problems with both loudness and clarity of sounds

b) will only have problems with loudness of sounds

c) will only have problems with clarity of sounds

d) generally will not have problems unless the hearing loss is profound

e) none of the above

18) The hearing cells are located in the:

a) ear canal

b) cochlea

c) eardrum

d) middle ear

e) none of the above

19) Hearing loss is measured:

a) in a loss of decibels

b) in errors of understanding speech

c) as a %

d) all of the above

e) none of the above

20) Earplugs should be inserted in the ear by:

a) reaching under the chin, pulling the ear down and back and inserting the plug

b) reaching behind the head, pulling the ear back, and inserting the plug

c) reaching over the head, pulling the ear up and back and inserting the plug

d) reaching in front of the head, pulling the ear forward, and inserting the plug

e) none of the above

PRE-TEST ANSWER SHEET

FORM________

1) ________
2) ________
3) ________
4) ________
5) ________
6) ________
7) ________
8) ________
9) ________
10) ________
11) ________
12) ________
13) ________
14) ________
15) ________
16) ________
17) ________
18) ________
19) ________
20) ________
21) ________
22) ________
23) ________
24) ________
25) ________
26) ________
27) ________
28) ________
29) ________
30) ________
31) ________
32) ________
33) ________
34) ________
35) ________
36) ________
37) ________
38) ________
39) ________
40) ________

POST-TEST ANSWER SHEET

FORM________

1) ________
2) ________
3) ________
4) ________
5) ________
6) ________
7) ________
8) ________
9) ________
10) ________
11) ________
12) ________
13) ________
14) ________
15) ________
16) ________
17) ________
18) ________
19) ________
20) ________

ANSWER KEY

PRE-TEST
FORM A

1) d
2) d
3) a
4) c
5) a
6) c
7) a
8) d
9) d
10) c
11) c
12) b
13) a
14) a
15) d
16) e
17) e
18) b
19) b
20) b
21) a
22) e
23) d
24) b
25) a
26) c
27) e
28) b
29) b
30) b
31) b
32) e
33) a
34) e
35) a
36) c
37) e
38) c
39) b
40) c

ANSWER KEY

PRE-TEST
FORM B

1) d
2) e
3) b
4) c
5) c
6) a
7) a
8) e
9) c
10) a
11) b
12) d
13) e
14) a
15) e
16) b
17) d
18) a
19) d
20) e
21) d
22) b
23) c
24) d
25) e
26) b
27) a
28) c
29) c
30) b
31) a
32) c
33) e
34) e
35) d
36) d
37) c
38) e
39) b
40) d

ANSWER KEY

POST-TEST
FORM A

1) e
2) e
3) c
4) e
5) b
6) a
7) c
8) d
9) a
10) e
11) d
12) a
13) e
14) c
15) d
16) b
17) d
18) d
19) d
20) c

ANSWER KEY

POST-TEST
FORM B

1) d

2) a

3) b

4) e

5) a

6) c

7) c

8) b

9) b

10) d

11) e

12) e

13) b

14) b

15) a

16) c

17) a

18) b

19) a

20) c

APPENDIX D

SPEAKER WIRING DIAGRAMS

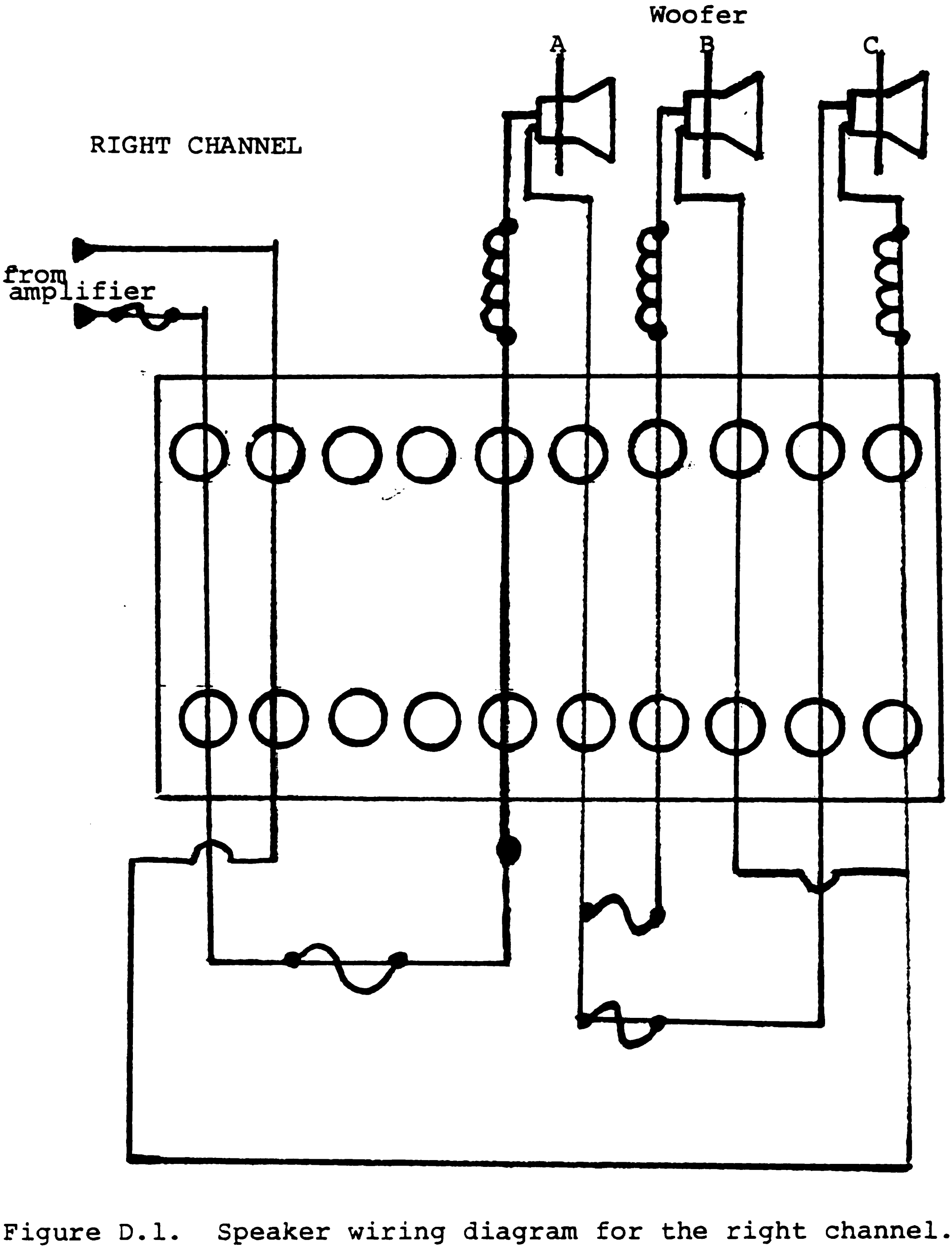

Figure D.1. Speaker wiring diagram for the right channel.

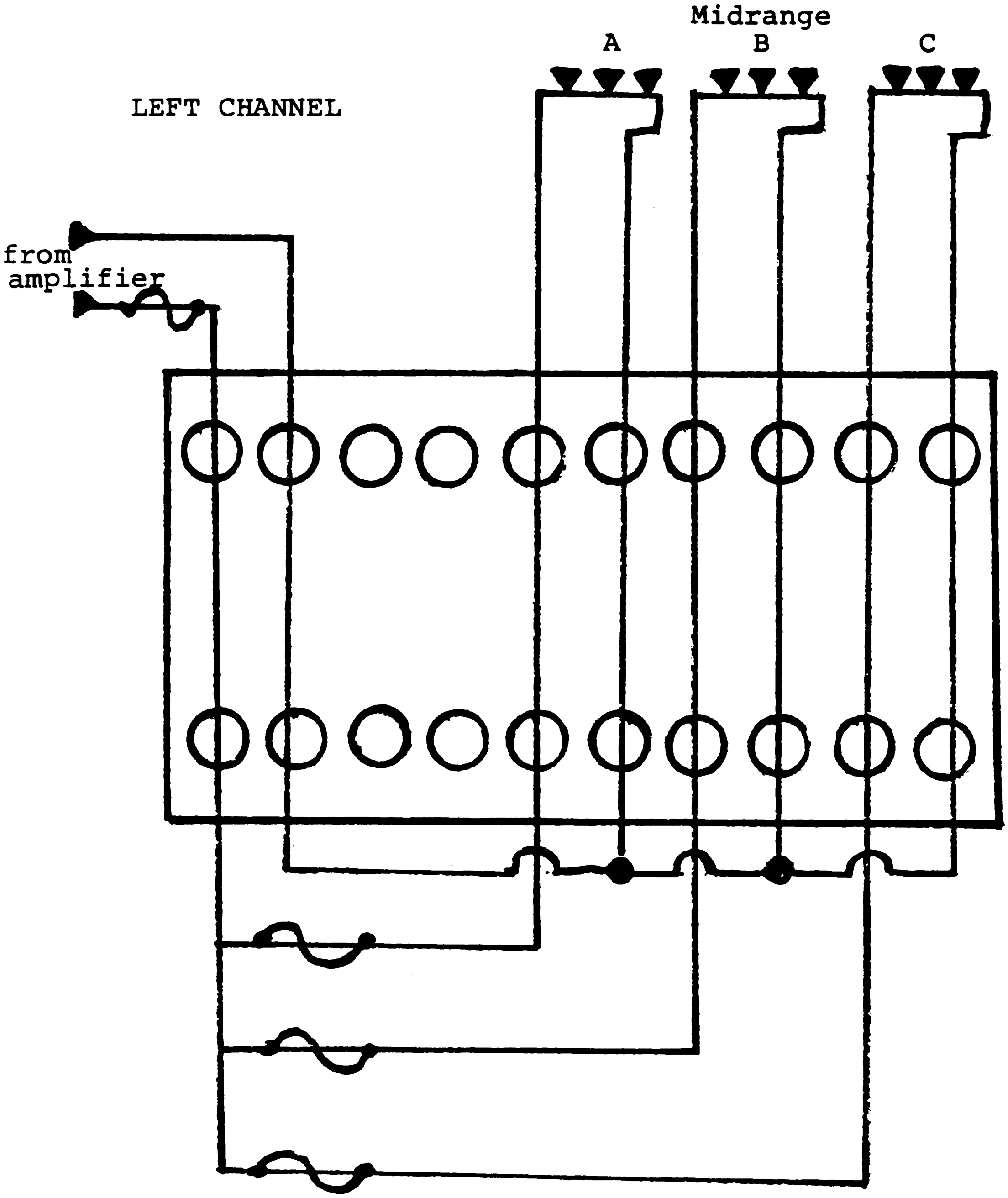

Figure D.2. Speaker wiring diagram for the left channel.

APPENDIX E

INSTRUMENTATION, METHODS AND RESULTS OF REVERBERATION TIME MEASUREMENTS

Appendix E. Instrumentation, Methods and Results of Reverberation Time Measurements.

Instrumentation and Methods

Figure E.1 presents the block diagram of the instrumentation used for reverberation time measurements. A free- field microphone (Bruel & Kjaer Model 4145) was routed to a pre-amplifier (Bruel & Kjaer Model 2619) and powered by a microphone power supply (Bruel & Kjaer Model 2804). The output was routed to a measurement amplifier (Bruel & Kjaer Model 2607) and displayed on a graphic level recorder (Bruel & Kjaer Model 2305). The paper speed and writing speed of the graphic level recorder were set at 100 mm/second and 250 mm/second, respectively. The microphone was calibrated with a level calibrator (GenRad Model 1986).

Prior to recording reverberation times, the rise/fall time of the electronic switch was set to a minimum of 100 microseconds and the attenuator of the Bekesy audiometer was set to the 100 dB position. The tape recorder was put into playback mode and reverberation time was measured for each of the nine test bands and the white noise. Measurements were made without a subject present as specified in ANSI S3.19-1974.

Results

Table E.1 presents the measured reverberation times of the test capsule. ANSI S3.19-1974 specifies that reverberation times should be between 500 and 1600 msec. As can be seen

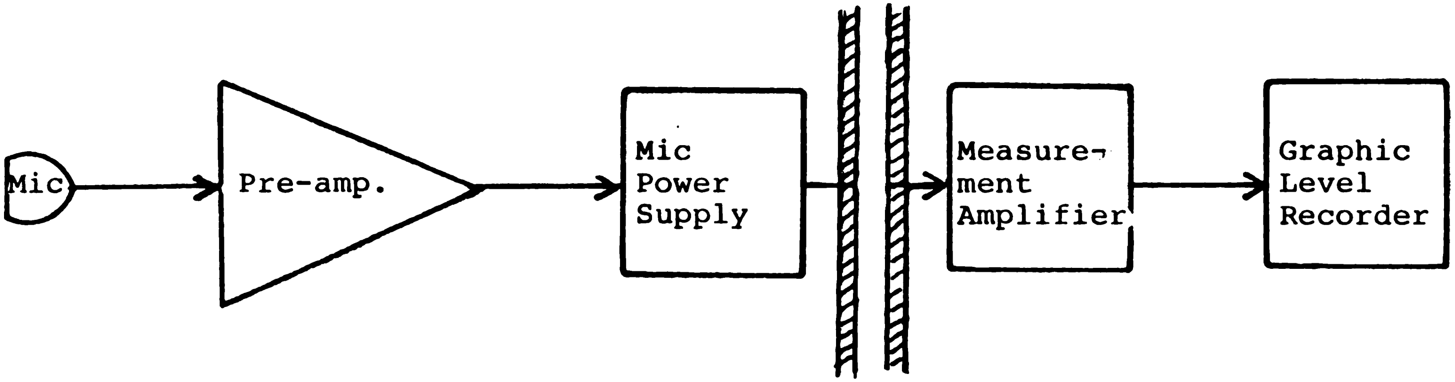

Figure E.1. Block diagram of instrumentation for reverberation time measurements.

Table E.1. Measured reverberation times of test capsule.

Signal	Reverberation Time
White Noise	320 msec
125 Hz	300 msec
250 Hz	300 msec
500 Hz	300 msec
1000 Hz	390 msec
2000 Hz	460 msec
3150 Hz	450 msec
4000 Hz	420 msec
6300 Hz	400 msec
8000 Hz	360 msec

from Table E.1, measured reverberation times are shorter than ANSI S3.19-1974 specifications. Although reverberation times are not within specifications, this result is not expected to significantly affect the outcome of this study.

APPENDIX F

INSTRUMENTATION, METHODS AND RESULTS OF SPATIAL UNIFORMITY OF ACOUSTIC FIELD MEASUREMENTS

Appendix F. Instrumentation, Methods and Results of Spatial Uniformity of Acoustic Field Measurements.

Instrumentation and Methods

The spatial uniformity of the acoustic field was defined in terms of (1) field diffussion and (2) random incidence field measurements. Figure F.1 presents the block diagram of the instrumentation used for the field diffussion and random indicidence field measurements. A pressure microphone (Bruel & Kjaer Model 4144) was routed to a pre-amplifier (Bruel & Kjaer Model 2619) and powered by a microphone power supply (Bruel & Kjaer Model 2804). The output was routed to a measurement amplifier (Bruel & Kjaer Model 2607). The microphone was calibrated with a level calibrator (GenRad Model 1986). Measurements were made at six positions around the center position of a subject's head (subject absent) for the field diffussion measurements (as specified in ANSI S3.19-1974).

For all field diffussion measurements, the attenuator on the Bekesy audiometer was set at the 90 dB position. The 20 dB pad was engaged and disengaged at various measurement points (noted in results section). The reference SPL for white noise was 80 dB. Readings on the power amplifier for the right and left channels were -40 dB and -30 dB, respectively. The tape recorder was set into playback mode and SPL readings were obtained on the measurement amplifier for each of the nine test bands and the white noise bands preceeding and following the noise bands for each of the six positions specified in

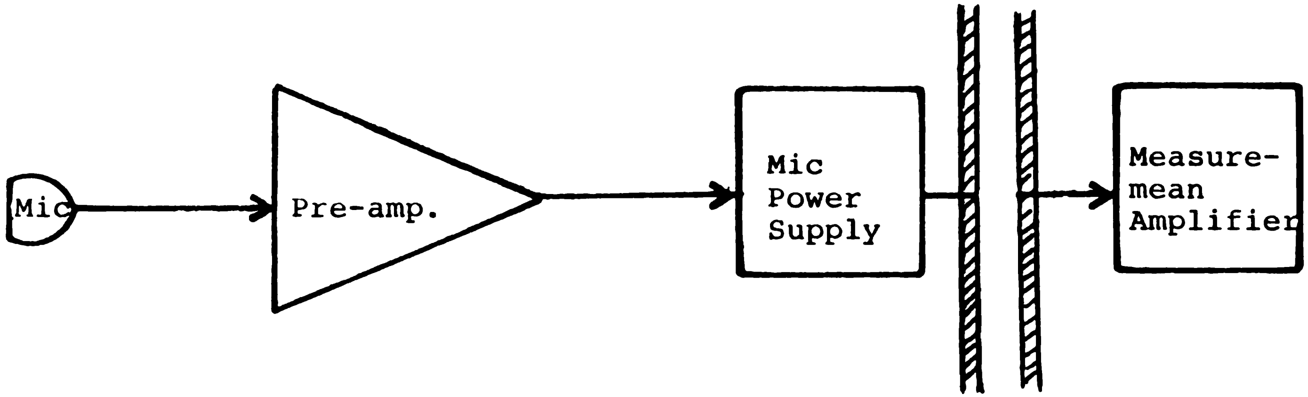

Figure F.1. Block diagram of instrumentation for field diffussion and random incidence field measurements.

ANSI S3.19-1974.

Random incidence field measurements were also obtained. Instrumentation and methods were identical to the field diffussion measurements with the exception of microphone position. The microphone was placed in the center of the area representing the position of a subjects head and rotated in three directions:

(1) microphone facing ceiling; diaphram parallel to floor;

(2) microphone facing front wall; diaphram perpendicular to floor; and

(3) microphone facing door; diaphram perpendicular to floor.

Results

Table F.1 presents the results of the field diffussion measurements for the six microphone positions. ANSI S3.19-1974 specifies that the SPL measured at these six positions must remain within a range of 6 dB for all test bands. It is further specified that the difference in SPL between the left-right positions shall not exceed 2 dB. As can be seen from these results, the measured values are within specifications of ANSI S3.19-1974.

Table F.2 presents the results of the random incidence field measurements. These results are within specifications of ANSI S3.19-1974.

Table F.1. Field diffussion measurement results.

	Measured Values					
Signal	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5	Pos. 6
White Noise	84.5 dB	84.0 dB	84.0 dB	84.5 dB	84.5 dB	85.0 dB
125 Hz	87.5 dB	86.5 dB	87.0 dB	85.5 dB	86.0 dB	85.5 dB
250 Hz	98.5 dB	97.0 dB	96.0 dB	95.0 dB	97.5 dB	97.5 dB
500 Hz	94.0 dB	92.5 dB	91.5 dB	93.5 dB	92.5 dB	92.5 dB
1000 Hz	83.0 dB	81.0 dB	85.5 dB	82.0 dB	80.5 dB	84.0 dB
2000 Hz	85.0 dB	84.5 dB	85.5 dB	84.5 dB	85.0 dB	87.5 dB
3150 Hz*	106.5 dB	104.5 dB	105.5 dB	107.5 dB	104.5 dB	105.0 dB
4000 Hz*	104.5 dB	105.0 dB	105.0 dB	103.5 dB	105.5 dB	104.0 dB
6300 Hz*	97.5 dB	97.5 dB	97.5 dB	96.5 dB	97.0 dB	95.5 dB
8000 Hz*	95.0 dB	98.0 dB	100.0 dB	97.5 dB	101.0 dB	95.0 dB
White Noise*	107.5 dB	107.0 dB	106.5 dB	107.0 dB	107.0 dB	107.5 dB
White Noise	86.0 dB	85.0 dB	85.0 dB	85.5 dB	85.5 dB	86.0 dB

*20 dB pad engaged.

Table F.2. Random incidence field measurement results.

		Measured Values	
Signal	Mic Facing Ceiling	Mic Facing Front Wall	Mic Facing Door
White Noise	81.5 dB	81.5 dB	81.5 dB
125 Hz	84.0 dB	84.0 dB	83.0 dB
250 Hz	94.0 dB	95.0 dB	94.0 dB
500 Hz	90.5 dB	90.5 dB	90.0 dB
1000 Hz	78.0 dB	78.5 dB	79.0 dB
2000 Hz	82.5 dB	82.0 dB	82.0 dB
3150 Hz*	103.5 dB	102.5 dB	102.0 dB
4000 Hz*	102.0 dB	101.5 dB	100.5 dB
6300 Hz*	92.5 dB	93.5 dB	93.0 dB
8000 Hz*	96.5 dB	96.5 dB	93.5 dB
White Noise*	105.5 dB	105.5 dB	105.0 dB
White Noise	83.0 dB	83.0 dB	82.5 dB

* 20 dB pad engaged.

APPENDIX G

COMPUTER PROGRAM FOR COMPUTATION OF NRR

File

```
100  REM                          EPA NRR CALCULATOR
110  :
120  REM                  AN APPLESOFT BASIC PROGRAM
130  REM                        MICHAEL R. CHIAL
140  REM                            07/08/83
150  :
160  REM                             ABSTRACT
170  :
180  REM   THIS PROGRAM ASSUMES THE METHOD SPECIFIED BY THE EPA
190  REM   (1979) [FEDERAL REGISTER, VOL 42, NO. 190, 40 CFR
200  REM   PART 211, PP.  56139-56147].  SPECIFICALLY, A HYPOTHETICAL
210  REM   NOISE IS ASSUMED TO HAVE EQUAL LEVELS AT OCTAVE BANDS (OB)
220  REM   BETWEEN 125 HZ AND 8000 HZ (I.E., PINK NOISE IS ASSUMED).
230  REM   FURTHER, A- AND C-WEIGHTINGS ARE ASSUMED IN THE MEASUREMENT
240  REM   OF ANY SUCH NOISE.
250  :
260  REM   PROGRAM PROMPTS FOR MEANS AND STANDARD DEVIATIONS
270  REM   OF REAL-EAR ATTENUATIONS TAKEN FROM A GROUP OF LISTENERS.
280  REM   PER EPA, IT IS ASSUMED THAT AT LEAST 10 TRAINED, NORMAL-
290  REM   HEARING PERSONS HAVE BEEN TESTED VIA METHOD OF EXPERIMENTER
300  REM   FIT OF HEARING PROTECTORS PROGRAM OUTPUTS COMPUTED NOISE
310  REM   REDUCTION RATING (NRR) FOR THE HEARING PROTECTOR SPECIFIED.
320  :
330  :
340  REM                          VARIABLE LIST
350  :
360  REM       BM(I)    =  OCTAVE BAND MEAN REAT FOR I=9 BANDS
370  REM                   CENTERED AT THE FOLLOWING FREQUECIES:
380  REM                   BM(1) = 125 HZ
390  REM                   BM(2) = 250 HZ
400  REM                   BM(3) = 500 HZ
410  REM                   BM(4) = 1  KHZ
420  REM                   BM(5) = 2  KHZ
430  REM                   BM(6) = 3  KHZ
440  REM                   BM(7) = 4  KHZ
450  REM                   BM(8) = 6  KHZ
460  REM                   BM(9) = 8  KHZ
470  REM       BS(I)    =  OCTAVE BAND STAND. DEVIATION REAT FOR
480  REM                   I=9 BANDS AS NOTED ABOVE.
490  REM       BA(I)    =  A-WEIGHTED OB LEVELS FOR UNPROTECTED
500  REM                   EAR, PER EPA STEP 4.  THESE CONSTANTS
510  REM                   APPEAR AT LINE 10210.
520  REM       OC       =  OVERALL C-WEIGHTED LEVEL OF HYPOTHETICAL
530  REM                   NOISE:  108 DB(C), A CONSTANT.
540  REM                   THIS IS EPA STEP 3.
550  REM       A(I)     =  INTERMEDIATE VALUES PER EPA STEP 7
560  REM       LS       =  LOG SUM OF PROTECTED LEVELS PER EPA STEP 8.
570  REM       D$       =  DATE STRING
580  REM       K$       =  GROUP CODE STRING
590  REM       N$       =  HEARING PROTECTOR NAME STRING
600  REM       R$       =  USER RESPONSE STRING
610  REM       FN LG    =  BASE-10 LOG FUNCTION
620  REM       P1$      =  OUTPUT DEVICE DRIVER
630  :
1000 :
1010  REM  ISSUE GREETING, GET HPD & TEST GROUP ID INFORMATION
1020 :
1030  TEXT : NORMAL
1040  HOME : CLEAR : RESTORE
```

```
1050  DEF  FN LG(X) =  LOG (X) /  LOG (10)
1060  HTAB (9): PRINT "--EPA NRR CALCULATOR--": PRINT : HTAB ( ): PRINT
    "BY MICHAEL R. CHIAL, PH.D.": HTAB (4): PRINT "_______________________
    ____________"
1070  POKE 34,4: REM  PROTECT TOP 4 LINES
1080  HOME : VTAB (10)
1090  INPUT "ENTER NAME OF PROTECTOR:  ";N$
1100  INPUT "ENTER EXP. OR GROUP CODE: ";K$
1110  INPUT "ENTER DATE (MM/DD/YY):    ";D$
1120  PRINT
1130  INPUT "OUTPUT TO PRINTER OR SCREEN (S OR P)? ";R$
1140  IF R$ <  > "S" AND R$ <  > "P" THEN  GOTO 1130
1150  IF R$ = "S" THEN S$ = "0": GOTO 1180
1160  IF R$ = "P" THEN  INPUT "PRINTER SLOT (NORMALLY 1)? ";S$
1170  IF  VAL (S$) < 0 OR  VAL (S$) > 7 THEN  GOTO 1160
1180 PI$ = "PR#" + S$
1190 :
5000  REM  GET MEAN ATTENUATION DATA (EPA STEP 5)
5010 :
5020  FOR I = 1 TO 9
5030  READ B$(I)
5040  NEXT I
5050  HOME
5060  PRINT : PRINT "REAL-EAR ATTENUATION DATA ENTRY": PRINT
5070  PRINT "IF THERE ARE NO DATA FOR 3 KHZ & 6 KHZ.": PRINT "ENTER 0 (Z
    ERO)."
5080  PRINT : PRINT
5090  FOR I = 1 TO 9
5100  PRINT "ENTER MEAN FOR ";B$(I);
5110  HTAB 30: INPUT "";BM(I)
5120  NEXT I
5130 :
5140  REM             GET ARITH, MEANS FOR 3 & 4 KHZ AND FOR 6 & 8 KHZ
5150 :
5160  IF BM(6) = 0 THEN  GOTO 5190
5170 BM(7) = (BM(6) + BM(7)) / 2
5180 BM(6) = 0
5190  IF BM(8) = 0 THEN  GOTO 5220
5200 BM(9) = (BM(8) + BM(9)) / 2
5210 BM(8) = 0
5220 :
6000  REM  GET STD. DEV. DATA & DOUBLE VALUES (EPA STEP 6)
6010 :
6020  HOME
6030  PRINT : PRINT "REAL-EAR ATTENUATION DATA ENTRY": PRINT
6040  PRINT "IF THERE ARE NO DATA FOR 3 KHZ & 6 KHZ,": PRINT "ENTER 0 (Z
    ERO)."
6050  PRINT : PRINT
6060  FOR I = 1 TO 9
6070  PRINT "ENTER STD. DEV. FOR ";B$(I);
6080  HTAB 30: INPUT "";BS(I)
6090 BS(I) = BS(I) * 2
6100  NEXT I
6110 :
6120  REM             GET ARITH. MEANS FOR 3 & 4 KHZ AND FOR 6 & 8 KHZ
6130 :
6140  IF BS(6) = 0 THEN  GOTO 6170
6150 BS(7) = (BS(6) + BS(7)) / 2
6160 BS(6) = 0
6170  IF BS(8) = 0 THEN  GOTO 6200
6180 BS(9) = (BS(8) + BS(9)) / 2
6190 BS(8) = 0
6200 :
7000  REM   COMPUTE A-WEIGHTED DB SOUND LEVELS (EPA STEP 7:
7010  REM  STEP 4-STEP 5+STEP 6)
7020 :
```

```
7030  FOR I = 1 TO 9
7040  READ BA(I)
7050  IF BA(I) = 0 THEN  GOTO 7070
7060 A(I) = BA(I) - BM(I) + BS(I)
7070  NEXT I
7080 :
8000  REM  COMPUTE LOG SUM OF DB SOUND LEVELS FROM STEP 7 (EPA STEP 8)
8010 :
8020 LS = 0
8030  FOR I = 1 TO 9
8040  IF A(I) = 0 THEN  GOTO 8080
8050 Y(I) = A(I) / 10
8060 A(I) = 10 ^ Y(I)
8070 LS = LS + A(I)
8080  NEXT I
3090 LS = 10 *  FN LG(LS)
8100 :
9000  REM  COMPUTE NRR AS STEP 3-STEP 8- 3 DB (EPA STEP 9)
9010 :
9020 OC = 108
9030 NRR = OC - LS - 3.0
9040 :
10000  REM  OUTPUT RESULTS AND PROMPT FOR REPEAT
10010 :
10020  HOME
10030  VTAB (10)
10040  PRINT  CHR$ (4);P1$
10045  PRINT : PRINT
10050  PRINT "HEARING PROTECTOR: "; TAB( 25);N$: PRINT "EXP. OR GROUP CO
    DE:"; TAB( 25);K$
10060  PRINT "DATE OF ANALYSIS:  "; TAB( 25);D$: PRINT : PRINT
10070 NRR =  INT (NRR * 10 + .5) / 10
10080  PRINT "THE COMPUTED NRR IS:"; TAB( 30);NRR;" DB"
10090  PRINT "CONSERVATIVE NRR IS:"; TAB( 30);NRR - 7;" DB"
10100  PRINT : PRINT
10110  PRINT  CHR$ (4);"PR#0"
10120  INPUT "PRESS RETURN TO CONTINUE ";R$
10130  PRINT "DO AGAIN? ";
10140  INPUT "(Y FOR YES, N FOR NO) ";R$
10150  IF R$ = "Y" THEN  POKE 34,0: GOTO 1040
10160  IF R$ <  > "Y" AND R$ <  > "N" THEN  GOTO 10120
10170 :
10180  REM  DATA FOR LABELS AND COMPUTATIONS
10190 :
10200  DATA  "125 HZ", "250 HZ", "500 HZ", " 1 KHZ", " 2 KHZ", " 3 KHZ",
    " 4 KHZ", " 6 KHZ", " 8 KHZ"
10210  DATA  83.9, 91.4, 96.8, 100.0, 101.2, 0.0, 101.0, 0.0, 98.9
10220 :
10230  REM  CLOSING ROUTINE
10240 :
10250  HOME : VTAB (10)
10260  PRINT "SO LONG!"
10270  POKE 34,0: REM  UNPROTECT TOP 4 LINES
10280  END
```

APPENDIX H

PRE-TEST, POST-TEST AND INFORMATION GAIN SCORES (RAW DATA)

Table H.1. Pre-test, post-test and information gain scores (raw data).

Subject	Pre-Test	Post-Test	Information Gain
Group A			
1	60	80	20
2	70	70	0
3	60	90	30
4	75	100	25
5	90	80	-10
6	55	100	45
7	75	85	10
8	40	85	45
9	90	60	-30
10	55	75	20
Group B			
11	35	55	20
12	70	85	15
13	75	65	-10
14	85	95	10
15	75	85	10
16	70	95	25
17	70	60	-10
18	45	75	30
19	75	80	5
20	55	80	25
Group C			
21	80	75	-5
22	75	45	-30
23	75	75	0
24	55	65	10
25	45	65	20
26	70	70	0
27	75	65	-10
28	80	50	-30
29	50	55	-5
30	55	55	0

Table H.1. Continued.

Subject	Pre-Test	Post-Test	Information Gain
Group D			
31	85	80	-5
32	70	70	0
33	80	75	-5
34	60	60	-0
35	75	70	-5
36	60	65	5
37	70	65	-5
38	75	70	-5
39	85	60	-25
40	55	85	30

APPENDIX I

DESCRIPTIVE STATISTICS FOR PRE-TEST, POST-TEST, AND INFORMATION GAIN SCORES

Table I.1. Descriptive statistics for percent-correct pre-test scores, post-test scores and information gain scores (N = 40).

	Pre-Test	Post-Test	Information Gain
Variance	187.2	181.8	348.5
Minimum	35	45	-30
Maximum	90	100	45
Range	55	55	75
Skewness	.502	.136	.073
Kurtosis	.384	.459	.164

Table I.2. Descriptive statistics for percent-correct pre-test scores, post-test scores and information gain scores across groups.

	Pre-Test	Post-Test	Information Gain
Group A (experimenter fit; training)			
Variance	256.7	156.9	563.6
Minimum	40	60	-30
Maximum	90	100	45
Range	50	40	75
Skewness	.053	.185	.615
Kurtosis	.544	.133	.013
Group B (subject fit; training)			
Variance	241.4	190.3	195.6
Minimum	35	55	-10
Maximum	85	95	30
Range	50	40	40
Skewness	1.033	.377	.553
Kurtosis	.247	.912	.703
Group C (experimenter fit; no training)			
Variance	176.7	107.7	254.4
Minimum	45	45	-30
Maximum	80	75	20
Range	35	30	50
Skewness	.489	.295	.612
Kurtosis	1.639	1.068	.019
Group D (subject fit; no training)			
Variance	111.4	66.7	183.6
Minimum	55	60	-25
Maximum	85	85	30
Range	30	25	55
Skewness	.227	.524	1.024
Kurtosis	1.154	.288	4.026

APPENDIX J

RAW ATTENUATION DATA

Table J.1. Raw attenuation data (table values are decibels).

Measure	Center Frequency (Hz) 125	250	500	1000	2000	3150	4000	6300	8000
Subject 1 F									
Trial 1	6.3	8.3	18.6	14.2	19.3	17.7	22.3	33.4	40.1
Trial 2	8.3	12.7	17.5	14.8	29.1	27.5	33.4	34.7	30.5
Trial 3	16.6	14.1	18.8	11.0	30.7	30.4	29.5	32.5	29.7
X̄	10.4	11.7	18.3	13.3	26.3	25.2	28.4	33.5	33.4
SD	5.4	3.0	.7	2.0	6.1	6.6	5.6	1.1	5.7
Subject 2 M									
Trial 1	3.2	4.2	13.2	15.1	23.8	26.5	31.9	33.7	33.3
Trial 2	1.7	.2	9.3	18.4	19.3	27.9	24.4	28.2	24.7
Trial 3	6.7	8.5	15.3	24.0	24.5	33.4	36.4	61.5	25.7
X̄	3.8	4.3	12.6	19.1	22.5	29.2	30.9	41.1	27.7
SD	2.5	4.1	3.0	4.4	2.8	3.6	6.0	17.8	4.8
Subject 3 F									
Trial 1	14.8	11.2	12.2	22.6	19.7	24.1	36.0	25.8	37.3
Trial 2	10.9	8.4	13.8	21.9	22.8	35.9	29.0	33.9	39.1
Trial 3	4.9	5.6	9.3	12.0	23.5	34.3	34.3	35.5	28.0
X̄	10.2	8.4	11.7	18.8	22.0	31.4	33.1	31.7	34.8
SD	4.9	2.8	2.2	5.9	2.0	6.4	3.6	5.2	5.9
Subject 4 F									
Trial 1	11.1	9.5	13.1	16.8	21.9	29.8	36.7	24.5	32.7
Trial 2	16.7	13.9	20.3	19.2	26.2	34.0	37.4	25.8	35.3
Trial 3	12.7	13.4	14.4	17.1	24.7	33.0	30.9	35.3	34.0
X̄	13.5	12.2	15.9	17.7	24.2	32.2	35.0	28.5	34.0
SD	2.8	2.4	3.8	1.3	2.1	2.1	3.5	5.8	1.3
Subject 5 M									
Trial 1	1.7	2.2	13.0	16.6	28.6	31.6	33.5	35.6	32.6
Trial 2	9.8	10.3	15.6	23.2	24.7	30.5	38.4	40.5	45.2
Trial 3	12.5	10.9	15.1	20.4	34.6	30.4	30.9	33.8	40.0
X̄	8.0	7.8	14.5	20.0	29.3	30.8	34.2	36.6	39.2
SD	5.6	4.8	1.3	3.3	4.9	.6	3.8	3.4	6.3
Subject 6 M									
Trial 1	3.8	5.4	15.8	16.3	26.0	34.3	39.4	42.6	45.7
Trial 2	2.4	10.1	17.9	15.6	23.4	25.6	32.0	37.5	26.5
Trial 3	1.1	9.1	10.7	15.7	22.5	25.3	28.2	26.6	30.1
X̄	2.4	8.2	14.8	15.8	23.9	28.4	33.2	35.5	34.1
SD	1.2	2.4	3.7	.4	1.8	5.1	5.6	8.1	10.2
Subject 7 M									
Trial 1	8.0	8.8	18.2	16.9	24.3	34.8	29.9	38.8	35.9
Trial 2	12.5	10.9	10.4	9.7	31.2	23.6	34.1	32.9	22.8
Trial 3	5.1	4.9	13.3	16.3	29.5	36.1	36.6	38.6	34.0
X̄	8.5	8.2	13.9	14.3	28.3	31.5	33.5	36.7	30.9
SD	3.7	3.0	3.9	3.9	3.5	6.8	3.3	3.3	7.0
Subject 8 F									
Trial 1	13.3	9.1	15.1	20.7	25.1	32.2	32.8	36.0	28.7
Trial 2	-.4	9.6	11.6	13.4	19.8	31.6	28.0	27.9	28.9
Trial 3	10.2	9.9	9.6	16.7	22.1	23.3	38.5	28.1	24.5
X̄	7.7	9.5	12.1	16.9	22.3	29.0	33.1	30.6	27.3
SD	7.1	.4	2.7	3.6	2.6	4.9	5.2	4.6	2.4

Measure	Test Frequency 125	250	500	1000	2000	3150	4000	6300	8000
<u>Subject 9</u> F									
Trial 1	10.6	8.4	14.0	17.4	21.4	33.3	36.0	42.2	35.3
Trial 2	8.9	8.5	14.7	12.9	27.0	31.5	33.5	36.9	40.0
Trial 3	6.0	-1.8	11.9	11.6	21.1	24.9	23.3	24.0	31.0
$\bar{X}$	8.5	5.0	13.5	13.9	23.1	29.9	30.9	34.3	35.4
SD	2.3	5.9	1.4	3.0	3.3	4.4	6.7	9.3	4.5
<u>Subject 10</u> M									
Trial 1	5.1	8.9	16.4	22.7	35.4	35.3	43.6	41.8	39.4
Trial 2	7.8	1.6	14.8	13.8	20.1	28.1	28.0	31.1	21.6
Trial 3	10.7	9.4	14.8	16.4	38.0	40.0	40.2	39.2	40.0
$\bar{X}$	7.8	6.6	15.3	17.6	31.1	34.4	37.2	37.3	33.6
SD	2.8	4.3	.9	4.5	9.6	5.9	8.2	5.5	10.4
<u>Subject 11</u> M									
Trial 1	5.7	-.2	5.5	-4.9	11.2	30.9	18.9	20.8	20.8
Trial 2	1.5	4.8	1.8	.5	3.8	1.3	30.9	4.8	20.6
Trial 3	16.9	-2.8	-3.2	1.1	-3.6	.5	-11.7	-3.7	2.4
$\bar{X}$	8.0	.6	1.3	-1.1	3.8	10.9	12.7	7.3	14.6
SD	7.9	3.8	4.3	3.3	7.4	17.3	21.9	12.4	10.5
<u>Subject 12</u> F									
Trial 1	18.3	9.9	14.4	12.4	30.9	36.4	30.5	37.4	36.0
Trial 2	6.8	7.8	13.2	14.6	24.2	22.3	30.8	33.5	23.5
Trial 3	6.4	10.3	14.8	15.2	28.5	32.8	31.3	32.3	26.1
$\bar{X}$	10.5	9.3	14.1	14.0	27.8	30.5	30.8	34.4	28.5
SD	6.7	1.3	.8	1.4	3.3	7.3	.4	2.6	6.5
<u>Subject 13</u> M									
Trial 1	27.2	10.2	21.0	20.5	31.8	28.1	39.9	41.3	46.9
Trial 2	23.8	19.4	27.1	18.5	33.4	33.8	39.1	39.9	41.1
Trial 3	22.0	19.9	21.1	24.2	33.2	37.3	37.0	42.4	48.6
$\bar{X}$	24.3	16.5	23.0	21.0	32.8	36.4	38.6	41.2	45.5
SD	2.6	5.4	3.4	2.8	.9	2.2	1.4	1.2	3.9
<u>Subject 14</u> M									
Trial 1	0	-1.3	16.3	13.5	19.0	28.6	29.7	32.9	26.9
Trial 2	1.9	3.0	9.8	13.5	18.4	25.7	26.4	34.4	35.8
Trial 3	4.1	8.9	11.4	16.1	22.7	30.4	29.2	36.3	38.3
$\bar{X}$	2.0	3.5	12.5	14.3	20.0	28.2	28.4	34.5	33.6
SD	2.0	5.1	3.3	1.5	2.3	2.3	1.7	1.7	5.9
<u>Subject 15</u> M									
Trial 1	4.9	12.9	15.7	13.0	21.8	32.7	26.0	32.4	29.9
Trial 2	.7	2.0	6.4	6.6	11.4	19.5	23.1	22.6	11.6
Trial 3	-2.7	.4	0	4.8	9.9	16.9	18.4	14.0	18.9
$\bar{X}$	.9	5.1	7.3	8.1	14.3	23.0	22.5	23.0	20.1
SD	3.8	6.8	7.8	4.3	6.4	8.4	3.8	9.2	9.2
<u>Subject 16</u> M									
Trial 1	8.2	6.0	15.4	14.7	20.2	25.5	24.6	29.7	30.1
Trial 2	7.4	3.1	9.8	15.3	20.5	23.6	23.5	31.6	31.9
Trial 3	3.7	3.6	10.1	12.3	20.0	23.0	26.9	31.6	33.7
$\bar{X}$	6.4	4.2	11.7	14.1	20.2	24.0	25.0	30.9	31.9
SD	2.5	1.5	3.1	1.5	.3	1.3	1.7	1.0	1.8

Measure	Test Frequency 125	250	500	1000	2000	3150	4000	6300	8000
Subject 17 F									
Trial 1	1.2	2.8	16.5	16.4	28.6	26.0	30.6	20.9	17.9
Trial 2	6.2	8.2	16.3	16.8	25.6	21.9	30.6	28.5	27.5
Trial 3	12.6	10.0	11.1	16.6	27.1	24.2	27.7	31.3	33.3
$\bar{X}$	6.6	7.0	14.6	16.6	27.1	24.0	29.6	26.9	26.2
SD	5.7	3.7	3.0	.2	1.5	2.0	1.6	5.3	7.7
Subject 18 F									
Trial 1	9.7	7.0	10.4	8.8	17.9	26.7	26.9	28.8	26.5
Trial 2	5.6	-1.4	1.0	9.3	11.2	18.5	24.5	25.9	29.0
Trial 3	4.0	4.4	2.9	8.4	15.4	30.4	27.5	31.4	23.0
$\bar{X}$	6.4	3.3	4.7	8.8	14.8	25.2	26.3	28.7	26.1
SD	2.9	4.3	4.9	.5	3.3	6.0	1.5	2.7	3.0
Subject 19 F									
Trial 1	5.6	7.5	12.0	12.1	23.2	26.1	31.5	39.8	35.3
Trial 2	2.1	6.6	11.7	9.5	22.6	32.3	31.3	41.6	37.4
Trial 3	2.3	4.5	9.3	12.0	19.9	27.1	24.1	36.6	39.4
$\bar{X}$	3.3	6.2	11.0	11.2	21.9	28.5	28.9	39.3	37.3
SD	1.9	1.5	1.4	1.4	1.7	3.3	4.2	2.5	2.0
Subject 20 F									
Trial 1	5.8	11.9	17.1	25.6	23.0	35.3	33.1	34.1	32.5
Trial 2	9.5	21.7	14.6	12.3	29.4	34.0	34.1	35.2	32.5
Trial 3	8.6	19.9	17.1	12.2	27.9	32.7	35.6	32.3	32.0
$\bar{X}$	7.9	17.8	16.2	16.7	26.7	34.0	34.2	33.8	32.3
SD	1.9	5.2	1.4	7.7	3.3	1.3	1.2	1.4	.3
Subject 21 F									
Trial 1	11.3	7.6	15.1	19.6	30.7	31.7	33.5	28.5	32.7
Trial 2	4.3	5.6	14.3	20.3	30.6	31.9	31.6	31.4	39.7
Trial 3	3.3	7.8	10.7	16.4	26.5	32.9	32.6	34.2	41.1
$\bar{X}$	6.2	7.0	13.3	18.7	29.2	32.1	32.5	31.3	37.8
SD	4.4	1.2	2.3	2.0	2.3	.6	.9	2.8	4.5
Subject 22 M									
Trial 1	20.7	16.8	14.6	9.1	22.7	29.5	31.3	36.6	20.4
Trial 2	12.2	17.8	22.0	19.4	27.5	27.1	27.3	33.9	37.5
Trial 3	9.0	14.2	13.7	10.1	20.3	23.5	17.0	35.3	25.5
$\bar{X}$	13.9	16.2	16.7	12.8	23.5	26.7	25.2	35.2	27.8
SD	6.0	1.8	4.5	5.6	3.6	3.0	7.3	1.3	8.7
Subject 23 F									
Trial 1	16.1	17.9	28.2	32.3	30.2	34.1	42.3	40.5	40.3
Trial 2	19.6	19.8	25.7	35.2	28.3	30.0	39.1	39.2	38.7
Trial 3	18.5	18.0	17.1	27.3	36.3	33.9	39.1	39.1	44.8
$\bar{X}$	18.0	18.5	23.6	31.6	31.6	32.6	40.1	39.6	41.2
SD	1.7	1.0	5.8	3.9	4.1	2.3	1.8	.8	3.1
Subject 24 F									
Trial 1	12.2	10.2	15.0	15.9	28.3	29.1	42.4	34.8	28.0
Trial 2	5.7	1.4	7.5	14.3	19.3	21.8	26.8	13.4	27.5
Trial 3	6.1	16.8	22.1	24.7	34.3	34.0	38.9	36.5	32.7
$\bar{X}$	8.0	9.4	14.8	18.3	27.3	28.3	36.0	28.2	29.4
SD	3.6	7.7	7.3	5.6	7.5	6.1	8.1	12.8	2.8

Measure		Test Frequency 125	250	500	1000	2000	3150	4000	6300	8000
Subject 25	F									
Trial 1		1.3	8.4	4.2	20.6	16.6	34.8	22.5	27.8	16.1
Trial 2		11.0	8.9	10.0	14.1	29.1	24.4	29.6	34.7	30.7
Trial 3		5.5	9.3	9.0	16.8	20.4	30.8	31.5	33.5	31.5
X̄		5.9	8.8	7.7	17.1	22.0	30.0	27.8	32.0	26.1
SD		4.8	.5	3.1	3.2	6.4	5.2	4.7	3.6	8.6
Subject 26	F									
Trial 1		1.9	3.6	13.4	9.4	15.7	29.4	24.9	32.4	30.8
Trial 2		1.9	5.1	10.7	13.7	26.4	36.5	38.3	38.2	33.9
Trial 3		6.5	10.2	18.3	14.8	23.2	33.7	36.3	39.9	29.7
X̄		3.4	6.3	14.1	12.6	21.7	33.2	33.1	36.8	31.4
SD		2.6	3.4	3.8	2.8	5.4	3.5	7.2	3.9	2.1
Subject 27	M									
Trial 1		25.0	11.5	6.6	18.5	22.8	48.9	41.8	34.4	37.3
Trial 2		15.7	13.3	8.9	10.6	30.7	39.7	30.5	31.7	29.6
Trial 3		12.8	14.8	12.2	4.8	20.3	38.5	33.2	33.0	26.7
X̄		17.8	13.2	9.2	11.3	24.6	42.3	35.1	33.0	31.2
SD		6.3	1.6	2.8	6.8	5.4	5.6	5.9	1.3	5.4
Subject 28	M									
Trial 1		7.9	7.4	14.9	20.4	27.1	32.8	34.4	29.8	35.6
Trial 2		9.7	4.9	11.3	16.1	17.8	26.2	23.9	26.7	25.0
Trial 3		9.6	5.6	13.2	23.1	24.0	35.9	39.8	30.9	30.3
X̄		9.0	5.9	13.1	19.8	22.9	31.6	32.7	29.1	30.3
SD		1.0	1.2	1.8	3.5	4.7	4.9	8.0	2.1	5.3
Subject 29	M									
Trial 1		8.4	6.5	17.0	21.3	27.2	31.5	32.7	35.6	38.0
Trial 2		10.4	6.3	11.7	11.9	25.7	24.3	26.2	32.3	37.4
Trial 3		14.2	7.4	17.2	19.6	19.0	18.9	27.7	34.1	31.1
X̄		11.0	6.7	15.3	17.6	23.9	24.9	28.8	34.0	35.5
SD		2.9	.6	3.1	5.0	4.3	6.3	3.4	1.6	3.8
Subject 30	M									
Trial 1		14.2	12.9	15.9	20.7	28.1	35.0	32.2	43.4	38.9
Trial 2		8.8	17.1	17.9	16.7	21.7	26.0	28.3	35.0	35.8
Trial 3		9.0	9.5	16.2	19.7	28.1	37.5	43.7	39.7	39.1
X̄		10.6	13.1	16.6	19.0	25.9	32.8	34.7	39.3	37.9
SD		3.0	3.8	1.0	2.0	3.6	6.0	8.0	4.2	1.8
Subject 31	F									
Trial 1		6.4	6.4	17.4	15.1	27.1	27.4	29.8	34.2	40.1
Trial 2		4.5	5.9	22.4	26.1	29.0	38.8	34.5	39.0	38.3
Trial 3		12.9	9.6	24.2	22.1	31.5	36.0	32.2	35.2	37.6
X̄		7.9	7.3	21.3	21.1	29.2	34.0	32.1	36.1	38.6
SD		4.4	2.0	3.5	5.5	2.2	5.9	2.3	2.5	1.2
Subject 32	F									
Trial 1		10.2	9.9	11.4	15.3	29.0	43.3	33.6	38.6	43.4
Trial 2		3.8	-1.2	11.3	8.2	20.5	29.8	24.8	35.1	37.2
Trial 3		13.8	14.7	17.6	13.1	27.9	35.4	35.9	34.2	33.7
X̄		9.2	7.8	13.4	12.2	25.8	36.1	31.4	35.9	38.1
SD		5.0	8.1	3.6	3.6	4.6	6.7	5.8	2.3	4.9

Measure	125	250	500	Test Frequency 1000	2000	3150	4000	6300	8000
Subject 33 M									
Trial 1	4.3	7.7	8.5	8.1	20.9	26.8	28.6	27.3	32.4
Trial 2	9.7	4.2	11.0	8.4	18.0	31.0	31.5	28.5	38.8
Trial 3	5.8	3.0	6.7	10.8	19.4	31.2	27.7	30.7	28.6
X̄	6.6	4.9	8.7	9.1	19.4	29.6	29.2	32.1	33.2
SD	2.7	2.4	2.1	1.4	1.4	2.4	1.9	5.7	5.1
Subject 34 M									
Trial 1	1.4	2.6	8.2	1.4	14.8	16.0	13.0	27.3	38.1
Trial 2	1.2	-4.8	6.4	-.8	6.1	15.1	5.9	13.6	28.9
Trial 3	6.8	8.9	2.9	8.6	21.7	22.8	25.3	25.3	28.9
X̄	3.1	2.2	5.8	3.0	14.2	17.9	14.7	22.0	31.9
SD	3.1	6.8	2.6	4.9	7.8	4.2	9.8	7.4	5.3
Subject 35 F									
Trial 1	12.7	11.1	9.3	18.7	27.8	29.4	32.7	35.0	25.1
Trial 2	7.9	7.4	10.5	15.0	27.3	26.1	36.2	34.4	23.5
Trial 3	8.1	6.0	13.8	16.8	25.9	29.1	31.4	42.6	29.7
X̄	9.5	8.1	11.2	16.8	27.0	28.2	33.4	37.3	26.1
SD	2.7	2.6	2.3	1.8	.9	1.8	2.4	4.5	3.2
Subject 36 F									
Trial 1	14.6	7.8	17.8	12.7	16.1	28.0	18.3	33.0	25.3
Trial 2	11.0	13.0	15.8	19.0	28.1	26.4	23.7	30.9	30.3
Trial 3	9.8	13.4	15.6	17.7	20.7	32.2	35.0	26.4	25.6
X̄	11.8	11.4	16.4	16.4	21.6	28.8	25.6	30.1	27.0
SD	2.4	3.1	1.2	3.3	6.0	2.9	8.5	3.3	2.8
Subject 37 M									
Trial 1	12.2	1.7	7.2	10.0	17.1	12.9	28.5	33.2	30.5
Trial 2	15.9	5.7	9.3	o1.4	19.5	21.3	27.4	35.6	31.4
Trial 3	18.1	9.8	8.8	14.6	22.0	21.7	29.0	34.5	35.0
X̄	15.4	5.7	8.4	12.0	19.5	18.6	28.3	34.4	32.3
SD	2.9	4.0	1.0	2.3	2.4	4.9	.8	1.2	2.3
Subject 38 M									
Trial 1	14.5	13.4	17.2	18.9	29.8	32.5	26.6	32.9	33.8
Trial 2	17.0	14.0	20.9	21.6	29.5	36.4	38.2	36.4	20.4
Trial 3	9.4	14.8	6.2	13.2	25.3	32.0	33.7	26.0	32.5
X̄	13.6	14.0	14.7	17.9	28.2	33.6	32.8	31.7	28.9
SD	3.8	.7	7.6	4.2	2.5	2.4	5.8	5.2	7.3
Subject 39 M									
Trial 1	6.7	9.9	12.7	19.7	27.0	35.3	34.4	34.7	31.9
Trial 2	16.6	14.1	21.1	20.7	31.8	35.4	36.8	42.2	42.1
Trial 3	17.0	14.6	16.9	19.9	28.5	38.6	38.8	35.9	40.5
X̄	13.4	12.8	16.9	20.1	29.1	36.4	36.6	37.6	38.1
SD	5.8	2.5	4.2	.5	2.4	1.8	2.2	4.0	5.4
Subject 40 F									
Trial 1	9.5	11.3	16.2	18.3	26.1	36.5	32.3	29.6	31.5
Trial 2	20.6	18.0	31.1	11.7	29.1	38.3	41.2	43.3	38.8
Trial 3	25.1	24.6	26.7	31.1	28.5	38.1	37.3	41.5	46.5
X̄	18.4	17.9	24.6	20.3	27.9	37.6	36.9	38.1	38.9
SD	8.0	6.6	7.6	9.8	1.5	.9	4.4	7.4	7.5

NOTE: Subjects 1-10 are from Group A (Experimenter fit and training); Subjects 11-20 are from Group B (Subject fit and training); Subjects 21-30 are from Group C (Experimenter fit and no training); Subjects 31-40 are from Group D (Subject fit and no training).

APPENDIX K

RESULTS OF RELIABILITY CHECK ON EXPERIMENTER DETERMINED THRESHOLDS

Table K.1. Results of reliability check on experimenter determined thresholds.

Frequency	Mean Attenuation* Experimenter	Mean Attenuation* Verifyer	Difference*	Mean Deviation*	r
Subject 1					
125	10.4	10.1	.3		
250	11.7	11.7	0		
500	18.3	18.3	0		
1000	13.3	13.4	.1		
2000	26.3	27.6	1.3		
3150	25.2	27.1	1.9		
4000	28.4	28.7	.3		
6300	33.5	33.9	.4		
8000	33.4	33.5	.1	.488	.99
Subject 2					
125	10.5	10.9	.4		
250	9.3	8.9	.4		
500	14.1	13.9	.2		
1000	14.0	14.3	.3		
2000	27.8	27.8	0		
3150	30.5	30.7	.2		
4000	30.8	30.8	0		
6300	34.4	34.2	.2		
8000	28.5	28.6	.1	.200	.99
Subject 3					
125	6.2	6.4	.2		
250	7.0	6.5	.5		
500	13.3	15.1	1.8		
1000	18.7	18.8	.1		
2000	29.2	29.3	.1		
3150	32.1	32.2	.1		
4000	32.5	31.6	.9		
6300	31.3	31.1	.2		
8000	37.8	36.1	1.7	.622	.99
Subject 4					
125	7.9	7.7	.2		
250	7.3	9.0	1.7		
500	21.3	21.5	.2		
1000	21.1	21.0	.1		
2000	29.2	27.9	1.3		
3150	34.0	34.6	.6		
4000	32.1	31.7	.4		
6300	36.1	36.4	.3		
8000	38.6	37.8	.8	.622	.99

*in dB.

APPENDIX L

CONFIDENCE INTERVALS OF MEAN ATTENUATION FOR ALL SUBJECTS

Table L.1. Confidence intervals of mean attenuation (in decibels) for four groups of ten subjects. Probability level = .05.

Frequency	Confidence Int. of Mean Group A*		Confidence Int. of Mean Group B*		Confidence Int. of Mean Group C*		Confidence Int. of Mean Group D*	
125	9.79	-6.40	19.5	4.31	19.3	-1.41	19.1	-2.65
250	12.7	-3.61	17.5	2.96	18.5	-2.43	17.8	-.58
500	17.6	-10.7	22.7	-.41	22.2	-6.5	24.9	-3.28
1000	20.9	-12.4	23.4	-1.11	28.1	-7.6	25.3	-4.45
2000	31.1	-19.4	36.2	-5.50	31.0	-19.3	33.4	-14.7
3150	34.7	-25.6	39.2	-13.5	40.0	-22.7	42.9	-17.2
4000	37.2	-28.5	40.3	-15.0	40.4	-24.7	41.8	-18.3
6300	41.1	-28.0	47.5	-12.4	40.9	-26.6	42.2	-24.7
8000	39.4	-26.5	45.5	-13.6	41.7	-23.8	42.2	-24.3

*Group A=experimenter fit and training; Group B=subject fit and training; Group C= experimenter fit and no training; Group D=subject fit and no training.

Table L.2. Confidence intervals of mean attenuation (in decibels) across subjects and trials for four groups of ten subjects. Probability level = .05.

Frequency	Confidence Int. of Mean Group A*		Confidence Int. of Mean Group B*		Confidence Int. of Mean Group C*		Confidence Int. of Mean Group D*	
125	16.5	.33	20.7	5.59	21.0	.23	21.3	-0.45
250	15.3	-1.05	19.2	4.61	19.6	-1.33	20.0	1.61
500	19.5	-8.88	23.8	.68	24.1	-4.68	26.3	-1.81
1000	23.4	-9.9	24.0	-0.56	29.8	-5.98	27.1	-2.61
2000	34.2	-16.3	36.8	-4.95	34.5	-15.8	34.9	-13.2
3150	38.9	-21.4	42.7	-10.0	42.3	-20.4	37.8	-22.3
4000	42.0	-23.7	44.1	-11.2	44.6	-20.5	44.0	-16.1
6300	48.1	-21.0	48.8	-11.1	43.8	-23.7	44.6	-22.3
8000	44.5	-21.4	47.3	-11.8	44.5	-21.0	44.8	-21.7

*Group A=experimenter fit and training; Group B=subject fit and training; Group C=experimenter fit and no training; Group D=subject fit and no training.

Table L.3. Confidence intervals of mean attenuation (in decibels) for all subjects (40). Probability level = .05.

Frequency	Confidence Interval of Mean	
125	18.3	- .035
250	17.0	- .552
500	22.3	- 4.80
1000	25.3	- 5.60
2000	33.9	-13.8
3150	40.0	-19.1
4000	41.1	-20.5
6300	44.2	-21.8
8000	42.8	-21.6

Table L.4. Confidence intervals of mean attenuation (in decibels) for four groups of ten subjects. Probability level = .05.

Frequency	Confidence Int. of Mean Groups A & C*		Confidence Int. of Mean Groups B & D*		Confidence Int. of Mean Groups A & B*		Confidence Int. of Mean Groups C & D*	
125	16.9	- 1.50	19.7	1.15	19.0	- 2.17	17.1	1.23
250	16.2	- 2.62	17.8	1.23	18.1	- 1.65	15.7	.082
500	20.3	- 8.25	23.9	- 1.90	23.6	- 4.92	21.3	- 4.47
1000	25.2	- 9.42	24.4	- 2.79	27.0	- 5.77	23.8	- 5.44
2000	31.2	-19.4	35.4	- 9.77	32.4	-17.0	35.2	-11.0
3150	37.6	-24.0	41.3	-15.3	41.6	-19.9	38.4	-18.2
4000	39.0	-26.6	40.9	-16.8	41.5	-21.3	40.9	-19.7
6300	40.9	-27.4	45.9	-17.7	41.6	-25.8	46.0	-18.6
8000	40.6	-25.2	44.5	-18.5	41.9	-24.3	43.6	-19.0

*Groups A & C=experimenter fit; Groups B & D=subject fit; Groups A & B=training; Groups C & D=no training.

REFERENCES

Abel, S.M., P.W. Alberti and K. Riko. 1982. "User fitting of hearing protectors: attenuation results." In Personal Hearing Protection in Industry. P.W. Alberti, Ed. New York: Raven Press.

Alberti, P.W. Ed. 1982. Personal Hearing Protection in Industry. New York: Raven Press.

Alberti, P.W., K. Riko, S.M. Abel and R. Kristensen. 1979. "The effectiveness of hearing protectors in practice." The Journal of Otolaryngology. 8:354-359.

American National Standards Institute. 1974. "Measurement of real-ear protection of hearing protectors and physical attenuation of earmuffs." S3.19 (American National Standards Institute, New York).

American National Standards Institute. 1969. "American National standard specification for audiometers." S3.6 (American National Standards Institute, New York).

American National Standards Institute. 1966. "Specification for octave, half-octave, and third-octave band filter sets." S1.11 (American National Standards Institute, New York).

Berger, E.H. 1983. "Using the NRR to estimate the real world performance of hearing protectors." Sound and Vibration. 17:12-18.

Berger, E.H. 1982. "Laboratory estimates of the real-world performance of hearing protectors." In Personal Hearing Protection in Industry. P.W. Alberti, Ed. New York: Raven Press.

Berger, E.H. 1980a. EARLog # 1 "The threshold shift method of measuring hearing protector attenuation." EAR Division, Cabot Corporation.

Berger, E.H. 1980b. EARLog # 4 "The performance of hearing protectors in industrial noise environments." EAR Division, Cabot Corporation.

Berger, E.H. 1980c. EARLog # 5 "Hearing protector performance: how they work-and-what goes wrong in the real world." EAR Division, Cabot Corporation.

Berger, E.H., J.E. Kerivan and F. Mintz. 1982. "Interlaboratory variability in the measurement of hearing protector attenuation." Sound and Vibration. 16: 14-19.

Edwards, R.G., W.P. Hauser, N.A. Moiseev, A.B. Broderson and W.W. Green. 1978. "Effectiveness of earplugs as worn in the workplace." Sound and Vibration. 12: 12-22.

Edwards, R.G., et al. 1978. "Effectiveness of earplugs as worn in the workplace." Sound and Vibration. 12:12-22.

Environmental Protection Agency. 1979. "General provisions for product noise labeling requirements for hearing protectors, approval and promulgation." Federal Register 40 CFT, Part 211, 56120-56147.

Forshaw, S.E. "Standards for evaluating and classifying hearing protection devices." Paper presented at the Annual Convention of the American Speech-Language-Hearing Association. Toronto, Canada. November 18-20, 1982.

Gescheider, George A. 1976. Psychophysics: Methods and Theory. New York: John Wiley and Sons.

Hays, William L. 1973. Statistics for the Social Sciences. New York: Holt, Rinehart and Winston, Inc.

Humes, Larry E. 1983. "A psychophysical evaluation of the dependence of hearing protector attenuation on noise level." Journal of the Acoustical Society of America. 73:297-310.

Jerger, J. 1970. "Clinical experience with impedance audiometry. Archives of Otolaryngology. 92:311.

Juneau, Roger P. 1982. "The NRR: laboratory test versus field performance - how do they relate." Hearing Instruments. 33:14-15;51.

Karmy, S.J. and A.M. Martin. 1982. "Employee attitudes towards hearing protection as affected by serial audiometry." P.W. Alberti, Ed. New York: Raven Press.

Levitt, H. 1971. "Transformed up-down methods in psychoacoustics." Journal of the Acoustical Society of America. 49:467-477.

Martin, Alan. 1982. "How realistic are standard subjective test methods for evaluating hearing protection attenuation?" In Personal Hearing Protection in Industry. P.W. Alberti, Ed. New York: Raven Press.

Melnick, William. 1978. "Temporary and permanent threshold shift." In Noise and Audiology. David D. Lipscomb, Ed. Baltimore: University Park Press.

Michael, Paul L. and Gordon R. Bienvenue. 1980. "Hearing protector performance - an update." American Industrial Hygiene Association. 41:542-546.

Michael, P.L., R.L. Kerlin, G.R. Bienvenue, J.H. Prout, and J.I. Shampan. 1976. "A real-ear field method for the measurement of the noise attenuation of insert-type hearing protectors." H.E.W. Publication No. (NIOSH) 76-181.

Nixon, Charles W. 1982. "Hearing protection standards." In Personal Hearing Protection in Industry. P.W. Alberti, Ed. New York: Raven Press.

Occupational Safety and Health Administration. 1981a. "Occupational noise exposure; hearing conservation amendment." Federal Register 29 CFR Part 1910, 4078-4179.

Occupational Safety and Health Administration. 1981b. "Occupational noise exposure; hearing conservation amendment; rule and proposed rule." Federal Register 29 CFR Part 1910, 42622-42639.

Occupational Safety and Health Administration. 1983. "Occupational noise exposure; hearing conservation amendment; final rule." Federal Register 29 CFR Part 1910, 9738-9785.

Padilla, M. 1976. "Earplug performance in industrial field conditions." Sound and Vibration. 10:33-36.

Regan, D.E. 1977. "Real-ear attenuation of personal ear protective devices worn in industry." Audiology and Hearing Education. 3:16-17.

Smith, Curtis R., and Thomas E. Borton. 1981. "Premolded insert hearing protection: concerns and considerations." Hearing Instruments. 32:11-12;42.

Smith, C.R., T.E. Borton, L.B. Patterson, M.T. Mozo and R.R. Camp. 1980. "Insert hearing protector effects on sound pressure levels in a simulated external ear canal: preliminary results using KEMAR." Ear and Hearing. 1:26-32.

Stevens, S.S. 1975. _Psychophysics_. New York: John Wiley and Sons.

Tobias, Jerry V. 1982. "Measurers' standard and nonstandard testing of hearing protector effectiveness." In _Personal Hearing Protection in Industry_. P.W. Alberti, Ed. New York: Raven Press.