

COMPARISON OF LABORATORY PROTOCOLS
FOR YIELDING IMPROVED ESTIMATES OF HEARING PROTECTION
IN-FIELD PERFORMANCE FOR USE IN STANDARDS DEVELOPMENT

by

Michael Llewellyn Richards

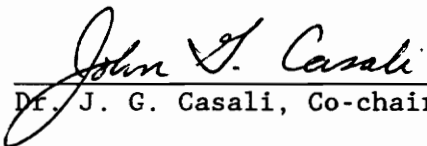
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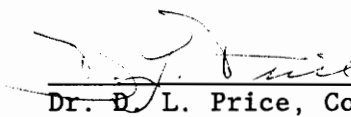
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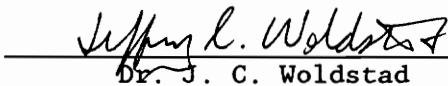
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APPROVED:


Dr. J. G. Casali, Co-chairman


Dr. D. L. Price, Co-chairman


Dr. J. C. Woldstad

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(ABSTRACT)

Federal law requires hearing protection device (HPD) manufacturers to provide attenuation ratings for use in estimating workers' protection levels. These ratings, which are laboratory-obtained, typically overestimate the actual protection levels achieved in the workplace. This research investigated laboratory protocols for yielding improved estimates of HPD in-field performance.

Two experiments were conducted. The first was a pilot study developed by an American National Standards Institute (ANSI) working group. In this experiment, two types of earplugs were tested, a user-molded, malleable foam plug and a pre-molded, multi-sized rubber plug. Attenuation data (obtained using a psychoacoustical real-ear-attenuation-at-threshold measurement procedure) were collected across 10 subjects who entered the study as novice HPD users but were considered experienced HPD users in the latter half of the study. Four testing protocols involving two levels of HPDs, two levels of instruction-insertion techniques, and two levels of user experience were investigated.

The same 10 subjects participated in all treatment conditions of the experiment.

The second experiment involved similar protocols as the first; however, only one plug type was tested (the pre-molded, multi-sized rubber plug). Four testing protocols involving two levels of instruction-insertion techniques, two levels of user experience, and two levels of auditory feedback [fitting noise] were investigated. Forty subjects participated; each subject was tested in two treatment conditions.

The attenuation results of each experiment were analyzed by statistical techniques. Statistical comparisons of results were made between the two experiments as well as between the experiments and selected field data.

The major finding of the research was that fitting noise did not help subjects achieve higher attenuation [better protection] when consciously used for that purpose. Other findings indicated that novice subjects using only HPD manufacturer's instructions achieved attenuation that more closely represented the field attenuation than subjects tested under other conditions. However, the results were plug specific, in that no laboratory protocols yielded attenuation similar to the field data for the foam plug.

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Thanks to all the subjects, with special thanks to the subjects of the first experiment for their endurance and commitment to the research; I couldn't have had a better group to work with.

The author would like to share the following verses, which have been especially meaningful throughout the time of this research:

Proverbs 4:7 Wisdom is the principle thing; therefore
 get wisdom: and with all thy getting get
 understanding (King James Version).

Proverbs 3:5-6 Trust in the Lord with all thine heart;
 and lean not unto thine own understanding.
 In all thy ways acknowledge him and he
 shall direct thy paths (King James Version).

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LIST OF ABBREVIATIONS

ASL -- Auditory Systems Laboratory (at Virginia Tech)

ANSI -- American National Standards Institute

ANSI S12/WG11-- Working group responsible for
revision of standard S12.6-1984

dBA -- decibel, A-weighted scale

EF -- Experimenter Fit (treatment condition)

EPA -- Environmental Protection Agency

ESF -- Experimenter Supervised Fit (treatment condition)

HCP -- Hearing Conservation Program

HPD -- Hearing Protection Device

IUF -- Informed User Fit (treatment condition)

NIHL -- Noise Induced Hearing Loss

NRR -- Noise Reduction Rating

NIOSH -- National Institute of Occupational Safety and Health

OB -- Octave Band

OHL -- Occupational Hearing Loss

OSHA -- Occupational Safety and Health Administration

REAT -- Real-Ear Attenuation at Threshold

SF -- Subject Fit (treatment condition)

SPL -- Sound Pressure Level

TWA -- Time-Weighted Average

INTRODUCTION

Background

The debilitating effects of high-intensity noise have been a detriment to humans throughout the last several centuries. These insidious effects include (1) tinnitus (ringing in the ears), (2) temporary hearing loss, (3) permanent thresholds shifts, (4) permanent conductive loss or neural deafness, (5) subsequent effects of noise-induced hearing loss (NIHL) such as interference with communication and warning sounds, and (6) psychological and social problems, such as fatigue, headaches, and inattention. Some recent articles which address these concerns include Casali (1989), Gasaway (1988), Ward (1986), and Willson (1985).

Exposure to high-intensity occupational noise is one of the most severe workplace health hazards (Casali, 1986; Willson, 1985). This occurs in spite of recent technological developments in sound abatement and the design of hearing protection devices (HPDs), as well as industrial educational programs for exposed workers. It has been previously reported that occupational hearing loss (OHL) affects more individuals than all other occupational diseases combined (Miller, 1978).

The current laws for industry, as mandated by the Occupational Safety and Health Administration (OSHA), are summarized by the following: (1) exposure not to exceed 90 dBA (decibels, A-weighted scale, re 20 micro Pa) time-weighted average (TWA) per 8-hour day, (2) exposure not to exceed 85 dBA TWA for an employee who has experienced a

hearing loss, (3) no exposure to steady-state sound levels greater than 115 dBA, (4) no exposure to impulsive or impact noise to exceed 140 dB peak sound pressure level, and (5) a hearing conservation program must be maintained if exposures are greater than 85 dBA TWA per 8-hour day (OSHA, 1990).

Even with current legislation to limit the high-intensity noise exposure of industrial workers, OSHA estimates that 2.9 million workers are exposed to noise levels of 90 dB or more, and another 2.3 million are exposed to levels in the 85 to 90 dB range (Willson, 1985).

For the safety engineer, the ultimate objective in hearing conservation efforts is to eliminate hearing loss resulting from job-related noise exposure (Casali, 1986). Noise abatement techniques should follow a systems approach with the goal of eliminating the noise at the source. Engineering controls and mechanical interventions (e.g., such as vibration isolators and machine enclosures) and system process controls (e.g., re-routing of material flow and changing drive speeds) are desirable means of reducing noise at the source (Casali, 1986). However, the cost to U. S. industry to implement engineering controls exclusively to lower noise to 90 dBA has been estimated at more than \$13 billion, and to reach 85 dBA the costs have been estimated at more than \$31 billion (Willson, 1985). Even with these proposed efforts for noise reduction, it is doubtful that no occupation hearing loss will occur. Many industries have focused their efforts for reducing noise exposure to administrative controls and the use of personal HPDs.

Administrative controls primarily involve scheduling workers in and out of noisy environments to avoid having any individual exposed to levels which exceed the OSHA standards for time-weighted averages. This method of control is often impractical because a large number of equally skilled workers would have to be rotated frequently and because of the large costs in time and money associated with the administrative process. Furthermore, these controls do not really solve the problem of hearing loss; instead, they cause a spread of smaller losses across the persons involved in rotation.

The use of personal HPDs has become the most popular method of protection against the effects of high-level noise exposures (Casali and Epps, 1986; Riko and Alberti, 1983; Willson, 1985). HPDs are divided into four categories: (1) aural inserts (earplugs), (2) supraaural earcaps, (3) circumaural earmuffs, and (4) enclosures (helmets).

Although many HPD designs have been improved since the mid-1970s (Gasaway, 1988), there are still many problems which confront safety engineers concerning the use of HPDs and the effectiveness of hearing conservation programs (HCPs). Some of these problems are HPD selection, user training, and surveillance of use. According to Gasaway (1988), the single greatest challenge of the hearing protection industry is motivating employees to accept the need for protection and then translating this acceptance into proper, consistent use.

A primary characteristic of noise-induced hearing loss, NIHL, is relatively good hearing at 500 and 1000 Hz (indicated by a relatively flat audiogram curve) with a distinct decrease in hearing ability at

mid-range frequencies (especially 4000 Hz) and then an upward return of hearing ability at 8000 Hz for both ears (Kryter, 1985; Morrill, 1986). The 4000-Hz dip distinguishes NIHL from other effects on hearing ability such as aging (presbycusis) and exposure to the sounds and noises of everyday living (sociocusis) (Kryter, 1985). The human ear is most sensitive to noise at 4000 Hz; also, hearing at this frequency (along with 500, 1000, and 2000 Hz) is critical for understanding consonants for speech intelligibility (Ward, 1986). For these reasons, industrial hygienist, nurses, and safety personnel should be especially careful in the HPDs they select for noise-exposed employees. It is important to know the spectral attenuation data of an HPD and the spectral sound pressure levels of the noisy environment to insure proper protection against NIHL. In the case of earplugs, plug type, size selection (in the case of multi-sized plugs) and proper insertion are key to achieving adequate attenuation.

Issues in the Present Study

The Environmental Protection Agency (EPA) has mandated that all HPDs available for industrial use have a single-number noise reduction rating (NRR) on their packaging to aid the user or safety engineer in choosing protectors (EPA, 1990). Manufacturers test HPDs in laboratories according to standards (ANSI S3.19-1974; ANSI S12.6-1984) that have been developed to yield optimum protection values. Research has shown that the mean attenuation achieved with HPDs in actual workplaces is much less than the optimum mean attenuation achieved in

laboratory tests (Alberti, Riko, Abel, and Kristensen, 1979; Behar, 1985; Berger, 1982a; Berger, 1982b; Edwards and Green, 1987; Lempert and Edwards, 1983; Pekkarinen, 1987; Riko and Alberti, 1983).

Some of the reasons for lower attenuation results in the workplace are the following: (1) use of incorrectly sized HPDs, (2) poor installation or fitting procedures, (3) lack of proper instruction, (4) poor maintenance, (5) use of eyeglasses (especially with earmuffs), and (6) misuse of devices (Behar, 1985; Pekkarinen, 1987; Riko and Alberti, 1983). Most laboratory attenuation measurements are taken under optimum fitting conditions with new protectors. In the EPA-required (EPA, 1990) standard protocol for testing, ANSI S3.19-1974, if the experimenter determines the protector fit is inadequate, he/she can actually fit the HPD properly for the listener and then closely inspect the fit and seal. In another standard (ANSI S12.6-1984) the experimenter closely supervises the fitting of the HPD by the subject and may ask for repeated re-fits if needed.

There is a definite need for a testing procedure that is a reasonable compromise between practical realism and experimental accuracy (Berger, 1982a; Berger, 1988; Martin, 1982). ANSI S12/WG11, the standards working group responsible for developing a testing standard to yield realistic estimates of actual HPD workplace performance, has been investigating different experimental protocols for evaluating HPDs. One alternative is the development of a testing protocol which will decrease the use of the experimenter's expertise in fitting and rely more on the manufacturer's package instructions and the

subject's ability to follow instructions and achieve proper fit.

ANSI S12/WG11 developed an inter-laboratory comparison study to be conducted in different HPD testing facilities. Two insertion/instruction techniques were to be evaluated. One technique involved the selection and fitting of HPDs by the subject while using the manufacturer's package instructions as the only guide to correct selection and fit. This technique, called Subject Fit (SF), was anticipated to yield more accurate estimates of field attenuation data (Berger, 1988; Berger 1982a). In the other technique, called Informed User Fit (IUF), the subject received instructions, demonstrations, and help from the experimenter in selecting and fitting the HPDs and a fitting noise was presented as an audio feedback aid for verifying a good seal. This second insertion/instruction technique was anticipated to yield higher attenuation results similar to the optimum results obtained when testing according to the standards (ANSI S3.19-1974 and ANSI S12.6-1984).

Other factors in the ANSI S12/WG11 study included HPD types and specific criteria for the research candidates (i.e., experience with using HPDs, experience with HPD testing, and hearing ability). ANSI S12/WG11 issued procedures in the fall of 1989 for conducting pilot research to investigate the aforementioned experimental conditions with two HPDs before commitments were made to conduct a larger study involving more HPDs and subjects.

The pilot research was conducted at the Auditory Systems Laboratory (ASL) of Virginia Polytechnic Institute and State University and at three other laboratories. At ASL, two experiments were conducted.

Experiment 1 involved testing subjects exactly according to the protocols of the pilot study developed by ANSI S12/WG11. Problems which were present in the pilot study were: (1) the possible learning and transfer effects of having the same 10 subjects participate in all treatment cells of the entire experiment (which is inherent in a within-subjects design), and (2) the confounding effects of presenting a fitting noise in the IUF condition but not in the SF condition.

Experiment 2 involved testing subjects according to alternative protocols developed by the ASL experimenters. The primary purposes of Experiment 2 were: (1) to test conditions similar to those of the pilot study under a different experimental design (mixed-factors) and to compare the results between the two experiments, and (2) to investigate the effects of fitting noise as an experimental factor. Further discussions of the experiments are presented later in the thesis.

Some of the results of this research were used by ANSI S12/WG11 to design a larger, full-scale study. ANSI S12/WG11 is expected to use the results of this research and their future study to determine the most appropriate conditions to include in a revised testing standard which is intended to yield attenuation results which better represent the attenuation actually being achieved in the workplace. The revised standard may replace the current standard and ultimately be required by the EPA for HPD attenuation testing for manufacturers' label ratings.

Before this research began, a literature review was conducted to investigate fundamental issues concerning HPDs and their noise attenuation characteristics. HPD testing standards, previous field

studies, and previous laboratory studies were also investigated with particular attention to the topics of SF and IUF protocols and the use of fitting noise.

LITERATURE REVIEW

The review presents background information necessary to understand how HPDs are tested and used effectively. Literature which bears on this research includes psychoacoustical investigations of different types of HPDs, field influences on HPD attenuation, and HPD occlusion effects. In regards to standards for testing HPDs, discussions of Real-Ear Attenuation at Threshold (REAT) methods, HPD attenuation ratings, ANSI Standard S12.6-1984, and the ANSI working group (S12/WG11) responsible for the revision of S12.6-1984 are presented. The latter sections of the literature review include investigation of HPD attenuation field studies and laboratory studies.

Hearing Protection Devices

HPDs have become the most widely used method of protection for noise-exposed employees. Noise exposure involves both amplitude (measured in sound pressure level) and duration (length of time in the noise). Effects such as wearing time, environmental conditions, user movement, HPD abuse, and HPD deterioration must be considered when choosing an HPD for use. Also, HPDs have different inherent characteristics such as ease of fitting, comfort, shape, and frequency-specific attenuation factors which influence their overall effectiveness for reducing sound pressure to the inner ear.

There are currently four types of HPDs available. These are: (1) aural (inserted in the ear canal) earplugs, (2) supraaural (seated over

the ear canal) earcaps or ear canal caps, (3) circumaural (over the ear) earmuffs, and (4) helmets (enclosures). In industry, earplugs, earcaps, and earmuffs are the most popular HPDs.

Earplugs. Earplugs are available in three types, these are: (1) user-molded, (2) pre-molded, and (3) custom-molded. The most popular user-molded (formable) earplugs are made of a malleable foam polymer. According to laboratory data, these plugs offer the highest mean attenuation of all the plugs that have been tested (Berger, 1988; Lempert and Edwards, 1983), but only when they are properly fit (Casali and Epps, 1986). Other formable plugs, made of mineral fiber, wax, or waxed cotton are available, but are not as popular as the foam plugs, especially in the United States.

Pre-molded earplugs are usually made of silicon, rubber, or soft plastic. Different shapes include one-flange, two-flange, three-flange, and cone-shaped plugs. Some pre-molded plugs are universal-fit (one size fits all), and others have multiple sizes to select from. These plugs may be worn more than several times and thus require cleaning and storage. Most of the pre-molded plugs come with carrying cases for clean storage when not in use.

Custom-molded earplugs, usually made of rubber or silicon, are cast from impressions of the left and right ear canals of the user. The impressions are usually made by a nurse or audiologist. They may be kept and used as long as they continue to seal properly and do not deteriorate. They require cleaning and proper storage, and to be

effective, they must be inserted properly in the ears for which they were molded.

In general, earplugs provide acceptable attenuation, but they are not as easy to use as earmuffs or earcaps (Berger, 1986). Inserting earplugs properly requires time (1 or 2 minutes for some plugs), fairly concentrated effort, and specific knowledge of inserting instructions. Some multi-sized plugs require size selection, which can further complicate the fitting.

Earmuffs. Earmuffs provide attenuation by enclosing the outer ears (pinnae) within a set of earcups that have cushions that seal against the head. These earcups are connected by a headband or are attached to a hard hat. The effectiveness of earmuffs depends on a number of factors, such as the size, volume, shape, and mass of the earcups, the area and filler substance (liquid and/or foam) of the cushions, the headband adjustability and compression force, and the physical features of the wearer's head (Berger, 1986).

In general, earmuffs are more durable than earplugs, are easier to use, and are good for environments where dirt, grease, paint, or other contaminants may accumulate on the hands and head. Earmuff use is easier to monitor than that of earplugs; however, hair, ear jewelry, and eyeglasses can degrade the seal of the muffs, thus resulting in lower attenuation. Also, if the headband tension is weakened (a common intentional practice by wearers to achieve more comfort) then substantial attenuation is lost (Berger, 1986). Other disadvantages of muffs are that they require cleaning and maintenance and they may be

considered cumbersome and uncomfortable by some wearers.

Earcaps. Earcaps, or supraaural devices, are made of pods or flexible tips attached to a lightweight metal or plastic headband. The tips, usually made of vinyl or silicon, seal the openings of the ear canals. Primarily, earcaps are intended for use in intermittent exposure conditions where they may need to be removed and replaced frequently. They are a compromise between earplugs and earmuffs, and they are generally easy to use. Earcaps generally give less protection than earplugs or earmuffs and tend to create the most noticeable "occlusion effect" (to be explained).

Factors which influence HPD field performance

Many factors that are present in the industrial environment are not present in the laboratory unless intentionally presented or simulated. These effects may degrade the achievable attenuation of HPDs (Berger, 1986; Casali and Epps, 1986; Casali and Lam, 1986). Such factors include:

- (1) comfort -- usually overlooked in the laboratory
(often because of short wearing time and the
objective of optimal fit for attenuation),
- (2) utilization -- because of poor comfort, poor
motivation, or poor training, many HPDs are misused,
- (3) fit -- proper fit of earplugs for each ear is
essential for effective use,

- (4) readjustment -- may be needed due to worker's head or jaw movement which can cause HPD to work loose or lose proper position,
- (5) deterioration -- no HPDs are permanent or maintenance-free,
- (6) abuse -- employees often modify HPDs to improve comfort at the expense of protection,
- (7) wearing time -- some HPD attenuation decreases over time, and
- (8) fitting instruction -- different instruction techniques result in different achievable attenuation, from little attenuation to almost optimum attenuation (Berger, 1986; Casali and Epps, 1986).

Noise Attenuation With HPDs

To understand how HPDs work -- or fail to work -- it is important to understand some of the physical and physiological characteristics of the occluded ear. The following sections address important terms or definitions used to describe these characteristics.

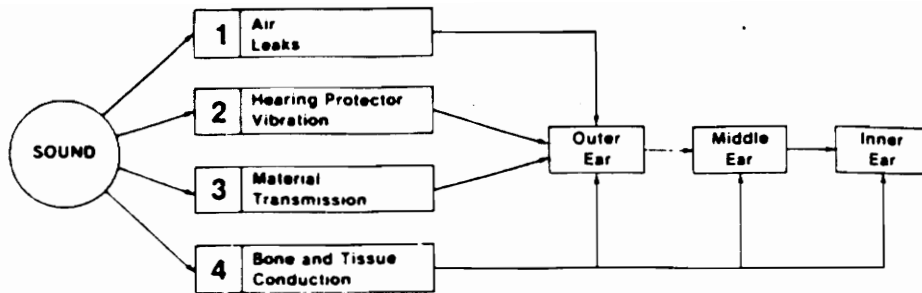
Sound pathways. The occluded ear receives sound energy by four primary transmissions paths. These pathways are: (1) air leaks -- occur when the HPD fails to form an air tight seal, (2) hearing protector vibration -- due to the flexibility of ear canal flesh or flesh around the ear, (3) material transmission -- vibrations passing through the

protector (dependent upon mass, stiffness, and internal damping of the material), and (4) bone and tissue conduction -- paths by which sound may bypass the HPD, even if perfectly inserted, to reach the inner ear (Berger, 1986). These paths are illustrated in Figures 1a, 1b, and 1c.

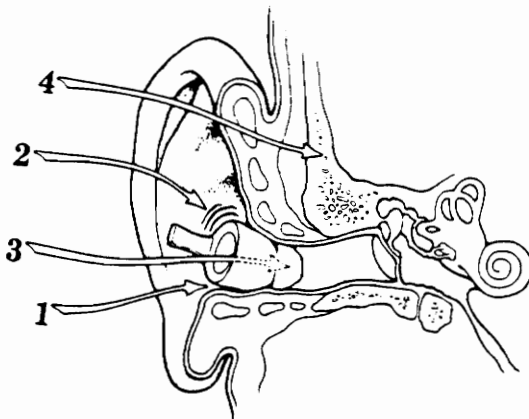
Occlusion effect. When the ear is occluded by low-volume earcups, earcaps, or shallow-inserted earplugs, the efficiency of transmission of bone-conducted energy is enhanced for low frequencies (below 2000 Hz) (Berger, 1986). This causes one's own voice to take on a bass, resonant quality which is considered unpleasant by some HPD users. This effect is partially caused by the volume of air trapped in the ear canal. This trapped air causes vibrations of the canal wall (and the concha and pinna in the case of muffs). The occluded effect diminishes when the volume of air is reduced, as with more deeply inserted plugs, or when the volume is increased, as with large volume ear muffs.

Insertion loss and noise reduction. Insertion loss and noise reduction are two precisely defined acoustical terms. Insertion loss is a measurement of sound pressure level (SPL) in dB at a fixed location (i.e., in the ear canal) before and after a noise control measure (i.e., the HPD) has been implemented. An example of insertion loss is the measurement of SPL in dB in a cadaver ear canal with a small microphone before and after inserting an earplug.

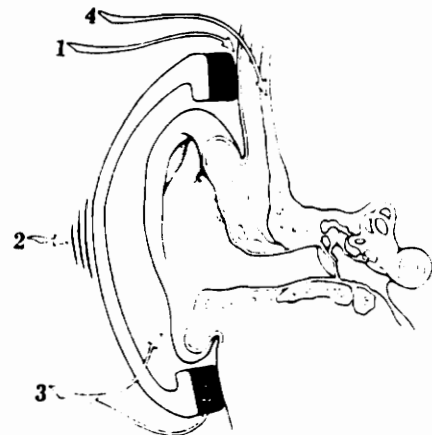
Noise reduction is a measurement of SPL in dB at two different locations, one at either side of the control device (i.e., one location outside of the HPD, the other inside of the HPD) at the same time. An example of noise reduction with earmuffs is the difference between the



a - Generalized block diagram of the four primary sound pathways to the occluded ear.



b - Sound pathways for an earplug.



c - Sound pathways for an earmuff.

Figure 1a, 1b, and 1c. Sound paths for HPDs (Adapted from Berger, 1986).

SPL measured with a microphone on the outside of an earcup and the SPL measured with another microphone inside the earcup.

REAT Method for Measuring HPD Attenuation

In psychoacoustic research, attenuation is the occluded threshold of audibility minus the unoccluded threshold of audibility. Of the numerous attenuation measurement methods for HPDs that have been proposed and tested throughout the past few decades, the Real-Ear Attenuation at Threshold, REAT, method is the most common and widely accepted. The REAT method was adopted by the American National Standards Institute (ANSI) in 1957, within the standard ANSI Z24.22-1957, "Method for the Measurement of Real-Ear Attenuation of Ear Protectors at Threshold." Through the ANSI revision process, other standards have evolved such as ANSI S3.19-1974 and Z24.22-1977 which both specify REAT procedures. The latest ANSI standard which uses the REAT procedure in its protocol is ANSI S12.6-1984, which is a revision of the real-ear measurement section of S3.19-1974 (ANSI, 1984). However, the EPA (1990) currently requires that the older standard (S3.19-1974 -- with specification of "Experimenter-fit" condition) be used when HPDs are tested for labeling purposes.

REAT is a psychophysical method of measuring thresholds. It is considered a subjective method of measurement because of its dependence on human physiological hearing thresholds of perceived sound pressure levels. In acoustical research, objective methods of measurement are those which use microphones and specialized meters to detect sound

pressure levels, usually inside and outside an HPD on a human, cadaver, or artificial head. The common psychophysical procedures used are either the method of limits (experimenter control of levels) or the method of adjustment (subject control of the levels) (Gescheider, 1985).

The following paragraph provides a clear definition of the REAT method:

The REAT method is based upon the determination of the difference between the minimum level of sound that a subject can hear without wearing an HPD (open threshold) and the level needed when the subject is wearing the HPD (occluded threshold). The difference between these two thresholds, the threshold shift, is a measure of the REAT afforded by the device (Berger, 1986, p. 325).

With this method, a certain frequency tone or noise band is presented to a human subject in a series of trials. The trials generally alternate in ascending and descending directions with respect to sound pressure level (in dB) increments or decrements. The REAT is determined by the average of the hearing level responses across all ascending and descending trials. These trials may be presented manually or automatically with the appropriate audiometric equipment.

Berger (1986) identifies sound field REAT and headphone REAT as two implementations of the test method. Sound field REAT utilizes airborne signals that are generated and presented to a subject in a test booth

through loudspeakers, thus, constituting a binaural test (both ears). The headphone REAT method involves the use of small precision loudspeakers located in a set of headphones that the subject wears; thus, it allows monaural (one ear only) testing to be performed. The headphone method has some advantages because it simplifies the test equipment required and eliminates the acoustical sound field calibration, but its greatest disadvantage is that it can only be used to test earplugs, not earmuffs, canal caps, or helmets.

Rating HPD Attenuation

The attenuation and standard deviation results of the REAT method can be reduced to a single-number rating that provides a simple and efficient way of choosing HPDs for a given industrial setting. The primary advantage of a single-number rating is that it can be pre-calculated by the manufacturer and supplied to the user with the device as currently required by the EPA (Berger, 1986).

The most accepted single-number rating was adapted by the EPA in 1979; it is called the Noise Reduction Rating (NRR). The calculation is based on the use of a pink noise spectrum (equal energy in each octave band from 125 Hz to 8000 Hz). Table 1 illustrates how to calculate the NRR for an HPD. In computing the NRR, the mean attenuation values are reduced by subtracting 2 standard deviations (a correction factor) across frequencies so the final NRR should theoretically estimate the degree of protection for 98% of the user population; thus, the NRR is often denoted NRR(98) (Berger, 1986).

TABLE 1

Noise Reduction Rating (NRR) Calculation (per EPA, 1990¹; from attenuation data obtained per ANSI S12.6-1984²)

1/3 octave band center (Hz)	125	250	500	1000	2000	4000	8000	
1. assumed pink noise (dB)	100	100	100	100	100	100	100	
2. c-weighting corrections (dB)	-0.2	0	0	0	-0.2	-0.8	-3.0	
3. c-weighted level unprotected ear (dB)	99.8	100	100	100	99.8	99.2	97.0	107.9 Logarithmic Σ
4. a-weighted corrections (dB)	-16.1	-8.6	-3.2	0	1.2	1.0	-1.1	
5. unprotected ear a-weighted level (dB) (step 1 + step 4)	83.9	91.4	96.8	100	101.2	101	98.9	
6. mean attenuation at frequency (dB)*								
7. standard deviation at frequency (x 2) (dB)*								
8. protected A-weighted sound levels (dB) (step 5 - step 6 + step 7)								Logarithmic Σ
9. NRR = (step 3 log Σ) - (step 8 log Σ) - (3dB correction factor)								
NRR = 107.9 - 3 =								

* 4000 Hz values are mean of 3150 and 4000 Hz data.
8000 Hz values are mean of 6300 and 8000 Hz data.

¹Environmental Protection Agency (EPA), (1990). Product noise labeling. Code of Federal Regulations, CFR 40, Part 211, 128-144.

²ANSI S12.6-1984 (1984). Method for the measurement of the real-ear attenuation of hearing protectors. New York: American National Standards Institute, Inc.

To use the NRR to derive the estimated noise exposure (in dBA), the noise level of the environment must be measured in dBC with a sound level meter (OSHA, 1990). The equation for computing the estimated noise exposure is:

$$\text{Average Noise Level (dBC)} - \text{NRR} = \text{Effective Noise Exposure (TWA, dBA)}$$

(EPA, 1990; OSHA, 1990)

Subtracting the NRR from noise measured with the C-weighted scale to achieve the A-weighted exposure is justified because of the relationship that exists between HPD attenuation and the A-weighted scale. Specifically, the A-weighted noise reduction of most standard HPDs decreases as the proportion of low-frequency energy in the noise spectrum increases (i.e., the attenuation of HPDs decreases with low frequency, approximately at the same rate as the increase in difference between C- and A-weighted curves) (Berger, 1986). This relationship can be accounted for by taking the difference between the C- and A-weighted sound levels of the noise spectrum (Berger, 1986).

OSHA (1990) requires subtracting 7 dB from the NRR when it is used with (subtracted from) A-weighted sound levels. This correction is necessary due to the reduced accuracy of using the NRR with A-weighted sound levels and it accounts for the largest differences typically expected between the C- and A-weighted sound levels of industrial noises (Berger, 1986).

An in-field noise reduction rating, termed the NRR(84) or the Real

World NRR(84) was developed to represent the degree of attenuation theoretically achieved by 84% of the user population, as suggested by Berger (Berger, 1983b; Berger, 1986). Berger (1983b) based the NRR(84) on field and laboratory studies for the real-world performance of HPDs. The NRR(84) uses 1 standard deviation rather than 2 standard deviations for the correction factor to be subtracted from the mean attenuation results across frequencies.

The NRR(84), which is considered a more appropriate estimate of the protection achieved in the field, was compared to NRR values for earplugs and earmuffs in a study by Berger (1983b). The results of the study showed that the average difference between the manufacturers' labeled NRR(98) and the NRR(84) across all devices was 13 dB (on average, the NRR(84) was lower by this amount) (Berger, 1983b). A graph of these results is shown in Figure 2, for all of the HPDs tested.

If no correction factor is used (no subtraction of standard deviation from the mean attenuation for each frequency) the NRR(50), protection for 50% of the user population, can be calculated (Behar, 1985; Edwards and Green 1987).

ANSI S12.6-1984

The most recent ANSI standard that involves REAT procedures for the testing of HPDs is S12.6-1984, which defines the testing facility's physical requirements, listener requirements, and test procedures that laboratories should follow to achieve optimum attenuation results with well-informed and motivated listeners.

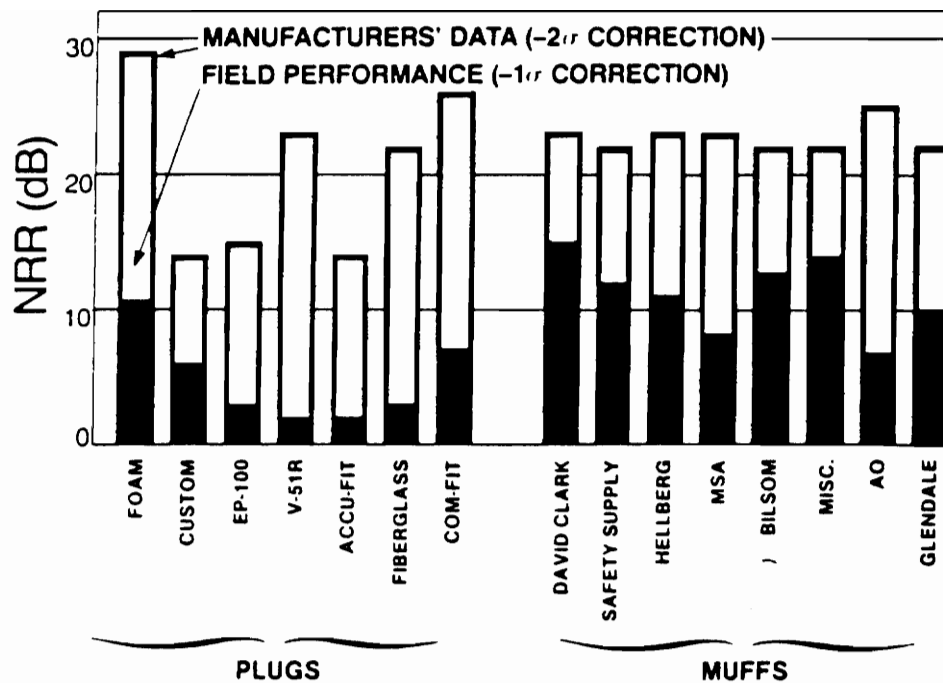


Figure 2. Labeled NRRs versus real-world performance
 NRR(84)) (Adapted from Berger, 1986).

This standard specifies that the test sounds be one-third octave bands of noise with center frequencies of 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. Other specifications of the standard include the ambient noise and reverberation time for the test booth and the electro-acoustic requirements for the noise generator, one-third octave band filter set, control circuits, and loudspeakers.

The requirements for listeners include hearing threshold levels, the variability of open threshold of audibility, and the ability to achieve a good fit with the protector. The standard also specifies that listeners be completely informed regarding the test situation and procedure, and that the experimenter supervise the fitting of the protector and instruct the listener according to the manufacturer's instructions (ANSI, 1984). After instruction and supervised fitting, the standard calls for the presentation of a fitting noise with overall sound pressure level of 60 to 70 dB at listener's position with reference to 20 micro Pa (ANSI, 1984). The listener is to manipulate the protector until satisfied that the noise is minimal. The experimenter then inspects the fit a final time to insure a good fit and acoustical seal.

Since the adoption of this standard, as well as its earlier counterpart, S3.19-1974, there has been growing concern about the differences of attenuation reported in the laboratory and those reported from the field. As stated in the standard, ANSI S12.6-1984 is intended to yield optimum attenuation results with informed listeners. However, there is a current effort (ANSI S12/WG11) to develop and promote a

consensus testing standard which would yield attenuation that is more representative of achievable field attenuation.

ANSI Working Group S12/WG11

ANSI standards are subject to revision every five years. In 1989, ANSI Working Group S12/WG11 began work to consider the development of a new standard, essentially providing a major revision of S12.6-1984. By the late eighties, there was considerable research literature (Behar, 1985; Berger, 1983b; Edwards and Green, 1987; and Pekkarinen, 1987) which indicated that laboratory attenuation results and the EPA attenuation ratings (NRRs) were significantly higher than the protection levels actually being achieved in the field.

Although the discrepancies between the field and laboratory attenuations are indisputable, the methods for reducing the discrepancies are still rigorously debated among hearing conduction researchers and practitioners (Berger, 1988). The improvement of in-field protection by increased education, better manufacturer's instructions, and improved management and motivation techniques is essential to decreasing the discrepancy between the field and laboratory data. At the same time, repeatable laboratory protocols need to be developed. These protocols must specify the testing conditions of instructions and fitting procedures, as well as other possible factors, to bring the attenuation results closer to the actual performance of the users in the workplace (Berger, 1988).

In their proposed study of 1989, ANSI S12/WG11 called for a comparison of an experimenter-supervised laboratory condition, called "Informed User Fit" (IUF) to a non-supervised, self-fitting condition, called "Subject Fit" (SF). The differences between the IUF condition (intended to represent fitting in the laboratory) and the SF condition (intended to represent typical fitting in the field) are discussed in more depth in the Experiment 1 section. Both the IUF and the SF conditions have undergone testing in previous studies (Berger, 1982a) which will be reviewed later.

The information presented in the Literature Review thus far has been intended to describe the terms, procedures, and standards used in HPD testing. The next sections will address studies that have been performed to evaluate attenuation in the field and in the laboratory. The field and laboratory studies involve different testing procedures and protocols for HPD testing. Key concerns are the experience level of subjects, training of subjects for HPD fitting, and the use of fitting noise.

Workmen's Compensation Study

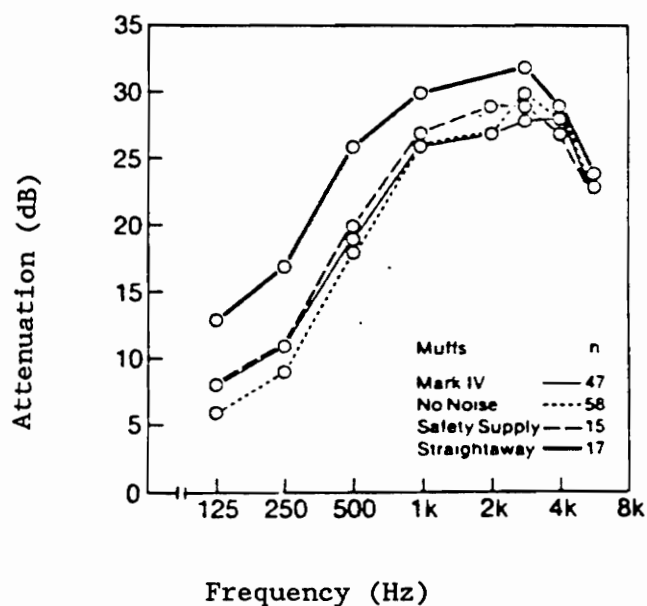
Abel, Alberti, and Riko (1982) reported a study to investigate attenuation provided by a variety of plugs and muffs when donned by workers without aid of experimenter instruction. The subjects were 347 workmen referred for assessment of noise-induced hearing loss (NIHL) by the Workmen's Compensation Board of Ontario. Most of these men were steelmakers or miners ranging in age from 35 to 65 years old.

In this study, each of the workers was asked to fit and wear his own hearing protectors as he would in the workplace. The test booth met the specification limits of ANSI S3.1-1977, "Ambient Noise During Audio Testing" (ANSI, 1977). Free-field hearing thresholds were determined by the method of limits for one test trial (one occluded and one unoccluded measure) for each of the narrow-band noises centered at 125, 250, 500, 1000, 2000, 3000, 4000, and 6000 Hz.

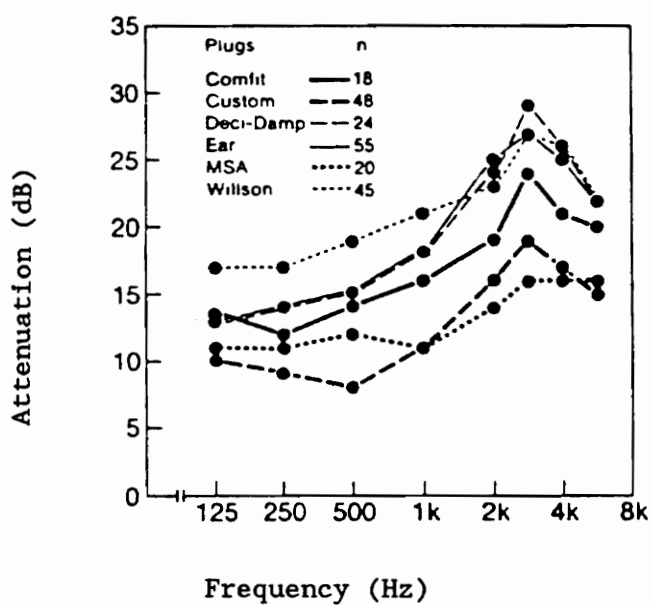
Figures 3a and 3b graphically show the mean attenuation scores obtained for each type of muff and plug, respectively. The four muffs gave poor low-frequency attenuation, but provided attenuation in the range of 20 to 30 dB for frequencies between 500 and 6000 Hz, which is considered good (Abel et al., 1982).

For the six types of plugs, the attenuation values were 12 to 20 dB on average, with fairly constant performance across the range of frequencies (Abel et al., 1982). The authors reported no significant difference in the variation of attenuation between plugs and muffs (Abel et al., 1982). The overall results of the study indicated poorer attenuation across all type of protectors than was indicated by the manufacturer's attenuation ratings.

In conclusion, the authors attributed the poorer attenuation values to both protector conditions and fitting factors. The effects of improperly sized devices, deformities from use, faulty seals, improper spring (headband) pressure, and missing sealing liners (for muffs) were some of the protector conditions listed. Because of the physical conditions of some of the protectors in the study, it was not possible



a - Muffs.



b - Plugs.

Figure 3a and 3b. Attenuation of HPDs from Workmen's Compensation Study (Adapted from Abel, Alberti, and Riko, 1982).

to directly attribute the lack of attenuation to poor fitting procedures alone, but improper fitting was also considered as an influencing factor.

This study is unique from the others because it is neither truly field testing nor laboratory testing. All of the workers in the study had filed for compensation for occupational NIHL; however, the number of workers that received compensation was not reported. Workers' hearing levels were not reported in the article, nor was the use of a standard procedure for testing the attenuation (such as ANSI S3.19-1974). The data provided by the study are pertinent to the current research, but due to large procedural differences, the results were not used for any comparisons to the results of this research.

Field Studies

Ontario Hydro study. This Canadian field study was reported by Behar (1985). This study involved 177 workers at three electric power generating plants of the Ontario Hydro Company. The purpose of the study was to measure attenuation and headband force (of muffs) of hearing protectors according to procedures similar to (but not exactly) ANSI S3.19-1974 (Behar, 1985). Only the attenuation results are pertinent to the current research, therefore the headband force results are not discussed here.

The manufacturer, device model, device type, plant site, and number of subjects that participated in the study are shown in Table 2.

TABLE 2

Protectors Tested in the Ontario Hydro Study

(Adapted from Behar, 1985)

Manufacturer	Model	Type	Site	Subjects
Siebe Norton	Decidamp	Plug	A	24
Peltor	H7P3E	Cap-mounted muff	A	36
E-A-R	E-A-R	Foam Plug	B	18
			C	24
Bilsom	Propp-O-Plast	Plug	B	23
			C	5
Willson	Sound Ban 20	Semi-aural	B	22
			C	10
AOCO	11776K	Cap-mounted muff	B	16
			C	10
Safeco	204	Muffs	C	9

Concerning the workers tested, 119 had used HPDs regularly for more than 2 years and 39 others had used HPDs for more than 1 year (together, 89% of all workers tested). Also, 67% of the workers had received some instruction from a nurse, supervisor, or other person.

The test signals consisted of pink noise filtered by one-third octaves centered at 250, 500, 1000, 2000, 4000, and 8000 Hz. The sound generating equipment met the S3.19-1974 standards for sound-field testing. An audiometric booth was located at each of the three sites. The background noise levels for the booths were above the limits specified in ANSI S3.19-1974 at 250 and 4000 Hz for all three booths, and at 500 and 2000 Hz for two of the three booths. Therefore, noise masking effects were a possible confounding influence in the results at these frequencies.

On the days of the tests, workers were asked to sit in a quiet area for 30 minutes prior to the test to minimize the possible effects of a temporary threshold shift in hearing levels. The workers were asked to don their HPDs in the test booth in the manner which they were accustomed to; no special instruction, fitting noise, nor other assistance was provided (Behar, 1985). New disposable plugs were provided at the test site and workers were allowed to use their own HPD if it was a muff, most of which were in good condition. If the workers wore eyeglasses, they were invited to do so in the testing (which allowed for further confounding of the results). One trial was conducted at the six frequencies for each of the workers.

The attenuation results and standard deviations are presented in Table 3. These results were compared to the manufacturers' laboratory results in graphical form by Behar. The single-rating NRR and NRR(50) results were compared to the manufacturers' NRR results in tabular form, shown in Table 4. The comparisons to the manufacturers' laboratory attenuation data for the E-A-R malleable foam plug, the Siebe Norton "Decidamp" plug and the Willson "Propp-O-Plast" plug are shown in three different graphs in Figures 4a, 4b, and 4c respectively.

No statistical analysis was performed on the data. Also, Behar (1985) warned that a straight comparison between the manufacturers' data and the field data should not be made without caution because the standard testing procedures were not identically followed, the ambient noise for the booths was above the standard limits, and only six of the nine required test frequencies were tested.

In conclusion, the field attenuation data and NRR values of the study are much lower than the manufacturers' data. However, no rigorous statistical analysis was conducted (and it may not have been reliable anyway because the standard protocol was relaxed in gathering the field data). The study does however present evidence that attenuation achieved in the laboratory is not being achieved in the field.

The low attenuation results and the workers' self-fitting of the protectors indicate that, most likely, the manufacturers' instructions were not being used or were not adequate to insure proper fitting. This is especially disturbing in the case of the new plugs, considering that 94 of the 177 worker wore plugs as their regular HPD in the study, 67%

TABLE 3

Mean Attenuation (Standard Deviations) of HPDs Tested in the Ontario Hydro Study

(Adapted from Behar, 1985)

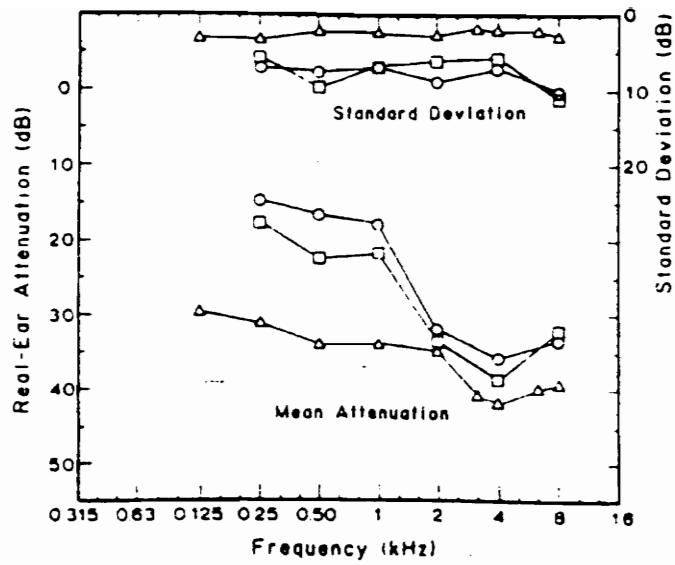
HPD	Site	Frequency (Hz)					
		250	500	1000	2000	4000	8000
Decidamp	A	16.9 (6.0)	20.0 (9.1)	22.5 (6.4)	30.2 (5.2)	38.8 (6.8)	33.3 (9.9)
H7P3E	A	6.9 (4.3)	19.2 (5.5)	29.3 (4.6)	27.4 (6.5)	26.2 (6.5)	20.5 (7.4)
E-A-R	B	14.7 (7.2)	16.5 (7.6)	17.7 (6.9)	31.9 (8.7)	35.8 (7.2)	33.4 (10.2)
	C	17.7 (5.7)	22.5 (9.5)	21.8 (6.8)	33.6 (6.2)	38.7 (5.8)	32.1 (11.1)
Propp-O-Plast	B	9.6 (4.7)	13.1 (5.1)	16.1 (6.3)	24.5 (6.5)	28.5 (7.1)	29.6 (7.2)
	C	10.5 (8.4)	8.5 (6.8)	14.0 (4.1)	26.5 (4.2)	25.0 (4.0)	27.5 (6.4)
Sound Ban	B	12.5 (8.0)	10.9 (7.0)	15.5 (5.9)	28.7 (8.7)	35.7 (11.3)	27.7 (12.6)
	C	11.2 (5.0)	15.2 (7.4)	17.0 (7.0)	30.5 (3.5)	37.3 (5.9)	27.3 (11.1)
1776K	B	11.4 (4.6)	16.7 (7.3)	25.7 (7.5)	28.9 (4.1)	26.2 (7.2)	17.2 (6.9)
	C	10.8 (4.6)	22.5 (5.5)	32.3 (3.6)	30.5 (5.1)	31.5 (6.5)	24.8 (7.4)
204	C	15.8 (4.4)	24.6 (3.7)	33.8 (4.5)	33.1 (3.0)	37.7 (6.3)	33.3 (6.0)

TABLE 4

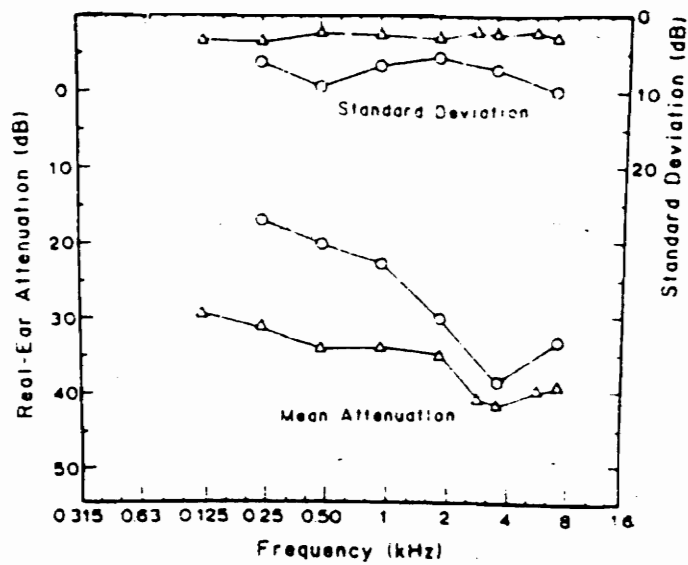
NRR Comparisons from the Ontario Hydro Study

(Adapted from Behar, 1985)

Protector	Type	Site	Manufacturer's NRR	Field NRR	NRR(50)
Decidamp	Plug	A	29	7	22
H7P3E	Cap-mounted muff	A	25	6	17
E-A-R	Plug	B	29	4	19
		C		7	23
Propp-O-Plast	Plug	B	22	4	16
		C		0	13
Sound Ban 20	Semi-aural	B	19	1	15
		C		3	17
11776K	Cap-mounted muff	B	21	5	18
		C		10	21
204	Muffs	C	22	17	26

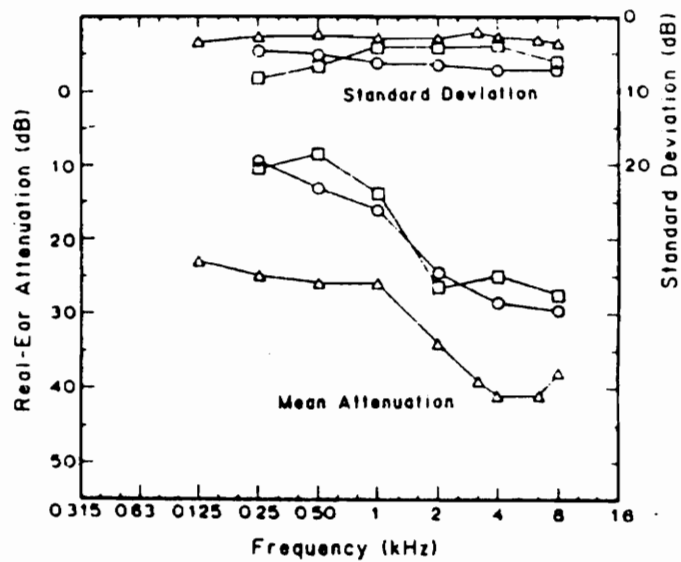


a - E-A-R plugs: (Δ) E-A-R manufacturer, ($\circ$) Site B, ($\square$) Site C.



b - Decidamp plugs: (Δ) Decidamp manufacturer, ($\circ$) Site A

Figure 4a and 4b. Attenuation and standard deviations of E-A-R and Decidamp plugs tested in the Ontario Hydro study (Adapted from Behar, 1985).



c - Propp-O-Plast plugs:
 (△) Propp-O-Plast manufacturer, (○) Site B
 (□) Site C

Figure 4c. Attenuation and standard deviations of Propp-O-Plast plugs tested in the Ontario Hydro study (Adapted from Behar, 1985).

of total workers reported having had some personal instruction, and 89% of the total workers had one year of experience or more.

NIOSH studies. Lempert and Edwards (1983) reported on NIOSH (National Institute for Occupational Safety and Health) field investigations conducted in 1977 and 1981 (NIOSH (1978) and Edwards, Broderson, Green, and Lempert (1982) presented full technical reports on the individual studies, respectively). The purpose of these studies was to determine the actual effectiveness of HPDs as they were worn in the workplace. Lempert and Edwards (1983) stated the following concerns: (1) Do earplugs, as worn at the workplace, differ in effectiveness due to their construction characteristics?, and (2) How well do manufacturers' (or distributors') attenuation ratings represent the earplugs' effectiveness when data are obtained under actual working conditions?

The studies involved a total of 15 industrial plants, with 28 workers tested per plant for a total of 420 workers. Six different types of plugs, shown in Figure 5, were tested in the investigations. The specific plugs that were tested in the different plants, and the number of workers who used each type of plug are shown in Table 5. The results of the E-A-R malleable foam plug and the V-51R multi-sized, pre-molded plug are discussed in more depth than the other results, because these plug types were used in this research.

The testing procedure closely followed ANSI S3.19-1974 except that earphones were used. An audiometric test van with two booths was used (both booths met the S3.19-1974 ambient noise limits). The signals were

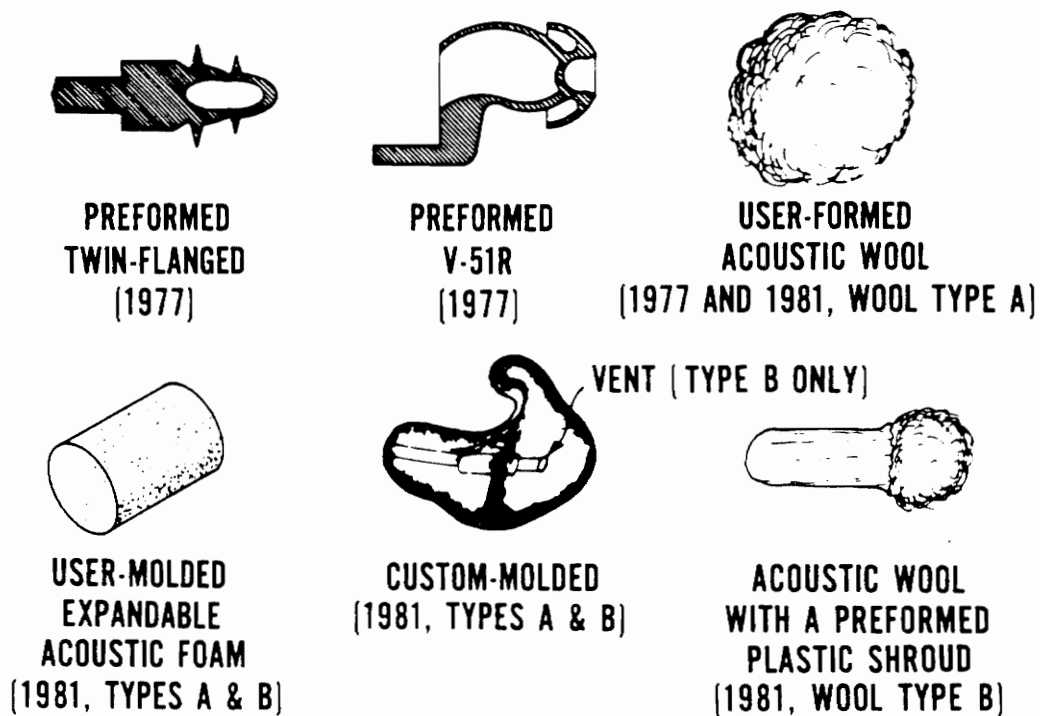


Figure 5. Earplug types evaluated in the NIOSH studies
(Adapted from Lempert and Edwards, 1983).

TABLE 5

Earplug Types and Number of Workers Tested for the NIOSH Studies

(Adapted from Lempert and Edwards, 1983)

Earplug Types	Plants	Workers
Pre-formed		
Twin flanged (sm. and reg. sizes)	1	28
V-51R (single flange, 5 sizes)	3	84
Acoustical Wool		
Type A (cotton-like, user formed)	2	56
Type B (cotton-like, plastic shroud)	1	28
Custom Molded		
Type A ¹ ₂	2	56
Type B ²	2	56
Acoustical foam		
Type A ₃ (expand. foam, user molded)	2	56
Type B ³	2	56
Total	15	420

¹Original impression in final mold²Final mold cast by manufacturer, vented³Identical to Type A except for color and user's instructions

presented binaurally through a special set of circumaural headphones designed for testing earplugs.

In the testing, each of the 28 workers was randomly selected five times over a five day period. The workers were taken directly from the workplace with the earplugs being inserted for at least 30 minutes prior to test time. There was no delay allowed for the workers to overcome the possible effects of a temporary threshold shift due to noise exposure, so attenuation could have been slightly overestimated (Lempert and Edwards, 1983). Only one trial was run for each of the five visits.

The attenuation and standard deviation results from the study and from the manufacturers' laboratory tests used for comparison are shown in Table 6. Only the last four testing visits of the field study were used for data calculation. The first visit for all subjects yielded results that were significantly higher than the other four visits, so the authors did not include those values for calculation.

Lempert and Edwards (1983) used a technique for "correcting" the data before comparisons were made based on pooling the data and applying an equation and correction factors based on research reported by Michael, Kerlin, Bienvenue, Prout, and Shampan (1976).

The laboratory (manufacturers') test results were obtained re ANSI S3.19-1974 with the exception of one type of plug, the twin-flanged plug, re ANSI Z24.22-1957. The results shown for the V-51R plugs are the average results provided by the two distributors of the plugs. Mean attenuation and standard deviation comparisons of the field data to the laboratory data for the V-51R plug are shown in Figure 6. Comparisons for the E-A-R foam plugs are similarly shown in Figure 7.

TABLE 6

Mean Attenuation and Standard Deviations from the NIOSH Studies

(Adapted from Lempert and Edwards, 1983)

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

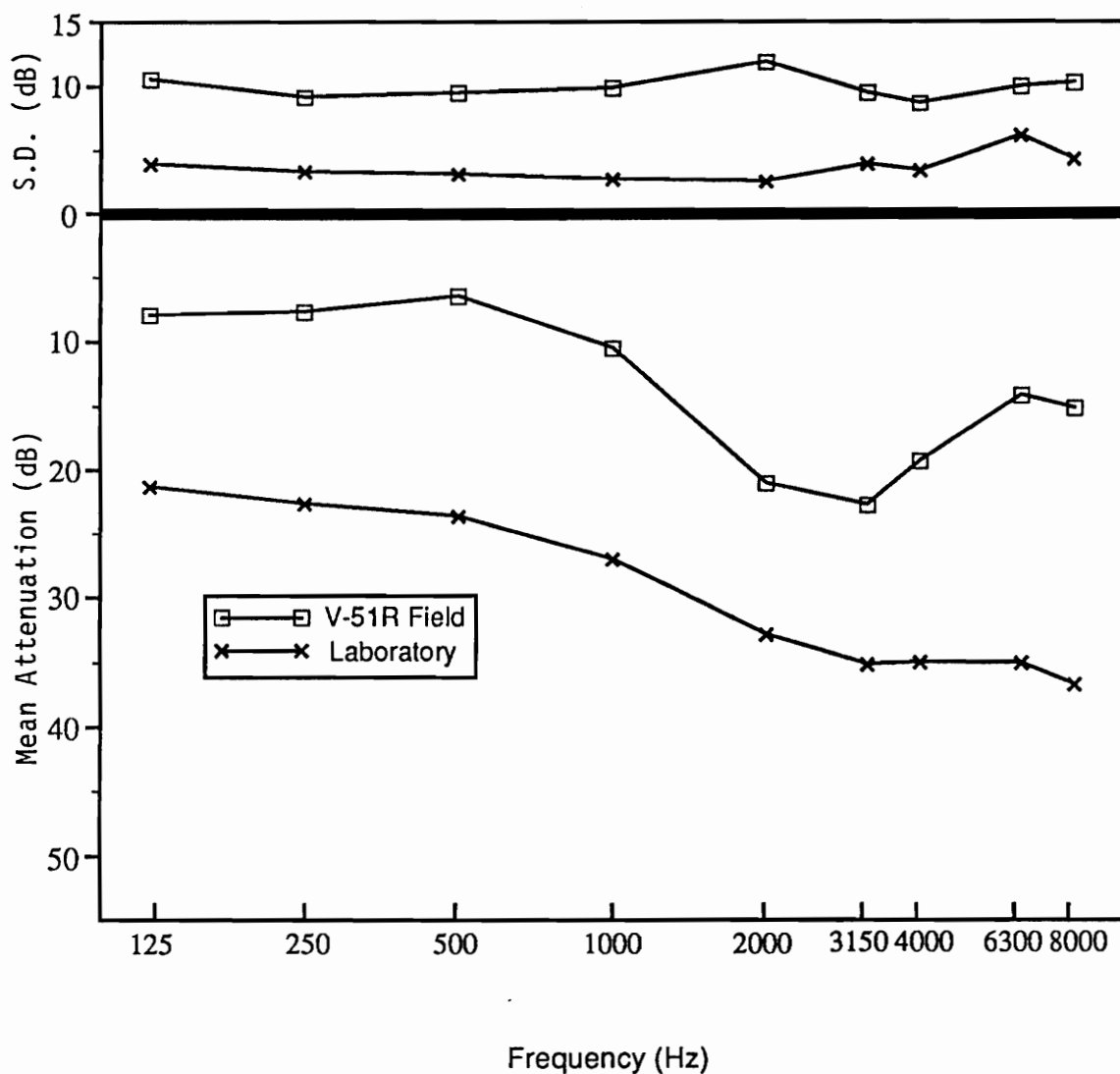


Figure 6. Mean attenuation and standard deviations for the V-51R plug from the NIOSH studies (Data adapted from Lempert and Edwards (1983) and re-plotted).

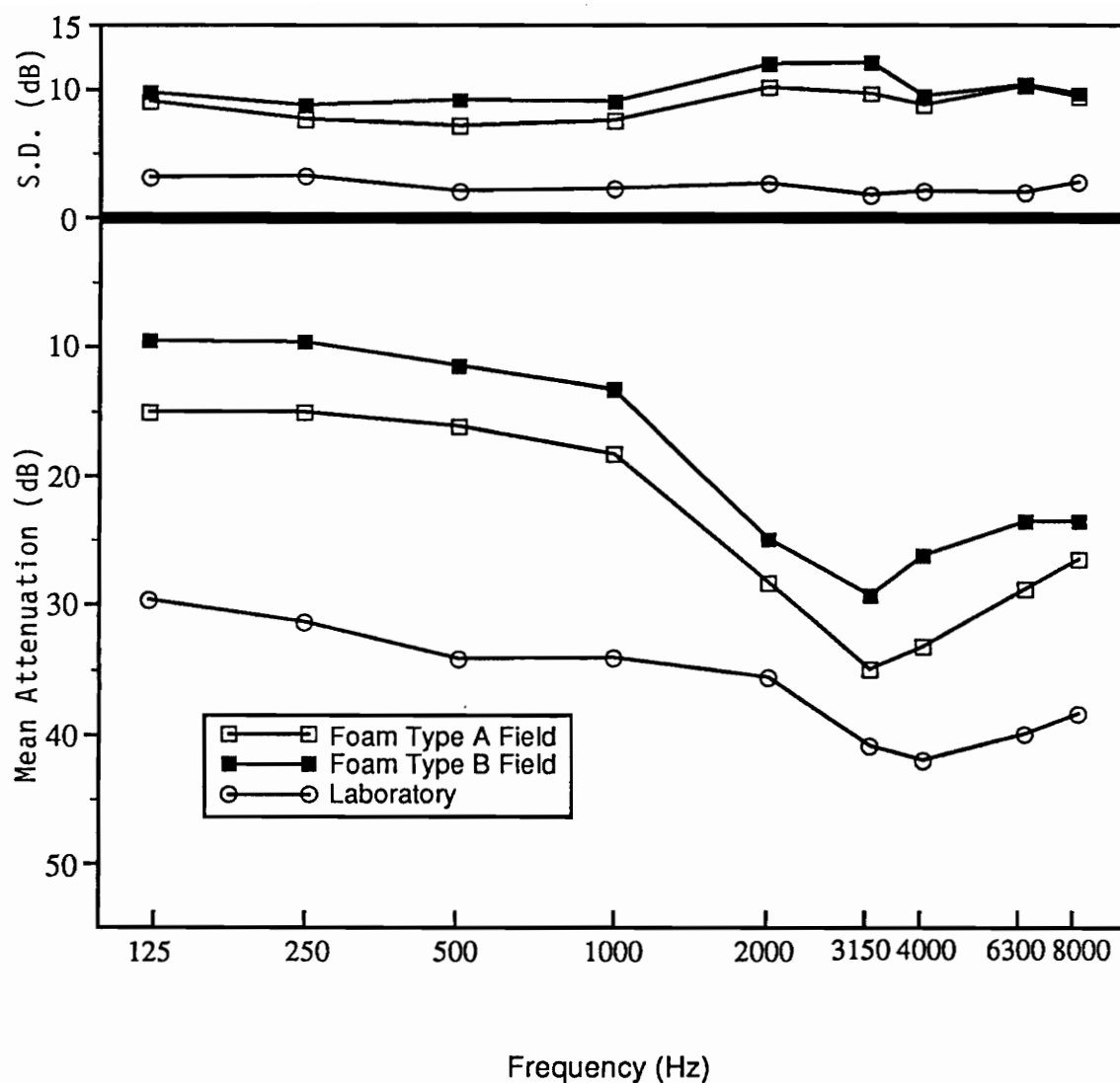


Figure 7. Mean attenuation and standard deviations for the E-A-R plugs (Types A and B) from the NIOSH studies (Data adapted from Lempert and Edwards (1983) and re-plotted).

Lempert and Edwards (1983) also made corrections to the attenuation data to derive a median A-weighted noise reduction factor for each test of each worker, with reference to Michael et al. (1976). These results were compared to laboratory medians that were estimated using the mean attenuation at each test frequency (Table 7). The authors demonstrated that the effectiveness of the various types of earplugs differed from one type to the next in the workplace. However, they never clearly showed that this difference was due to the design characteristics of the plugs. The effects of wearing time, motion, fitting, worker experience, proper HPD sizing, etc. could all possibly cause differences. Also, it was shown graphically that there were differences between field and laboratory attenuations at the nine test frequencies; but, there were no statistical inferences reported.

In their results, the author concluded that there may well be large differences between the laboratory attenuation values and the attenuation actually being achieved in the workplace for any given earplug design. (Lempert and Edwards, 1983). Overall, the authors conducted a well-controlled field experiment, but neglected to apply inferential statistical procedures to the data. There were no ANOVAs, correlations, or any other tests to provide statistical comparisons between the field data and the manufacturer's laboratory data.

TABLE 7

Median A-weighted Noise Reductions from the NIOSH Studies

(Adapted from Lempert and Edwards, 1983)

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

DuPont/NIOSH study. A follow-up study to the previous NIOSH investigations was reported by Edwards and Green (1987). This study involved the comparison of two DuPont plants' hearing conservation programs (HCPs) to four of the previously studied NIOSH plants in terms of noise attenuation.

The study was commissioned to answer three questions:

- (1) How well do DuPont employees wear their hearing protectors,
- (2) How do these results compare to those of previous studies, and
- (3) Is the hearing of DuPont employees being protected? (Edwards and Green, 1987, p. 56).

Twenty-eight employees at each plant were chosen to participate for a total of 56 workers. Only one plug type was tested, the E-A-R malleable foam plug. The experiment protocol replicated that of the previous NIOSH studies (Lempert and Edwards, 1983).

The attenuation results of each of the different plants are shown in Figure 8 and Table 8. A statistical analysis revealed that the data from DuPont Plants I and II were not significantly different so the authors pooled the data of the these two plants into one group (Edwards and Green, 1987). Based on similar analyses, the data from the four NIOSH plants were pooled into two groups of two plants each. The authors did not indicate the test statistic nor the p value. These pooled-data comparisons are shown in Figure 9 and Table 9.

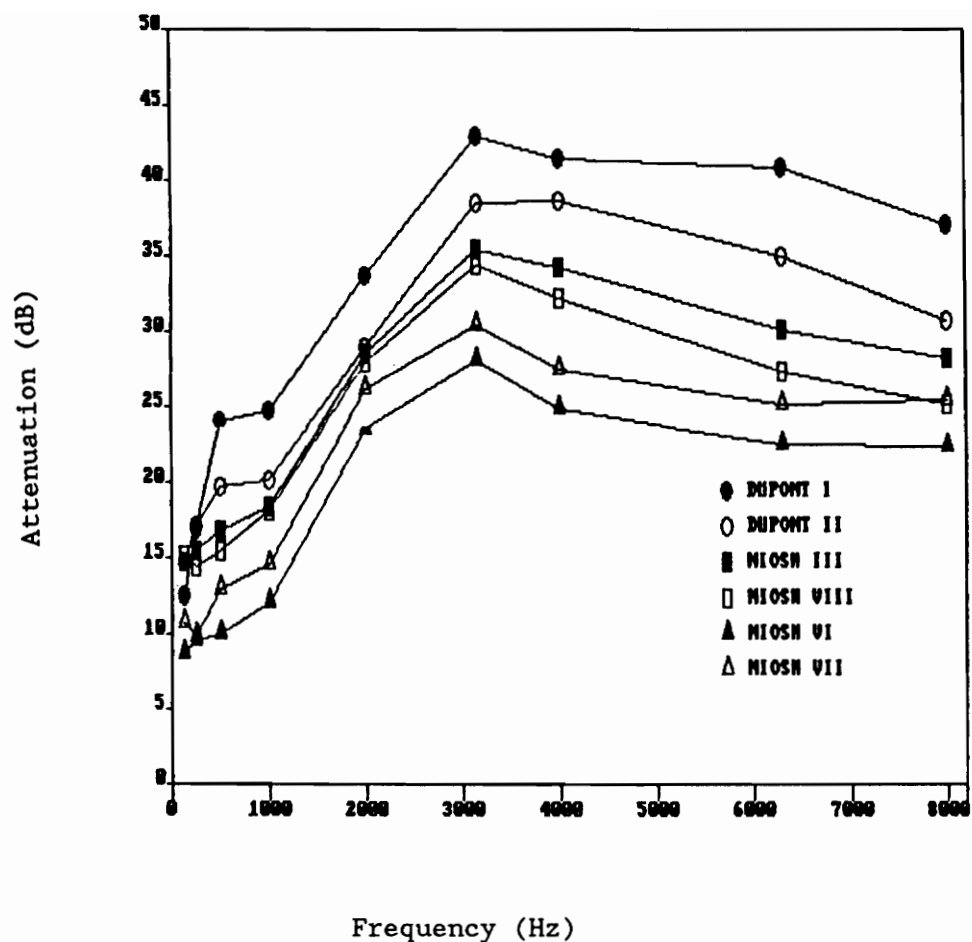


Figure 8. Attenuation comparisons for the E-A-R foam plug from the DuPont study (Adapted from Edwards and Green, 1987).

TABLE 8

**Mean Attenuation (Standard Deviations) with the E-A-R Foam Plug
from the DuPont Study**

(Adapted from Edwards and Green, 1987)

Plant	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
<u>DuPont</u>									
I	12.5 (7.5)	16.9 (8.3)	23.9 (8.0)	24.7 (7.6)	33.7 (7.7)	43.0 (7.9)	41.5 (7.6)	40.9 (7.1)	37.1 (7.8)
II	14.8 (8.8)	17.1 (8.0)	19.7 (8.0)	20.2 (8.7)	28.9 (8.8)	38.5 (9.3)	38.7 (8.5)	35.0 (9.1)	30.8 (9.1)
<u>NIOSH</u>									
III	14.7 (8.6)	15.6 (6.5)	16.7 (5.9)	18.4 (6.6)	28.5 (8.5)	35.4 (9.2)	34.4 (8.3)	30.2 (9.3)	27.9 (8.6)
VIII	15.2 (9.5)	14.4 (8.7)	15.4 (8.4)	18.1 (8.5)	28.1 (11.8)	34.4 (10.2)	32.1 (9.2)	27.4 (11.1)	25.2 (10.0)
VI	8.4 (9.8)	9.3 (9.3)	9.9 (8.9)	11.9 (9.1)	23.5 (12.8)	27.9 (12.1)	24.8 (9.3)	22.5 (10.4)	22.3 (9.9)
VII	10.6 (9.7)	9.8 (8.3)	13.0 (9.2)	14.7 (9.1)	26.3 (11.0)	30.8 (12.0)	27.6 (9.6)	24.5 (10.4)	24.8 (9.3)

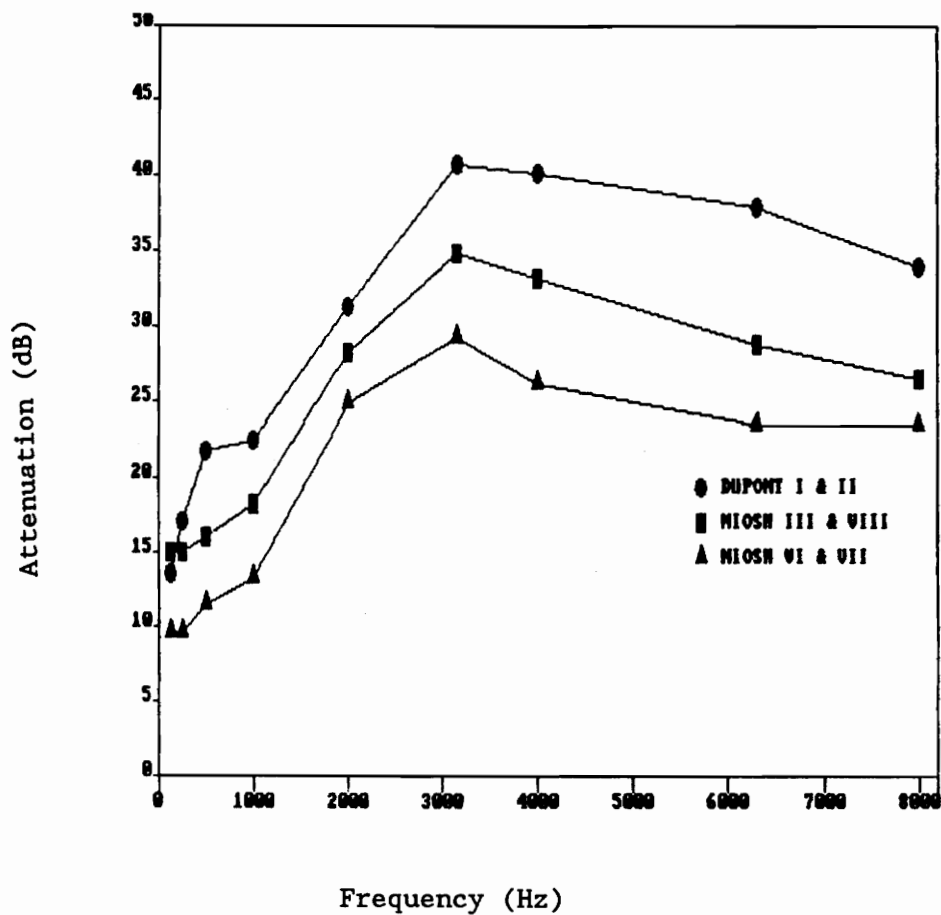


Figure 9. Attenuation results from pooled-data comparisons with the E-A-R foam plug from the DuPont study (Adapted from Edwards and Green, 1987).

TABLE 9

Mean Attenuation (Standard Deviations) of Pooled Data with the E-A-R Foam Plug from the DuPont Study

(Adapted from Edwards and Green, 1987)

Plant	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
<u>DuPont</u>									
I & II	13.6 (8.2)	17.0 (8.2)	21.8 (8.0)	22.5 (8.2)	31.3 (8.3)	40.7 (8.6)	40.1 (8.1)	38.0 (8.1)	34.0 (8.4)
<u>NIOSH</u>									
III & VIII	15.0 (9.1)	15.0 (7.7)	16.1 (7.2)	18.2 (7.6)	28.3 (10.2)	34.9 (9.7)	33.2 (8.8)	28.8 (10.3)	26.5 (9.4)
VI & VII	9.5 (9.8)	9.6 (8.8)	11.5 (9.2)	13.3 (9.1)	24.9 (12.0)	29.3 (12.1)	26.2 (9.5)	23.5 (10.4)	23.5 (9.7)

ANOVA of the pooled data revealed that the DuPont attenuations were significantly different [higher] ($p < 0.01$) from those of the NIOSH plants (Edwards and Green, 1987). The authors did not indicate how the data differed statistically by frequency. The single number attenuation ratings (i.e., the MAWR [mean A-weighted noise reduction], NRR(50), and NRR(84)) of all six plants are shown in Table 10.

This study demonstrated that the field attenuation data from plants with long standing HCPs (the DuPont HCPs were in existence before the Hearing Conservation Amendment of 1983) were significantly different [higher] from the results of plants that did not have HCPs (Edwards and Green, 1987). These results also indicated that training efforts to educate employees about the hazards of excessive noise exposure can indeed "pay off" in better protection of workers' hearing (Edwards and Green, 1987).

Non-REAT field studies. There have been other studies which have tested HPD attenuation with methods other than REAT (Chung, Hardie, and Gannon, 1983; Erlandsson, Hakanson, Ivarsson, and Nilsson, 1983; and Pekkarinen, 1987). Microphone dosimetry has been used by several experimenters to obtain field attenuation for earmuffs.

Dosimetry is a method of obtaining the time-weighted average noise dose for an individual. The instrument, an audiodosimeter, integrates a function of sound pressure over a period of time, and measures the fraction of the daily noise dose which can be compared to the exposure limits allowed by the OSHA regulations (Peterson, 1979). The field attenuation results of two dosimetry field studies warrant discussion,

TABLE 10

Mean A-Weighted Noise Reduction (MAWNR) and NRR Values for the E-A-R Foam Plug from the DuPont Study

(Adapted from Edwards and Green, 1987)

Plant	Decibels (dB)		
	MAWNR ¹	NRR(50) ²	NRR(84) ³
DuPont I	26.9	24.8	17.0
DuPont II	23.9	21.8	13.4
NIOSH III	21.9	19.8	13.1
NIOSH VIII	21.0	18.9	9.9
NIOSH VI	15.5	13.4	4.0
NIOSH VII	17.8	15.8	6.6

¹MAWNR: Calculated by reducing the A-weighted octave band sound levels by the amounts of mean attenuation provided by the earplugs at each of the corresponding center frequencies and then computing the reduction in the overall A-weighted level (Edwards and Green, 1987).

²NRR(50) = protection level theoretically achieved by 50% of user population.

³NRR(84) = protection level theoretically achieved by 84% of user population (often used as an estimate of field NRR).

but they were not directly comparable to the data obtained from the current research due to the large differences in measurement procedures.

Chung et al. (1983) performed a study using two modified Quest M-8 dosimeters. One dosimeter measured noise exposure outside of the earmuff by a microphone located on the outer surface of the earcup. The other dosimeter measured noise exposure inside the earmuff with a miniature microphone connected by a small (0.5 mm) wire that was reported not to degrade the seal of the muff. The difference in the exposure ratings between the two dosimeters was considered to be the attenuation of the muff. The 101 workers wore their personal muffs, some with missing or worn cushions, cracked cups, and weak headbands. User conditions ranged from wearing the muffs over hats, turbans, and long hair, or the use of helmet-mounted muffs.

The results of the study showed a mean attenuation of 20.3 dB for all muffs pooled together, and a standard deviation of 6.5 dB (Chung et al., 1983). The authors concluded that muffs were capable of providing workers with some attenuation but the adequacy of the protectors depended on the noise exposure levels. Chung et al. (1983) also stated that the hearing protectors' fit, maintenance, and headband tension were the most important factors in achieving good attenuation.

Pekkarinen (1987) conducted a dosimetry study to measure the ability of earmuffs to block out impulse noise. Mean attenuation results were reported for the impulse data of 21 industrial settings (measurements were taken on a total of 238 workers). The results of the study showed that earmuffs were effective in protecting workers' hearing against

steady-state noise as well as against impulse noise for 90% of the measurements taken in the study. The means of the equivalent noise levels were 93 dB outside the earmuffs and 76 dB inside them, with mean earmuff attenuation of 17 dB (Pekkarinen, 1987).

Laboratory Studies

The following studies were conducted in laboratories typical of those contracted to measure attenuation for manufacturer's reported attenuation levels. Certain of these laboratories (EARCAL and VPI & SU) have been reported to be in accordance with ANSI S3.19-1974 and/or ANSI S12.6-1984. (Berger and Wright, 1979; Casali, 1988).

E-A-R Division: study 1: 1982. In the EARCAL laboratory, Berger (1982a) compared mean attenuation data and standard deviations for three laboratory fitting conditions with the E-A-R malleable foam earplug. The three fitting conditions were (1) subject fit, SF, (2) experimenter fit, EF, and (3) experimenter-supervised fit, ESF.

The SF and EF conditions were tested in an experiment involving 65 subjects, of which 45% had never used a HPD, 28% had some experience using HPDs, but had never had any supervised instruction, and 28% had used HPDs regularly, mostly the E-A-R foam plug (Berger, 1982a).

The 65 subjects were tested with four test conditions, respectively named A, B, C, and D, always presented in alphabetical sequence (Table 11). The last three tests (B, C, and D) follow the testing sequence set forth in ANSI S3.19-1974; however, for this study only one instead of three measurements were taken for each fitting condition.

TABLE 11

Test Sequence and Description for E-A-R Division Study 1: 1982

(Adapted from Berger, 1982a)

Test	Sound Field on Headphone	Test Signal	Treatment
A	TDH-50/MX41-AR	Pure tones	Unoccluded
B	Diffuse	1/3 OB Noise	Unoccluded
C	Diffuse	1/3 OB Noise	Occluded--SF
D	Diffuse	1/3 OB Noise	Occluded--EF

For the SF treatment (Test C), the subjects were given detailed instructions, including drawings showing plug roll down and insertion, and were told to read the instructions carefully and insert the plugs however they thought correct. The experimenter offered no assistance nor comments about the fit prior to the test for the SF treatment. For the EF treatment (Test D), the experimenter rolled down and inserted the plug as he deemed correct (Berger, 1982a).

The data for the experimenter-supervised fit (ESF) condition, were obtained from a prior experiment which involved 10 standard-trained subjects. Each of these 10 subjects was tested three times each (three trials of occluded and unoccluded thresholds at each frequency). Berger (1982a) gave no definition or reference for the ESF condition. The resulting attenuation data and standard deviations for the three fitting conditions were plotted (Figure 10).

The SF condition yielded poorer attenuation below 2000 Hz than did the EF condition (Berger, 1982a). The mean attenuations of the EF condition and the ESF condition were similar between the two groups of subjects (i.e., 65 subjects and 10 standard-trained subjects); however, the standard deviations were lower for the attenuation of the standard-trained subjects (Berger, 1982a).

Comparisons within the group of 65 subjects were made to determine if the subjects who had regularly used HPDs had biased the attenuation results of the whole group. Comparisons of the data [individual subject data is assumed, i.e., not mean attenuation data] between the frequent users (18 in all) and the rest of the group revealed differences no greater than 1.5 dB (Berger, 1982a).

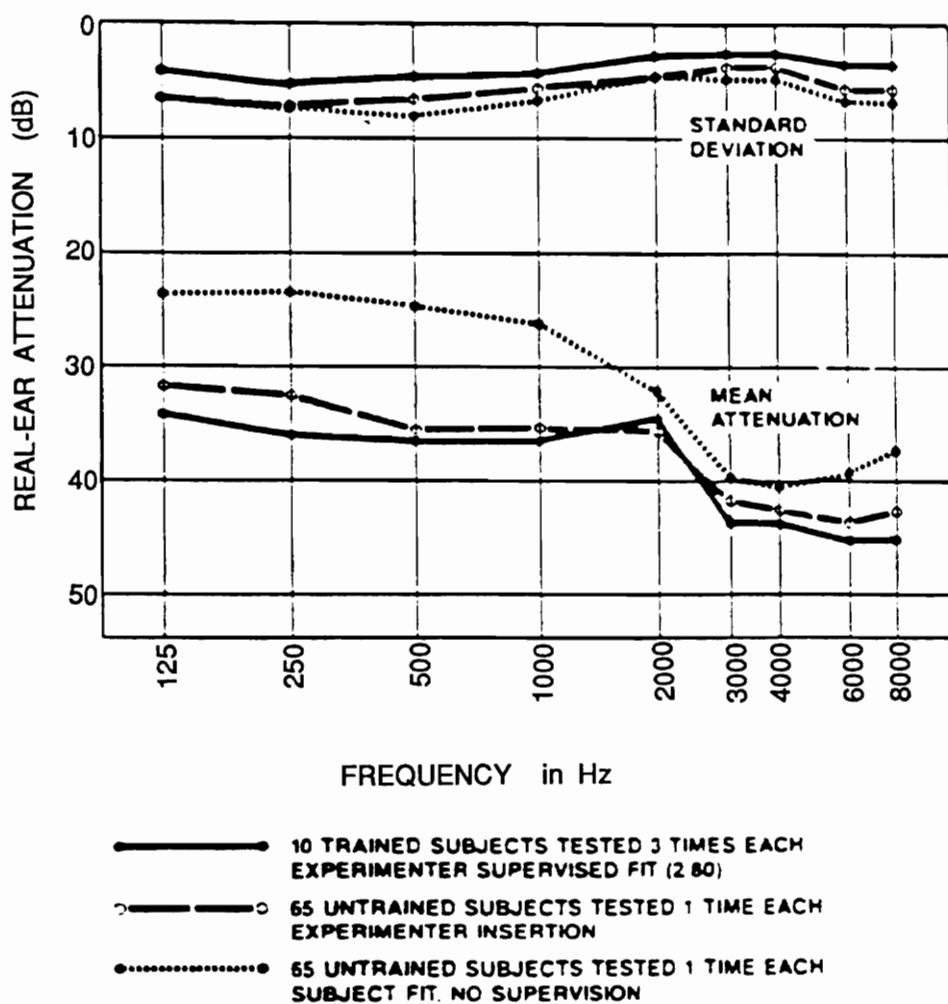


Figure 10. Attenuation data for E-A-R foam plug from E-A-R Division study 1: 1982 (Adapted from Berger, 1982a).

Overall, there were no statistical tests to show differences in the mean attenuations, and there was no discussion of the mean attenuation data at frequencies at or above 2000 Hz. Also, it is unclear why data were taken for 65 subjects tested for only one trial, (which was attributed to time limitations) when the data were to be compared to dependent data of 10 subjects tested at three trials. Fewer subjects tested at three trials might have taken less time, and also could have provided more statistically comparable results. The use of subjects that have multiple experience levels using the HPD being tested is a questionable practice for behavioral research if all of the subjects are going to be treated as if they were from the same population. In general, the study lacks rigorous statistical analysis of the results; however, it does indicate that untrained subjects participating in a SF condition achieve less mean attenuation than: (1) untrained subjects in an EF condition, and (2) trained subjects in an ESF condition.

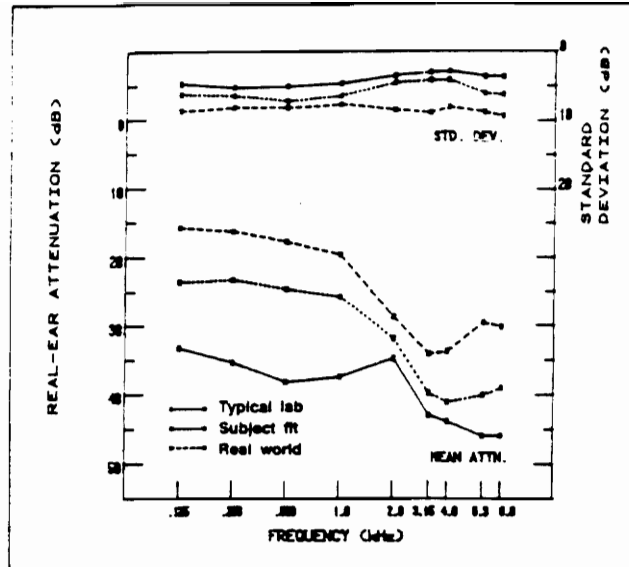
E-A-R Division: study 2: 1988. Berger, (1988) compared the attenuation achieved with a Subject Fit condition to field ("real world") attenuation data. The purpose of the study was to compare attenuation achieved in the laboratory with a SF condition to attenuation achieved in the field by a typical wearer who "makes a conscientious effort to properly use the device in a manner consistent with a reasonable degree of comfort" (Berger, 1988, p. 26).

Three HPDs were tested: (1) the E-A-R foam plug, (2) a pre-molded three-flanged earplug, and (3) a small-volume earmuff (with plastic headband and foam-filled cushions) (Berger, 1988). The subjects (60%

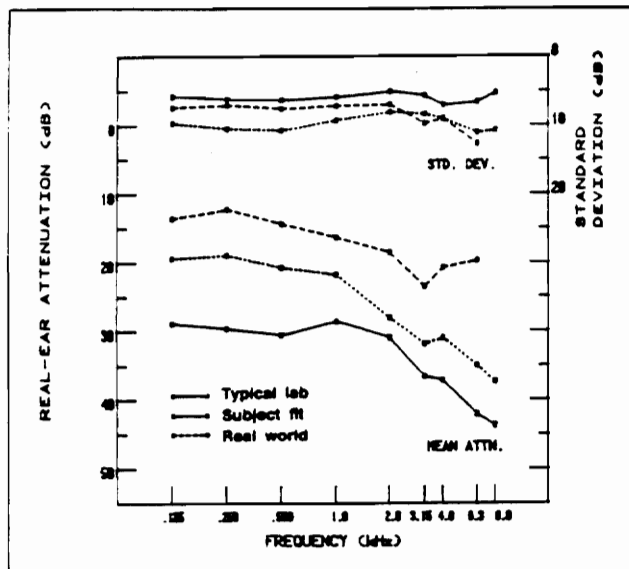
male, 40% female) entered the study with various levels of experience; however, Berger (1988) stated that the majority had not participated in previous HPD attenuation tests and that 50% or more had not worn HPDs prior to the experiment. Persons with hearing thresholds up to 50 dB at any frequency in either ear were accepted.

There were 100 subjects tested with the foam plug, and 50 subjects tested with each of the other two HPDs. The only instructions offered in this SF condition were the manufacturers' instructions. No fitting noise was offered unless specifically requested by the subject (Berger, 1988). The testing consisted of taking an audiogram followed by a single-trial REAT test in concordance with the electroacoustic requirements of ANSI S12.6-1984 (Berger, 1988).

The attenuation and standard deviation results of the SF condition were compared to typical laboratory data (gathered according to appropriate ANSI standards, i.e., ANSI S3.19-1974, or ANSI S12.6-1984) and to field data (gathered according to a variety of methods). The results indicated that the SF protocol yielded mean attenuation values that fell between typical laboratory means and the mean results achieved in industrial settings (Berger, 1988). These results are shown in Figures 11a, 11b, and 11c. In comparison to the three-flanged plug, the field data were obtained on a different type of plug, but of the same style (there were no field studies on the identical plug type) and the field data compared to the muff was actually data obtained from an assortment of muffs (Berger, 1988).

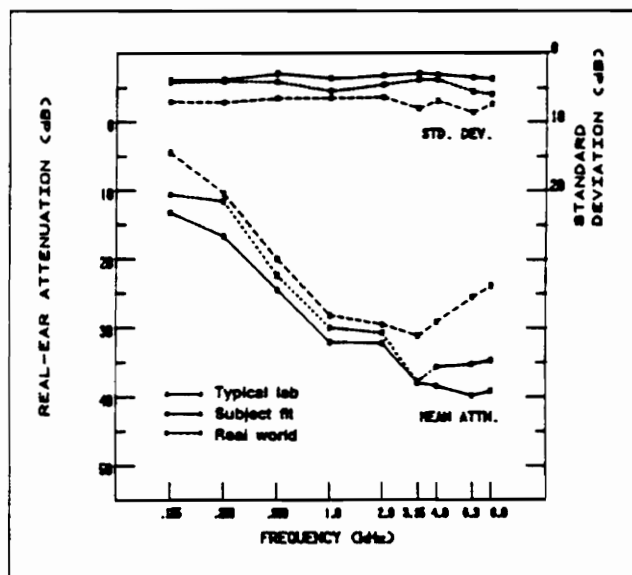


a— Comparison of three procedures for measuring the attenuation of foam earplugs. Typical lab data are an average of 18, 10-subject tests; subject fit included 100 subjects; average real world included 10 studies with 402 subjects.



b— Comparison of three procedures for measuring the attenuation of a premolded earplug. Typical lab data are an average of three, 10-subject tests; subject fit included 50 subjects; average real world is one, 18-subject study.

Figure 11a and 11b. Comparisons between different testing protocols from E-A-R Division study 2: 1988 (Adapted from Berger, 1988).



C - Comparison of three procedures for measuring the attenuation of an earmuff. Typical lab data are an average of three, 10-subject tests; subject fit included 50 subjects; average real world included seven studies with 319 subjects.

Figure 11c. Comparisons between different testing protocols from E-A-R Division study 2: 1988 (Adapted from Berger, 1988).

The results of the study indicate that use of a SF protocol in the laboratory can provide more realistic estimates of attenuation being achieved in the field (Berger, 1988). A characteristic of the SF data is higher within-test variability than that of other laboratory results (such as those obtained in EF conditions). No statistical comparisons of the mean attenuations were performed for the three test conditions.

E-A-R Division: study 3, fitting noise: 1981 and 1983. Berger (1981 and 1983a) reported results of a single study that was designed to test the effects of plug size differences, size selection of multi-sized pre-molded plugs, and wearing time on plug seal. Included in the results were the findings from an investigation on fitting noise.

Berger tested attenuation across 125, 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz of 10 subjects with the V-51R plug for the SF condition according to ANSI S3.19-1974. Under the heading, Instructions to Listeners, the standard gives the following requirement: "Listeners shall be completely informed regarding the test situation and procedure" (ANSI, 1974, p. 4). A broadband noise, 60 to 70 dB re: 20 micro Pa, is required to be presented to the listener while he/she is fitting the HPD (ANSI, 1974). In this study, tests were conducted both with and without the fitting noise to determine the effect that the noise might have on attenuation (Figure 12).

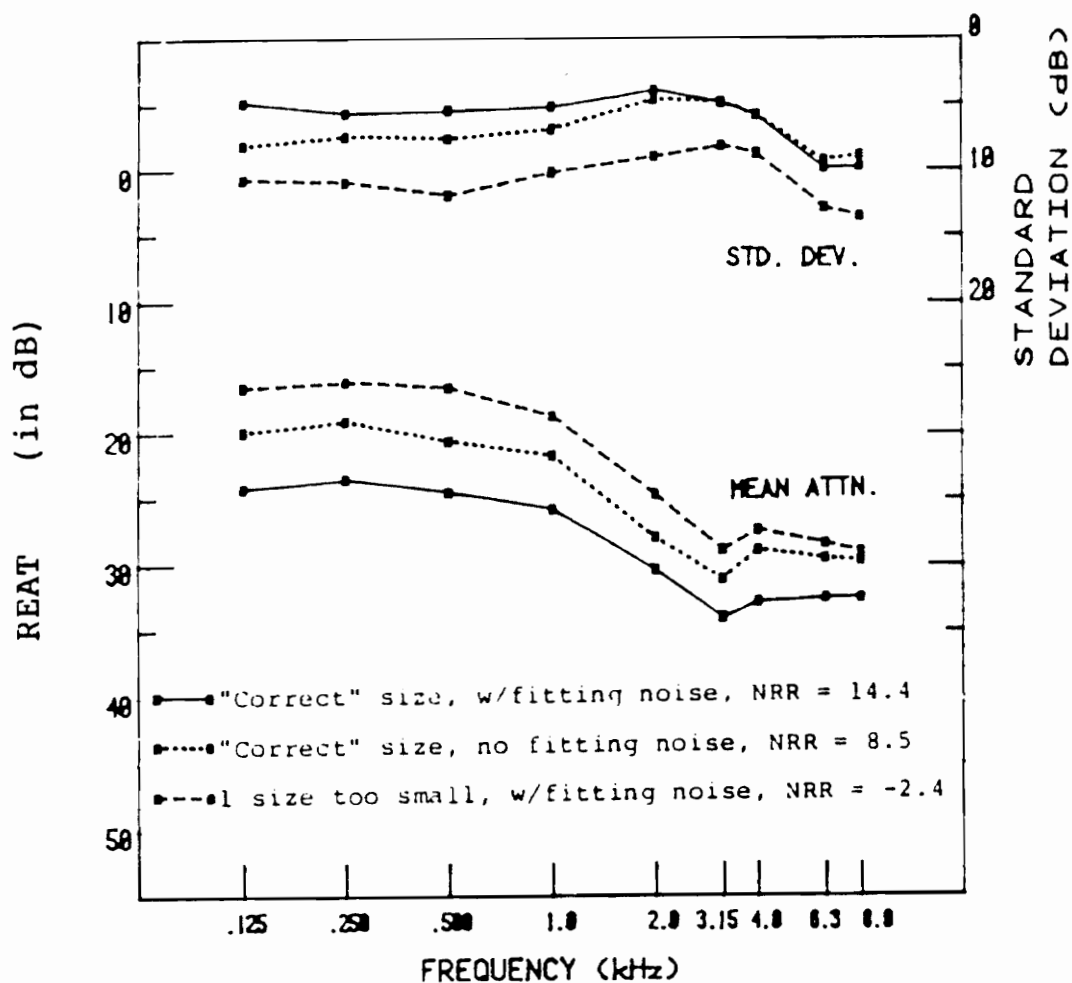


Figure 12. Effects of fitting noise on attenuation for the V-51R plug from E-A-R Division study 3: 1981 and 1983 (Adapted from Berger, 1983a).

Concerning the results of testing with and without fitting noise, Berger stated:

Although the variances are not significantly different (the criterion for all the statistical tests was $p < 0.05$) based on an F -test, the means are significantly different (t -test, 58 df) at all frequencies except 6 and 8 kHz. Examination of individual subject data revealed that three of the ten subjects had more trouble getting a good fit without the noise, whereas the results for the other seven were unaffected. The NRR was reduced from 14.4 to 8.5. (Berger, 1981, p. 148).

Concerning the analysis of the results, the ANOVA procedure (which uses the F -test to determine if significant differences exist between treatment means) is a more conservative and probably more appropriate test on which to base the conclusions of the results. It is presumed that the F -test used by Berger was the ANOVA. Due to the within-subjects (repeated-measures) design, the analysis relies on the robustness of the ANOVA procedure.

The proper t -test to use with a repeated-measures design (also called a correlated-samples design) takes into account the correlation between the two sets of outcomes and involves the analysis of the differences of paired scores (i.e., each subject's scores should be paired, because they are not independent samples) (Spatz and Johnson,

1976). Based on the $df = 58$, it appears that the t -test used did not involve paired scores. Therefore, it is possible that the t -test results are misleading, at least for the 0.05 alpha level (differences may have been picked up by the test, but the significance level is questionable). [Further discussion of using the t -test with repeated-measures designs can be found in Spatz and Johnson (1976).] Thus, the overall conclusion from this study should be that the fitting noise was not significant at $p > 0.05$ based on the ANOVA procedure.

Furthermore, Berger did not indicate what methods (subjective, objective, or others) were used to examine the individual data to determine that "three of the ten subjects had more trouble getting a good fit without the noise" (Berger, 1981, p. 148).

No instructions for the use of the fitting noise were indicated by Berger in the article. The only instructions specifically for fitting noise stated in ANSI S3.19-1974 are under the heading, Subject Fit; these instructions are: "The listener shall be instructed to manipulate the hearing protector until satisfied that the noise is minimal" (ANSI, 1974, p. 5).

VPI and SU: study 1: 1986. Casali and Epps (1986) performed an experiment to examine the effects of five different techniques of fitting instructions on the attenuation achieved with five common universal-fit earplugs. The two primary objectives of this experiment were to determine: (1) which instructional technique resulted in the highest noise attenuation across different test frequencies and for each earplug, and (2) which earplug designs, if any, were most resilient to

instruction differences (Casali and Epps, 1986).

Fifty paid volunteer subjects (25 males, 25 females) were randomly selected to participate in the experiment. All subjects were novices (i.e., no prior experiences with earplugs) and were screened for the study based on their audiometric data and absence of any hearing and ear disorders. The subjects were assigned to five ordinal hearing-level groups, (10 subjects per group; 5 males, 5 females) based on their overall hearing levels.

The equipment used in the experiment consisted of an audiometric test booth with single loudspeaker system and a Beltone Model 114 Pure-Tone Audiometer. All of the equipment met the requirements of ANSI Z24.22-1957, which specifies pulsed pure-tone test stimuli to be presented at 125, 250, 500, 1000, 2000, 4000, and 8000 Hz frequencies.

The instruction techniques were tested as a between-subjects variable, with five levels, 10 subjects per level. These five techniques were: (1) no instruction, (2) no instruction with auditory feedback (i.e., fitting noise) [subjects were told to adjust plug to attain the best noise blocking possible], (3) manufacturer's package instructions, (4) detailed instructions (typed instructions and pictures of a model fitting the plug), and (5) model instruction (verbal instructions and demonstration of fitting the device) (Casali and Epps, 1986).

The earplugs were tested as a within-subject variable. Each of the five levels were presented to each of the 50 subjects (counterbalancing was done to minimize learning effects). The five earplug types tested

were: (1) Flent's Wax Cotton (user-molded plug made of wax-impregnated cotton, NRR = 25 dB), (2) Willson EP-100 Sound Silencer (pre-molded, twin-flange rubber plug, NRR = 26 dB), (3) E-A-R foam plug (user-formed cylindrical plug made of expandable foam, NRR = 29 dB), (4) Bilsom Propp-O-Plast (POP) (plug made of fibrous material (down) surrounded by thin plastic, NRR = 20), and (5) Tasco RD-1 Safety Cone (pre-molded, single-flange, plastic plug, NRR = 24 dB) (Casali and Epps, 1986; Epps, 1984).

An extensive analysis of results was conducted for the experiment, but only the results pertinent to this research are discussed. The Earplug-by-Instruction interaction on noise attenuation was highly significant, ($p < 0.001$), demonstrating that the type of instruction strategy used prior to plug insertion affected the level of noise attenuation achieved with different plugs. In general, the model instruction technique provided the highest mean attenuation collapsed across all plugs, and the no instruction technique provided the lowest mean attenuation collapsed across all plugs. The expandable foam plug was the most sensitive to the various levels of insertion instruction (Casali and Epps, 1986).

The insertion-instruction factor exhibited a significant main effect ($p < 0.001$), and post hoc analysis demonstrated that instruction by model was superior to auditory feedback, manufacturer's package, and no instructions ($p < 0.05$) (Casali and Epps, 1986). Detailed, feedback, and manufacturers' package instructions did not produce statistically different results from each other; however, each of them gave

significantly better attenuation results than no instructions (Casali and Epps, 1986).

Overall, the results indicated that auditory feedback (fitting noise) can be as effective as manufacturer's instructions and detailed instructions for some plugs. On average across the five earplugs, both auditory feedback and manufacturers' instructions did significantly improve attenuation over the no instruction condition by approximately 6 to 7 dB (Casali and Epps, 1986).

All of the instruction techniques, and even different combinations of them, were considered feasible for the industrial setting by the authors. Casali and Epps (1986) also stated that the auditory feedback condition might be considered to simulate a field condition where workers don earplugs in ambient noise.

Questions arise as to whether a condition of combined auditory feedback with manufacturers' instructions would yield higher attenuation results than either of the two conditions alone, even for novice subjects. This is an important issue that the current research investigated.

VPI and SU: study 2: 1986. Casali and Lam (1986) performed a sister study to that performed by Casali and Epps (1986). The effects of instruction technique, HPD type (earmuffs or earcaps), and pure-tone test frequency were tested. The instruction techniques were identical to the earplug study (i.e., no instruction, no instruction with auditory feedback, manufacturers', detailed, and modeled instruction) but they were specifically for the earmuffs and earcaps, not earplugs. The four

muff styles and two earcap styles tested were selected to represent a broad sample of HPDs which differed in style and construction, so that the interaction of different types of HPDs and instructions could be assessed (Casali and Lam, 1986).

The testing methodologies and laboratory conditions were almost identical to those described in the Casali and Epps (1986) study. Only the results pertinent to the current research are discussed because the HPD types tested (caps and muffs) do not directly affect this research.

From the overall ANOVA, the main effects of instruction, HPD type, and test frequency were found to significantly influence attenuation ($p < 0.001$) as was the HPD-by-Frequency effect (Casali and Lam, 1986). The authors concluded that HPD (in this study, earmuffs/earcaps) attenuation could be improved with proper instructions over that obtained with no instructions at all (Casali and Lam, 1986). There were no large differences among the attenuation values achieved with auditory feedback, manufacturer's, detailed, and modeled instructions. However, fitting noise was again shown to significantly affect the attenuation results, yielding higher attenuation than no instructions at all.

Summary of Reviewed Research on Field and Laboratory Studies

All of the studies reviewed have been described and scrutinized with specific detail given to the procedures and testing apparatus used. The purpose for such detail has been to make the reader aware of the varying techniques and procedures that experimenters have followed in testing HPDs. The standards which define HPD testing procedures are subject to

review change. This is currently the case with ANSI S12.6-1984.

It should be clearly understood that only a few field studies have been conducted with close adherence to the established standards for testing HPDs. A matrix of major aspects of each field study reviewed is shown in Appendix A. Because of the differences in the field testing procedures used, many of the data obtained cannot be used for determining a baseline of actual field attenuation. It should also be clearly understood that the workplace poses many factors which can influence and affect attenuation.

In essence, it may be more appropriate to consider the achievable field attenuation as a range of attenuation for different HPD types rather than as a set baseline. This range should be expected to vary between HPD types just as the laboratory attenuation varies. Attenuation is also expected to vary between industrial settings because of differences in environment, type of work, HCP effectiveness, user motivation, and other factors. The results of the DuPont and NIOSH studies (Edwards and Green, 1987) revealed significant differences in field attenuation data at different plant sites as obtained by accurate and reproducible procedures for the same plug type (E-A-R foam plug).

Field attenuation should also be expected to change throughout time as HCPs gain acceptance, new technologies are incorporated in the design of HPDs, new instruction techniques are implemented, and as the workforce changes. These are important considerations for the future of HPD testing and HCP development.

In the design of laboratory protocols to estimate field attenuation, it is necessary to consider the effects of variables that may influence the users in the field. Two prominent variables are experience level of listeners and the presence of fitting noise. In general, there has been a lack of research for determining the effects of fitting noise on HPD fitting and achieved attenuation. The aims of the current research were to include an investigation which would provide information concerning experience level effects and fitting noise.

Furthermore, a statistical analysis technique for determining if laboratory protocols yield data that are valid estimates of the actual field data needs to be developed. Graphical comparisons of mean attenuation results lack the power and confidence level needed to validate whether or not the laboratory results model the field results.

RESEARCH OBJECTIVES

The objectives of this research, in addition to providing ANSI S12/WG11 with valuable data for their pilot study, were the following:

1. Determine the effects of fitting noise on attenuation results of both novice and experienced subjects when consciously used as an aid in HPD fitting for both Subject Fit (SF) and Informed User Fit (IUF) conditions (as investigated in Experiment 2). It was hypothesized that the presentation of fitting noise and instructions for its proper use would result in significantly higher (better) attenuation than that achieved without the fitting noise.
2. Determine if differences occur between: (1) testing the fitting conditions (Subject Fit and Informed User Fit) and experience levels (Novice and Experienced) as within-subjects factors as in the ANSI protocol (Experiment 1), and (2) testing the fitting conditions and experience levels as between-subjects factors (Experiment 2) as appears more appropriate from an experimental design, independent observations standpoint. It was hypothesized that there would be detectable differences in the attenuation results between the two experiments because of the differences in their experimental designs. Specifically, differences were expected to occur between the IUF, Novice

conditions of the two experiments in that the IUF, Novice subjects of Experiment 1 were anticipated to achieve higher (better) mean attenuation because of their prior experience with the earplugs in the SF, Novice condition. Also, the experienced subjects of Experiment 2 were anticipated to achieve higher mean attenuation than the experienced subjects of Experiment 1 (this issue was also addressed in Research Objective 3).

3. Determine if differences occur between the attenuation results of (1) transfer-to-experienced subjects (subjects who enter the study as novices but are considered experienced in the latter part of the experiment, as in Experiment 1), and (2) enter-as-experienced subjects (subjects who enter the study with experience of correct HPD use, as in Experiment 2). This has important implications for subject selection purposes in HPD testing. Some laboratories have difficulty keeping subjects in their subject pool as experienced listeners (such as with students), while other laboratories have difficulty finding naive subjects. It was hypothesized that the transfer-to-experienced subjects would achieve significantly different attenuation than the enter-as-experienced subjects for both SF and IUF conditions.
4. Compare the attenuation results of Experiment 1 and Experiment 2 to appropriate HPD field attenuation data and evaluate the

statistical and practical differences between the laboratory attenuation and the field attenuation. It was hypothesized that the attenuation results from the SF, Novice laboratory conditions would not be significantly different from the field attenuation results of the previously conducted studies.

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METHOD

Background

This research involved two distinct experiments with different experimental designs. The first experiment, Experiment 1, was developed largely by ANSI S12/WG11, the working group for the revision of ANSI S12.6-1984, of which the thesis co-chairman, Dr. Casali, was a member, and the author was an associate. Specifically, Experiment 1 was the pilot study for a larger experiment that ANSI S12/WG11 planned to conduct.

The experimental design, developed by ANSI S12/WG11, was expected to yield confounded results due to learning effects from the repeated measures that were taken on the same subjects, and because the fitting noise was not considered a factor in the design (the design was confounded by the presentation of fitting noise in the IUF conditions but not in the SF conditions). ANSI S12/WG11 presumed that subjects would not benefit from the fitting noise in the SF condition; however, this caused the experimental design to be unbalanced. It should be noted that not all ANSI S12/WG11 committee members (e.g., Dr. Casali) agreed with this protocol, but that it was adopted through consensus of the committee.

Experiment 2 was developed by the experimenters of the Auditory Systems Laboratory and by Dr. Dennis Price, all of VPI and SU. The experimental design of Experiment 2 was developed to avoid the learning effects and confounding that were expected to have influenced the

results of Experiment 1. The effects of fitting noise were also investigated in a factorial design, for both the SF and the IUF conditions in Experiment 2.

Experimental Conditions

Apparatus. Both of the experiments were conducted in the Auditory Systems Laboratory at VPI and SU. The facility was in full accordance with ANSI S12.6-1984 as electroacoustically verified by Casali (1988). The HPD test facility included a test chamber (anechoic chamber), an IBM Personal System (PS)/2 Model 70 computer system with VGA color display, hard drive, and two floppy disk drives, and a Norwegian Electronics integrated HPD test signal presentation and measurement system.

The chamber used for the attenuation measurements was an Eckel Corporation anechoic chamber with 150 Hz low-frequency cutoff. Within the chamber, a near-diffuse sound field was generated using four frequency response-matched loudspeakers. These loudspeakers (three mounted on floor tripods, one mounted in the ceiling) were located in the corners of an imaginary tetrahedron which surrounded the position of the subject's head. The sound field met the requirements of ANSI S12.6-1984 for HPD REAT testing, as empirically verified by Casali (1988). The ambient noise levels of the anechoic chamber and the maximum permissible ANSI S12.6-1984 levels are shown in Table 12. A two-way communications system incorporating an intercom was used to allow for instant communication between the experimenter, located outside the chamber, and the subject, located inside the chamber.

TABLE 12

Ambient Noise Levels in VPI and SU Test Chamber

(Adapted from Casali, 1988)

OB ¹ Center (Hz)	Permissible Ambient OB Level, dB ²	Measured Ambient OB Level, dB	Permissible Minus Measured OB Level, dB
125	28	23.3	4.7
250	18	5.5	12.5
500	14	5.7	8.3
1000	14	7.5	6.5
2000	8	5.6	2.4
4000	9	7.3	1.7
8000	20	9.3	10.7

¹OB = Octave Band²As per Table I, ANSI S12.6-1984.

Also, a closed-circuit television (CCTV) system was used for visual monitoring of the subject during testing.

The HPD test system was a fully integrated, IBM PS/2 (Model 70)-controlled Norwegian Electronics Type 828 system. This system included test signal generation, amplification and control apparatus, and four frequency response-matched loudspeakers (model TEP S-2). The block diagram for the system is shown in Figure 13. The system was used in the automatic Békésy (Békésy, 1960) mode. In this mode, the subject controlled the signal attenuation by pressing a button on a silent hand switch for the duration that the signal was heard, which in response caused the signal level to decrease at a predetermined rate. The subject then released the button when the signal was not heard, which in turn caused the signal level to increase at the same predetermined rate.

The Békésy method of limits used for tracking the threshold of audibility had an attenuator rate of 5 dB/sec in 1 dB steps. The threshold tests were conducted for one-third octave noise centered at 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz and pulsed on and off at a rate of 2 Hz. The computer was operated with a program which continuously sampled a trace to determine if it met ANSI S12.6-1984 criteria for an acceptable trial. The criteria was stated in Section 3.3.1.4 of ANSI S12.6-1984 as the following:

The audiogram produced by an automatic recording audiometer shall be scored as follows:

- (1) A trace is considered of doubtful reliability and shall be repeated if, ignoring the first reversal

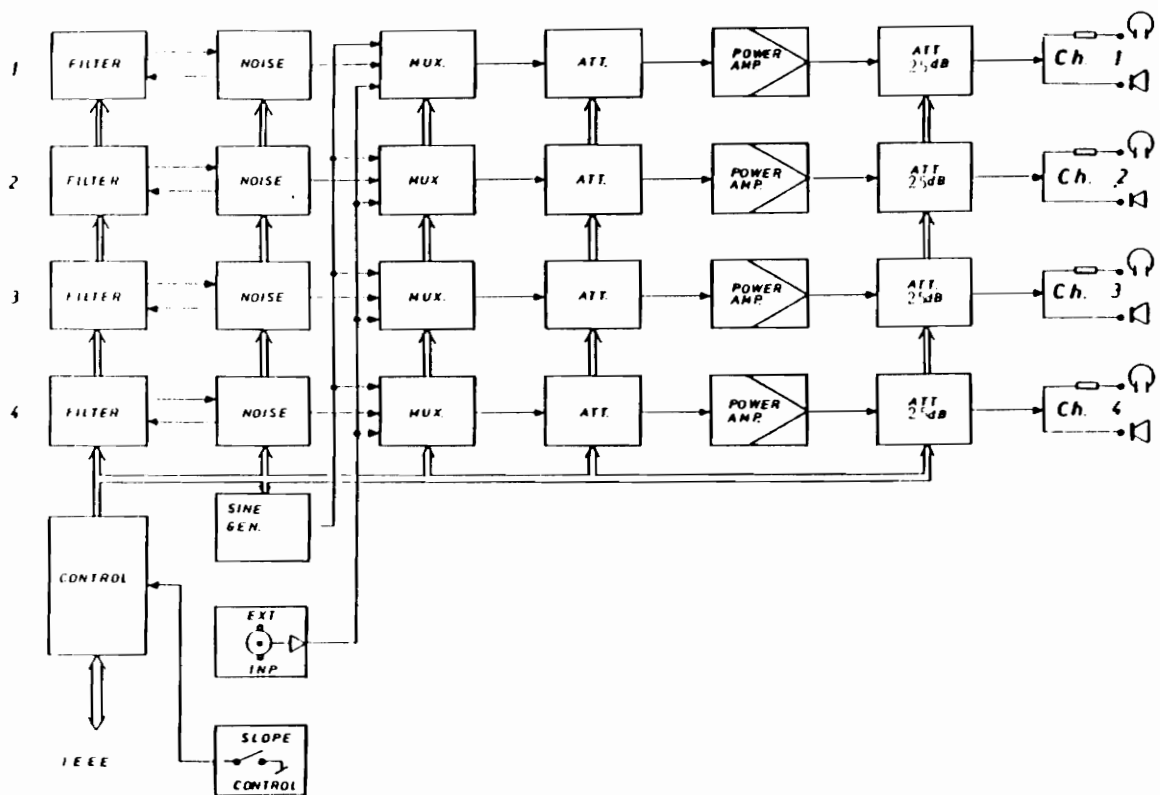


Figure 13. Block diagram of the Norwegian-Electronics test system (Adapted from Norwegian Electronics, 1988).

following a change of frequency and occasional reversals associated with trace excursions of 3 dB or less:

- (a) There are less than six (6) reversals.
 - (b) Any peak is lower than any valley.
 - (c) The range of excursions (any peak to valley difference) exceeds 20 dB.
- (2) Acceptable traces shall be scored by ignoring the first reversal following a change of frequency and then averaging together an equal number of peaks and valleys of the tracing at a given frequency.
- (3) The average value shall be rounded to the nearest whole number in decibels.
- (4) When the trace excursions meet the above criteria, very similar results may be obtained more simply by "visual averaging," in which a horizontal line drawn through the center of the tracing is used to estimate the average value (ANSI, 1984, p. 5).

These criteria were stored internally in the computer program and could be changed through keyboard control if needed. The method of "visual averaging," which is a subjective scoring procedure associated with automatic audiometry, was not used in this research. Further

specifications of the Békésy method and the computer programs are given by Casali:

At the end of an audiogram, the threshold for a given frequency is calculated by the computer as the midpoint of the trace excursions for that frequency. When sufficient (usually 3) unoccluded and occluded trial pairs have been completed, the computer calculates the attenuation (occluded minus unoccluded threshold values in dB) for each pair and stores both the raw threshold data and the attenuation data on floppy disk. When the desired number of subjects (at least 10) have undergone the threshold test for a given HPD, the attenuation means, standard deviations, and range are calculated from the stored data using an IBM-PC program. The data values for all subjects, the statistics for the specific HPD, and the attenuation-by-frequency curves for the HPD are printed on an EPSON LX-800 dot-matrix printer for documentation. These data can then be used to calculate a Noise Reduction Rating (NRR) or any other single-number rating for the HPD (Casali, 1988, pp. 10-11).

A second test chamber, an Industrial Acoustics Corporation (IAC) booth, was used for audiometric testing. Pure-tone audiometry was used to measure the subjects' left and right ear hearing to screen them for the study. The pure-tone frequencies were 125, 250, 500, 1000, 2000,

4000, and 8000 Hz. The audiometric test system included a Beltone clinical audiometer (Model 114) and a Telephonics headphone set (Model TDH-50P). The IAC booth's octave band ambient noise levels were within the specifications of ANSI S3.21-1978, "Methods for Manual Pure-Tone Threshold Audiometry."

The instrumentation was calibrated daily with a Larson-Davis Model 800-B precision sound level meter and one-third octave analyzer, with ACO Model 7013 half-inch microphone and Larson-Davis Model 825-10 preamplifier. This device met ANSI S1.4-1971 (Type 1) for precision sound measurement equipment. The sound levels at the subject's ear-height position were calibrated using the Minimum Audible Field (MAF) curve shown in Table 13. A Bruel and Kjaer standard source calibrator (Type 4230) was used for the calibration of the sound level meter at the beginning of each day of testing. A Larson-Davis artificial ear (Model AE100) with headphone coupler and one-inch ACO Model 7023 microphone was used to calibrate the audiometer at the beginning of the subject screening process.

ANSI S12/WG11 specified six anatomical measurements to be taken in the study. These included (1) head height, (2) Bitragus breadth, (3) ear protrusion, (4) ear breadth, (5) ear length, (6) ear canal size. These measurements are defined and shown graphically in Appendix C.

The instruments that were used for measuring the anatomical dimensions of the head and ears were the following: (1) horizontal head board mounted on a vertical shaft with locking collar for sliding and locking head board height position, and a T-square rule to measure head

TABLE 13

Minimum Audible Field Values for VPI and SU Test Chamber

(Adapted from Casali, 1988)

1/3 OB Center, Hz	MAF, dB ¹	Free to Diffuse Field Correction ²	Diffuse ³ MAF, dB	Fixed MAF for System
125	27.9	0	27.9	-33.3
250	15.8	0	15.8	-20.1
500	7.4	-1.0	6.4	-7.9
1000	3.0	-2.5	0.5	-0.5
2000	1.0	2.0	3.0	-3.7
3150	-2.9	2.0	-0.9	-2.8
4000	-3.9	1.5	-2.4	-1.1
6300	4.6	-2.0	2.6	-7.1
8000	15.3	-5.0	10.3	-15.7

¹Values from 125 through 1000 Hz obtained from mean MAF values in Table 4, Berger (1981). Values from 2000 through 8000 Hz obtained from ISO R226-1961. (11 of 14 studies summarized in Berger, 1981 are free-field; ISO R226-1961 is free-field.)

²Correction factors added to free-field MAF to produce diffuse field MAF, obtained from Table 3, column e of Berger (1981).

³Diffuse field MAF, used for HPD test system described herein, measured at centered head position.

height, (2) curved, spreading caliper to measure Bitragus breadth, (3) standard vernier caliper to measure ear breadth and ear length, (4) straight, metric scale to measure ear protrusion, (5) American Optical EARGAGETM to measure ear canal size. Photographs of these devices are shown in Appendix C.

Fitting noise. A fitting noise was required by the ANSI S12/WG11 protocol (Experiment 1), but only in the IUF condition. This same fitting noise was used in Experiment 2 for one level of both SF and IUF conditions. The specifications set forth by ANSI S12/WG11 for the fitting noise were:

The fitting noise shall be a broadband random noise without audible tonal components, presented at an overall A-weighted sound pressure level of 65 dB (re 20 micro Pa) at the head center position. Its frequency response, also at the head center position, should fall within a range of 20 dB from 100 Hz - 8 kHz, with the response in each of the 1/3 octave-bands from 100 - 250 Hz exceeding the value in the 1-kHz 1/3 octave band by at least 15 dB (Berger, 1989, p. 5).

These specifications were met with the use of a Realistic Model Number 31-2020A one-third octave band frequency equalizer to set the levels of the random noise as specified by the above requirements. The noise was presented by Realistic normal bias 120 micro sec EQ audio cassette played through a Realistic Model Number 14-633 cassette tape

deck (SCT-34), with a Scott Model Number 458A integrated stereo amplifier. The fitting noise was presented to the subject by a Realistic (Minimus-22, 8 ohms) single dome and woofer speaker placed directly in front of the subject's head position, 125 cm away. The sound pressure levels at the subject's head for the one-third octave band frequencies as measured with the Larson-Davis Model 800-B precision sound level meter are shown in Table 14.

TABLE 14
Spectral Analysis of the Fitting Noise

1/3 dB Center Frequency (Hz)	Sound Pressure Level ¹ (dB)
100	66
125	66
160	66
200	66
250	64
315	62
400	57
500	55
630	56
800	53
1000	47
1250	49
1600	48
2000	47
2500	47
3150	46
4000	49
5000	54
6300	51
8000	47
10000	47

¹Sound pressure level measured in dB linear, re 20 micro Pa

EXPERIMENT 1

Subjects

The 10 subjects that participated in Experiment 1 consisted of five males (mean age 21.4 years) and five females (mean age 21.8 years), all previous non-users (hereafter referred to as novices) of hearing protectors. ANSI S12/WG11 proposed multiple additions to Section 3.2 "Listeners," of the S12.6-1984 standard. All of the requirements proposed were met by the subjects who participated in Experiment 1. The following requirements were taken from S12.6-1984 (Sections 3.2.1 through 3.2.4) with the proposed changes of ANSI S12/WG11 inserted. Also listed are the new requirements (Sections 3.2.5 through 3.2.9) as stated by ANSI S12/WG11 in their 1989 proposal for the pilot study (Berger, 1989):

3.2 Listener Requirements

- 3.2.1. Listeners to be used in the test described in the following section shall have hearing thresholds levels that are no better [lower] than -10 dB and no worse [higher] than 25 dB at all frequencies as measured by a standard audiometer (American National Standard S3.6-1969, Specifications for Audiometers).
- 3.2.2. No subject shall be used whose unoccluded thresholds (the average of three determinations) in the test room are better than 8 dB below the ambient noise levels measured in the test room at the seven octave

bands centered on the test frequencies from 125 to 8000 Hz.

3.2.2.1. An exception to this requirement is based on the lowest unoccluded hearing threshold levels at each test frequency of all prior subjects measured in the test facility. Listeners whose unoccluded hearing thresholds (average of three determinations) are 3 dB or more above the minimum threshold previously measured at each frequency under the same ambient noise conditions may also be used as subjects.

3.2.3. The variability of the open threshold of audibility of listeners selected as subjects for these tests shall be, on three successive open threshold measurements, no greater than 6 dB at all test frequencies, as measured in the sound field.

3.2.4. Subjects' ears, as determined by an otoscopic inspection, shall be free from impacted cerumen or obvious signs of irritation and/or infection. They shall be selected without respect to sizes and shapes of heads, pinnae and ear canals except that those with obvious abnormalities affecting the fitting of hearing protectors, such as might arise from birth defects or prior ear surgery, shall be excluded.

3.2.5. Measurements shall be conducted on novice (new) subjects. Novice is defined with respect to the subjects' familiarity with the use of hearing protectors. Subjects shall be asked the following questions:

- (a) Have you ever participated in an experiment designed to measure hearing protector noise reduction?
- (b) Have you ever received personal instruction in the use of hearing protectors?
- (c) Have you ever worn hearing protectors because you were exposed to noise as part of your occupation?
- (d) How many times have you worn earplugs or earmuffs within the last year? Include in your estimate any use of earplugs for sleeping or swimming.
- (e) How many hearing tests/audiograms have you had in the past 2 years?

Subjects shall be rejected if they answer "yes" to questions (a), (b), or (c), or if in response to (d) they estimate that they have worn hearing protectors more than 5 times in the past year. Question (e) is for information purposes only.

3.2.6. Unless the hearing protector under test is (new) designed to fit only males or only females, the gender mix of the test population shall be 50% $\pm$ 10%.

- 3.2.7. Subjects shall possess a level of literacy
(new) sufficient to be able to read hearing protector instructions. In the announcement for subjects and/or during the interview process they shall be told that "instructions for devices we will be testing are often written in small print, and therefore ability to read small print is a requirement for participation in this study." Unless subjects respond affirmatively they shall not be accepted for the study.
- 3.2.8. When laboratories have access to a (parent)
(new) population of listeners that exceeds the number required for testing, the actual subjects utilized shall be randomly selected from that parent population.
- 3.2.9. With the exception of illness or physical
(new) inability to participate on the day of the test, no subjects shall be rejected for any reasons other than failure to meet the requirements of Sections 3.2.1 through 3.2.8. However, at their own choosing, subjects may withdraw from the study at any time, without restriction (ANSI, 1984, p. 4; and Berger, 1989, pp. 6-8).

Experimental Design

The experimental design for Experiment 1 was developed by ANSI S12/WG11. The design was a three-factor within-subjects (repeated measures) design with 10 subjects. The independent variables, all within-subjects and with 2 levels each, were: (1) HPDs (H), (2) Fitting Conditions (F), and (3) Experience Level (E). The dependent variable was the real-ear attenuation of each subject at each of the nine 1/3 octave band test frequencies. The design was partially counterbalanced within subjects across HPDs and across ordering of occluded and unoccluded trials. A schematic drawing of the design matrix is shown in Figure 14, and the ordering of plug presentation for each subject is shown in Table 15.

Independent variables. The independent variables (HPDs, Fitting Conditions, and Experience Levels) were controlled by the experimenter. Each of these variables is discussed separately below.

The two HPDs (with manufacturers' NRRs at time of study) were the E-A-R malleable foam plug (NRR = 35), hereafter referred to as the E-A-R plug; and, the Mediprint Quiet Zone V-51R pre-molded, multi-sized plug (NRR = 23), hereafter referred to as the V-51R plug. The E-A-R foam plug is single-sized, in that one size is intended to fit all adult users. To properly fit this plug, the user must compress the plug into a thin cylinder by rolling it between the thumb and fingers before inserting it into the ear canal. Instructions for correctly compressing and inserting the E-A-R plug are shown in figures on the plug's packaging. The instructions for the E-A-R plug and the V-51R plug are shown in Figures 15a and 15b, respectively.

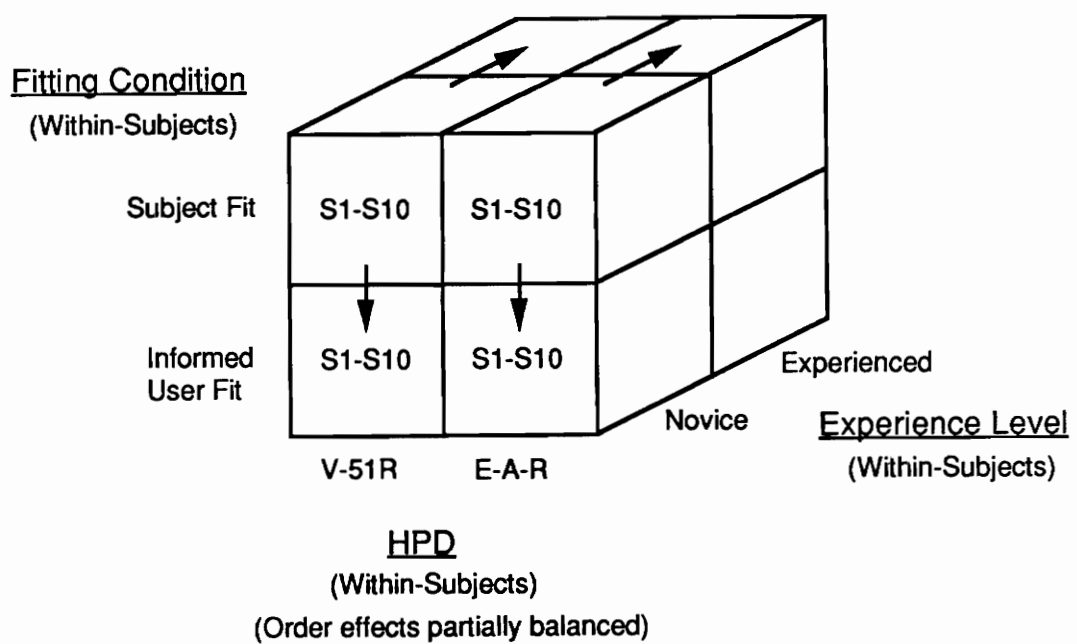


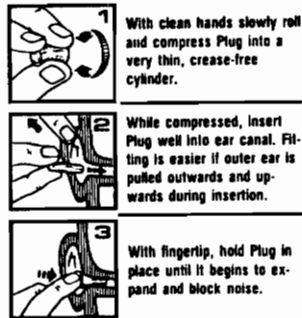
Figure 14. Experimental design matrix for Experiment 1.

TABLE 15

Plug Presentation Order for Experiment 1

		Experience Level							
		Novice				Experienced			
		Fitting Conditions							
		Subject Fit (Visit 1)		Informed User Fit (Visit 2)		Subject Fit (Visit 3)		Informed User Fit (Visit 4)	
Session		A	B	A	B	A	B	A	B
<u>Subject</u>									
1		OEOE ¹	OVOV	OEOE	OVOV	OEOE	OVOV	OEOE	OVOV
2		EOEO	VOVO	EOEO	VOVO	EOEO	VOVO	EOEO	VOVO
3		OVOV	OEOE	OVOV	OEOE	OVOV	OEOE	OVOV	OEOE
4		VOVO	EOEO	VOVO	EOEO	VOVO	EOEO	VOVO	EOEO
5		EOEO	VOVO	EOEO	VOVO	EOEO	VOVO	EOEO	VOVO
6		OVOV	OEOE	OVOV	OEOE	OVOV	OEOE	OVOV	OEOE
7		EOEO	VOVO	EOEO	VOVO	EOEO	VOVO	EOEO	VOVO
8		VOVO	EOEO	VOVO	EOEO	VOVO	EOEO	VOVO	EOEO
9		OEOE	OVOV	OEOE	OVOV	OEOE	OVOV	OEOE	OVOV
10		OVOV	OEOE	OVOV	OEOE	OVOV	OEOE	OVOV	OEOE

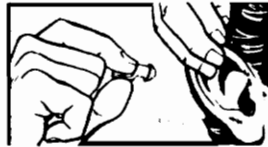
¹O = Unoccluded (Open-ears) trial
E = Occluded trial with E-A-R plugs
V = Occluded trial with V-51R plugs



a. E-A-R foam plug

HOW TO USE

Grasp the tab by placing your right index finger on the hollow center of the ear plug and your right thumb on the outside of the tab. Place the round flange into your right ear, pressing it in with your index finger while rocking the plug back and forth. While inserting, use your left hand to reach behind your head and gently pull the top of your right ear upward. (This will ease insertion and help straighten your ear canal.) Carefully adjust your ear plugs for greatest noise reduction. (Your ear may feel blocked, as if by water.) For your left ear use opposite hands.



CARE AND HYGIENE

After each use, wash your ear plugs with warm water and soap. Rinse well and store in a clean dry container. Wear only your own protectors. Discontinue the use of any type of insert protector during ear inflammation or infection, and consult a physician. Do not boil.

REPLACEMENT

QUIET ZONE V51R ear plugs are reusable. However, ear chemicals, contaminants, and aging may cause eventual material shrinkage or hardening. A change in the material or shape of the ear plug is reason to assume a loss of hearing protection. Replace with new QUIET ZONE V51R ear plugs.

SIZE

Protectors are size lettered.
EXTRA-SMALL SMALL MEDIUM LARGE EXTRA-LARGE

quiet zone V51R™
HEARING PROTECTORS
PLASMED INC.

P.O. BOX 80/WALLINGFORD, CT 06492

The QUIET ZONE V51R™ hearing protector is a proven design worn in noise intensive industrial and military environments for over a quarter century. Today millions of QUIET ZONE V51R are worn around the world. The success of the design is due to the noise reduction capability, comfort of the extremely soft polymer material and cost economy. Ready to use, QUIET ZONE V51R ear plugs are easily inserted, and may be worn repeatedly.

Noise
Reduction **23** DECIBELS
Rating (WHEN USED AS DIRECTED)

THE RANGE OF NOISE REDUCTION RATINGS
FOR EXISTING HEARING PROTECTORS
IS APPROXIMATELY 0 TO 30
(HIGH NUMBERS DENOTE GREATER EFFECTIVENESS)

PLASMED INC.
WALLINGFORD, CT 06492

QUIET ZONE V51R

Federal law prohibits
removal of this label
prior to purchase



LABEL REQUIRED BY
U.S. E.P.A. REGULATION
40 CFR Part 211, Subpart B

b. Quiet Zone V-51R pre-molded plug

Figure 15a and 15b. Manufacturer's fitting instructions for individual user packages (obtained directly from packages).

The V-51R plug is available in five sizes (extra-small, small, medium, large, and extra-large). There are no units or dimensions given with these nominal sizes in the manufacturer's package instructions. The user must select the size(s) that feels most comfortable and best fits his/her ear canals (the size may be different for each canal). The user inserts each plug by gently rocking it back and forth into the ear canal. Manufacturer's fitting instructions and a diagram for insertion are printed on the individual package (Figure 15b).

Each of the two plugs, the E-A-R and the V-51R, represents a different category of plugs, namely user-molded plugs and pre-molded, respectively. These plugs were chosen for the study to test subjects' abilities to use different insert devices and manufacturer's fitting procedures as well as to minimize the learning effects that one plug may have had on the other plug.

The fitting conditions for Experiment 1 were Subject Fit (SF) and Informed User Fit (IUF). The SF condition involved size-selection (only in the case of the V-51R plug) and fitting of the HPDs by the subject while using the manufacturer's package instructions as the only guide to correct selection and fit. The experimenter remained passive and did not provide any assistance other than to read the verbatim procedural instructions that were presented and read to the subjects. These instructions are included in the stepwise protocol procedures for Experiment 1 (shown in Appendix B).

The IUF condition involved the size-selection (again, only in the case of the V-51R plug) and fitting of the HPDs by the subject while

using the manufacturer's package instructions as well as the experimenter's instructions and demonstrations as a guide to correct selection and fit. According to the ANSI S12/WG11 protocol, the experimenter did not augment, add to, or change the instructions from the manufacturer, but demonstrated the procedures described in the manufacturer's package instructions. The experimenter visually inspected the subject's fit of the plugs and asked for a refit if he (the experimenter) deemed necessary (no acoustic criterion was used by the experimenter to assess fit). Also in the IUF condition, the subject was instructed to adjust the plugs while listening to the broadband fitting noise as auditory feedback, as previously described in the Method section.

The two experience levels for Experiment 1 were Novice and Experienced. For the Novice level, the subject had to meet the requirements previously given under the Subjects section.

Once a subject had completed audiometric screening, threshold tracking practice sessions, and actual testing on two trials (i.e., two occluded and two unoccluded tests, each at nine frequencies) under SF; and two trials under IUF, the subject was considered "Experienced," as defined by ANSI S12/WG11. The term "Experienced" referred to both donning HPDs and in being tested for attenuation in the laboratory. This experimental level should be thought of as "Transfer-to-Experienced" within the study. In Experiment 2, the Experience level was "Enter-as-Experienced" in that the subjects were already experienced in using the HPD, as well as in the HPD testing procedures, before participation in the study.

Dependent variable. The dependent variable measured was the real-ear attenuation at threshold, REAT (in dB) of each subject at each of the nine frequencies for each unique treatment cell. Attenuation was taken as the occluded threshold of audibility minus the unoccluded threshold of audibility. For this experiment, each subject was tested on two trials (i.e., two occluded and two unoccluded measures) for each of the nine test frequencies for each unique treatment cell. The two trials yielded two attenuation values that were arithmetically averaged to give a single attenuation value for each subject, at each frequency, and for each unique treatment cell. These average values (10 per cell) were used to calculate the mean attenuations and standard deviations for the different comparisons that were made in the analysis of results.

Procedure

The procedure for Experiment 1 exactly followed the protocol stated by ANSI S12/WG11. There were a total of five visits to the laboratory by each subject. The first visit was for subject screening and obtaining subject consent, while the remaining four visits were for data collection. Detailed, stepwise procedures describing the visits from the time the subject entered the laboratory until the time he/she completed the visit appear in Appendix B. The verbatim instructions that were handed to and read to the subjects as stated by ANSI S12/WG11 and the ASL experimenters are included in the stepwise procedures. The following sections provide an overview of the experimental protocol.

Visit 0: subject screening. The initial visit, called Visit 0, consisted of an otoscopic examination (to determine if the candidate for participation had any obstructions/infections or impacted cerumen in the ear canals), audiometric screening, and threshold tracking practice.

When the candidate entered the laboratory, he/she was given a copy of the informed consent form (Appendix E). After the otoscopic exam, any questions from the candidate that were not considered to introduce bias to the experiment were addressed by the experimenter. Once the candidate agreed to participate and signed the form, he/she then underwent an audiometric test in accordance with ANSI S3.21-1978, "Methods of Manual Pure-Tone Threshold Audiometry." The equipment for pure-tone audiometry is described under the Apparatus section.

For each ear, the mean hearing threshold at each pure-tone frequency of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz was determined by the Hughson-Westlake audiometric testing procedure (Morrill, 1984). In this procedure, the experimenter decreased the sound pressure in 10 dB steps (usually from a starting point of 30 dBHL [dB normalized for hearing level] until the candidate did not respond. The experimenter then increased the sound pressure in 5 dB steps until the candidate responded. The level was then decreased 10 dB from the response level, and alternately increased in 5 dB steps until the candidate responded again. Threshold at each frequency was taken as the level at which the candidate responded on the ascending trials, with agreement on at least two of three trials. The candidate was accepted for the study if he/she met all of the criteria listed previously in the Subject section.

Two candidates were rejected during screening because of hearing thresholds that exceeded the acceptable limits. One candidate was referred to the VPI and SU infirmary because of impacted cerumen in the ear canals. The ears were inspected after an infirmary physician removed the cerumen and the candidate was allowed to participate in the experiment. Five male and five female candidates were approved for participation as subjects. The candidates were assigned subject numbers in the sequence that they were screened and deemed qualified for the study. Each subject was given a minimum of five practice open-ear audiograms with the Norwegian-Electronics testing system in the anechoic chamber.

Visit 1: Novice, SF treatment. Visit 1 consisted of testing the subjects with both earplug types at the Novice level and for the SF condition. One HPD was tested in "Session A", the other HPD was tested in "Session B." Only one subject was allowed in the laboratory at a time. After entering the laboratory, the subject was given a general description of the visit's proceedings, then Session A began according to the experimental protocol.

Each subject was instructed to size-select (in the case of the V-51R plug) and fit the HPD based on the manufacturer's package instructions alone (exact procedures varied for the different plug types, refer to stepwise procedures in Appendix B for details). Each subject was given up to five minutes for size selection, reading manufacturer's package instructions, and fitting. The experimenter did not aid the subject at all. After four minutes, the subject was given a warning of the limited

time remaining. Five minutes after the initial instructions, the subject was told to stop fitting the device if he/she had not already finished.

In the case of the disposable E-A-R plugs, the practice plugs were thrown away and two new pairs were used in the testing, one new pair for each occluded trial. In the case of the V-51R plugs, the experimenter recorded the size selected for each ear and the subject used the plugs for the testing in that visit. All plugs inserted into ears were discarded at the end of the visit in which they were inserted.

After receiving instructions concerning the test chamber and the test procedure, the subject took the HPD and the manufacturer's package instructions into the anechoic chamber and was seated. Instructions and plugs were placed on a platform marked "L" for left and "R" for right. The experimenter closed the door of the chamber, allowed five minutes for accommodation to the chamber (time allowed for subject to relax), and then proceeded to test the subject for the two occluded and two unoccluded trials using the HPD test system.

The experimenter entered the chamber before the first occluded test and instructed the subject concerning the testing procedure and reminded him/her to review the manufacturer's package instructions if needed. The experimenter then exited the chamber, closed the door, and returned to the test station. The subject signaled when the fitting was completed and time was allowed for plug expansion to occur in the case of the E-A-R plug (two minutes was given for expansion time). Testing then began, and as the subject completed each test, the data were stored

on the computer floppy disk and printed on the dot-matrix printer after each trial.

Throughout the test procedures, the experimenter was able to communicate with the subject via intercom and view the subject via the CCTV. No communication took place during audiometric signal tracking, however. When the testing was completed, the subject exited the anechoic chamber and was given a short break. The entire process was then repeated for Session B with the other HPD. At the end of Visit 1, the subject was scheduled for Visit 2, which occurred within five days.

Visit 2: Novice, IUF treatment. Visit 2 consisted of testing each novice subject with both earplug types under the IUF condition. One HPD was tested in Session A, the other in Session B. This visit utilized the fitting noise described in the previous Apparatus section. After entering the laboratory, each subject was given a general description of the visit's proceedings, then Session A began.

Each subject was instructed to fit the HPD based on the manufacturer's package instructions (exact procedures varied for the different plug types, refer to stepwise procedures in Appendix B for details) as well as according to instructions and demonstrations that were provided by the experimenter. Each subject had up to seven minutes for reading manufacturer's package instructions, experimenter demonstration, size selection (in the case of the V-51R plugs), and fitting.

The experimenter standardized his procedures by reading through the manufacturer's package instructions with the subject. The experimenter

then proceeded to follow these instructions and inserted a pre-selected plug into his own ear as the subject watched. He then told the subject to select and insert one of the sample plugs into his/her own ears in a manner similar to the way he had demonstrated. The experimenter then inspected the fit and advised the subject to try again (sometimes with a different size plug) if he (the experimenter) deemed necessary. After six minutes, the subject was given a warning of the limited time remaining. Seven minutes after the initial instructions, the subject was told to stop fitting the device if he/she had not already finished. In the case of the E-A-R plugs, the practice plugs were thrown away and two new pairs were used in the testing, one new pair for each occluded trial.

In the case of the V-51R plugs, the experimenter recorded the size selected for each ear and the subject used the plugs for the testing in that visit. As before, all plugs inserted into ears were discarded at the end of the visit.

After receiving instructions concerning the test procedure, the subject took the HPD and manufacturer's package instructions into the anechoic chamber and was seated. Instructions and plugs were placed on a platform marked "L" for left and "R" for right. The experimenter closed the door, allowed five minutes for accommodation to the chamber, and then proceeded to test the subject for the two occluded and two unoccluded trials using the system and method previously described.

The experimenter entered the chamber before the first occluded test and instructed the subject concerning the testing procedure and the use

of the fitting noise, and reminded him/her to review the manufacturer's package instructions if needed. After giving the printed fitting noise instructions to the subject and reading them aloud, the experimenter then exited the chamber, closed the door, and returned to the test station.

The fitting noise was turned on before HPD fitting and was turned off when the subject signaled that the fitting had been completed. Two minutes then were allowed for plug expansion in the case of E-A-R plugs. Testing then began, and as the subject completed each test, the data were stored on floppy disk and printed on the dot-matrix printer after each trial.

The test procedures followed the same format as previously mentioned until Session A was finished. The entire process was then repeated for Session B with the other HPD. At the end of Visit 2, the subject was scheduled for Visit 3, which had to occur after a time span of at least 10 days.

Visit 3: Experienced, SF treatment. Visit 3 followed the same protocol as Visit 1, except that the subject was considered "Experienced." Refer to the section on Visit 1 for a description of Visit 3. At the end of Visit 3, the subject was scheduled for Visit 4, which occurred within 5 days.

Visit 4: Experienced, IUF treatment. Visit 4 followed the same protocol as Visit 2, except that the subject was considered "Experienced." Refer to the section on Visit 2 for a description of Visit 4. At the end of Visit 4, the last visit, the head and ear

anthropometric measurements were obtained. These measurements were the Bitragus breadth, head height, ear protrusion, ear breadth, ear length and ear canal sizes. Detailed descriptions of each of these measurements and their drawings are shown in Appendix C along with the actual data. These measurements were requested by ANSI S12/WG11 to be included in their data base of head and ear dimensions. Only the ear canal size data were used for analysis purposes in this research.

Each subject was seated outside of the chamber and was presented drawings of the measurements to be taken. The experimenter then performed the measurement procedures, using the devices described in the Apparatus section. Each measurement was recorded, in mm, as it was taken. The subject was then debriefed, paid, and allowed to leave.

EXPERIMENT 2

Subjects

Forty subjects participated in Experiment 2, 20 novice and 20 experienced. Gender was balanced with the assignment of five males and five females to each of the four unique treatment conditions. The mean age of the males was 21.2 years and the mean age of the females was 22.2 years.

Novice subjects. The novice subjects met the same requirements and criteria as the subjects who participated in Experiment 1 (refer to Subjects section of Experiment 1).

Experienced subjects. The experienced subjects also met the same requirements and criteria of Experiment 1 with the exception of requirement 3.2.5 (which specified the conditions for being a novice subject). The experienced subjects also met one of the following two requirements: (1) participation in at least two auditory experiments (with at least six nine-frequency trials across experiments) involving earplug testing within the last two years, where the subject was informed about the proper fit and donning procedure of the plugs; or, (2) participation in the first experiment of this research (which involved 16 nine-frequency trials).

In the proposal for this research, it was not anticipated that the subjects of Experiment 1 would participate in Experiment 2. A lack of local female subjects who had participated in previous studies of the Auditory Systems Laboratory made it necessary to ask the female subjects

of Experiment 1 to participate. To assure balance between gender, the males of Experiment 1 were also asked to participate.

All 10 subjects of Experiment 1 agreed to participate in Experiment 2 and nine of them did so successfully. One male subject was unable to participate because of prolonged illness during the period of testing for Experiment 2. Another male who had participated in several of ASL's previous experiments was asked to participate in place of the ill subject. This replacement subject met all of the necessary criteria; however, his hearing level was rated better than that of the experienced male who could not participate. In the five categorical ratings of the grand mean hearing levels, the replacement subject's hearing level was in the first (best or lowest) quantile, while the original subjects was in the third quantile.

To balance the experience levels of use with the V-51R plug, the 11 experienced candidates who had not participated in Experiment 1 were given the equivalent of an IUF session during their screening. These candidates were then tested for two trials (each trial consisted of an opened and an occluded test) of attenuation using the V-51R plug at all nine test frequencies.

By using the method of matched (equated) pairs (Blommers and Forsyth, 1977), the experimenter matched experienced subjects based on their gender, whether they had or had not participated in Experiment 1, and their grand mean hearing level ranks (to be explained in the forthcoming section). When 10 matched pairs of subjects were identified, they were assigned to the experimental treatment cells.

Experimental Design

The experimental design was mixed-factors with three independent variables of 2 levels each. The independent variables were: (1) Fitting Condition (F), between-subjects; (2) Fitting Noise (Z), within-subjects; and (3) Experience Level (E), between-subjects. The dependent variable that was measured was the real-ear attenuation of each subject at each of the nine test frequencies. The trial sequence (occluded and unoccluded thresholds) as well as the ordering sequence of fitting noise presentation were partially counterbalanced in the design. Complete counterbalancing was not possible because of the sample size of 10 subjects per unique treatment cell. The sample sizes of 10 were chosen to be the same as in Experiment 1 for purposes of statistical comparison. A schematic drawing of the design matrix is shown in Figure 16. The order arrangements for plug and fitting noise presentation for novice and experienced subjects are shown in Tables 16 and 17, respectively.

HPD. Only one HPD type was tested in Experiment 2. The V-51R plug was chosen instead of the E-A-R plug because its fit was considered easier to adjust and manipulate in fitting noise as an attempt to achieve better attenuation. The E-A-R plug is virtually impossible to adjust once it has been inserted into the ear canal. To improve the fit of a poorly placed E-A-R plug, it must be taken completely out of the canal and allowed to re-expand, then be re-compressed and re-inserted. The subjects were expected to be able to utilize the fitting noise more advantageously with the V-51R plug, since it could be adjusted once in the ear canal.

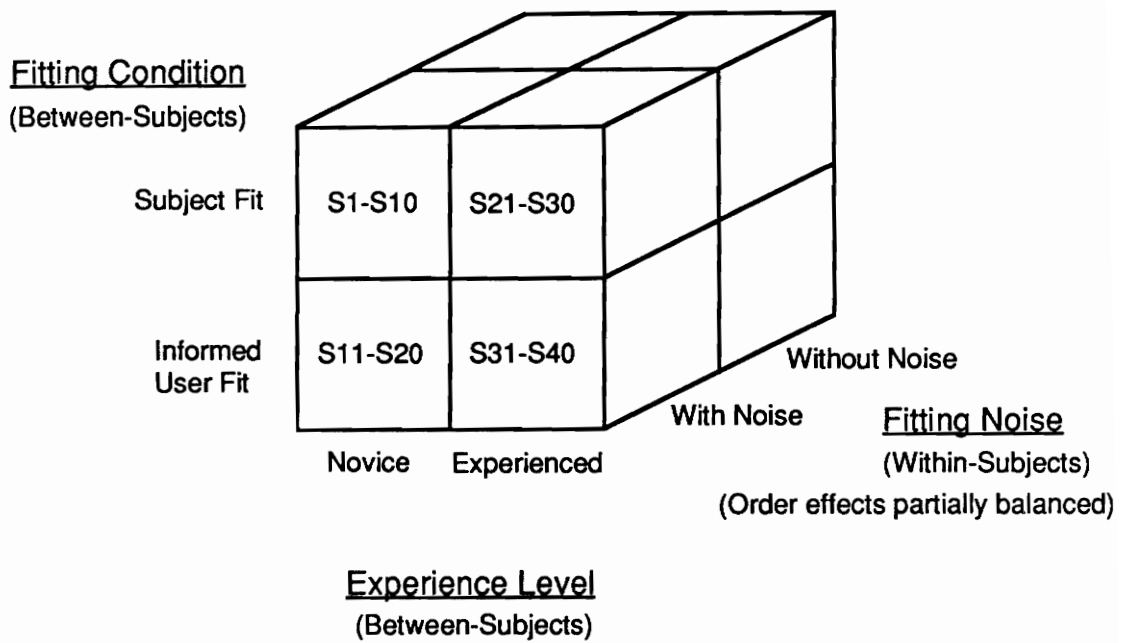


Figure 16. Experimental design matrix for Experiment 2.

TABLE 16

Partial Counterbalanced Design for Order Effects and Hearing Levels
for Novice Subjects of Experiment 2

Fit	Subject	Gender	Hearing Level	Order		Session A	Session B
SF	1	F	1	¹ WN	² VOVO	WON	OVOV
	2	F	5	WON	OVOV	WN	VOVO
	3	M	1	WN	OVOV	WON	VOVO
	4	F	3	WON	VOVO	WN	OVOV
	5	M	2	WN	VOVO	WON	OVOV
	6	M	4	WON	OVOV	WN	VOVO
	7	M	5	WN	OVOV	WON	VOVO
	8	F	4	WON	VOVO	WN	OVOV
	9	F	2	WN	VOVO	WON	OVOV
	10	M	3	WON	OVOV	WN	VOVO
IUF	11	M	3	WN	VOVO	WON	OVOV
	12	F	5	WON	OVOV	WN	VOVO
	13	M	1	WN	OVOV	WON	VOVO
	14	F	4	WON	VOVO	WN	OVOV
	15	F	1	WN	VOVO	WON	OVOV
	16	F	2	WON	OVOV	WN	VOVO
	17	M	4	WN	OVOV	WON	VOVO
	18	M	2	WON	VOVO	WN	OVOV
	19	F	3	WN	OVOV	WON	VOVO
	20	M	5	WON	VOVO	WN	OVOV

¹WN = With Fitting Noise; WON = Without fitting noise

²VOVO: V = Occluded trial with V-51R plugs; O = Unoccluded trial

TABLE 17

Partial Counterbalanced Design for Order Effects and Hearing Levels
for Experienced Subjects of Experiment 2

Fit	Subject	Gender	Hearing Level	Order		Session A	Session B
SF	21	M	5	¹ WN	² VOVO	WON	OVOV
	22	M	3(1)	WON	OVOV	WN	VOVO
	23	F	5	WN	OVOV	WON	VOVO
	*24	M	1	WON	VOVO	WN	OVOV
	25	F	4	WN	VOVO	WON	OVOV
	*26	F	2	WON	OVOV	WN	VOVO
	27	F	3	WN	OVOV	WON	VOVO
	*28	F	1	WON	VOVO	WN	OVOV
	29	M	4	WN	OVOV	WON	VOVO
	*30	M	2	WON	VOVO	WN	OVOV
IUF	*31	F	1	WN	VOVO	WON	OVOV
	32	F	3	WON	OVOV	WN	VOVO
	*33	F	2	WN	OVOV	WON	VOVO
	*34	M	2	WON	VOVO	WN	OVOV
	35	M	4	WN	VOVO	WON	OVOV
	*36	F	4	WON	OVOV	WN	VOVO
	37	M	5	WN	OVOV	WON	VOVO
	*38	M	1	WON	VOVO	WN	OVOV
	39	M	2	WN	VOVO	WON	OVOV
	40	F	5	WON	OVOV	WN	VOVO

¹WN = With Fitting Noise; WON = Without fitting noise

²VOVO: V = Occluded trial with V-51R plugs; O = Unoccluded trial

* denotes subjects who participated in Experiment 1

Independent variables. The independent variables, Fitting Condition, Fitting Noise, and Experience Level, are each discussed separately below.

The two levels of Fitting Condition were again SF and IUF. But in Experiment 2, these two levels were between subjects, such that no subject had to participate at both SF and IUF levels. The between-subjects format was applied to avoid the possible learning effects that could have occurred if the subjects were tested with one fitting condition and then the other, which was the case in Experiment 1, where IUF always followed SF for all of the subjects.

The SF condition again involved size-selection and fitting of the V-51R plug by the subject while using the manufacturer's package instructions as the only guide to correct size selection and fit, as previously discussed in Experiment 1. However, in Experiment 2, one of the SF sessions included presentation of fitting noise and the instructions for its use. The stepwise protocol procedures are shown in Appendix D.

The IUF condition involved the size-selection and fitting of the V-51R plug by the subject while using manufacturer's package instructions as well as the experimenter's instructions and demonstrations as a guide to correct selection and fit as in accordance with the ANSI S12/WG11 protocol previously discussed in Experiment 1.

The two levels of Fitting Noise, a within-subjects variable, were With Fitting Noise (WN) and Without Fitting Noise (WON). In the WN condition, the fitting noise that was specified by ANSI S12/WG11 (see

the previous Apparatus section) was presented to the subject during the fitting of the earplugs. The instructions for using the fitting noise differed from those given in Experiment 1. These instructions are included in the stepwise procedures for Experiment 2 (Appendix D). In the WON condition, the fitting noise was not presented to the subject during the fitting of the earplugs. WN and WON conditions were counterbalanced between subjects to avoid any contamination from learning effects or confounding that could have possibly occurred otherwise.

The two levels of Experience Level, a between-subjects variable, were Novice and Experienced. There were 20 subjects in each of these two levels (the definitions and requirements of these two levels have been previously discussed in the Subject section of Experiment 2). The novice subjects were chosen according to the same requirements and criteria as the novice subjects of Experiment 1. The experienced subjects, however, were "Enter-as-Experienced" subjects as opposed to "Transfer-to- Experienced" subjects of Experiment 1, as discussed previously.

Dependent variable. The dependent variable measured was the real-ear attenuation at threshold, REAT, (in dB) of each subject at each of the nine test frequencies for each unique treatment cell. Attenuation was the occluded threshold of audibility minus the unoccluded threshold of audibility. For this experiment, each subject was tested for two trials (i.e., two occluded and two unoccluded measures) for each of the nine test frequencies for each unique

treatment cell. The two trials yielded two attenuation values that were arithmetically averaged to give a single attenuation value for each subject, at each frequency, and for each unique treatment cell. These average values (10 per cell) were used to calculate the mean attenuations and standard deviations that were used in the analysis of results.

Blocking variables. This experiment contained blocking variables to refine the error estimate for the between-subjects variables. The variables which were used for blocking were (1) gender, and (2) subject threshold hearing levels. Subjects were assigned to matched groups and then randomly assigned to the experimental design as previously discussed in the Subjects section. The threshold hearing levels were determined by calculating the grand mean threshold hearing level for each subject based on the results of the screening audiograms. The grand mean was the mean of all levels (of both left and right ears) for all frequencies.

For this research, the screening pure-tone frequencies were 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. A total of 14 monaural hearing levels were averaged to compute the grand mean for each subject. The grand means were arranged in increasing orders for males and females, novice subjects and experienced subjects. These levels were then divided into five ordered groups (quantiles). Each quantile contained two subjects of the same gender and experience level.

Procedure

In Experiment 2, each subject visited the laboratory twice. The first visit, Visit 0, was for screening and obtaining informed consent. The remaining visit, either Visit 1/SF or Visit 1/IUF, was for data collection. Visit 1/SF was for testing the SF condition, for both WN and WON, for 10 novice and 10 experienced subjects. Visit 1/IUF tested the IUF condition, for both WN and WON, for the other 10 novice and 10 experienced subjects. Detailed stepwise procedures and verbatim instructions, describing the visits from the time the subject entered the laboratory until the time he/she completed the visit, are shown in Appendix D.

Visit 0: subject screening. The initial visit, called Visit 0, consisted of an otoscopic examination, auditory screening, and threshold tracking practice, as previously discussed for Experiment 1. The candidate was accepted for the study if he/she met all of the criteria listed previously in the Subjects section of Experiment 2.

If the experienced candidate had recent (within the last 6 months) audiometric records filed with the Auditory Systems Laboratory, then he/she was only required to take the initial manual screening (headphone) audiogram and two practice open-ear audiograms in the sound field instead of the minimum of five practice sound field audiograms required for novice candidates (Experienced subjects who had participated in Experiment 1 were exempt from the screening of Experiment 2).

Experienced candidates who had not participated in Experiment 1 were

given the equivalent training of an IUF session with the V-51R plug and two attenuation trials as previously discussed in the Subjects section.

One candidate had to be rejected during screening because of a hearing threshold that exceeded the acceptable limits. Three candidates were referred to the VPI and SU infirmary because of impacted cerumen in the ear canals. The ears were inspected after a physician removed the cerumen and the candidates were allowed to participate in the experiment.

Visit 1/SF treatment. Visit 1/SF consisted of testing the subject (either novice or experienced) with the V-51R plug for the SF condition and for both WN and WON conditions. After entering the laboratory, the subject was given a general description of the visit's proceedings, then the first test session began with either the WN or WON condition, which were counterbalanced between subjects.

Each subject was instructed to size-select and fit the earplugs based on the manufacturer's package instructions alone. The same procedures used in the Experiment 1 SF treatment conditions were followed in this test treatment condition, with the exception of the session in which fitting noise was presented.

If the session included fitting noise, the experimenter instructed the subject concerning its use. The fitting noise instructions for Experiment 2 included written and spoken descriptions of how to "cup" the hands over the ears. Those instructions, written by the ASL experimenters, were not used in Experiment 1 (see stepwise procedures for exact differences), but were deemed necessary for investigating the

effects of fitting noise as an experimental factor. At the end of the visit, the anthropometric measurements were taken of the head and ears, as discussed previously. The subject was then debriefed, paid, and allowed to leave.

Visit 1/IUF treatment. Visit 1/IUF consisted of testing each subject (either novice or experienced) with the V-51R plug for the IUF condition and for both WN and WON conditions. The same procedures used in the Experiment 1 IUF treatment conditions were followed in this treatment condition. The fitting noise instructions were identical to those used in the Visit 1/SF treatment of this experiment. After both sessions of the visit were completed, the anthropometric measurements were taken and the subject was allowed to leave after having been paid and debriefed.

RESULTS

The attenuation results of the two experiments were analyzed at each of the nine one-third octave-band frequencies. The primary analysis for each experiment was the analysis of variance (ANOVA) of spectral attenuation data. Post hoc analyses were performed for the interaction effects that were significant at $p < 0.05$ in the ANOVA. Secondary analyses were conducted using the randomization test procedure (RTP) to statistically compare the laboratory attenuation results between the two experiments and to the field attenuation results of the NIOSH studies (Edwards et al., 1982; Lempert and Edwards, 1983; NIOSH, 1978).

The RTP was also used to validate the ANOVA results of Experiment 1 because of the known violations to the assumptions of ANOVA inherent in within-subjects experimental designs. Also, comparisons of the Noise Reduction Ratings (NRRs) of each experimental treatment cell were made with the manufacturer's published NRRs. Mean attenuations and standard deviations were plotted for the unique treatment cells of both experiments.

Experiment 1 Data Analysis

Primary analysis: ANOVA on spectral attenuation data. The ANOVAs on attenuation data were performed for each of the nine one-third octave-band frequencies. The statistical calculations were performed

using the Statistical Analysis System (SAS, 1985) computer package on VPI and SU's IBM 3090 mainframe computer.

Data reduction. Each subject completed two test trials for each of the nine test frequencies for each unique treatment cell. The attenuation of each trial was obtained by subtracting the unoccluded threshold of audibility from the occluded threshold of audibility. This procedure was done automatically by the IBM PS-2 Model 70 computer which controlled the HPD test system. Each subject's two attenuation values at each test frequency for each unique treatment cell were arithmetically averaged. This averaging reduced the number of attenuations per unique treatment cell from 20 to 10 for each test frequency. Averaging was necessary because the experimental design required that each unique treatment cell have only one dependent measure (i.e., attenuation value) from each of the 10 subjects for each of the test frequencies. By averaging the attenuation results, the effect of replications per subject was removed from the statistical analysis.

The mean attenuations and standard deviations are plotted across the nine test frequencies for each of the four laboratory visits in Figures 17 and 18 for the V-51R and E-A-R plugs, respectively. The mean and standard deviation attenuation for all treatment conditions are shown in tabular form in Appendix F.

Overall ANOVA. An exemplary ANOVA summary table (for 125 Hz) is shown in Table 18; the ANOVA summary tables for the other eight frequencies are in Appendix F. Table 19 summarizes the significant ($p < 0.05$) results of the nine ANOVAs.

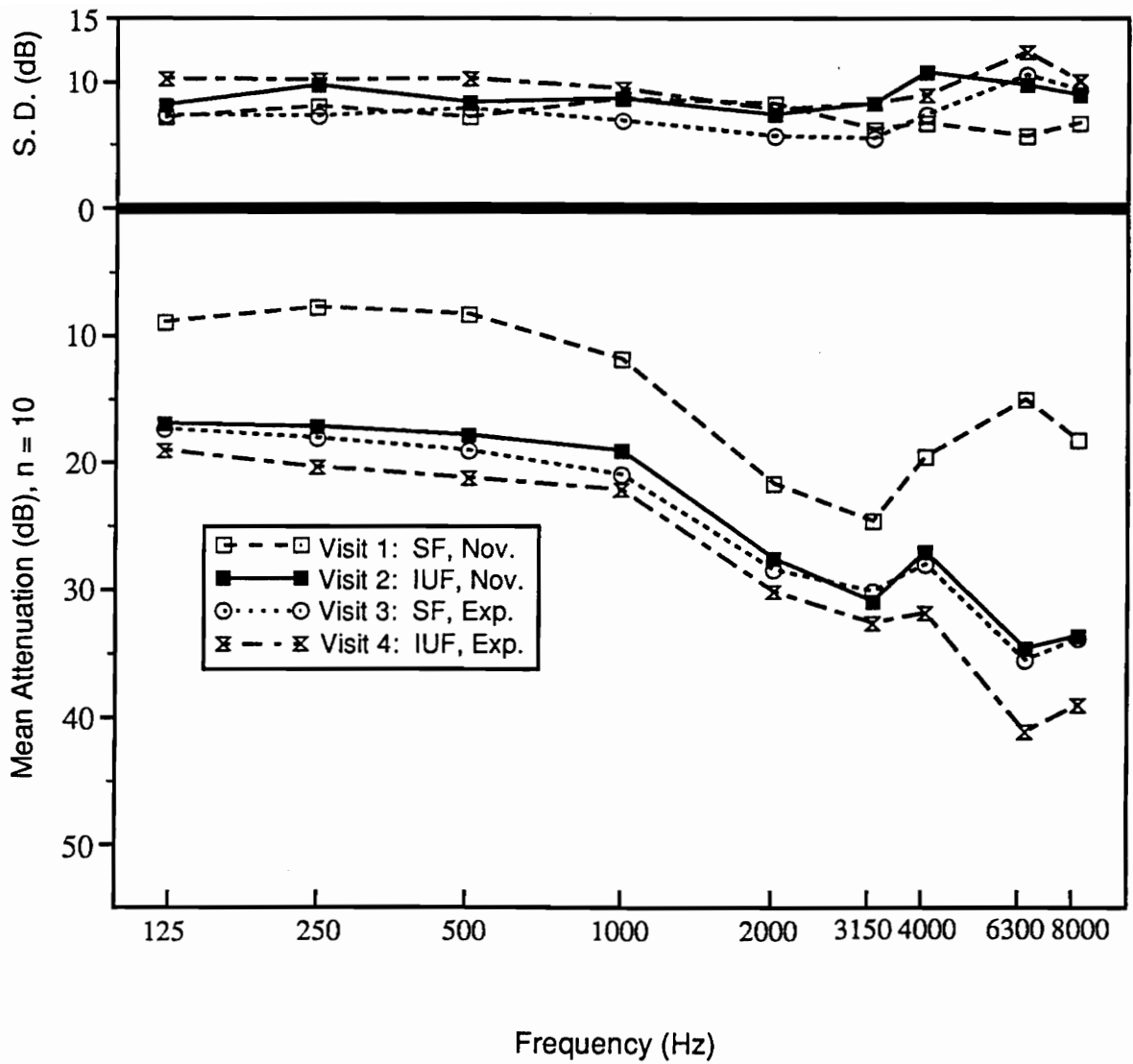


Figure 17. Mean attenuation and standard deviation results for the V-51R plug from Experiment 1.

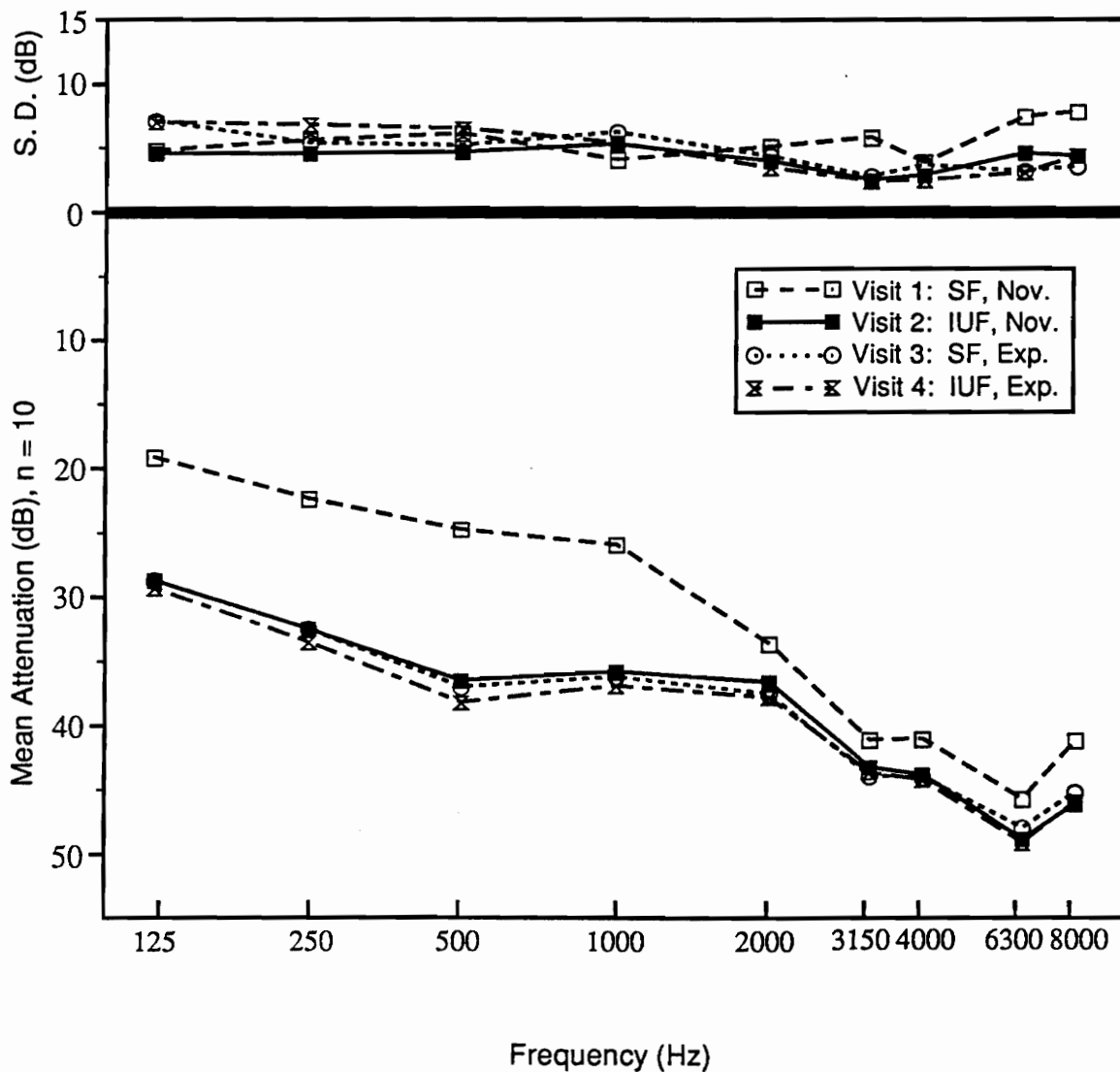


Figure 18. Mean attenuation and standard deviation results for the E-A-R plug from Experiment 1.

TABLE 18

Experiment 1 ANOVA Summary Table for Attenuation at 125 Hz¹

Source	df	MS	F	p
<u>Between-subjects</u>				
Subjects (S)	9	236.13		
<u>Within-subjects</u>				
HPD (H)	1	2389.30	67.33	0.0001
Fit (F)	1	493.02	15.21	0.0036
Experience Level (E)	1	540.80	21.07	0.0013
HxS	9	35.49		
FxS	9	32.42		
ExS	9	25.66		
HxF	1	0.26	0.01	0.9214
HxE	1	0.03	0.00	0.9774
FxE	1	297.22	21.52	0.0012
HxFxS	9	25.71		
HxExS	9	37.82		
FxExS	9	13.81		
HxFxE	1	8.84	0.59	0.4616
<u>HxFxExS</u>	<u>9</u>	14.96		
Total	79			

¹Experiment 1 ANOVA tables for other frequencies appear in Appendix F.

TABLE 19

Experiment 1 Overall ANOVA Significant Results (*F* and *p* values¹)

Frequency (Hz)	H	F	E	FxE	HxF	HxE
125	67.33 (.0001)	15.21 (.0036)	21.07 (.0013)	21.52 (.0012)	-	-
250	79.32 (.0001)	21.08 (.0013)	39.35 (.0001)	19.07 (.0018)	-	-
500	130.62 (.0001)	29.70 (.0004)	67.95 (.0001)	26.47 (.0006)	-	-
1000	72.20 (.0001)	31.62 (.0003)	38.39 (.0002)	18.64 (.0019)	-	-
2000	38.19 (.0002)	14.18 (.0044)	22.87 (.001)	8.83 (.0157)	-	-
3150	81.69 (.0001)	9.53 (.013)	15.87 (.0032)	-	5.37 (.0456)	-
4000	107.06 (.0001)	11.25 (.0085)	17.44 (.0024)	-	-	-
6300	36.21 (.0002)	38.16 (.0002)	34.07 (.0002)	11.44 (.0081)	17.91 (.0022)	11.76 (.0075)
8000	44.80 (.0001)	46.18 (.0001)	41.88 (.0001)	7.60 (.0222)	11.77 (.0075)	7.85 (.0206)

¹ Exact *p* values shown in parentheses.

For the main effects, the loci of significance is readily known from the overall ANOVA because there are only two levels of each of these effects. All three of the main effects, HPD, Fitting Condition, and Experience Level, were significant at $p < 0.05$ for all nine test frequencies. The mean attenuations and standard deviations of all three main effects are shown in Table 20. For the significant interactions, post hoc analyses were necessary to determine the loci of significance.

Fit-by-Experience Level interaction. The Fit-by-Experience Level (FxE) interaction was significant at seven out of nine test frequencies, with the two exceptions being 3150 Hz and 4000 Hz. Newman-Keuls sequential range tests were performed to determine the loci of significance between the six possible combinations of interactions. The results of these tests are shown in Table 21.

The mean attenuations of the SF, Novice treatment condition were significantly different ($p < 0.05$) from the mean attenuations of the other three conditions for all seven frequencies. None of the other comparisons were significantly different at the $p < 0.05$ level.

The results of the post hoc analysis for the FxE interaction imply that mean attenuations do not regress to levels that were achieved with manufacturers' instructions only (SF, Novice condition) once the experimenter has assisted in the process of HPD selection and/or instruction for proper fit as in the IUF condition.

HPD-by-Fit interaction. The HPD-by-Fit Interaction (HxF) was significant at 3150 Hz, 6300 Hz, and 8000 Hz. A total of six possible comparisons could have been analyzed in the post hoc analysis. The four

TABLE 20

Mean Attenuation (Standard Deviations) for the Main Effects of Experiment 1

Main Effect	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
<u>HPD</u>									
V-51R	15.5 (8.8)	15.8 (9.7)	16.6 (9.5)	18.5 (9.0)	26.9 (7.7)	29.5 (7.5)	26.6 (9.3)	31.5 (13.6)	31.2 (11.5)
E-A-R	26.4 (7.1)	30.2 (7.1)	34.1 (7.7)	33.7 (6.8)	36.3 (4.4)	42.9 (3.3)	43.3 (3.4)	47.9 (4.8)	44.6 (5.4)
<u>Fit</u>									
SF	18.5 (9.5)	20.1 (10.9)	22.2 (12.1)	23.7 (10.8)	30.3 (8.3)	34.9 (9.2)	33.1 (11.3)	36.0 (14.7)	34.6 (12.3)
IUF	23.4 (9.2)	25.8 (10.6)	28.4 (11.6)	28.5 (10.6)	33.0 (7.1)	37.6 (8.3)	36.7 (10.2)	43.4 (9.9)	41.2 (8.8)
<u>Experience Level</u>									
Nov.	18.4 (9.3)	19.9 (11.3)	21.8 (12.1)	23.1 (11.1)	29.8 (8.4)	34.9 (9.4)	32.8 (11.9)	36.0 (14.8)	34.8 (12.6)
Exper.	23.6 (9.4)	26.1 (10.0)	28.9 (11.4)	29.0 (10.1)	33.5 (6.8)	37.6 (8.0)	37.0 (9.4)	43.4 (9.7)	41.0 (8.6)

TABLE 21

Results of the Newman-Keuls Sequential Range Test for Post Hoc Analysis of the Fit-by-Experience Level Interaction (Mean Attenuation Data in dB)¹

Treatment	Center Frequency (Hz)						
	125	250	500	1000	2000	6300	8000
SF x NOV	14.0 A	15.0 A	16.5 A	18.8 A	27.6 A	30.3 A	29.7 A
IUF x NOV	22.8 B	24.8 B	27.2 B	27.4 B	32.0 B	41.7 B	39.5 B
SF x EXP	23.0 B	25.2 B	28.0 B	28.5 B	32.9 B	41.7 B	39.9 B
IUF x EXP	24.1 B	26.9 B	29.7 B	29.5 B	34.0 B	45.1 B	42.5 B

¹ Means (n=10) within a table column with the same letter are not significantly different at $p < 0.05$.

comparisons within a common fitting procedure and between the two levels of HPDs were not considered for analysis because of the prior known differences between attenuation performance with these different plug types. By not including these comparisons, statistical power was maximized for the two comparisons that remained. These two comparisons were (1) V-51R plug: SF versus IUF; and (2) E-A-R plug: SF versus IUF.

The results of the Simple Effect F tests conducted for each of the two HPD types revealed that the HxF interaction was significant ($p < 0.01$) for the V-51R plug at 3150 Hz, 6300 Hz, and 8000 Hz; but, was not significant for the E-A-R plug ($p > 0.05$) at any of these three frequencies. The results of these tests are shown in Table 22. At these three frequencies, the results imply that attenuation performance achieved by subjects is more susceptible to changes in fitting conditions (i.e., level of instructions, experimenter interaction, fitting noise, etc.) with the V-51R plug than with the E-A-R plug. Although the specific influences of such variables as fitting noise, levels of instruction, and experimenter intervention were present in the study, they could not be determined because of the confounded experimental design.

HPD-by-Experience Level interaction. The HPD-by-Experience Level (HxE) interaction was significant at 6300 and 8000 Hz. Out of the six possible comparisons, only the two comparisons within the HPD levels were analyzed. These two comparisons are (1) V-51R plug: Novice versus Experienced; and (2) E-A-R plug: Novice versus Experienced. Reasons for limiting the analysis to two comparisons are the same as previously mentioned in the analysis for the HxF interaction.

TABLE 22

Simple Effect F Test¹ for Post Hoc Analysis of the HPD-by-Fit Interaction

HPD	Statistic	Center Frequency (Hz)		
		3150	6300	8000
V-51R	MS (F)	193.60	1586.34	1052.68
	MS ($H \times F \times S$)	11.27	47.60	36.17
	F^2	17.18	33.33	29.10
	p	< 0.01	< 0.01	< 0.01
E-A-R	MS (F)	8.46	46.66	80.94
	MS ($H \times F \times S$)	11.27	47.60	36.17
	F	0.75	0.98	2.24
	p	> 0.05	> 0.05	> 0.05

¹To determine the difference in the Fit effect for each HPD.

² $F = MS (F) (df = 1) / MS (H \times F \times S) (df = 9)$

$F (0.05, 1, 9) = 5.12$

$F (0.01, 1, 9) = 10.60$

The results of the Simple Effect F tests conducted for each of the two HPD types revealed that the HxE interaction was significant ($p < 0.01$) for the V-51R plug at 6300 Hz and 8000 Hz; but, was not significant for the E-A-R plug ($p > 0.05$) at either of these two frequencies. The results of these tests are shown in Table 23.

Observation of Figure 17 reveals that the only difference in the trend of mean attenuations across visits is at 6300 Hz and 8000 Hz for Visit 1 (SF, Novice).

Secondary analysis: Randomization test procedure (RTP). The experimental design of Experiment 1 was within-subjects (repeated measures) such that the same ten subjects participated in all eight unique treatment cells. Consequently, the data were not independent of each other. The underlying assumptions of ANOVA include independence of observations; however, when the assumption is not met, as in the case of within-subjects designs, homogeneity of covariances becomes a necessary assumption.

ANOVA is a robust test in that it provides accurate statistical results (in regards to p values and significant levels) in many cases where its underlying assumptions are not met. For Experiment 1, the author chose to perform a secondary analysis to verify the ANOVA results. The secondary analysis involved the randomization test procedure (RTP), which was also used to compare the current laboratory results to previously documented field results. The following paragraphs provide background information on the RTP.

The theory of what is commonly known as randomization tests was

TABLE 23

Simple Effect F Test¹ for Post Hoc Analysis of the HPD-by-Experience Level Interaction

HPD	Statistic	Center Frequency (Hz)	
		6300	8000
V-51R	MS (E)	1821.15	1098.30
	MS ($H \times E \times S$)	41.87	31.61
	F^2	43.50	34.75
	p	< 0.01	< 0.01
E-A-R	MS (E)	15.63	34.41
	MS ($H \times E \times S$)	41.87	31.61
	F	0.37	1.09
	p	> 0.05	> 0.05

¹To determine the difference in the Experience Level effect for each HPD.

$$^2F = MS(E) (df = 1) / MS(H \times E \times S) (df = 9)$$

$$F(0.05, 1, 9) = 5.12$$

$$F(0.01, 1, 9) = 10.60$$

developed by Sir Ronald Fisher in the 1930's. Randomization tests are statistical tests in which research data are repeatedly divided or permuted. For each time the data are permuted, a statistic, usually an F or t , is computed. To determine the significance level of the comparison being made, the proportion of the data permutations that result in a statistic value equal to or greater than the actual experimental outcome (before the data permutations were made) are considered.

Edgington (1980) describes the use of a randomization test by stating:

The probability distribution of the test statistic, whether it be t or F or some other statistic, is generated by the experimenter when he uses a randomization test. He computes every test statistic value for the various data permutations and uses that theoretical distribution to compute the significance value associated with his experimental results. The "significance table" used with a randomization test... is derived directly from the experimental data by computations performed by the experimenter. The experimenter has a complete understanding of the origin of the significant values (Edgington, 1980, p. 11).

It is important to realize that a randomization test is not based on any one particular statistic, but is a procedure in which a statistic is

chosen and used to determine significance. The procedure of the randomization test is not an alternative to conventional tests, but is an alternative to conventional significance tables (Edgington, 1980).

The randomization test can be used in circumstances where the assumptions of the ANOVA procedure are not met. Assumptions such as sampling from a normally distributed population, random sampling from the population, homogeneity of the population's variance, equal sample sizes, and sample sizes larger than one are not necessary when using the randomization test procedure (Edgington, 1980; Foutz, Jensen, and Anderson, 1985). The ability to avoid the assumptions of the ANOVA procedure while maintaining statistical power and validity, as is possible with randomization tests, is an important consideration for researchers. Many researchers do not know the true distribution of the population that they are sampling from, and in many cases, researchers are unable to select samples randomly. Time, money, and availability of subjects often make random sampling infeasible, especially in behavioral research (Edgington, 1980). With randomization tests, the only assumption that must be made is random assignment of subjects to treatment conditions.

Concerning the validity, power, and practicality of the randomization test procedure, Edgington (1980) provides theoretical justification as well as quotes and references from other sources. Articles by Foutz (1984) and Foutz, Jensen, and Anderson (1985), support the validity, power, and practicality of the randomization test procedure in cases where the assumptions of the ANOVA technique are not

met.

A statistical technique was required to compare the results of the laboratory attenuation results obtained in this research to field attenuation results from other studies. The test had to provide valid statistical results to assess which laboratory protocols modeled the field results most closely, if any.

The randomization test procedure was recommended for use in this research by the VPI and SU Department of Statistics and the computer programs and statistics used in this research for the randomization test procedures were developed by their faculty and graduate students.

For the secondary analysis of Experiment 1, six different comparisons were made between the four unique treatment cells for each level of HPD. This is essentially the same as analyzing the Fit-by-Experience Level interaction within HPD levels. The results of the RTP for the analysis of Experiment 1 are shown in Table 24.

The attenuation results for Visit 1 (SF, Novice) are significantly different from the attenuation results of the other three visits for each plug at $p < 0.01$. The other three visits, however, are not significantly different from one another within the HPD levels. These results agree with the post hoc analysis of the FxE interaction and are supported by comparisons of the mean attenuation values shown in tabular form in Appendix F and plotted in Figures 17 and 18.

Noise Reduction Ratings. The mean attenuations and standard deviations ($n = 10$) for each frequency were used to compute the NRR(98), NRR(84), and NRR(50) (as previously discussed in Literature Review

TABLE 24

Experiment 1 Data Analysis by Randomization Test Procedure

HPD	Comparison	^1_N	^2_p
V-51R			
	SF, NOV - vs - IUF, NOV	6	0.006
	SF, NOV - vs - SF, EXP	8	0.008
	SF, NOV - vs - IUF, EXP	1	0.001
	IUF, NOV - vs - SF, EXP	983	0.983
	IUF, NOV - vs - IUF, EXP	415	0.415
	SF, EXP - vs - IUF, EXP	504	0.504
E-A-R			
	SF, NOV - vs - IUF, NOV	1	0.001
	SF, NOV - vs - SF, EXP	1	0.001
	SF, NOV - vs - IUF, EXP	1	0.001
	IUF, NOV - vs - SF, EXP	975	0.975
	IUF, NOV - vs - IUF, EXP	981	0.981
	SF, EXP - vs - IUF, EXP	980	0.980

^1_N = Number of times $F_{.j} \geq F_{.0}$ for 1000 permutation cycles
where:

$F_{.j}$ = summary statistic of the nine frequency-dependent
F statistics for the permutations where $j = 1$ to 1000;

$F_{.0}$ = summary statistic of the nine frequency-dependent
F statistics for the actual experimental outcome.

^2_p = Actual significance level of comparison based on 1000
permutation cycles where 1 permutation cycle involves a
single data permutation at each of the nine test frequencies.

section) for each of the two HPD types for each of the four treatment conditions. These NRR values are shown in comparison to the manufacturers' NRR values in Table 25.

The NRR values vary substantially depending on the standard deviation correction factor used (i.e., minus two sd for the NRR(98); minus one sd for the NRR(84); and no correction factor for the NRR(50) [refer to footnotes of Table 25 for definition of NRRs]).

Ear canal sizes and V-51R plug size data. The V-51R plug size data were compared across the four treatment conditions to determine if subjects' plug selections differed between the conditions. For experimental control, the experimenter prompted the same size selection in both of the IUF treatment conditions (i.e., Visits 2 and 4).

The ear canal sizes were measured at the end of the last visit, so neither experimenter nor subjects had any personal anthropometric data available on which to base their recommendations or choice of plug size. After the experiment was completely finished, the plug data for each of the treatment conditions was analyzed. Based on each subject's measured ear canal sizes, each plug size selected in the experiment was considered either a correct match (to the ear canal in which it was used) or as an incorrect match. The ear canal sizes and plug selections are shown in Table 26.

The results of the test for differences between two proportions (Walpole and Myers, 1985) showed a significant difference ($p < 0.05$) between the percentages of correct plug selection for SF, Novice (20% correct plug selection) compared to IUF, Novice and IUF, Experienced

TABLE 25

Experiment 1 NRRs and Manufacturers' NRRs

HPD	Treatment	NRR(98) ¹	NRR(84) ²	NRR(50) ³	Manufacturers' NRR(98)
V-51R					23
	SF, NOV	-3.8	4.1	12.0	
	IUF, NOV	3.0	11.8	20.5	
	SF, EXP	7.2	14.6	21.8	
	IUF, EXP	4.3	14.0	23.6	
E-A-R					35
	SF, NOV	16.7	22.0	27.1	
	IUF, NOV	26.4	31.1	35.6	
	SF, EXP	25.3	30.8	36.1	
	IUF, EXP	26.3	31.7	36.8	

¹ NRR(98) = protection level theoretically achieved by 98% of user population.

² NRR(84) = protection level theoretically achieved by 84% of user population (often used as an estimate of field NRR).

³ NRR(50) = protection level theoretically achieved by 50% of user population.

TABLE 26

Ear Canal Sizes and V-51R¹ Plug Size Selections for Experiment 1

Subject	Gender	Canal Size	<u>Novice</u>		<u>Experienced</u>	
			SF	IUF ²	SF	IUF
1	M	L: M R: L	L L	M ³ S	S M	M S
2	F	L: M R: L	L EL	M L	M M	M L
3	M	L: L R: L	EL EL	L L	L L	L L
4	M	L: M R: L	EL EL	M M	M M	M M
5	F	L: M R: L	L M	M M	M M	M M
6	F	L: EL R: L	M S	M L	M L	M L
7	F	L: EL R: L	EL EL	L L	L EL	L L
8	M	L: M R: M	L L	M M	L L	M M
9	M	L: L R: L	L L	L L	L L	L L
10	F	L: M R: M	L L	S S	S S	S S
Percent of Correct Selections:			20%	65%	40%	65%

¹V-51R plug sizes are ES = extra small, S = small, M = medium, L = large, EL = extra large.

²IUF: Identical plug selections were made for each individual subject in the IUF conditions as mandated in the experimental design.

³Boldface letters indicate correct match with ear canal size as measured at end of last visit.

(65% correct plug selection). This analysis indicated that the novice subjects of this experiment significantly improved their plug size selection with the aid of the experimenter such that an additional 45% of the plug selections were correct as compared to selections with no experimenter guidance (i.e., SF conditions).

These results also indicate that some of the subjects learned and retained information about which plug size was a better fit for each of their ears during the IUF, Novice condition. This is shown by the increase from 20% to 40% correct size selection from the SF, Novice to the SF, Experienced conditions, respectively.

Experiment 2 Data Analysis

Data reduction. Each of the 40 subjects completed two test trials for each of the nine test frequencies for each of the two unique treatment cells he/she participated in. As discussed in the Experiment 1 Data Analysis section, each subject's two attenuation values at each test frequency were averaged to reduce the number of attenuation measurements from 20 to 10 for each test frequency for each of the 8 unique treatment cells.

The mean attenuations and standard deviations are plotted across the nine test frequencies for novice subjects and experienced subjects in Figures 19 and 20, respectively. The mean attenuation and standard deviations for each condition are shown in tabular form in Appendix G.

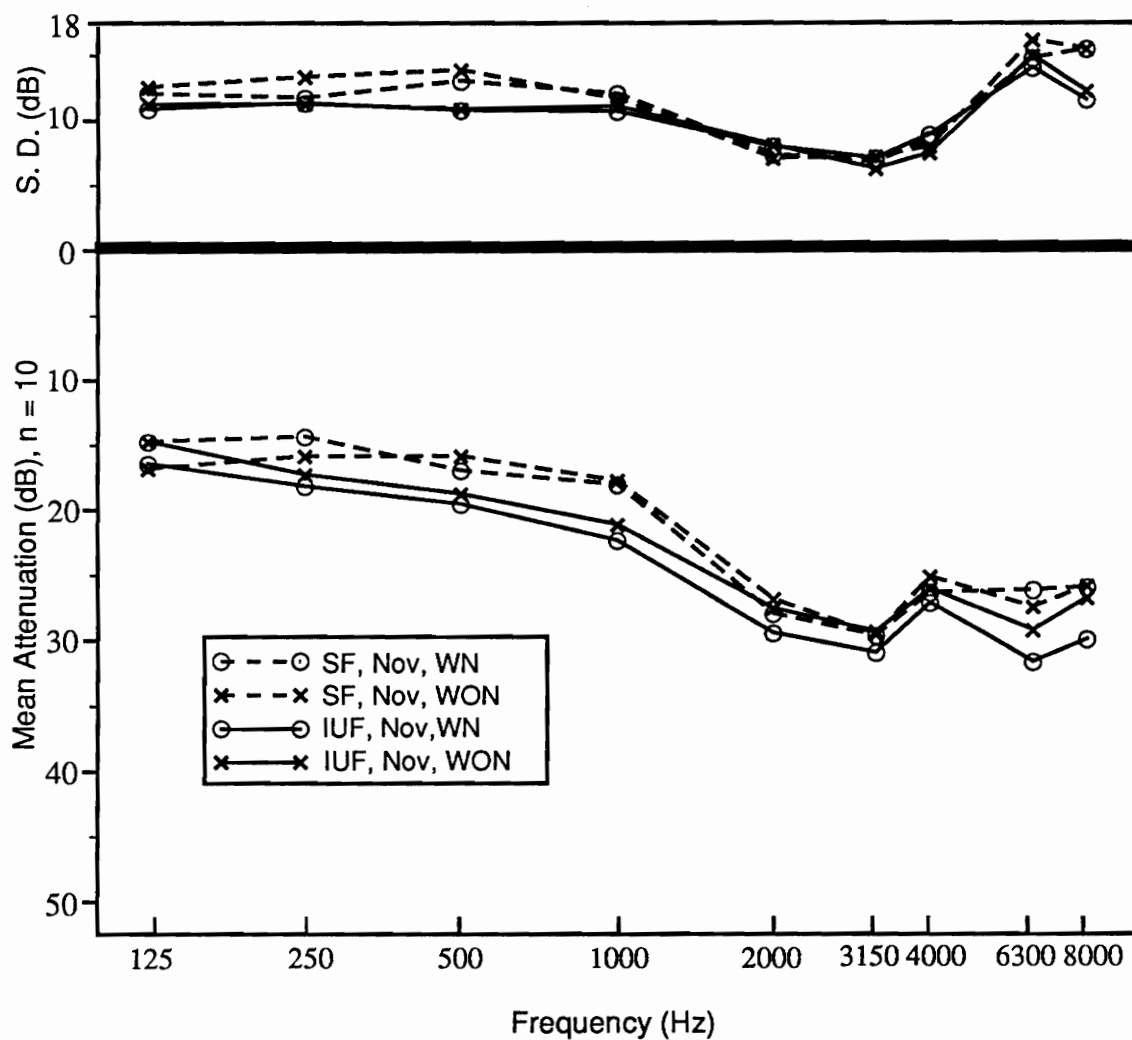


Figure 19. Mean attenuation and standard deviation results for novice subjects in Experiment 2.

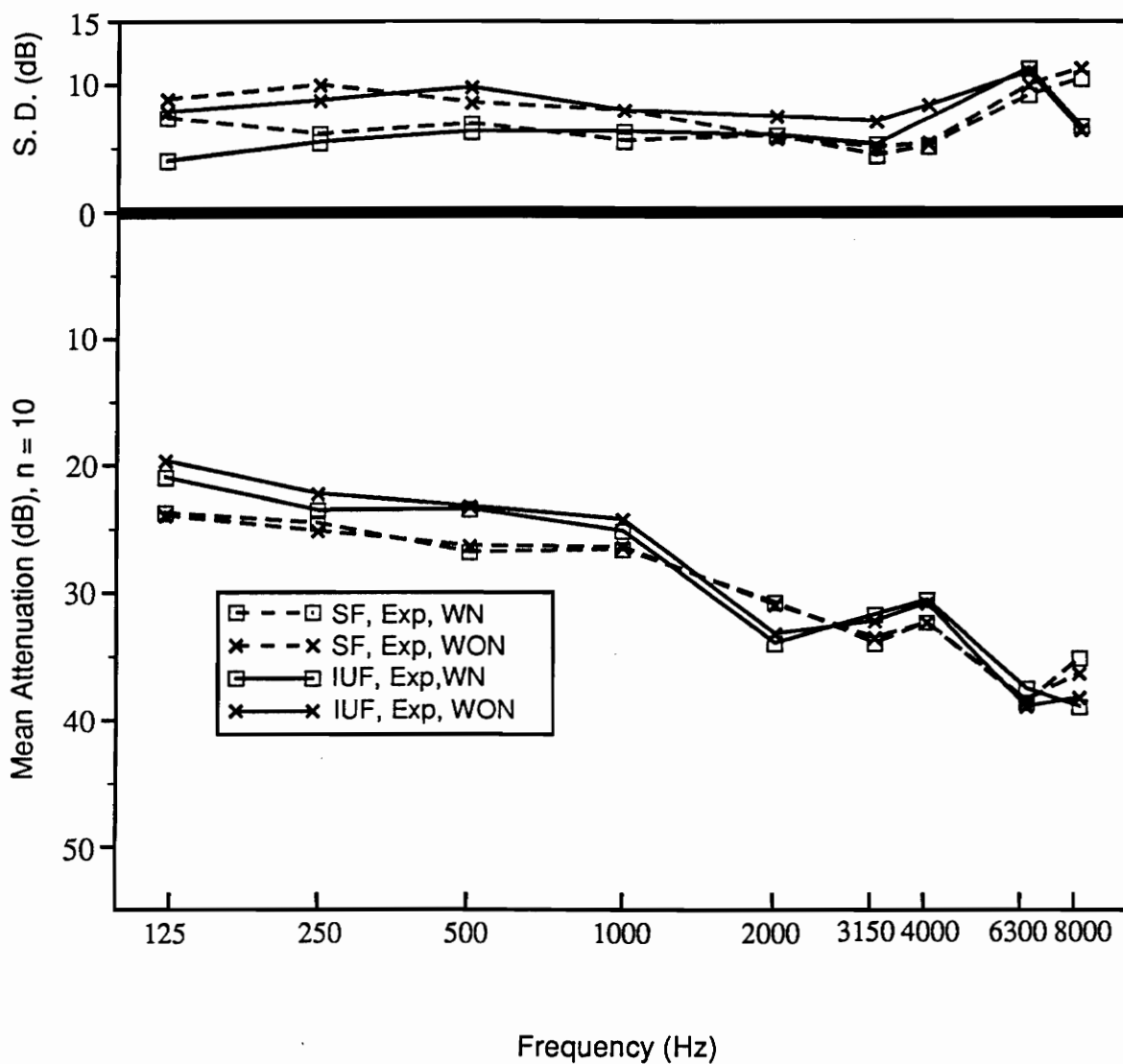


Figure 20. Mean attenuation and standard deviation results for experienced subjects in Experiment 2.

Primary analysis: ANOVA of spectral attenuation data. A total of nine mixed-factors ANOVAs were performed, one for each test frequency. An exemplary ANOVA summary table (125 Hz) is shown in Table 27; the ANOVA summary tables for the other eight frequencies are in Appendix G. The only significant effect ($p < 0.05$) revealed by the overall ANOVA was the Experience Level main effect, which was significant at 125, 250, 500, 1000, 4000, 6300, and 8000 Hz. The mean attenuations and standard deviations of all three main effects are shown in Table 28.

Because many of the F values for the ANOVAs were less than 1.00 at each of the nine test frequencies, inverted F values (Keppel, 1982) were computed for the Fit and Noise main effects and for the Fit-by-Experience Level interaction effect. The F values and the inverted F values are shown in Table 29. Extremely low F values can be an indication that the wrong model was used or that the error term should have been refined. Based on the inverted F table value (Keppel, 1982) the inverted F values would have to be greater than or equal to 250.60 to indicate the wrong model. Based on the values shown in Table 29, the use of the wrong model does not seem to be the case.

Selected attenuation results of Experiment 2 were also analyzed with the RTP which has been previously described. The results of the RTP confirmed the results of the overall ANOVA (none of the treatments analyzed were significantly different at $p < 0.05$). These results appear in tabular form in Appendix G.

Gender blocking. The experimental design was developed such that a blocking factor for gender could be used to refine the error term from

TABLE 27

Experiment 2 ANOVA Summary Table for Attenuation at 125 Hz¹

Source	df	MS	F	p
<u>Between-subjects</u>				
Fit (F)	1	68.45	0.39	0.5374
Experience Level (E)	1	810.26	4.59	0.0390
FxE	1	56.11	0.32	0.5764
Subjects (S)	36	176.49		
<u>Within-subjects</u>				
Noise (Z)	1	0.58	0.04	0.8430
ZxF	1	35.91	2.47	0.1246
ZxE	1	2.38	0.16	0.6880
ZxFxE	1	7.56	0.52	0.4752
<u>ZxS/FE</u>	<u>36</u>	14.53		
Total	79			

¹Other Experiment 2 ANOVA tables for other frequencies appear in Appendix G.

TABLE 28

Mean Attenuation (Standard Deviations) for the Main Effects of Experiment 2

Main Effect	125	250	500	Frequency (Hz)					
				1000	2000	3150	4000	6300	8000
<u>Fit</u>									
SF	19.7 (10.8)	20.2 (11.5)	21.5 (11.7)	22.2 (10.2)	29.0 (6.5)	31.6 (6.1)	29.0 (7.4)	32.6 (13.6)	30.8 (13.6)
IUF	17.9 (8.9)	20.3 (9.5)	21.2 (9.4)	23.2 (8.8)	31.0 (7.5)	31.0 (6.2)	28.6 (8.1)	34.3 (13.0)	33.4 (10.6)
<u>Experience Level</u>									
Nov.	15.6 (11.2)	16.3 (11.5)	17.7 (11.7)	19.8 (11.0)	27.9 (7.3)	29.8 (6.5)	26.1 (7.8)	28.6 (14.4)	27.1 (13.2)
Exper.	22.0 (7.2)	24.1 (7.7)	25.0 (7.8)	25.6 (6.7)	32.1 (6.2)	32.8 (5.4)	31.5 (6.7)	38.3 (9.9)	37.1 (8.7)
<u>Noise</u>									
With	18.9 (9.4)	20.4 (9.9)	21.6 (10.0)	23.0 (9.2)	30.5 (6.9)	31.5 (5.9)	29.0 (7.8)	33.5 (13.0)	32.4 (12.0)
Without	18.7 (10.4)	20.1 (11.1)	21.0 (11.2)	22.4 (9.9)	29.6 (7.3)	31.1 (6.4)	28.6 (7.7)	33.4 (13.7)	31.8 (12.5)

TABLE 29

Experiment 2 Inverted F Ratios

Frequency (Hz)	<u>Between-subjects</u>				<u>Within-subjects</u>	
	Fit (F)		FxE		Noise (Z)	
	F^1	$1/F$	F	$1/F$	F	$1/F$
125	0.39	2.56	0.32	3.13	0.04	25
250	0.00	-	0.66	1.52	0.08	12.50
500	0.01	100	0.91	1.10	0.41	2.44
1000	0.13	7.69	0.97	1.03	0.45	2.22
2000	0.83	1.20	0.14	7.14	2.59	0.39
3150	0.11	9.09	0.40	2.50	0.26	3.85
4000	0.03	33.33	0.30	3.33	0.36	2.78
6300	0.18	5.56	0.26	3.85	0.00	-
8000	0.56	1.79	0.00	-	0.45	2.22

$$^1F_{\text{table}} = F_{(36, 1, 0.05)} = 250.60$$

36 to 32 degrees of freedom. With the Gender blocking variable considered in the model, the overall ANOVA results changed very little. The only significant effects ($p < 0.05$) were again for the main effect of Experience Level (significant at all frequencies tested except 1000 Hz and 3150 Hz) and for the main effect of Gender at 2000 Hz. Therefore, the gender analysis was not pursued further.

Noise Reduction Ratings. The mean attenuations and standard deviations ($n = 10$) for each of the eight unique treatment conditions were used to compute the NRR(98), NRR(84), and NRR(50) as previously discussed. These NRR values are shown in comparison to the manufacturer's NRR(98) value in Table 30.

Ear canal sizes and V-51R plug size data. The ear canal sizes were measured at the end of the data collection visit for each of the subjects, excluding those who had participated in Experiment 1 and had already had the measurements taken. The ear canal sizes and V-51R plug selections are shown in Table 31 for novice subjects and in Table 32 for experienced subjects. These results indicate that the experimenter interaction does not necessarily insure better plug size selection when only visual inspection of inserted plugs is used.

Results of the test for differences between two proportions (Walpole and Myers, 1985) were not significant at the $p < 0.05$ level for any of the comparisons.

Experiment 2 Versus Experiment 1 Data Analysis. The RTP was used to statistically compare attenuation results of the different treatment conditions of Experiment 2 to Experiment 1. The results of the analysis are shown in Table 33. The actual significance level of each comparison

TABLE 30
Experiment 2 NRRs and Manufacturer's NRR for the V-51R plug

Treatment	NRR(98) ²	NRR(84) ³	NRR(50) ⁴	Manufacturer's NRR(98)
				23
SF, NOV, WN	-5.8	6.9	19.1	
SF, NOV, WON	-7.1	6.2	18.8	
	(-6.5) ¹	(6.6)	(19.0)	
IUF, NOV, WN	1.0	11.8	22.4	
IUF, NOV, WON	-0.8	10.4	21.2	
	(0.1)	(11.1)	(21.8)	
SF, EXP, WN	14.7	21.2	27.4	
SF, EXP, WON	11.1	19.4	27.3	
	(12.9)	(20.3)	(27.4)	
IUF, EXP, WN	13.3	19.7	26.0	
IUF, EXP, WON	8.1	16.9	25.5	
	(10.7)	(18.3)	(25.8)	

¹Values in parentheses are the averages of the two preceding column values.

²NRR(98) = protection level theoretically achieved by 98% of user population.

³NRR(84) = protection level theoretically achieved by 84% of user population (often used as an estimate of field NRR).

⁴NRR(50) = protection level theoretically achieved by 50% of user population.

TABLE 31

Ear Canal Sizes and ¹V-51R Plug Size Selections for Experiment 2
Novice Subjects

Fit	Subject	Gender	<u>Canal Size</u>		<u>Plug Size</u>		Percent of Correct Selections
			Left	Right	Left	Right	
SF	1	F	M	M	S	S	55%
	2	F	² S+	M	S	S	
	3	M	EL	L	M	L	
	4	F	ES	S	S	S	
	5	M	EL	EL	EL	EL	
	6	M	M	M	M	M	
	7	M	L	M+	L	L	
	8	M	M+	M+	S	M	
	9	F	S	ES	S	S	
	10	M	L	M	M	M	
IUF	11	M	ES	ES	S	S	30%
	12	F	ES	ES	S	ES	
	13	M	EL	L	M	M	
	14	F	M	M	S	M	
	15	F	S	S	S	S	
	16	F	M	S	S	ES	
	17	M	L	L	M	M	
	18	M	M	S+	S	S	
	19	F	M	M	S	S	
	20	M	M	S+	S	S	

¹V-51R plug sizes: extra small, small, medium, large, extra large.

²Boldface letters indicate correct match with ear canal size.

TABLE 32

Ear Canal Sizes and ¹V-51R Plug Size Selections for Experiment 2
Experienced Subjects

Fit	Subject	Gender	<u>Canal Size</u>		<u>Plug Size</u>		Percent of Correct Selections
			Left	Right	Left	Right	
SF	21	M	² S	S+	S	S	50%
	22	M	M	M	M	M	
	23	F	S	S+	S	S	
	24*	M	M	L	L	L	
	25	F	M	M	S	S	
	26*	F	M	L	M	L	
	27	F	M	S	ES	ES	
	28*	F	EL	L	L	EL	
	29	M	M	M	S	S	
	30*	M	M	L	M	M	
IUF	31*	F	EL	L	L	M	40%
	32	F	M+	L	S	S	
	33*	F	M	M	S	S	
	34*	M	M	M	M	M	
	35	M	S	S	ES	S	
	36*	F	M	L	L	M	
	37	M	M	M	M	M	
	38*	M	L	L	M	M	
	39	M	M	M+	M	M	
	40	F	S	M	M	M	

¹V-51R plug sizes: extra small, small, medium, large, and extra large.

²Boldface letters indicate correct match with ear canal size.

* denotes subjects who also participated in Experiment 1.

TABLE 33

Experiment 2 Attenuation Versus Experiment 1 Attenuation Analysis
for the V-51R Plug by the Randomization Test Procedure

Comparison		N^1	p^2
<u>Experiment 2</u>	<u>Experiment 1</u>		
SF, NOV, WON	- vs - SF, NOV	92	0.092
	- vs - IUF, NOV	597	0.597
	- vs - SF, EXP	467	0.467
	- vs - IUF, EXP	166	0.166
IUF, NOV, WN	- vs - SF, NOV	18	0.018
	- vs - IUF, NOV	815	0.815
	- vs - SF, EXP	868	0.868
	- vs - IUF, EXP	362	0.362
IUF, NOV, WON	- vs - SF, NOV	41	0.041
	- vs - IUF, NOV	629	0.629
	- vs - SF, EXP	613	0.613
	- vs - IUF, EXP	200	0.200
SF, EXP, WON	- vs - SF, NOV	1	0.001
	- vs - IUF, NOV	108	0.108
	- vs - SF, EXP	120	0.120
	- vs - IUF, EXP	487	0.487
IUF, EXP, WON	- vs - SF, NOV	1	0.001
	- vs - IUF, NOV	254	0.254
	- vs - SF, EXP	316	0.316
	- vs - IUF, EXP	844	0.844

N^1 = Number of times $F_{.j} \geq F_{.0}$ for 1000 permutation cycles
where:

$F_{.j}$ = summary statistic of the nine frequency-dependent
F statistics for the permutations where $j = 1$ to 1000;
 $F_{.0}$ = summary statistic of the nine frequency-dependent
F statistics for the actual experimental outcome.

p^2 = Actual significance level of comparison based on 1000
permutation cycles where 1 permutation cycle involves a
single data permutation at each of the nine test frequencies.

indicates how similar or different attenuations were for the treatment conditions of the different experiments. Note that only five treatment conditions of Experiment 2 were used in these comparisons. Economizing the analysis was justified because of the lack of significant differences for the Noise main effect of Experiment 2.

The SF, Novice treatment condition attenuation results of Experiment 1 were significantly different ($p < 0.05$) from four of the five Experiment 2 treatment conditions that were used for comparison with the exception being the SF, NOV, WON treatment condition. These results agree with the ANOVA post hoc analysis of the Fit-by Experience Level interaction of Experiment 1.

The SF, NOV, WON treatment condition attenuation results of Experiment 2 were not significantly different ($p > 0.05$) from any of the Experiment 1 treatment condition results. These results were similar to the ANOVA results of the Fit-by-Experience Level interaction of Experiment 2. The comparisons between the treatment conditions involving experienced subjects were not significant ($p > 0.05$), thus indicating that the experience levels of transfer-to-experienced subjects and entered-as-experienced subjects were for all practical purposes equivalent.

These results also indicate that the fitting condition does not significantly affect the attenuation achieved by experienced subjects, as was shown by the previous analyses of both experiments.

Laboratory Results Compared to Field Results

The primary purpose of the RTP was to compare the attenuation results of this research to previous field attenuation results. One of the objectives of this research was to identify a valid statistical technique which could be used to compare laboratory results to field results to help determine the validity of laboratory tests in predicting actual protection performance. The randomization test proved to be a practical, powerful, and valid tool for performing the analysis. The first step in the development of the randomization test was to define the set of field data that was to be compared to the current laboratory results.

Field study selection. The field studies that were evaluated for consideration in the comparisons were the Ontario Hydro study (Behar, 1985), the NIOSH study of six insert-type hearing protectors (Edwards et al., 1982; Lempert and Edwards, 1983; NIOSH, 1978), and the NIOSH and DuPont study of the E-A-R foam plug (Edwards and Green, 1987). All of these studies have been previously discussed in detail in the Literature Review.

The results of the Ontario Hydro study were not acceptable for use because the data were only collected for six frequencies instead of nine and because the testing protocol was relaxed from the standard protocol (i.e., ANSI S3.19-1974). Another factor that led to the dismissal of this study was that the ambient noise levels measured in the testing booths were above the limits specified by ANSI S3.19-1974.

The results of the NIOSH study (Edwards et al., 1982; Lempert and

Edwards, 1983; NIOSH, 1978) of six insert-type hearing protectors were accepted for comparison to the results of the current research. The NIOSH study field results were actually obtained from two separate studies, one in 1976 (NIOSH, 1978) and one in 1981 (Edwards et al., 1982). Each of these studies used the same test equipment and testing protocols as previously discussed in the Literature Review. The field attenuation results of the V-51R pre-molded plug and the E-A-R foam plug were used for comparisons against those plugs' results from the current study.

The E-A-R foam plug results obtained from the DuPont plants as reported by Edwards and Green (1987), were not included in the comparison. These studies used similar equipment and protocol to the NIOSH study, but the results were dismissed from consideration due to practical reasons. The DuPont results were obtained in two plants with well-established hearing conservation programs and were shown to be significantly ($p < 0.05$) better than the NIOSH results (Edwards and Green, 1987). The ASL experimenters decided that the DuPont attenuation results were not accurate representations of typical field attenuation due to bias caused by the long term HCPs.

Field data selection. The only field data used in comparisons to the current research were those of the NIOSH studies of 1976 and 1981. For both the E-A-R foam plug and the V-51R pre-molded plug, there were seven subjects (workers) in each of the following four field conditions: (1) high noise levels with active job description, (2) high noise levels with passive job description, (3) low noise levels with active job

description, and (4) low noise levels with passive job description (Edwards et al., 1982; Lempert and Edwards, 1983; NIOSH, 1978).

The V-51R plug field results were obtained from three manufacturing plants where 28 workers participated at each plant giving a total of 84 workers. These 84 workers were divided equally among the four field conditions, thus, resulting in 21 workers per field condition.

Each of the workers had a total of five attenuation tests (one occluded and one unoccluded measure per test). Each test was binaural at 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. The raw data is shown in Appendix H. The results of the first test were not used in the RTP because they were found to be significantly ($p < 0.05$) higher than the other four tests' results by the NIOSH investigators (Lempert and Edwards, 1983; NIOSH, 1978).

Some data points were missing from the raw data. All workers had at least two complete test scores available (2 data points at each of the nine frequencies) without including the first test. All available measures were used in the comparisons, even if they did not make a full set of nine.

Of the maximum possible 84 field data points on the V-51R plug available for comparison at any one frequency, one was randomly selected for exchange with one of the 20 laboratory data points (raw data not averaged for each subject) at each frequency for comparison to each of the unique treatment cells.

The E-A-R plug field results were obtained from four manufacturing plants where 28 workers participated at each plant giving a total of 112

workers. These 112 workers were divided equally among the four field conditions, thus providing 28 workers per field condition.

Each of the workers had a total of five binaural attenuation tests at each of the nine test frequencies as mentioned previously (raw data shown in Appendix H).

For some of the workers, not all of the data for all frequencies was available because of problems during data collection. The workers whose data were inadequate were not included; therefore, other workers' records were discarded at random to balance the sample sizes across the four conditions. The number of workers per condition was reduced to 26, giving a total of 104 individual sets of data used for comparison.

As mentioned before, the results of the first test were not used in the RTP because they were found to be significantly ($p < 0.05$) higher than the other four tests' results (Edwards et al., 1982; Lempert and Edwards, 1983). All of the workers' records that were used for comparison had at least two complete test scores available (2 data points at each of the nine frequencies), without including the first test.

Of the maximum possible 104 field data points available for comparison at any one frequency, one was randomly selected for exchange with one of the 20 laboratory data points at each frequency for comparison to each of the unique treatment cells.

Laboratory data selection. All of the data collected for Experiment 1 were used for comparison to the appropriate field data. For the results of Experiment 2, only five of the eight unique laboratory

treatment cells were compared to the field data. Economizing the analysis was justified because of the lack of significant differences for the Noise main effect. The treatments that contained the With Fitting Noise (WN) level were not analyzed with the exception of the IUF, Novice, WN treatment. This treatment was analyzed because its mean attenuations differed the most from its counterpart condition without fitting noise, the IUF, Novice, WON treatment (cumulative differences of mean attenuations across all nine frequencies was 14.8 dB). Of the five unique treatment cells of Experiment 2 considered for comparison, the 20 attenuation measures obtained for each of the nine test frequencies were used for comparison to the appropriate field data.

Permuting the data. For each of the nine test frequencies, one field data point and one experimental data point were randomly selected for exchange. This exchange of the data is known as a permutation. After each permutation, the test statistic was calculated for each frequency.

In testing the SAS programs written to permute the data and compute the test statistic for the RTP, the values of the statistic and the significant levels were compared between 100, 500, and 1000 data permutations for the overall results. The results of 1000 data permutations differed only slightly from those of 100 permutations. Because of the relatively fast running time, all tests were therefore performed with a full set of 1000 data permutations.

Calculating the statistic. An F statistic (the actual statistic was the F typically used in ANOVA calculations) was calculated at each

frequency for each data permutation. The nine F statistics associated with the nine test frequencies for each data permutation were used to compute a summary statistic for each permutation. The overall significance level for each comparison was computed based on 1000 summary statistics taken across the nine test frequencies. A table representing the statistics and permutations is shown in Table 34.

Heterogeneity of the field data across conditions. Before comparisons to the laboratory results were made, the field data were analyzed with the RTP to determine if the four different field conditions could be collapsed into one set of data for V-51R plug and one set of data for the E-A-R plug. The results of the six possible comparisons within each of the two plug types are shown in Table 35. Some results were significantly different at the $p < 0.05$ level; therefore, the data were not collapsed across the four field conditions.

Experiment 1 results vs. field results: V-51R plug. The RTP results of the comparisons between Experiment 1 and the field for the V-51R plug are shown in Table 36. The significant levels of the RTP comparisons indicated that only the SF, Novice laboratory condition yielded results not significantly different from the field results at $p < 0.05$.

Comparisons of the means of the field data to the means of the SF, Novice laboratory condition of the current research for the V-51R plug revealed a minimum difference of 0.1 dB at 250 Hz and a maximum difference of 3.1 dB at 8000 Hz. The means for the field results of the V-51R plugs are shown in Table 6 in the Literature Review.

TABLE 34

Tabular Representation of Data Permutations with the Randomization Test Procedure

Frequency (Hz)					
125	250	500	...	8000	
Individual Frequency Statistics					Summary Statistics
¹ $F_{1,0}$	$F_{2,0}$	$F_{3,0}$	...	$F_{9,0}$	$F_{.0}$ ²
Exchange (permute) data points					
$F_{1,1}$	$F_{2,1}$	$F_{3,1}$	...	$F_{9,1}$	$F_{.1}$ ³
Exchange (permute) data points					
$F_{1,2}$	$F_{2,2}$	$F_{3,2}$	...	$F_{9,2}$	$F_{.2}$
Exchange (permute) data points					
.	.	.		.	.
.	.	.		.	.
.	.	.		.	.
$F_{1,1k}$	$F_{2,1k}$	$F_{3,1k}$	...	$F_{9,1k}$	$F_{.1k}$

¹ F_{ij} where $i = 1, 2, 3, \dots, 9$ for the test frequency
 $j = 0$ for the actual experimental outcome
 $j = 1, 2, 3, \dots, 1000$ for the permutation number.

² $F_{.0}$ = summary statistic of the nine frequency-dependent F statistics for the actual experimental outcome which all of the permuted outcomes are compared to for the calculations of the significant levels.

³ $F_{.j}$ = summary statistic of the nine frequency-dependent F statistics for the permutations where $j = 1$ to 1000.

TABLE 35

Statistical Significance Levels of Field Attenuation Data¹
 Comparisons by the Randomization Test Procedure

HPD	Comparison	N ²	p ³
V-51R			
	High/Active - vs - High/Passive	272	0.272
	High/Active - vs - Low/Active	289	0.289
	High/Active - vs - Low/Passive	30	0.030
	High/Passive - vs - Low/Active	937	0.937
	High/Passive - vs - Low/Passive	422	0.422
	Low/Active - vs - Low/Passive	213	0.213
E-A-R			
	High/Active - vs - High/Passive	664	0.664
	High/Active - vs - Low/Active	17	0.017
	High/Active - vs - Low/Passive	147	0.147
	High/Passive - vs - Low/Active	42	0.042
	High/Passive - vs - Low/Passive	302	0.302
	Low/Active - vs - Low/Passive	342	0.342

¹Field attenuation data for V-51R plug: NIOSH Publication No. 79-115 (NIOSH, 1978); E-A-R plug: NIOSH Contract No. 210-81-3001 (Edwards et al., 1982).

²N = Number of times $F_{.j} \geq F_{.0}$ (reference Table 34) for 1000 permutation cycles where:

$F_{.j}$ = summary statistic of the nine frequency-dependent F statistics for the permutations where $j = 1$ to 1000;

$F_{.0}$ = summary statistic of the nine frequency-dependent F statistics for the current experimental outcome.

³p = Actual significance level of comparison based on 1000 permutation cycles where 1 permutation cycle involves a single data permutation at each of the nine test frequencies.

TABLE 36

Comparisons of V-51R Plug Experiment 1 Data to Field Attenuation Data¹ by the Randomization Test Procedure

Comparison	² N	³ p
SF, NOV - vs - High/Active	374	0.374
- vs - High/Passive	761	0.761
- vs - Low/Active	799	0.799
- vs - Low/Passive	218	0.218
IUF, NOV - vs - High/Active	36	0.036
- vs - High/Passive	9	0.009
- vs - Low/Active	3	0.003
- vs - Low/Passive	1	0.001
SF, EXP - vs - High/Active	21	0.021
- vs - High/Passive	5	0.005
- vs - Low/Active	3	0.003
- vs - Low/Passive	1	0.001
IUF, EXP - vs - High/Active	7	0.007
- vs - High/Passive	3	0.003
- vs - Low/Active	1	0.001
- vs - Low/Passive	1	0.001

¹Field attenuation data for V-51R plug are from NIOSH Publication No. 79-115 (NIOSH, 1978).

²N = Number of times $F_j \geq F_0$ (reference Table 34) for 1000 permutation cycles^j where:

F_j = summary statistic of the nine frequency-dependent F statistics for the permutations where $j = 1$ to 1000;

F_0 = summary statistic of the nine frequency-dependent F statistics for the current experimental outcome.

³p = Actual significance level of comparison based on 1000 permutation cycles where 1 permutation cycle involves a single data permutation at each of the nine test frequencies.

Plots of (1) the NIOSH mean field data (NIOSH, 1978) for the V-51R plug (all four field conditions collapsed across the three manufacturing plants), (2) the NIOSH mean laboratory data (Table 6 in Literature Review) presented in Lempert and Edwards (1983), and (3) the mean attenuation results of Experiment 1 with the V-51R plugs are presented in Figure 21. Based on the results of Experiment 1 alone, it appears that the SF, Novice protocol would yield attenuation results which would closely model, but still slightly overestimate, the field data for the V-51R plug.

Experiment 1 results vs. field results: E-A-R plug. The RTP results of the comparisons between Experiment 1 and the field for the E-A-R plug are shown in Table 37. All of the comparisons yielded significantly different results at the $p < 0.005$ level. The RTP was not performed to provide significant values for the separate test frequencies nor directionality of the results. Comparisons of plots of the data reveal that the attenuation results of Experiment 1 are higher than the field results for the E-A-R plug.

Comparisons of the means of the field data to the means of the SF, Novice condition (perhaps the condition most like that of the field) of the current research for the E-A-R foam plug revealed a minimum difference of 4.1 dB at 125 Hz (compared against E-A-R foam type A) and a maximum difference of 22.2 dB at 6300 Hz (compared against E-A-R foam type B). The E-A-R plug data was collapsed across the two foam types A and B (which differed only in color) for the RTP analysis. The means for the field results of these two types of E-A-R foam plugs are shown in Table 6 in the Literature Review.

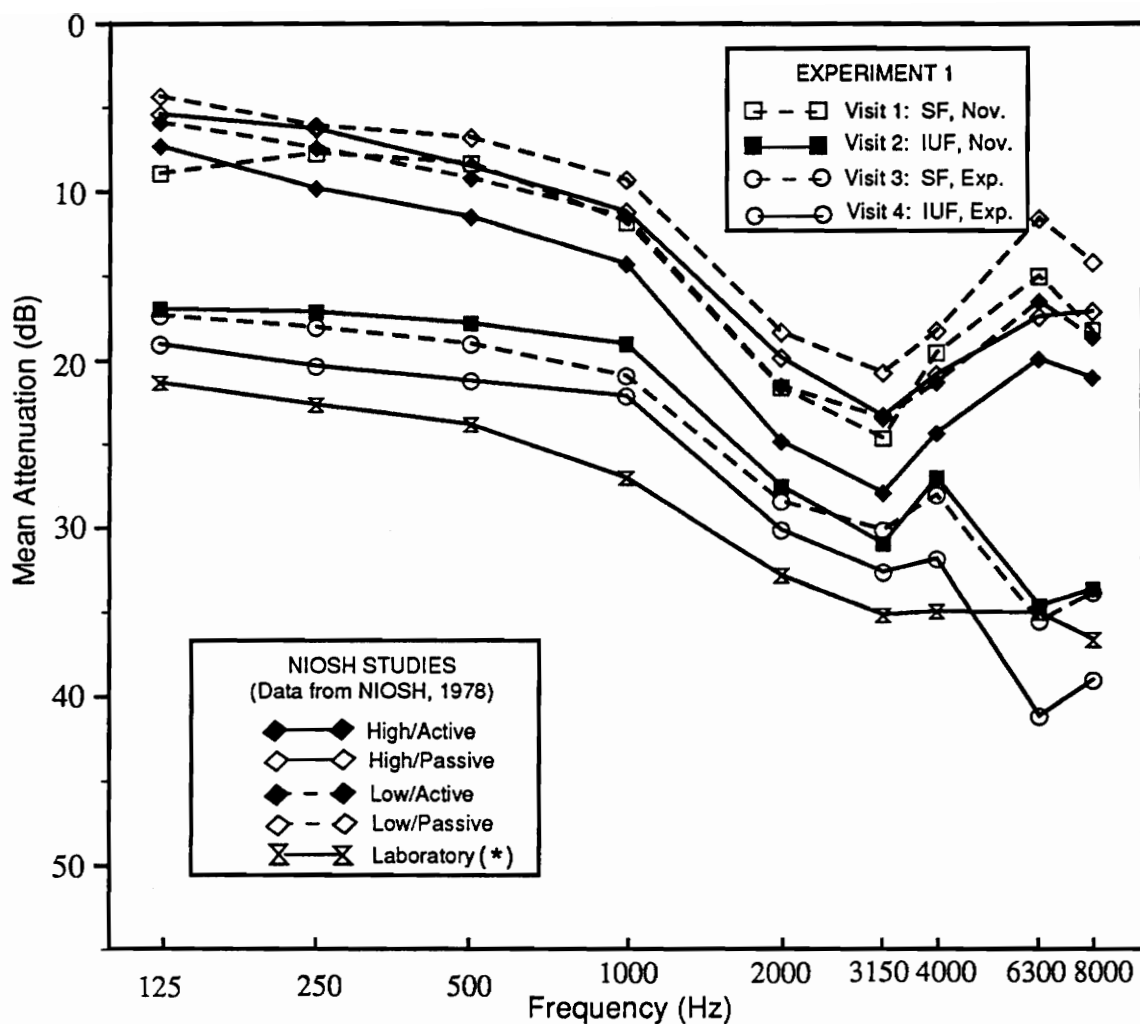


Figure 21. Mean attenuation of field and laboratory results with Experiment 1 results for the V-51R plug (Raw data of previous study from NIOSH, 1978; prior laboratory (*) results from Lempert and Edwards, 1983).

TABLE 37

Comparison of E-A-R Plug Experiment 1 Attenuation Data to Field Attenuation Data¹ by the Randomization Test Procedure

Comparison	N ²	p ³
SF, NOV - vs - High/Active	4	0.004
- vs - High/Passive	1	0.001
- vs - Low/Active	1	0.001
- vs - Low/Passive	2	0.002
IUF, NOV - vs - High/Active	1	0.001
- vs - High/Passive	1	0.001
- vs - Low/Active	1	0.001
- vs - Low/Passive	1	0.001
SF, EXP - vs - High/Active	1	0.001
- vs - High/Passive	1	0.001
- vs - Low/Active	1	0.001
- vs - Low/Passive	1	0.001
IUF, EXP - vs - High/Active	1	0.001
- vs - High/Passive	1	0.001
- vs - Low/Active	1	0.001
- vs - Low/Passive	1	0.001

¹Field attenuation data for E-A-R plug are from NIOSH Contract No. 210-81-3001 (Edwards et al., 1982).

²N = Number of times $F_j \geq F_0$ (reference Table 34 for 1000 permutation cycles) where:
 F_j = summary statistic of the nine frequency-dependent F statistics for the permutations where j = 1 to 1000;
 F_0 = summary statistic of the nine frequency-dependent F statistics for the actual experimental outcome.

³p = Actual significance level of comparison based on 1000 permutation cycles where 1 permutation cycle involves a single data permutation at each of the nine test frequencies.

Plots of (1) the NIOSH mean field data (Edwards et al., 1982) for the E-A-R plugs (all four field conditions collapsed across the four manufacturing plants), (2) the NIOSH mean laboratory data (Table 6 in the Literature Review) presented in Lempert and Edwards (1983), and (3) the mean attenuation results of Experiment 1 with the E-A-R foam plug are presented in Figure 22. Based on the Experiment 1 results of the E-A-R foam plug, it seems unlikely that any of the laboratory protocols used would yield attenuation results which would reasonably predict this plug's field performance.

Experiment 2 results vs. field results: V-51R plug. The RTP results of the comparisons between Experiment 2 and the field for the V-51R plug are shown in Table 38. Two of the laboratory conditions, SF, Novice, WON and IUF, Novice, WON yielded results that were statistically similar to the High/Active field results at $p < 0.05$. The SF, Novice, WON was also statistically similar to the High/Passive field results at $p < 0.05$.

Comparisons of the means of the field data to the means of the SF, Novice, WON laboratory conditions of the current research revealed a minimum difference of 5.8 dB at 2000 Hz and a maximum difference of 13.3 dB at 6300 Hz. The means for the field results of the V-51R plugs are shown in Table 6 in the Literature Review.

Plots of (1) the NIOSH mean field data for the V-51R plug (all four field conditions collapsed across the three manufacturing plants), (2) the NIOSH mean laboratory data (Table 6 in Literature Review) presented in Lempert and Edwards (1983), and (3) the Experiment 2 mean attenuation

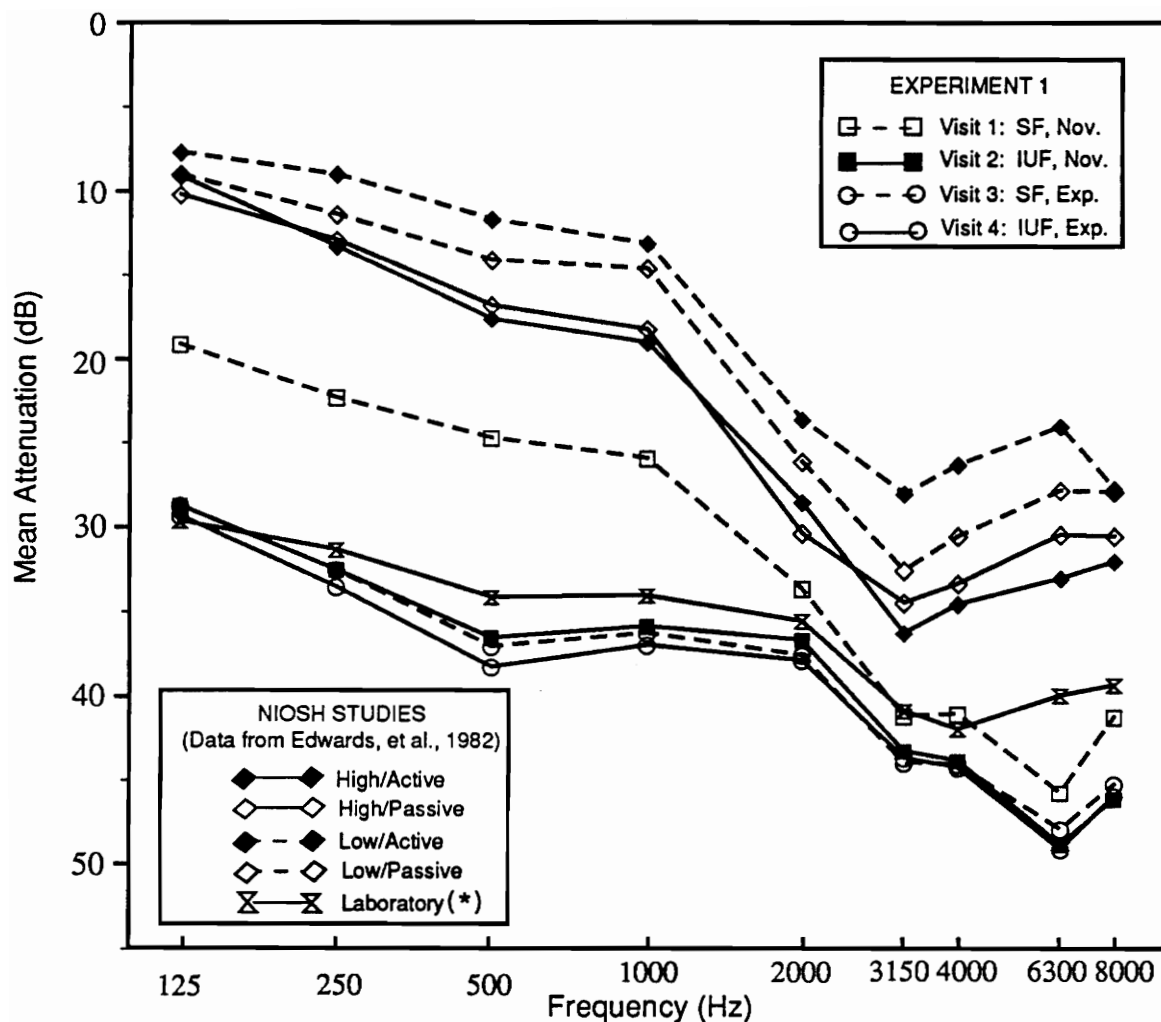


Figure 22. Mean attenuation of field and laboratory results with Experiment 1 results for the E-A-R foam plug (Raw data of previous study from Edwards et al., 1982; prior laboratory (*) results from Lempert and Edwards, 1983).

TABLE 38

Comparison of V-51R Plug Experiment 2 Attenuation Data to Field¹
Attenuation Data by the Randomization Test Procedure

Comparison	N ²	p ³
SF, NOV, WON - vs - High/Active	194	0.194
- vs - High/Passive	70	0.070
- vs - Low/Active	37	0.037
- vs - Low/Passive	3	0.003
IUF, NOV, WN - vs - High/Active	42	0.042
- vs - High/Passive	15	0.015
- vs - Low/Active	4	0.004
- vs - Low/Passive	1	0.001
IUF, NOV, WON - vs - High/Active	116	0.116
- vs - High/Passive	33	0.033
- vs - Low/Active	15	0.015
- vs - Low/Passive	1	0.001
SF, EXP, WON - vs - High/Active	2	0.002
- vs - High/Passive	2	0.002
- vs - Low/Active	1	0.001
- vs - Low/Passive	1	0.001
IUF, EXP, WON - vs - High/Active	3	0.003
- vs - High/Passive	1	0.001
- vs - Low/Active	1	0.001
- vs - Low/Passive	1	0.001

¹Field attenuation data for V-51R plug are from NIOSH Publication No. 79-115 (NIOSH, 1978).

²N = Number of times $F_{.j} \geq F_{.0}$ for 1000 permutation cycles where:

$F_{.j}$ = summary statistic of the nine frequency-dependent F statistics for the permutations where j = 1 to 1000;

$F_{.0}$ = summary statistic of the nine frequency-dependent F statistics for the actual experimental outcome.

³p = Actual significance level of comparison based on 1000 permutation cycles where 1 permutation cycle involves a single data permutation at each of the nine test frequencies.

results of novice subjects with the V-51R plugs are presented in Figure 23. Based on the results of Experiment 2 alone, the protocols that seem most likely to yield attenuation results that would reasonably predict the field performance of the V-51R plug would be the SF, Novice, WON and IUUF, Novice, WON.

Overall, the results of the statistical comparisons of Experiment 1 and Experiment 2 to the field data indicated that the SF, Novice treatment (without fitting noise) was a protocol which yielded attenuation results not significantly different ($p > 0.05$) from certain field attenuation results with the V-51R plug.

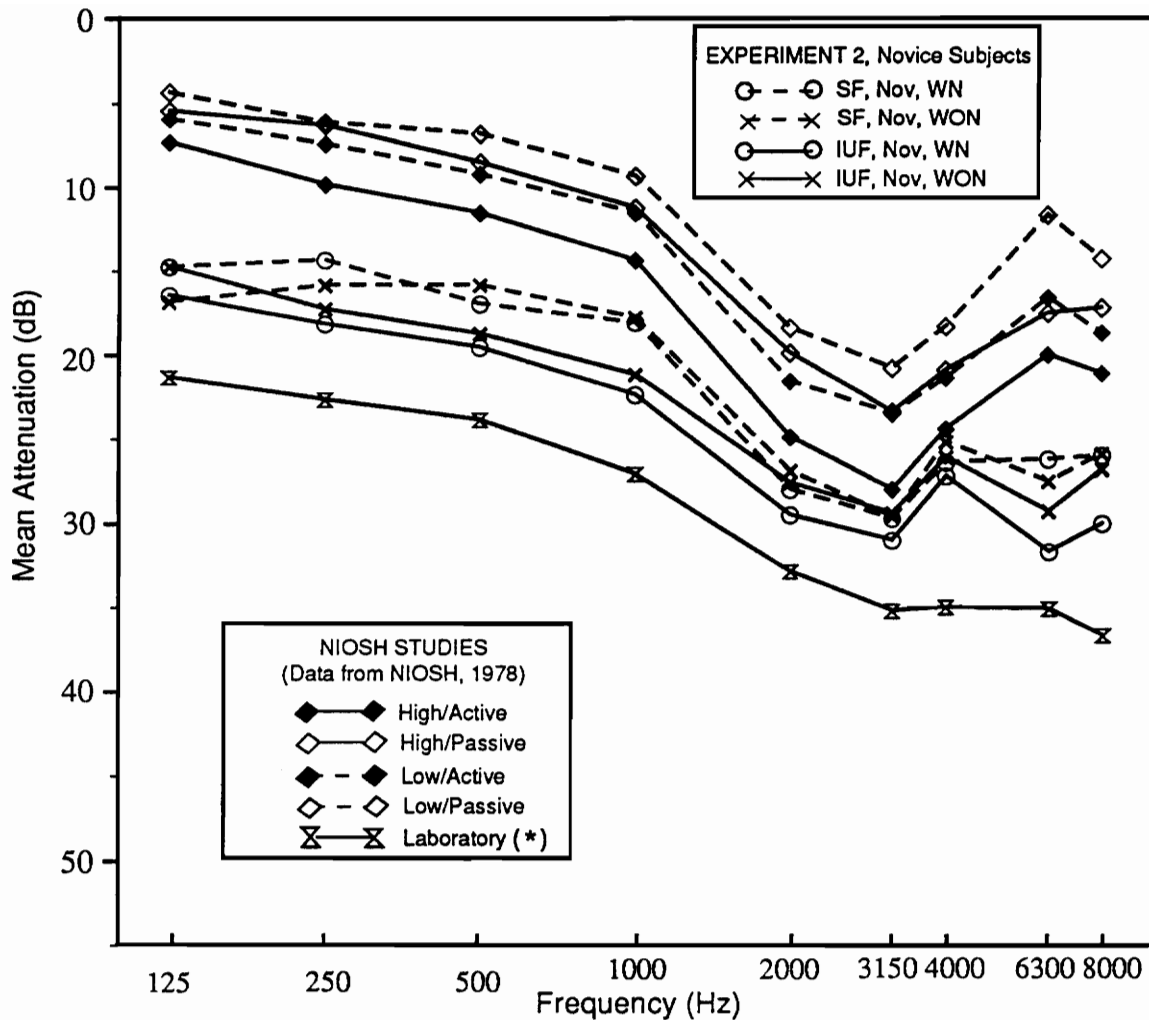


Figure 23. Mean attenuation of field and laboratory results with Experiment 2 novice subject results for the V-51R plug (Raw data of previous study from NIOSH, 1978; prior laboratory (*) results from Lempert and Edwards, 1983).

DISCUSSION AND CONCLUSIONS

The objectives of this research, as stated in the Research Objectives section, were largely met. In this section, discussion and conclusions based on this research are presented along with comparisons of the results to prior research findings.

Fitting Noise: Research Objective 1

The first research objective was to determine the effects of fitting noise on attenuation results. In Experiment 2, the fitting noise was intended to be consciously used as an aid in HPD fitting by both novice and experienced subjects in both SF and IUF conditions. The hypothesis was that the presentation of fitting noise and instructions for its proper use would result in significantly higher (better) attenuation than that achieved without the fitting noise. The results of this research indicate that the hypothesis cannot be accepted, at least not for the V-51R plug. It should be noted that the V-51R plugs were chosen for use in Experiment 2 because their fit and seal are considered easier to adjust than some other plugs, especially user-molded foam plugs.

Neither the Fitting Noise main effect, nor any of the interactions with the fitting noise were significant for any of the nine test frequencies. The mean attenuation results (Table 28) for the Fitting Noise main effect show only slightly higher (less than 1.0 dB at all test frequencies) spectral attenuation for the With Noise condition. This directional difference, although present in the results, was not

large enough to generate a p value less than 0.05, which was chosen as the significance level before the experiment.

Because a uniform directional difference (higher attenuation with the noise) was present at all of the nine test frequencies, the possible benefits of using fitting noise cannot be completely ruled out based on the results of this experiment. Although the results were neither practically nor statistically different with the current experimental design, a more sensitive design, perhaps with different HPDs, may have indicated larger differences. With this possibility in mind, a statistical power analysis was performed on the data set.

Before the current research began, the probability [alpha level] of having a type I error (i.e., false rejection of a true null hypothesis) was set at 0.05. Once this level was chosen, the probability [beta level] of having a type II error (i.e., failure to reject a false null hypothesis) was unknown until the results were obtained. The statistical power of an experiment is the probability that a type II error will not occur [power = $1 - \text{Beta level}$]. Power is dependent on the following factors: (1) size of the treatment effects, (2) sample size, (3) degree of error variance, and (4) the significance [alpha] level (Keppel, 1982).

Based on the mean attenuation results of the Fitting Noise main effect and the error variance at each test frequency, power calculations (shown in Appendix I) were performed to determine the power level of the experiment with regards to fitting noise. The power of the experiment was very low for all nine test frequencies. The highest power level was

0.50 at 2000 Hz; the power levels for the other frequencies were less than 0.30. To achieve a power level of 0.90 while maintaining alpha at 0.05, 20 subjects per unique treatment cell would have been necessary to detect the difference at 2000 Hz, and more than 100 subjects per unique treatment cell would have been necessary to detect the differences at the other frequencies.

Using the error variances of the Experiment 2 results, further fitting-noise power calculations were computed to determine the number of subjects per unique treatment cell that would be necessary to detect a minimum difference of 2 dB for an identical mixed-factors design (3 factors with 2 levels each). The number of subjects necessary to have power of 0.90 and significance level of 0.05 would be the following: 125 Hz: $s = 10$; 250 Hz: $s = 14$; 500 Hz: $s = 14$; 1000 Hz: $s = 12$; 2000 Hz: $s = 5$; 3150 Hz: $s = 8$; 4000 Hz: $s = 9$; 6300 Hz: $s = 18$; 8000 Hz: $s = 14$. From these values, it can be concluded that the current experiment included enough subjects to detect differences of 2 dB as significant at 125, 2000, 3150, and 4000 Hz, had they been present; but, for the other five frequencies, more subjects would have been needed.

Previous studies concerning fitting noise. Two previous studies (detailed descriptions are given in the Literature Review) that involved testing subjects with and without fitting noise were reported by Casali and Epps (1986), and Berger (1981, 1983a). The results of the two

studies concerning fitting noise were as follows:

A. Casali and Epps (1986): The results of the study were as follows:

1. Fitting with use of fitting noise provided higher mean attenuations than fitting with no instructions for all nine frequencies, data collapsed across 5 earplugs.
2. Fitting conditions with:
 - (a) fitting noise only,
 - (b) manufacturer's package instructions only,
 - (c) detailed instructions from experimenter onlydid not produce statistically different ($p > 0.05$) results for data collapsed across 5 earplugs.

B. Berger (1981 and 1983a): The results of the study were as follows:

The spectral attenuation achieved with the use of fitting noise was not significantly different (based on the F -test [ANOVA], $p > 0.05$) from the attenuation achieved without the use of fitting noise.

Figure 24, adapted from Casali and Epps (1986), shows the attenuation results for the five instruction techniques of that study collapsed across the five earplugs evaluated. Figure 25, also adapted from Casali and Epps (1986), shows the attenuation results achieved with a pre-molded, cone-shaped earplug [Tasco RD-1] which was a similar design to the V-51R plug. The results show that equivalent or less attenuation was achieved with the Auditory Feedback-only [fitting noise] treatment condition as compared to the Manufacturers' Instructions-only or the Detailed Instructions-only treatment conditions.

The results of the present research confirm the ANOVA results reported by Berger (1981 and 1983a). However, further investigation by Berger indicated a trend of higher spectral mean attenuation with the presence of fitting noise (Berger, 1981 and 1983a). Such a trend was also found in this research.

Currently, fitting noise requirements are included in both ANSI S3.19-1974 and ANSI S12.6-1984 standards for HPD attenuation measurement. These requirements are listed below for each of the standards:

ANSI S3.19-1974, Section 3.3.3.1:

(1) Subject Fit: (a) After the hearing protector has been installed, a white noise shall be introduced whose overall sound pressure level at the listener's position is 60 to 70 dB with reference to 20 micro N/m^2 (20 micro Pa).

The listener shall be instructed to manipulate

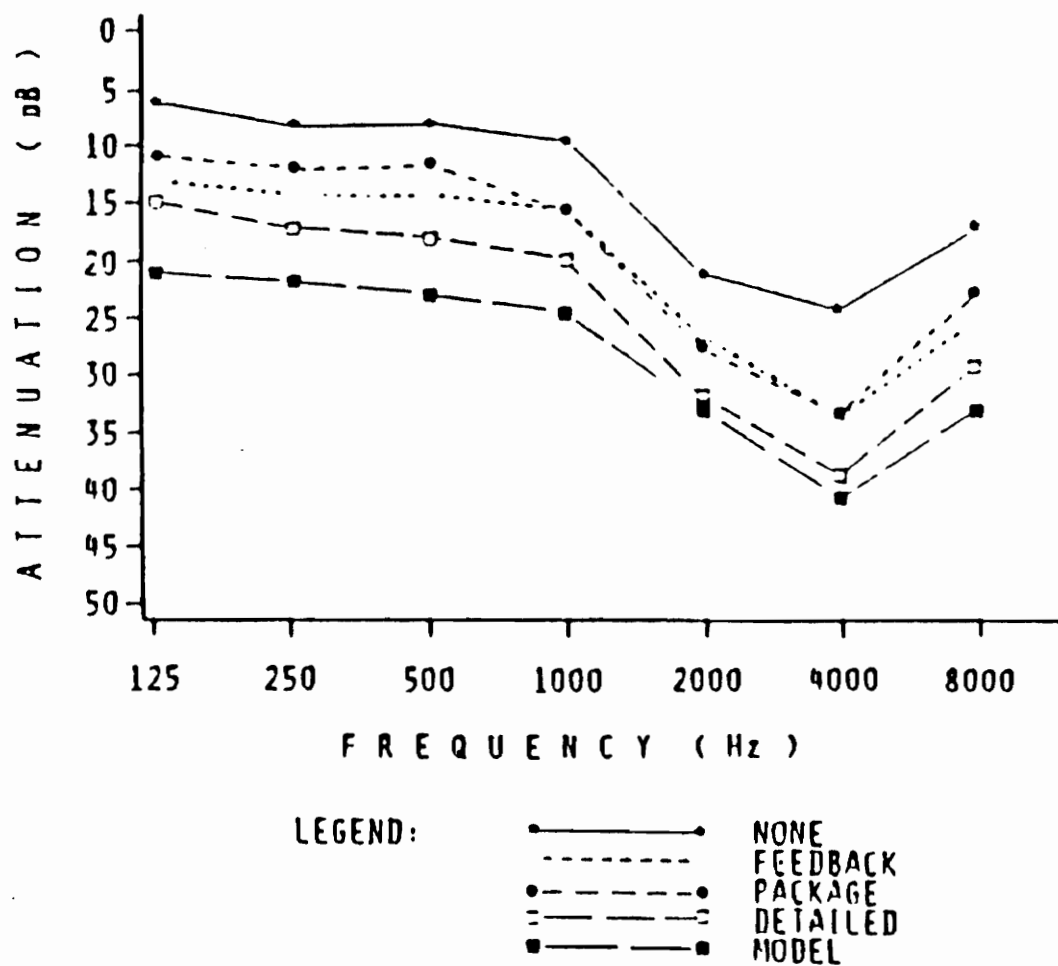


Figure 24. Attenuation results achieved with each insertion-instruction technique (Data collapsed across five earplug types) (Adapted from Casali and Epps, 1986).

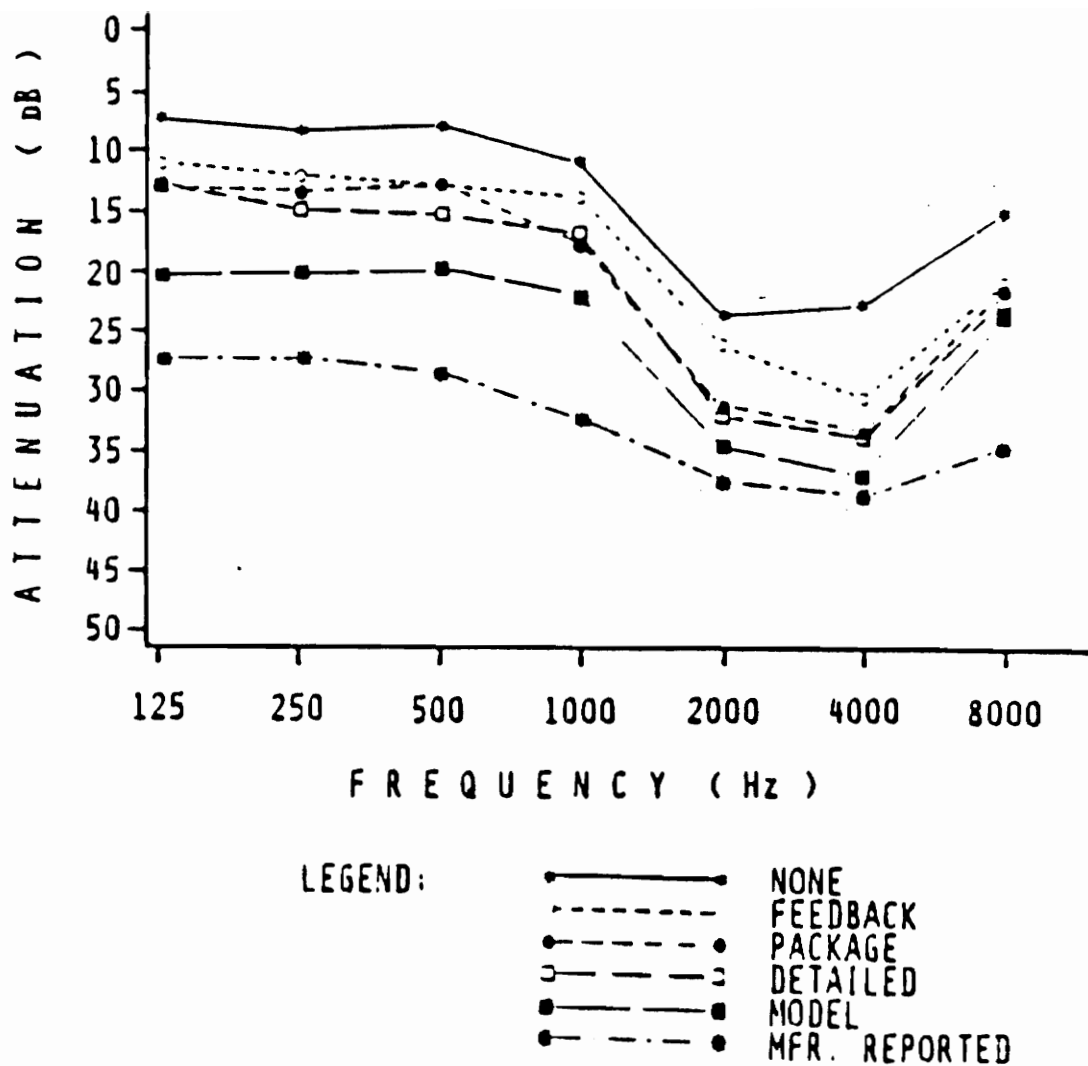


Figure 25. Noise attenuation achieved with pre-molded cone-shaped earplug [Tasco RD-1] for each insertion-instruction condition (Adapted from Casali and Epps, 1986).

the hearing protector until satisfied that the noise is minimal (ANSI, 1974, p. 5).

ANSI S12.6-1984, Section 3.3.3.2:

Earplugs shall be inserted and earmuffs shall be put on by the listener in the test chamber. After the hearing protector has been installed, a noise shall be introduced whose overall sound pressure level at the listener's position is 60 to 70 dB with reference to 20 micro Pa. The listener shall be instructed to manipulate the hearing protector until satisfied that the noise is minimal (ANSI, 1984, p. 5).

It is believed that the purpose for inclusion of fitting noise in the standards was: (1) to simulate industrial noise which may provide auditory feedback to workers, and (2) to optimize attenuation achieved with the experimenter-supervised fit condition.

Conclusions. Based on the obtained data and the statistical tests that were performed, it is concluded that insertion-instruction techniques supplemented with fitting noise and fitting-noise instructions will not yield significantly higher (better) spectral attenuation than insertion-instruction techniques alone. However, because a uniform directional difference of higher mean attenuation was present in the With Fitting Noise condition, it is suggested that future

experiments be conducted to determine if this monotonic difference is stable (in essence, not due to random variation alone).

Overall, the potential benefits that fitting noise may offer to subjects need to be weighed against the additional costs and efforts required for its presentation and use. Future research may show that there is a trend of higher mean attenuation with the use of fitting noise, but the increased attenuation may not be practically significant enough to warrant its use in HPD testing standards. The author suggests that ANSI S12/WG11 take the results of this research into consideration and for it to conduct further research to address the usefulness of fitting noise before ANSI S12.6-1984 is revised. Based solely on the results of this research, the author does not believe that fitting noise should be required in HPD testing standards for earplug devices.

Experiment 1 versus Experiment 2: Research Objective 2

The second research objective was to determine if differences occurred between (1) testing the fitting conditions and experience levels as within-subjects factors as in the ANSI pilot study (i.e., Experiment 1), and (2) testing fitting conditions and experience levels as between-subjects factors as in Experiment 2. The hypothesis was that there would be detectable differences in the attenuation results between the two experiments because of the differences in their experimental designs. Specifically, differences were expected to have occurred between the IUF, Novice conditions of the two experiments and between the conditions involving experienced subjects. Attenuation differences did occur for various testing conditions between the two experiments; however, because no significant differences occurred for similar treatment conditions, including IUF, Novice conditions and those conditions involving experienced subjects, the hypothesis could not be accepted based on the *F*-test results from the randomization procedure.

Overall, the comparisons between treatment conditions of the two experiments (V-51R plug only) by the RTP (Table 33) revealed significant differences only for the comparisons involving the Experiment 1, SF, Novice treatment condition to the non-similar conditions of Experiment 2 (i.e., not the SF, Novice conditions).

As previously discussed, Experiment 2 was necessary to properly investigate the effect of fitting noise on attenuation because fitting noise was a confound in the design of Experiment 1. Experiment 2 was also warranted because the Fit effect of Experiment 1 was confounded by

order effects due to the within-subjects design (i.e., IUF always followed SF) The following section discusses some of the advantages and disadvantages of within-subjects designs.

Discussion of within-subjects designs. Within-subjects (repeated measures) designs are efficient and sensitive (statistically powerful) by nature, especially in comparison to between-subjects designs. The main advantage of within-subjects designs is the control of subject heterogeneity (i.e., individual differences) that it offers (Keppel, 1982). It should be noted that individual subjects respond differently, even under the same conditions of within-subjects designs. Therefore, error components still occur within the treatments being investigated. However, these differences are usually not as great as the differences produced through the random assignment of different subjects to the different experimental conditions, as with between-subject designs (Keppel, 1982). The reduction of error variance associated with within-subjects variables provide a direct increase in statistical economy and power.

However, within-subjects designs have drawbacks as well. The three major disadvantages of within-subjects designs are: (1) practice effects which affect treatment conditions equally, (2) differential carry-over effects, which can be thought of as specific differences in subject performance between treatment conditions, and (3) the underlying statistical assumptions that must be made before applying the design (Keppel, 1982). The use of counterbalancing order effects can often solve the problems of practice effects; however, the experimenter must

be willing to assume the risks of the differential carry-over effects and whatever assumption violations are made when using within-subjects designs. The problems of confounding that were present in Experiment 1 were avoided in Experiment 2 by the use of a mixed-factors design, which has both within- and between-subjects factors.

The following sections address the findings of the research related to the SF, Novice conditions, which are of particular interest, and the other effects of both Experiments 1 and 2.

Discussion of SF, Novice condition results. The most unexpected outcome of the research was the exceptionally high mean attenuation achieved by the subjects in the SF, Novice conditions of Experiment 2. Based on the results of the RTP, the attenuation of the SF, Novice conditions of Experiment 2 were not significantly different from any of the treatment conditions used for comparisons of either Experiment 1 or Experiment 2 (Table 33 and RTP table in Appendix G). Novice subjects participating in SF conditions are usually expected to achieve significantly lower (worse) attenuation than novice subjects in IUF conditions or experienced subjects in either SF or IUF conditions. It must be kept in mind that the RTP did not indicate frequency specific differences or similarities; therefore, frequency specific differences may have occurred. The differences between results of the SF, Novice conditions of the two experiments are of interest even though no significant differences were indicated by the RTP.

With regard to practical comparisons of mean attenuation between the SF, Novice conditions, the minimum difference was 4.9 dB (3150 Hz) which

occurred between the SF, Novice and SF, Novice, WON conditions of Experiment 1 and 2, respectively. The maximum difference in mean attenuation between the SF, Novice conditions between the two experiments was 12.4 dB (6300 Hz) which also occurred between the SF, Novice and SF, Novice, WON conditions.

The standard deviations were considerably higher in Experiment 2 with minimum of 6.8 dB (3150 Hz; SF, Novice, WN treatment) and maximum of 16.2 dB (6300 Hz; SF, Novice, WON treatment). In comparison, the minimum and maximum standard deviations for the SF, Novice condition of Experiment 1 (V-51R plug) were 6.2 dB (3150 Hz) and 8.7 dB (1000 Hz) respectively. The averaged NRR(98) for the two SF, Novice conditions of Experiment 2 was -6.5 (Although high mean attenuation was achieved, the NRR(98) is negative because of the large magnitude of the standard deviations).

There is no definite explanation as to why the novice subjects of Experiment 2 had such relatively high attenuation and standard deviation results. The laboratory environment and equipment were not subject to error as daily calibration checks verified correct operation. The experimenter strictly followed the stepwise procedures throughout both experiments for all testing protocols. Furthermore, the SF protocols were essentially identical (with the exception of the fitting noise presented in one of the levels of Experiment 2); therefore, protocol and procedural errors were highly unlikely.

Based on the measurements of the ear canals taken at the end of the visits, 55% (i.e., 11 out of 20) of plug selections were made correctly

by the novice subjects of the SF conditions of Experiment 2. This was the highest percent of correct plug selections for Experiment 2. For Experiment 1, only 20% (i.e., 4 out of 20) of plug selection were made correctly by the novice subjects of the SF condition. Ear canal sizes of the 10 subjects who participated in Experiment 1 were graphically compared to the 10 subjects who participated in the SF, Novice conditions of Experiment 2. Although the distributions were not identical, there were no outliers or other discrepancies that would indicate why the subjects of the SF, Novice conditions of Experiment 2 would do so well in selecting the plugs and achieving higher mean attenuation than the novice subjects of the similar treatment of Experiment 1.

Concerning the low attenuation of the SF, Novice subjects of Experiment 1, two of the four sound pathways to the occluded ear (i.e., air leaks and hearing protector vibration) and depth of earplug insertion warrant further discussion for providing possible explanation for the results.

To prevent sound passage via air leaks, earplugs must precisely fit the contours of the ear canals and must virtually make airtight seals with the canals (Berger, 1986). For earplugs in general, the seal is dependent on the size of the plug, the depth of insertion, and the orientation of the plug in the ear canal. Air leaks are prevalent with cone-shaped or single-flange plugs (such as the V-51R) if they are not correctly sized and inserted. When properly sized and inserted, multiple-flanged and expandable-foam plugs are less susceptible to seal

breakage than single-flanged plugs because the multiple-flanged and expandable-foam plugs typically have more surface area to seal against the contours of the ear canals.

The second sound pathway, earplug vibration, can occur due to the flexibility of the ear canal flesh. When this occurs, the plugs generally vibrate in a piston-like manner within the ear canals, thus causing a limit to the achievable low-frequency attenuation (Berger, 1986; Zwislocki, 1957). Similarly, vibration can occur within the plug itself as its exterior surfaces undergo some deformation of shape in response to the forces of the impinging sound waves (Berger, 1986; Zwislocki, 1957).

Depth of plug insertion is a key factor for reducing sound passage through the ear canals. For example, when the E-A-R foam plug is properly inserted without creases, the deeper the plug is inserted, the lesser the chances for air leaks and plug vibration (mostly because of the better seal which is achieved). For this research, the low attenuation at frequencies below 2000 Hz for the SF, Novice treatment condition (as compared to the other treatment conditions with the E-A-R foam plug) could have been primarily due to lack of proper insertion depth.

With the V-51R plugs, deeper insertion does not necessarily provide a better seal. A V-51R plug which is too small for the ear canal can be inserted such that it "falls" into the canal and does not provide a proper seal. Furthermore, if an over-sized V-51R plug is used, it is unlikely that the user will be able to insert the plug deep enough into the ear canal to achieve a good seal. A shallow-inserted, over-sized

V-51R plug will most likely form a weak seal with the flesh of the ear canal and may induce earplug vibration. Also, the tab of the V-51R plug will not fit flat and snug against the concha floor if the plug is either too large or too small; thus, improper size and orientation of the V-51R plug can attribute to a weak seal, and plug vibration.

Another possible problem with using an over-sized V-51R plug is that the flange may become creased or develop a wrinkle if the user tries to achieve proper insertion depth. Air leaks are usually inevitable when using a creased plug, thus the subject achieves lower (worse) attenuation than when using a properly sized and fitted plug.

Out of 20 V-51R plug size-selections, the SF, Novice subjects only made 4 correct-size selections for Experiment 1, with the majority (13) of incorrect selections being over-sized. One possible conclusion that can be drawn from the poor attenuation achieved by these subjects is that the predominant use of improperly-sized plugs with lack of experience in fitting resulted in air leaks and plug vibration during testing.

In Experiment 2, the SF, Novice subjects made 11 correct-size selections out of the 20 plug size-selections. This greater number of correct size-selections may have attributed to more properly fitted plugs (with possibly fewer air leaks and less plug vibration); thus, the results were higher (better) mean attenuation for the subjects of Experiment 2.

Unfortunately, it is unclear as to why or how the novice subjects of Experiment 2 were able to select more correct-sized plugs than the

novice subjects of Experiment 1 when the prior experience backgrounds of the two groups were essentially equivalent. The previous discussion of air leaks, earplug vibration, and depth of insertion provides good explanation as to what factors may have influenced the SF, Novice conditions; however, it does not explain why the subjects performed differently.

The most obvious potential explanation for the differences of the novice subjects' attenuation and standard deviations for the two experiments are inter-subject variability of naive listeners and inadequate (too small) sample size ($n = 10$). The results of this research indicate that the achievable attenuation of naive listeners is more variable than that of experienced listeners; and, that sample sizes of 10 may not be appropriate for sampling the naive listener population. The sample size of 10 is the minimum sample size recommended in the HPD attenuation measurement standards (ANSI, 1974; and ANSI, 1984).

Discussion of Experiment 1 results. The HPD main effect was significant at all nine test frequencies. Higher mean attenuations were achieved with the E-A-R foam plug than with the V-51R plug for all testing protocols in Experiment 1.

The Fit main effect was significant at all nine frequencies; however, because the within-subjects design was confounded by treatment order effect, confounding occurred for the Fit main effect. The confound was that the IUF condition followed the SF condition in all cases, such that the IUF condition was actually IUF preceded by SF. The learning and practice effects from prior use of the plugs in the SF

conditions before the IUF conditions were not controlled or evaluated in the pilot study mandated by ANSI S12/WG11. The possible benefits of using the fitting noise in the IUF condition was an additional confound which was not balanced or experimentally controlled across the Fit main effect.

Because of the within-subjects design and the unbalanced fitting noise effect in Experiment 1, it is difficult to assess the true impact of the experimenter's interaction with the subjects based on the dependent variable (i.e., attenuation results) alone.

The Experience Level main effect was significant at all nine frequencies, and the FxE interaction was significant at 125, 250, 500, 1000, 2000, 6300, and 8000 Hz. The post hoc analysis revealed that the significant differences for the FxE interaction were in the SF, Novice condition. These results indicate that higher mean attenuation does not regress to lower attenuation levels that were achieved with only manufacturer's package instructions (SF, Novice condition) once the experimenter has assisted in the process of HPD selection (for multi-sized plugs) and/or provided instruction for proper fit as in the IUF condition.

The HxF interaction of Experiment 1 was significant at 3150, 6300, and 8000 Hz. Post hoc analysis revealed that the significant differences were in the treatments using the V-51R plug. The HxE interaction was significant at 6300 and 8000 Hz and the post hoc analysis revealed that the significant differences in this interaction were in the treatments using the V-51R plug. Figure 17 graphically

shows that the trend of higher attenuations at 6300 Hz and 8000 Hz was reversed in the SF, Novice condition with the V-51R plug. Air leaks, earplug vibration, and lack of insertion depth, as previously discussed for the SF, Novice conditions, provide a possible explanation for the reverse of the trend at 6300 Hz and 8000 Hz for the V-51R plug.

Discussion of Experiment 2 results. The Experience Level main effect was significant at 125, 250, 500, 1000, 4000, 6300, and 8000 Hz. However, the Fitting Noise main effect was not significant at any frequency, nor was the Fit main effect.

Concerning the Fit main effect, novice subjects are generally expected to achieve significantly higher attenuation in IUF treatment conditions as compared to their performance in SF conditions. On the other hand, experienced subjects are usually not expected to perform significantly different in SF or IUF treatment conditions.

The high attenuations achieved by the novice subjects in the SF, Novice conditions were not significantly different from those of the subjects of the IUF, Novice conditions, nor were they significantly different from any other testing conditions of Experiment 2. It can be concluded that the lack of a Fit main effect was largely due to the high attenuation of the novice subjects across both levels of Fit.

Conclusions. Based on the comparisons of attenuation results with the V-51R plug between the two experiments in this research, first-time HPD users who participate in a single SF treatment before an IUF treatment can be expected to achieve attenuation that is not significantly different from first-time HPD users who participate in

only an IUF treatment.

Likewise, once first-time HPD users have participated in an IUF treatment, they can be expected to achieve attenuation that is not significantly different from well-trained and experienced HPD users participating in similar or less informed treatment conditions. Note that all conclusions are drawn with regard to SF and IUF treatments as defined in this research. Previous research by Casali and Epps (1986) and Casali and Lam (1986) has shown that different levels of experimenter interaction in HPD training techniques can result in significantly higher or lower levels of attenuation.

In concert with these findings, a first-time HPD user should still be classified as a novice user if the only training exposure that he/she has had is the manufacturer's package instructions (as in the SF treatment). However, once a first-time HPD user has participated in an IUF treatment, he/she should no longer be considered a novice. It should be noted that practice effects of multiple SF treatments were not investigated in this research. Therefore, there still exists uncertainties as to how much practice effects contribute to the learning of fitting HPDs properly; especially with earplugs, which typically require more detailed instructions to achieve proper fit as opposed to earmuffs or canal caps.

The data obtained in this research also revealed that novice subjects (specifically, first-time HPD users) can be expected to perform with more variability in their attenuation results than more informed subjects, especially in SF treatments.

Experience Levels: Research Objective 3

Transfer-to-experienced versus enter-as-experienced subjects. The third research objective was to determine if differences occurred between the attenuation results of (1) the transfer-to-experienced subjects who participated in the Experienced treatment conditions of Experiment 1, and (2) the enter-as-experienced subjects who participated in the Experienced treatment conditions of Experiment 2.

It was hypothesized that the transfer-to-experienced subjects would achieve significantly different attenuation than the enter-as-experienced subjects for both SF and IUF conditions. Based on the statistical results of the RTP, this hypothesis was not accepted.

Plots of the mean attenuation results of Experiment 1 and Experiment 2 are shown in Figure 26 for all of the treatment conditions which involved experienced subjects. The maximum difference between the mean attenuations of experienced subjects was 7.8 dB (500 Hz) which occurred between the SF, Experienced and SF, Experienced, WN conditions of Experiments 1 and 2, respectively.

In comparing Experiment 1 to Experiment 2, the results of the RTP (shown in Table 33) indicated no significant differences between conditions that involved experienced subjects. Therefore, the performance of the transfer-to-experienced subjects and the enter-as-experienced subjects should be considered equivalent. However, the NRR(98) values of the experienced subjects of Experiment 2 (Table 30) are higher than those of the experienced subjects of Experiment 1

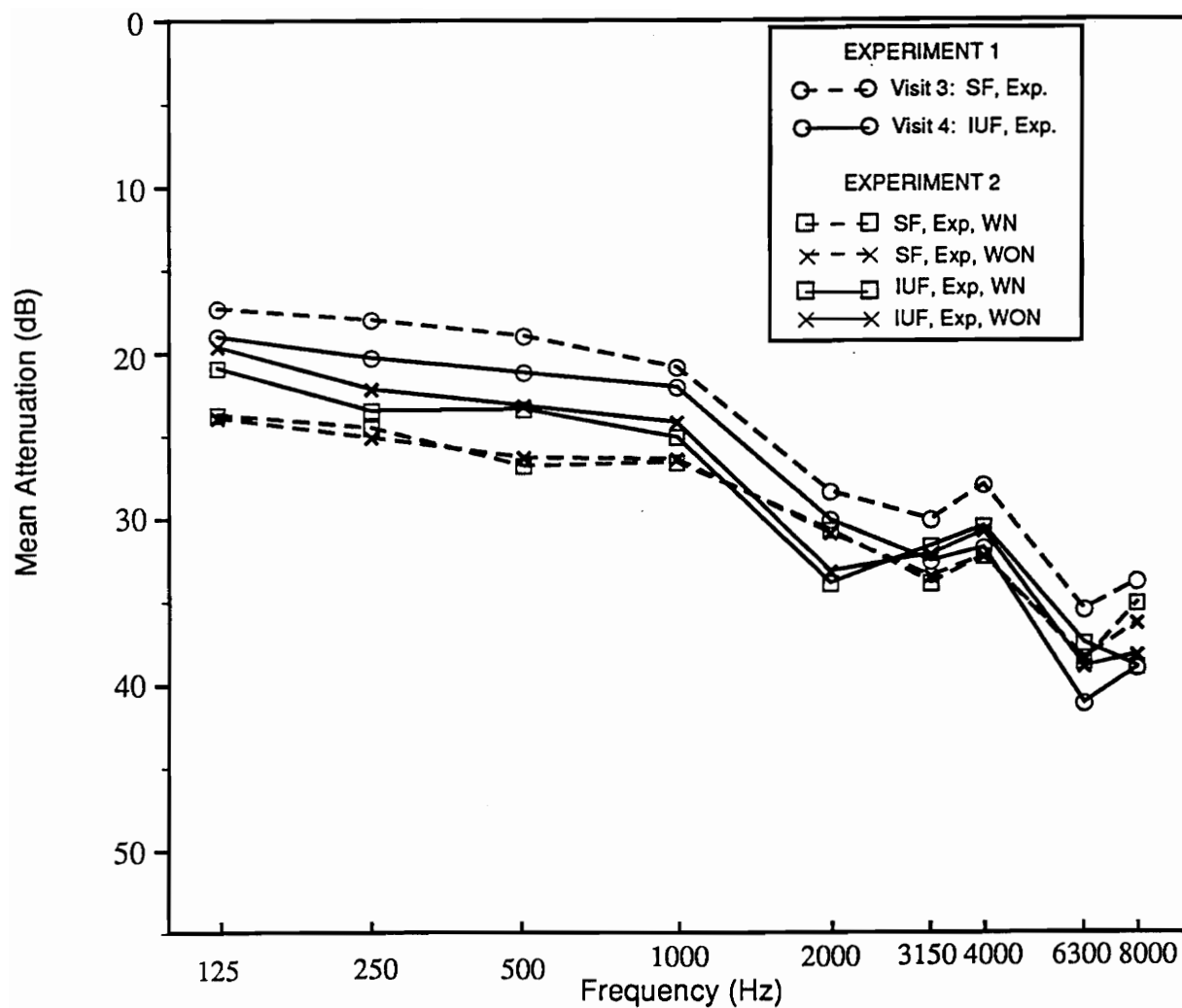


Figure 26. Attenuation in all treatment conditions of Experiments 1 and 2 involving experienced subjects with the V-51R plug.

(Table 25) for both the SF and IUF conditions by a magnitude of approximately 6 dB for all conditions.

Discussion of Novice subjects. Plots of the mean attenuation results of Experiment 1 and Experiment 2 are shown in Figure 27 for all of the treatment conditions which involved novice subjects.

The attenuation results of Experiment 2 alone indicate that there were no significant differences between the performance of the novice subjects regardless of which fitting condition they were assigned. However, this was not the case for the subjects of Experiment 1. As previously discussed, the most obvious potential explanations for the differences of the two SF, Novice groups are inter-subject variability of naive subjects (first-time HPD users) and inadequate sample sizes.

The NRR(98) values of the Experiment 2 novice subjects (Table 30) are lower than those of the Experiment 1 novice subjects (Table 25) for both the SF and IUF conditions by a magnitude of approximately 3 dB for all conditions (presumably due to the higher standard deviations of the results of Experiment 2).

Implications for HPD testing standards. In HPD attenuation research, there is currently no consensus classification of a person as either a novice or an experienced listener. Factors such as prior use of HPDs, frequency of use, prior auditory testing, frequency of testing, number of trials per test, learning ability, knowledge of how to achieve proper fit, and others must be considered prior to developing classifications of experience levels for auditory listeners.

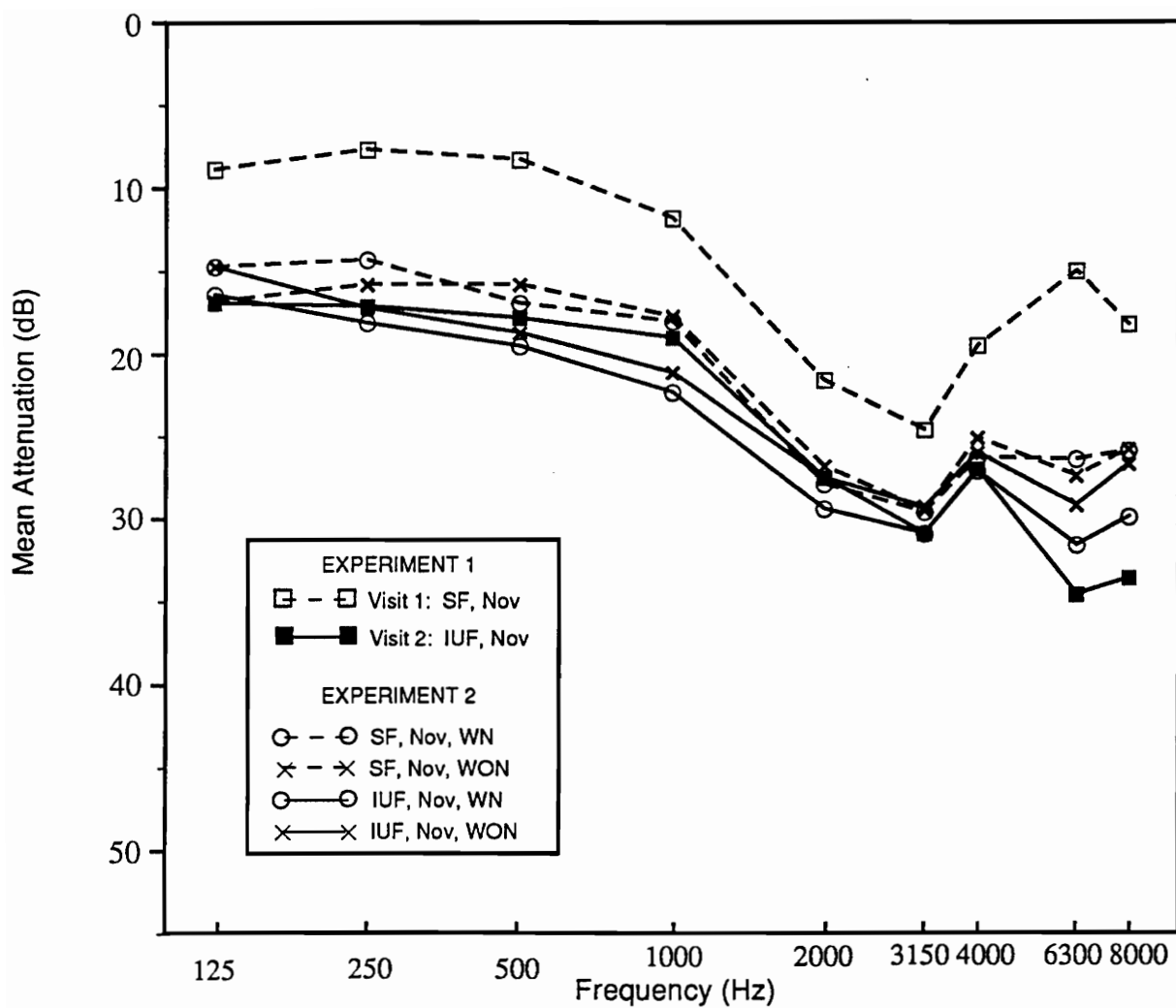


Figure 27. Attenuation in all treatment conditions of Experiments 1 and 2 involving novice subjects with the V-51R plug.

The implications for developing such classifications include: (1) control of homogeneity of sample populations to be tested at different laboratories, (2) control of subject variability for inter-laboratory comparisons, and (3) establishment of long standing subject pools prior to actual time of testing.

Prior use of HPDs or prior participation in auditory research are concerns which must be addressed before the revision of ANSI S12.6-1984. The revised standard is expected to be developed to yield attenuation results that are more reasonable estimates of actual in-field attenuation results; therefore, previous auditory research participants or previous HPD users may or may not be allowed to participate in testing. Subjects who repeatedly participate in HPD attenuation tests tend to be well-paid and motivated listeners. Laboratories will often use their own professional staff, students, or production personnel to participate in research or to test products for manufacturers.

Conclusions. Based on the results with the V-51R plug between the two experiments in this research, it is concluded that after a subject has participated in an IUF treatment, he/she should be able to achieve attenuation not significantly different from well-trained HPD users who have participated in multiple HPD testing experiments. With regard to Experiment 1, it can be argued that it was appropriate to have considered the subjects as experienced HPD users after the IUF, Novice condition.

However, caution must be taken before drawing causal relationships between experimental factors and the attenuation achieved by the

experienced subjects of Experiment 1, due to the within-subjects design and the confounding that was present because of order effects and fitting noise. Questions still remain regarding the number of trials (specifically, practice of fitting procedures and testing with ears occluded) that are necessary before a person should be considered an experienced HPD user.

Attenuation: Laboratory Versus Field: Research Objective 4

The fourth research objective was to compare the laboratory attenuation results of this study to the appropriate field attenuation data and to evaluate the statistical and practical differences between the results. It was hypothesized that the attenuation results from the SF, Novice laboratory conditions would not be significantly different from the in-field attenuation results of the previously conducted studies. This hypothesis was accepted only for the V-51R plug based on the results of the RTP analyses and practical comparisons of mean attenuation data.

Discussion of the results. The RTP was used to derive valid statistical comparisons between results of the laboratory and the field to aid in the determination of which laboratory protocols, if any, yield attenuation that represent the in-field attenuation. The results of the RTP (Table 36) indicated that the SF, Novice condition of Experiment 1 yielded data that was not significantly different from the attenuation data of the four field conditions with the V-51R plug. However, for the E-A-R foam plug, none of the treatment conditions of Experiment 1 yielded attenuation results that were similar to the in-field results.

In Experiment 2, the results of the RTP (Table 38) indicated that the SF, NOV, WON treatment conditions yielded data that was not significantly different from the attenuation data of two of the field conditions (High/Active and High/Passive) with the V-51R plug. Also from Experiment 2, the IUF, NOV, WON treatment attenuation results were not significantly different from one of the field conditions (High/Active).

Implications for HPD testing standards. In this research, the SF, Novice conditions yielded attenuation that best replicated the field attenuation (with the V-51R plug), despite differences in the experiments and the variability in the SF, Novice attenuation results between the two experiments.

In regard to revision of HPD testing standards, this research supports the use of a SF, Novice condition for yielding attenuation data that is to represent the actual workplace attenuation data. Currently, ANSI S12/WG11 is developing a study incorporating larger laboratory sample sizes (greater than 10) and a wider variety of HPDs to test the SF, Novice condition as well as other conditions to provide more empirical evidence as to which protocols may best represent the in-field data.

The RTP and future HPD research. In this research, individual subject data was used to calculate summary statistics collapsed across the nine test frequencies. Future application of the RTP to HPD testing may incorporate comparisons of the attenuation results at different frequencies rather than collapse the frequency data for the test conditions. Other uses of the RTP for HPD attenuation testing are suggested below:

1. Compare laboratory attenuation results that
were collected from different experimental designs.
2. Determine the usefulness of protocols or test
conditions for development of testing standards
(such as the work of ANSI S12/WG11).

3. Compare field results of future studies to determine if training and awareness programs influence or improve attenuation.
4. Validate or replace ANOVA procedures where assumptions of ANOVA are not met and where random sampling is not possible.

Conclusions. From the comparisons between the attenuation data achieved in the different laboratory protocols of this research and the attenuation data of previous field studies, it is concluded that the SF, Novice treatment condition is the best laboratory protocol for yielding attenuation closest to field attenuation. This conclusion is based solely on the statistical and practical comparisons with the V-51R plug.

It is not expected that the SF, Novice condition yields attenuation similar to field attenuation for all HPDs. With regard to the E-A-R foam plug, none of the laboratory protocols tested in Experiment 1 of this research yielded statistically similar data to the field data.

V-51R Plug Selection and Ear Canal Sizes

Although no research objective was set forth at the start of the study for hypothesis development and investigation of plug size-selection data, information from the results were considered important enough to include herein.

In this research, only subjective methods (visual and tactile) were allowed for determining the proper fit of earplugs (both V-51R pre-molded and E-A-R foam plugs). The measurements taken of the ear canals with the American Optical EargageTM at the end of the testing were used to determine how well the plugs were selected to match the ear canals for both the SF and the IUF conditions.

The experimenter instructed the subject according to manufacturers' package instructions and recommended sizes for use in the experiment. During the testing sessions, the experimenter did not measure the ear canals with the eargage, fit any plugs for the subjects, nor touch the plugs in the subjects' ears. Results (Tables 26, 31, and 32) of the two experiments revealed that the experimenter was not able to recommend the proper sized plugs consistently by visual inspection and subject feedback alone (i.e., with no eargage measurements).

Conclusions. The obtained data and statistical tests that were performed indicate that size selection based on visual inspection, and subjective feedback (as related to comfort of fit and occlusion effects) is an inadequate method of fitting a multi-sized HPD. Specifically concerning the V-51R plug (which has five sizes to choose from), the IUF treatments indicate improper plug selection based on experimenter's

visual inspection and subject's subjective feedback alone. Furthermore, it is not clearly understood how subjects determine which plug sizes fit their ear canals without any measurement devices, especially with regard to SF treatments and novice subjects. This research provides evidence that a need exists for a device(s) that can accurately measure the diameter and perhaps the shape of the ear canal which can be safely used by the HPD wearer. Such a device could help persons who use multi-sized HPDs to achieve proper fit.

Concluding Remarks

One of the underlying concerns behind this research was how to improve the usage of HPDs so that adequate protection levels will be achieved and noise-induced hearing loss prevented. Attention has been given primarily to industrial environments; however, HPDs are becoming more popular for the general public (most grocery stores, hardware stores, and gun shops sell various HPDs). Many events not related to the industrial setting are providing more and more loud noises that persons may (and should) want to protect themselves against. Automobile racing, monster truck events, rock music concerts, and even dance clubs are some examples of recreational events that may be causing damage to participants, performers, and spectators as well. Other activities such as operating a lawn mower, weed eater, chain saw, or shooting a gun produce noises which many persons consider undesirable, and may be harmful as exposure times increase.

Therefore, as more persons turn to the use of HPDs to protect their

hearing, HPD manufacturers inherently assume some degree of liability for the protection levels that will be achieved compared to those advertised. Also, as the user population grows to include a larger proportion of society as well as the industrial workforce, instructions for use and proper training become an even greater concern. Non-English speaking users, the illiterate, and mentally handicapped users all require special attention in instructions and training.

The results of this research indicate the difficulties of modeling field or "real world" attenuation in the laboratory. None of the laboratory protocols yielded attenuation that closely represented the field attenuation for the E-A-R foam plug. The SF, Novice condition yielded attenuation that best represented the field data for the V-51R plug for both experiments, but there is a need to test other HPD types. If the HPD testing standards are modified to yield less than optimum results, there are questions that remain unanswered as to what attenuation ratings should be required to be printed on the individual packages.

The author believes that two attenuation ratings should be printed on the individual packages: (1) an optimum laboratory rating (most likely achieved if the experimenter installs/inserts and inspects the HPD on an experienced audiogram participant), and (2) an approximate field rating (most likely achieved with first-time, novice users who use only the manufacturers' individual package instructions to aid in donning the HPD). Thus, a range of attenuation values, rather than a point estimator, could be provided.

The author is convinced that the field attenuation results that were reviewed and used in this study indicate a need for more training of proper fitting and usage techniques before HPDs are administered. Also needed is more periodic training throughout the time the device is used. Overall, more human interaction, such as through personal demonstration, video presentation, or detailed pictures of actual donning of devices is necessary to provide adequate training to the majority of the user population. Follow-up training, reinforcement, and motivational efforts are also needed to verify that the necessary protection levels are being achieved.

SUMMARY AND SUGGESTIONS FOR FUTURE RESEARCH

Summary of this Research

The major findings of the research are as follows:

1. The presentation of fitting noise and instructions for its use in four treatment conditions of Experiment 2 did not help subjects achieve significantly higher mean attenuation as compared to the results of similar treatment conditions which had no fitting noise. Based on these results, it seems unlikely that participants of HPD laboratory tests would benefit from using fitting noise in an attempt to achieve higher attenuation, at least not for fitting earplugs.
2. The transfer-to-experienced subjects of Experiment 1 did not perform significantly different than the enter-as-experienced subjects of Experiment 2. These results indicate that novice subjects, after receiving instructions and repeatedly fitting the plugs, can insert earplugs and achieve attenuation comparable to that of well informed and experienced users.
3. In comparing the attenuation results of similar treatment conditions between Experiment 1 and Experiment 2 for the V-51R pre-molded plug, none of the overall attenuation results of the similar treatments were significantly different. These results

indicate that the testing protocols can be repeated and that the results are predictable; both of which are necessary for the protocol of a testing standard.

4. For the V-51R plug, comparisons of Experiment 1 and Experiment 2 data to previously conducted field study data revealed that the attenuation achieved by novice subjects most closely represented the attenuation achieved by industrial workers. For Experiment 1, the SF, Novice condition yielded attenuation results that were similar to four out of four field conditions. For Experiment 2, the SF, NOV, WON condition yielded attenuation results that were similar to two out of four field conditions. Also for Experiment 2, the IUF, NOV, WON condition yielded results that were similar to one out of four field conditions.
5. For the E-A-R foam plug, none of the treatment conditions of Experiment 1 yielded attenuation results that were similar to the previously conducted field study data. Implications are that it may not be possible to model field data in the laboratory for all types of HPDs.

Suggestions for Future Research

Based on the results of this research, the following suggestions are made for future research:

1. In this research, fitting noise and instructions for its use did not help subjects achieve significantly higher attenuation than in conditions where no fitting noise was presented. If fitting noise is to be included in ANSI standards for testing HPDs, then it should be empirically justified as an aid for proper fitting by repeatable experiments in more than one laboratory. If future research confirms the results of this study, then fitting noise should be omitted from the standards. Suggestions for investigations of fitting noise include:
 - a. Determine the effects of using different instruction techniques for aiding the subject in the proper use of fitting noise.
 - b. Determine the effects of fitting noise on the attenuation of different types of HPDs.
 - c. Determine the effects of varying the characteristics of the fitting noise spectrum and manipulating the overall sound pressure level of the noise (In reference to this suggestion, low frequencies [below 2000 Hz] are of particular interest because attenuation is difficult to achieve at these frequencies without proper plug insertion or muff seal due largely to sound passage via air leaks and due to material transmission).

- d. Test fitting noise as a within-subjects factor (as done in Experiment 2 of this research) so that error variance due to individual differences between subjects can be reduced, thus increasing the chances of detecting differences caused by the fitting noise.
2. Current in-field studies need to be performed so that HPD attenuation can be verified, HCPs can be improved where there is a need for improvement, and protection levels can be increased where needed and controlled through monitoring, proper training schedules, and motivation strategies.
3. Currently, there is no consensus-developed standard criteria for the classification of HPD users as novice or experienced. Implications for developing classifications of experience levels include:
 - a. Control of homogeneity of sample populations to be tested at different laboratories.
 - b. Control of subject variability for inter-laboratory comparisons.
 - c. Establishment of long-standing subject pools prior to actual time of testing.
4. Currently, the NRR ratings that are supplied with HPDs by manufacturers are those which are obtained according to ANSI

S3.19-1974 (as required by the EPA) or ANSI S12.6-1984. These NRR values are considered optimum, and most all have been shown to be overestimates of the attenuation that is achieved in the workplace. Researchers need to address the issue of having several attenuation ratings placed on the HPD packages, such as an optimum laboratory rating and a approximate field rating. Optimum ratings may be of value to motivate users to fit the devices properly to achieve necessary protection, whereas approximate field ratings may provide better estimates for a safety engineer to use when deciding which protectors should be used in specific noisy environments.

5. There is a need for more research to address the design of devices for easy, safe, and accurate measurements of ear canal diameter and shape. Such a device could be used by audiologists and users of multi-sized HPDs for fitting purposes.
6. Further development of fitting instructions for proper HPD fitting, use, care, and storage is needed for various HPD types. Special considerations for the learning disabled and the illiterate also need to be addressed.

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APPENDIX A

SUMMARY MATRIX OF FIELD STUDIES

Summary Matrix of Field Studies

Title/ Author/ Date	Standard Followed	Frequencies Tested (Hz)	Trials per subject	Number and type of HPD tested	Number of Plants (Total Subjects)
Ontario Hydro Study Behar 1985	ANSI S3.19-1974 (Method was not exactly to standard)	250, 500, 1000, 2000, 4000, 8000	1	3 muffs 3 plugs 1 earcap	3 (177)
NIOSH Studies Lempert & Edwards 1977 & 1981	ANSI S3.19-1974 (Closely followed)	125, 250, 500, 1000, 2000, 3150, 4000, 6300, 8000	1 (5 visits)	6 plugs	15 (420)
DuPont & NIOSH Study Edwards & Green 1987	ANSI S3.19-1974 (Closely followed)	125, 250, 500, 1000, 2000, 3150, 4000, 6300, 8000	1 (5 visits)	1 plug	2 (56) DuPont Plants ----- 4 (112) NIOSH Plants

APPENDIX B

STEPWISE PROCEDURES FOR EXPERIMENT 1

PROTOCOL FOR EXPERIMENT 1

Visit 0: Subject Consent and Screening

1. Subject is told that the experiment will take four more visits to the laboratory, estimated at one hour each. A brief description of each visit is given.
2. Informed Consent is administered, and any questions are addressed by the experimenter, excluding those that will introduce bias. The subject is asked to remove any ear jewelry at this time.
3. Subject is given otoscopic examination to determine if impacted cerumen and/or irritation/infection are present.
4. Subject enters the audiometric chamber, is given instructions for audiogram, and practices a Hughson-Westlake threshold testing procedure using a pure-tone audiometer.
5. Subject is audiometrically tested in both ears using pure-tone stimuli.
6. Audiogram is scored to determine if subject qualifies as to < 25 dB HTL requirement. Subject takes 3 minute break.
7. Subject is seated in the test chamber and given explicit instructions for sound-field REAT test. The door is closed, and the experimenter communicates with the subject (via intercom) to insure that the subject is calm and relaxed. Video monitor is checked to ensure that subject is in view.
8. Experimenter administers the open-ear sound-field audiograms with the Békésy method that is programmed on the IBM PS-2 70 computer.
9. A minimum of 5 audiograms are given for practice of the testing procedure. The last 3 audiograms are scored according to the requirement: up to 6 dB of variability, scored on the 3 successive practice open-ear sound-field audiograms.
10. Subject exits the test chamber and sits in a chair. Subject is scheduled for subsequent visit and dismissed.

Notes on Data Collection Visits:

As soon as the subject arrives at the laboratory, he/she is given a brief description of the entire visit and removes any ear jewelry at that time.

For the second session in a visit, the test chamber accommodation time is reduced from 5 minutes to 2 minutes.

Once a test has begun, regardless of the fit of the hearing protector, or whether or not it changes position or breaks its acoustical seal, the data will still be accepted.

If a hearing protector falls out of the ear during the test, the experimenter shall terminate the test, enter the room and hand the subject the instructions and the earplugs, and ask him or her to reinsert the device for a retest. If the earplug falls out a second time, testing shall again be terminated and the subject dismissed from the experiment.

After subject completes both sessions of the visit, he/she is scheduled for the subsequent visit:

- Visit 1 and 2; within 5 days.
- Visit 2 and 3; minimum of 10 days.
- Visit 3 and 4; within 5 days.

Visit 1 (Novice, SF) and Visit 3 (Experienced, SF)

E-A-R Foam Plugs:

1. A copy of the stated purpose of the test is given to subject and is read aloud by experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. Subject is given a pair of E-A-R foam plugs in the manufacturer's container (pillow pack). The instructions are pointed out to subject by experimenter. Experimenter says, "Please read and note the instructions on the back of the package. You have 5 minutes to practice fitting the earplugs." [ASL] Experimenter starts the timer for 5 minutes.
3. Eyeglasses may be kept on throughout the study so subject can see to read manufacturer's instructions.
4. Subject practices inserting the plugs before entering the test chamber. Experimenter says, "I cannot assist you or answer any questions concerning the earplugs, but please practice inserting the plugs in both ears at this time." [ASL]
5. Subject is advised after 4 minutes to make his/her best attempt to fit the protector within the next minute. After five minutes, or when subject indicates fitting is complete, plugs are removed by subject and thrown away.
6. Experimenter tells subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on, there are no buttons to push.
 - g. the TV camera is always on.

7. Subject takes a fresh pair of plugs and the packaging into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair.
8. Experimenter exits the chamber, closes the door, and starts timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
9. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
10. When the accommodation time expires, experimenter tells subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is unoccluded).
11. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Once you indicate that you have completed fitting the protector, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a two-minute delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.
12. Immediately prior to second occluded trial, experimenter enters chamber, gives subject fresh pair of plugs in packaging, takes used plugs and used packaging and exits the chamber, closes the door, and returns to test station.
13. Subject inserts plugs and indicates to experimenter when finished. Experimenter starts timer for 2 minutes. At the end of 2 minutes, experimenter tells subject the test is about to begin. Experimenter begins test.
14. Experimenter offers no more assistance or additional explanations, nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.

15. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer printer and stores data on disk.
16. Step 9 through 15 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the E-A-R plug. Experimenter does not re-enter chamber at any time during this sequence.
17. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
18. When the complete testing sequence is finished, subject exits the chamber, and the next session immediately begins.

V-51R Pre-molded Plugs

1. A copy of the stated purpose of the test is given to subject and is read aloud by experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. One new pair of each size V-51R plugs with manufacturer's package instructions is placed on a table in front of subject. Experimenter says, "Please read these manufacturer's instructions. You have 5 minutes to choose and fit the plugs you will use in the test." [ASL] Experimenter starts the timer for 5 minutes.
3. Once subject has read the package instructions, experimenter gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "Please try these protectors on to find the size that is best for you. This may be different for each of your ears. Begin by trying a middle or regular size and then based on the looseness or tightness of the fit, and any guidance provided in the manufacturer's instructions, proceed to larger or smaller sizes as needed." No other recommendations or physical assistance is given.

4. Eyeglasses may be kept on throughout the study so subject can see to read manufacturer's instructions.
5. Subject begins fitting the different sized plugs. Experiment says, "I cannot assist you or answer any questions concerning the earplugs, but please practice inserting the plugs in both ears at this time." [ASL]
6. Subject is advised after 4 minutes to make his/her best attempt to choose and fit proper sized plugs within the next minute. After 5 minutes, or when subject indicates fitting is complete, plugs are removed by subject and placed on table. All plugs not chosen are removed from table by experimenter.
7. Experimenter tells the subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on, there are no buttons to push.
 - g. the TV camera is always on.
 - h. do not forget which plug goes in which ear.
8. Subject takes plugs and the package instructions into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair, in a way that subject will not forget which plug goes in which ear.
9. Experimenter exits chamber, closes the door, and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
10. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
11. When the accommodation time expires, experimenter tells subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is unoccluded).

12. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Once you indicate that you have completed fitting the protector, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a short delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.
13. Subject inserts plugs and indicates to experimenter when finished. After a short delay, experimenter tells subject the test is about to begin. Experimenter begins test.
14. Experimenter offers no more assistance or additional explanations nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.
15. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer printer and stores data on disk.
16. Steps 10 through 15 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the V-51R plug. Experimenter does not re-enter chamber at any time during this sequence.
17. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
18. When the complete testing sequence is finished, subject exits the chamber, and the next session immediately begins.

Visit 2 (Novice, IUF) and Visit 4 (Experienced, IUF)

E-A-R Foam Plugs

1. A copy of the stated purpose of the test is given to subject and is read aloud by experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. Subject is given a pair of E-A-R foam plugs in the manufacturer's container (pillow pack). The instructions are pointed out to subject by experimenter. Experimenter says, "Please read and note the instructions on the back of the package. You have 7 minutes to practice fitting the earplugs." [ASL] Experimenter starts the timer for 7 minutes.
3. Eyeglasses may be kept on throughout the study so subject can see to read manufacturer's instructions.
4. Subject practices inserting the plug before entering the test chamber. Experimenter instructs subject on how to fit earplugs in strict accordance with the manufacturer's written instructions. Also, experimenter demonstrates and physically assists in fitting the device in accordance with the manufacturer's written instructions. Experimenter does not augment inadequate or correct inaccurate manufacturer's instructions.
5. Subject is advised after 6 minutes to make his/her best attempt to fit the protector within the next minute. After 7 minutes, or when experimenter believes subject can fit device according to manufacturer's instructions, plugs are removed by subject and thrown away.
6. Experimenter tells subject the following :
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on, there are no buttons to push.
 - g. the TV camera is always on.

7. Subject takes a fresh pair of plugs and the packaging into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair.
8. Experimenter exits chamber, closes the door, and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
9. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
10. When the accommodation time expires, experimenter tells subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is unoccluded).
11. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Adjust the hearing protector, using the steady noise which I will present, so that it blocks the most sound from your ears, but is still reasonably comfortable. By 'blocking the most sound' I mean that the noise you hear under the protector should be reduced to a minimum. And by 'reasonably comfortable' I mean that you should consider your ability to wear the hearing protector for normal use while engaged in noisy occupational or recreational activities. Once you indicate that you have completed fitting the protector, the noise will be turned off, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." The experimenter will then say, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a two-minute delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.
12. Immediately prior to second occluded trial, experimenter enters chamber, gives subject fresh pair of plugs in packaging, takes used plugs and used packaging and exits the chamber, closes the door, and returns to test station.

13. Experimenter turns on fitting noise. Subject inserts plugs and indicates to experimenter when finished. Experimenter turns off fitting noise and starts timer for 2 minutes. At the end of 2 minutes, experimenter tells subject the test is about to begin. Experimenter begins the test.
14. Experimenter offers no more assistance or additional explanations, nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.
15. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial experimenter prints threshold table on computer printer and stores data on disk.
16. Steps 9 through 15 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the E-A-R plug. Experimenter does not re-enter chamber at any time during this sequence.
17. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
18. When the complete testing sequence is finished, subject exits the chamber, and the next session immediately begins.

V-51R Pre-molded Plugs

1. A copy of the stated purpose of the test is given to subject and is read aloud by the experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. One new pair of each size of V-51R plugs with manufacturer's package instructions is placed on a table in front of subject. Experimenter says, "Please read these manufacturer's instructions. You have 7 minutes to choose and fit the plugs you will use in the test." [ASL] Experimenter starts the timer for 7 minutes.

3. Once subject has read the package instructions, experimenter gives a copy of the following instructions to subject, and read them aloud (verbatim as stated in the S12/WG11 protocol):
"Please try these protectors on to find the size that is best for you. This may be different for each of your ears. Begin by trying a middle or regular size and then based on the looseness or tightness of the fit, and any guidance provided in the manufacturer's instructions, proceed to larger or smaller sizes as needed."
4. Eyeglasses may be kept on throughout the study so subject can see to read manufacturer's instructions.
5. Subject begins fitting the different sized plugs. Experimenter assists in selecting proper sized plugs and instructs subject on how to fit earplugs in strict accordance with the manufacturer's written instructions. Also, experimenter demonstrates and physically assists in fitting the device in accordance with the manufacturer's written instructions. Experimenter does not augment inadequate or correct inaccurate manufacturer's instructions.
6. Subject is advised after 6 minutes to make his/her best attempt to choose and fit proper sized plugs within the next minute. After 7 minutes, or when experimenter believes subject can fit device according to manufacturer's instructions, plugs are removed by subject and place on the table. All plugs not chosen are removed from the table by experimenter.
7. Experimenter tells subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on, there are no buttons to push.
 - g. the TV camera is always on.
 - h. do not forget which plug goes in which ear.

8. Subject takes the plugs and the package instructions into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair, in a way that subject will not forget which plug goes in which ear.
9. Experimenter exits chamber, closes the door and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
10. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
11. When the accommodation time expires, experimenter tell subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is an unoccluded).
12. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Adjust the hearing protector, using the steady noise which I will present, so that it blocks the most sound from your ears, but is still reasonably comfortable. By 'blocking the most sound' I mean that the noise you hear under the protector should be reduced to a minimum. And by 'reasonably comfortable' I mean that you should consider your ability to wear the hearing protector for normal use while engaged in noisy occupational or recreational activities. Once you indicate that you have completed fitting the protector, the noise will be turned off, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a short delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.
13. Experimenter turns on fitting noise. Subject inserts plugs and indicates to experimenter when finished. Experimenter turns off fitting noise. After a short delay, experimenter tells subject the test is about to begin.

14. Experimenter offer no more assistance or additional explanations nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.
15. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer and stores data on disk.
16. Steps 10 through 15 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the V-51R plug. Experimenter does not re-enter chamber at any time during this sequence.
17. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
18. When the complete testing sequence is finished, subject exits the chamber, and the next session immediately begins.

Anatomical Measurements:

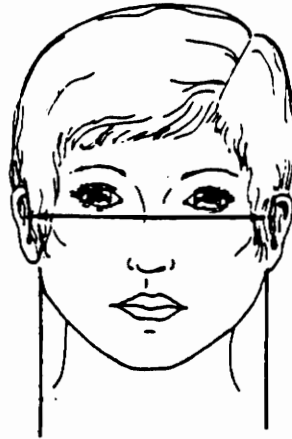
1. After completion of the threshold trials in visit 4, anatomical measurements are obtained from subject. Subject is seated in a chair and given drawings of the measurements to be taken. Experiment then takes measurements, recording each as it is taken.
2. Subject is debriefed, paid, and allowed to leave.
3. All data from all 4 sessions on subject is filed in hardcopy and on disk.

APPENDIX C

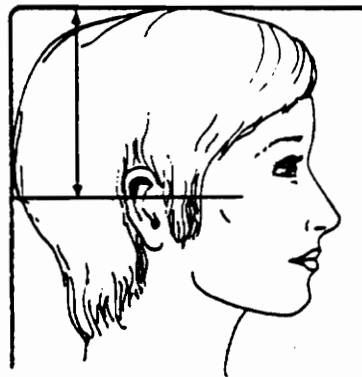
ANATOMICAL MEASUREMENTS

AND

EQUIPMENT

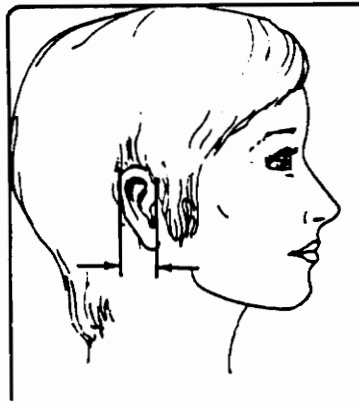


* Bitragus breadth: The breadth of the head as measured from the anterior base of the right tragus to the anterior base of the left tragus.

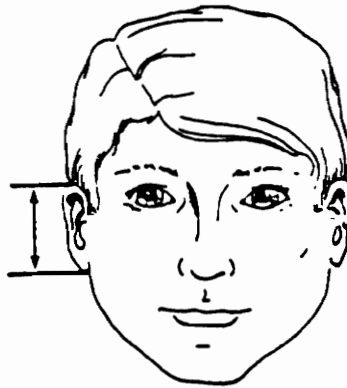


Head height: The distance from the anterior base of the tragus to the level of the top of the head.

* All drawings and definitions are from:
National Aeronautics and Space Administration (NASA), (1978).
Anthropometric source book volume 2: a handbook of
anthropometric data. NASA Reference Publication 1024,
NASA.



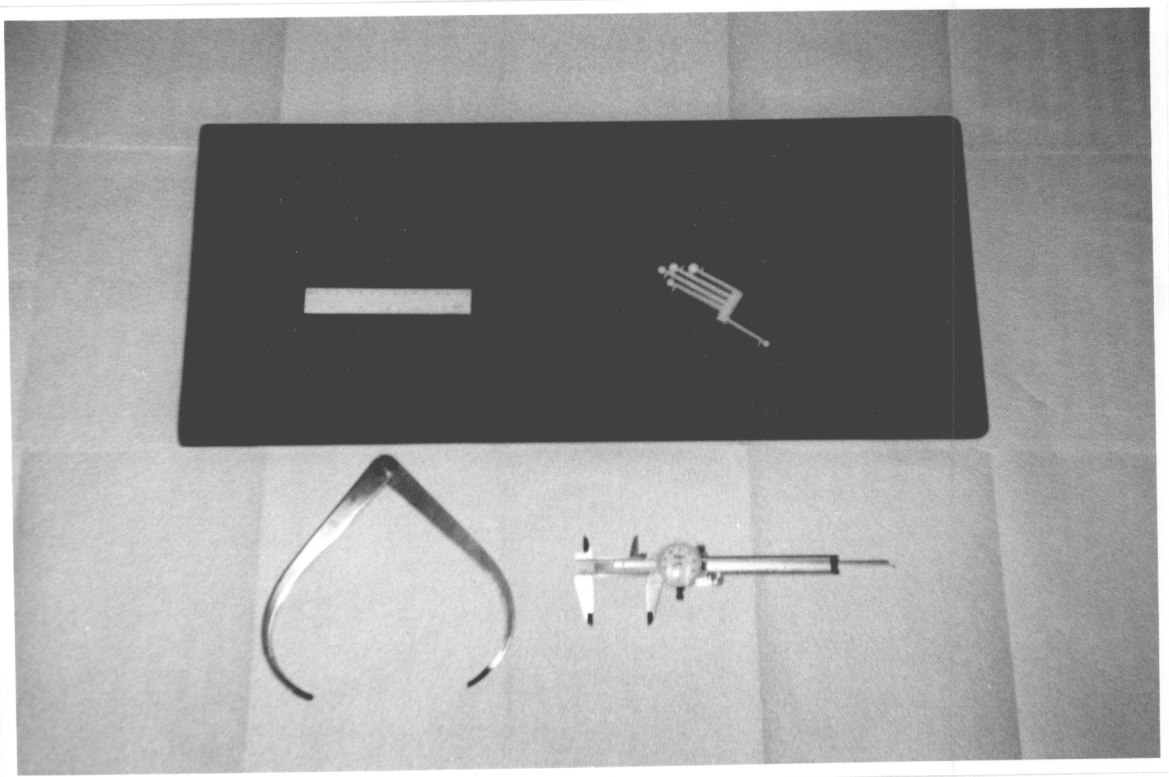
Ear breadth: The breadth of the ear measured perpendicular to its long axis.



Ear length: The maximum length of the ear as measured along the long axis.



Ear protrusion: The horizontal distance from the bony eminence directly behind the ear to the most lateral protrusion of the ear.



Equipment used for anatomical measurements: Strait scale, eargage, curved spreading caliper, vernier caliper.



Headboard used for measurement of head height
(T-square rule not shown)

Instruction for Using the American Optical EARGAGETM as Provided by ANSI S12/WG11

The device to be used for sizing ear canals shall be the American Optical EARGAGETM Ear Insert Fitting Device which consists of 5 plastic spheres denoted as extra small (XS), small (S), medium (M), large (L), and extra large (XL). The diameters of the spheres are 7.7, 8.4, 9.1, 10.4, and 11.4 mm respectively.

Choose a sphere which appears to be a little small for the ear canal being measured. Place into the ear canal opening until the tab of the gage lies flat on the floor of the concha. Use a slight pumping action of about 3-4 mm and ask the subject if s/he feels a suction or pressure change. Simultaneously, observe if all of the ear canal opening conforms to the sphere. Move up in gage size until the subject feels suction, the ear canal opening appears to conform to the sphere, and the gage tab still lies on the concha floor, indicating a fully inserted sphere. The sphere accommodating these requirements represents the size of the ear canal.

If suction can only be achieved with a partial insertion, recheck the next smaller size to confirm. The assigned size will then either be the smaller size (if suction is achieved) or the between size if suction can still only be achieved with a partial insertion of the size which is too large for a full insertion (i.e., M+ if the large sphere is required for suction but can only be partially inserted).

ANTHROPOMETRIC DATA FOR NOVICE SUBJECTS

S#	SEX	AGE	HL	RACE	LCS	RCS	ELL	ELR	EBL	EBR	PTL	PTR	HH	BB
1	F	20	1	W	M	M	56	56	30	29	21	20	130	130
2	F	26	5	A	S+	M	64	62	31	30	25	25	127	127
3	M	19	1	W	EL	L	65	66	40	37	18	21	133	132
4	F	21	3	B	ES	S	52	53	27	33	19	18	133	120
5	M	20	2	W	EL	EL	61	63	31	31	23	21	133	135
6	M	20	4	W	M	M	67	67	39	37	23	20	140	136
7	M	19	5	W	L	M+	56	55	35	32	21	21	140	134
8	F	20	4	A	M+	M+	57	59	30	31	22	19	130	130
9	F	21	2	W	S	ES	63	62	32	34	18	19	133	129
10	M	21	3	W	L	M	64	64	32	32	19	21	140	129
11	M	21	3	W	S	S	60	57	31	34	23	25	137	130
12	F	20	5	W	S	ES	58	57	29	29	16	16	137	125
13	M	19	1	B	EL	L	58	57	35	33	23	23	140	139
14	F	23	4	W	M	M	65	64	37	35	20	21	143	129
15	F	21	1	B	S	S	65	63	33	36	18	17	133	139
16	F	21	2	W	M	S	56	55	30	31	23	19	149	131
17	M	21	4	W	L	L	61	61	34	34	22	23	140	148
18	M	22	2	W	M	S+	62	60	36	32	25	24	143	139
19	F	21	3	A	M	M	58	61	24	26	22	24	140	125
20	M	23	5	W	M	S+	70	69	34	32	26	28	149	138

S# = Subject number
HL = Categorical ranking of hearing level:
1 being lowest, 5 being highest
LCS = Left-ear Canal Size, per AO Eargage
RCS = Right-ear Canal Size, per AO Eargage
ELL = Ear Length Left (mm)
ELR = Ear Length Right (mm)
EBL = Ear Breadth Left (mm)
EBR = Ear Breadth Right (mm)
PTL = Protrusion of Left ear (mm)
PTR = Protrusion of Right ear (mm)
HH = Head Height (mm)

ANTHROPOMETRIC DATA FOR EXPERIENCED SUBJECTS

S#	SEX	AGE	HL	RACE	LCS	RCS	ELL	ELR	EBL	EBR	PTL	PTR	HH	BB
21	M	23	5	W	S	S+	67	67	36	36	20	21	140	128
22	M	21	1	W	M	M	63	64	35	33	25	24	140	136
23	F	23	5	W	S	S+	61	59	33	34	23	25	137	122
24	M	23	1	A	M	L	61	63	32	33	24	20	127	146
25	F	21	4	W	M	M	56	57	30	29	16	18	133	130
26	F	24	2	W	M	L	62	61	36	37	24	23	137	136
27	F	27	3	W	M	S	53	56	30	31	18	17	127	117
28	F	21	1	W	EL	L	51	52	35	36	20	19	111	127
29	M	23	4	W	M	M	57	59	39	38	21	18	149	134
30	M	20	2	W	M	L	61	62	34	37	19	20	143	132
31	F	21	1	W	EL	L	64	66	36	36	23	24	117	132
32	F	25	3	W	M+	L	60	60	36	35	24	22	140	127
33	F	23	2	W	M	M	58	58	33	32	20	20	130	138
34	M	21	2	W	M	M	59	59	34	32	24	27	140	141
35	M	22	4	W	S	S	64	64	34	31	19	19	149	142
36	F	20	4	W	M	L	57	57	30	26	25	23	137	140
37	M	22	5	W	M	M	64	67	36	36	21	22	140	139
38	M	21	1	W	L	L	62	66	32	34	26	25	152	133
39	M	22	3	W	M	M+	60	62	38	36	18	20	146	135
40	F	25	5	W	S	M	61	60	28	30	20	21	137	127

S# = Subject number
 HL = Categorical ranking of hearing level:
 1 being lowest, 5 being highest
 LCS = Left-ear Canal Size, per AO Eargage
 RCS = Right-ear Canal Size, per AO Eargage
 ELL = Ear Length Left (mm)
 ELR = Ear Length Right (mm)
 EBL = Ear Breadth Left (mm)
 EBR = Ear Breadth Right (mm)
 PTL = Protrusion of Left ear (mm)
 PTR = Protrusion of Right ear (mm)
 HH = Head Height (mm)

APPENDIX D

STEPWISE PROCEDURES FOR EXPERIMENT 2

PROTOCOL FOR EXPERIMENT 2

Visit 0: Novice Subjects: Consent and Screening

1. Subject is told that the experiment will take one more visit to the laboratory, estimated at one hour and twenty minutes. A brief description of the visit is given.
2. Informed Consent is administered, and any questions are addressed by the experimenter, excluding those that will introduce bias. The subject is asked to remove any ear jewelry at this time.
3. Subject is given otoscopic examination to determine if impacted cerumen and/or irritation/infection are present.
4. Subject enters the audiometric chamber, is given instructions for audiogram, and practices a Hughson-Westlake threshold testing procedure using a pure-tone audiometer.
5. Subject is audiometrically tested in both ears using pure-tone stimuli.
6. Audiogram is scored to determine if subject qualifies as to < 25 dB HTL requirement. Subject takes 2 minute break.
7. Subject enters the anechoic chamber, and is given explicit instructions for sound-field REAT test. The door is closed, and the experimenter communicates with the subject (via intercom) to insure that the subject is calm and relaxed. Video monitor is checked to ensure that subject is in view.
8. Experimenter administers the open-ear sound-field audiograms with the Békésy method that is programmed on the IBM PS-2 70 computer.
9. A minimum of 5 audiograms are given for practice of the testing procedure. The last 3 audiograms are scored according to the requirement: up to 6 dB of variability, scored on the 3 successive practice open-ear sound-field audiograms.
10. Subject exits the test chamber and sits on a stool. Subject is given drawings of the anatomical measurements to be taken. Experimenter takes and records each individual measurement, except for ear canal sizes, which will be taken at the end of Visit 2. Subject is scheduled for subsequent visit and dismissed.

Visit 0: Experienced Subjects: Consent and Screening

1. Subject is told that the experiment will take one more visit to the laboratory, estimated at one hour and twenty minutes. A brief description of the visit is given.
2. Informed Consent is administered, and any questions are addressed by the experimenter, excluding those that will introduce bias. The subject is asked to remove any ear jewelry at this time.
3. Subject is given otoscopic examination to determine if impacted cerumen and/or irritation/infection are present.
4. If the subject's audiogram on file is more than 12 months old, subject enters the audiometric chamber, is given instructions for audiogram, and practices a Hughson-Westlake threshold testing procedure using a pure-tone audiometer.
5. Subject is audiometrically tested in both ears using pure-tone stimuli.
6. If subject's audiogram on file is less than 12 months old, it will be scored to determine if the subject qualifies for the experiment.
7. Audiogram is scored to determine if subject qualifies as to < 25 dB HTL requirement. Subject takes 2 minute break.
8. Subject enters the anechoic chamber, sits down, and is given explicit instructions for sound-field REAT test. The door is closed, and the experimenter communicates with the subject (via intercom) to insure that the subject is calm and relaxed. Video monitor is checked to ensure that subject is in view.
9. Experimenter administers the open-ear sound-field audiograms with the Békésy method that is programmed on the IBM PS-2 70 computer.
10. Two practice audiograms are required, however, more can be practiced if either experimenter or subject deem it necessary. These 2 audiograms are scored according to the requirement: up to 6 dB of variability, but only scored on 2 successive practice open-ear sound-field audiograms instead of 3.
11. If subject has not previously participated in the ANSI Pilot Study, then an IUF practice session with the V-51R plugs is administered. Manufacturer's instructions, verbal instructions, and a demonstration are given. There is no time limit for practice.

12. After practicing with the plugs, subject enters the anechoic chamber and places the plugs and manufacturer's instructions on the platform. After 2 minutes accommodation time, experimenter asks subject to insert plugs according to the manufacturer's instructions. After the occluded threshold is taken and stored on disk, subject removes the plugs. After a short delay, experimenter asks subject to reinsert the plugs. A second occluded threshold is taken and stored on disk. Subject removes plugs and exits the chamber.
13. Subject sits on a stool and is given drawings of the anatomical measurements to be taken. Experimenter takes and records each individual measurement, except for ear canal sizes, which will be taken at the end of Visit 2. Subject is scheduled for subsequent visit and dismissed.

Notes on Data Collection Visits:

As soon as the subject arrives at the laboratory, he/she is given a brief description of the entire visit and removes any ear jewelry at that time.

Eyeglasses may be kept on throughout the study so subject can see to read manufacturer's instructions.

For the second session in a visit, the test chamber accommodation time is reduced from 5 minutes to 2 minutes.

Once a test has begun, regardless of the fit of the hearing protector, or whether or not it changes position or breaks its acoustical seal, the data will still be accepted. If a hearing protector falls out of the ear during the test, the experimenter shall terminate the test, enter the chamber, and hand the subject the instructions and the earplugs, and ask him or her to reinsert the device for a retest. If the earplug falls out a second time, testing shall again be terminated and the subject dismissed from the experiment.

Before the second session in the visit, subject will take a two minute break outside of the chamber while leaving the plugs and instructions in the chamber on the platform. Experimenter does not talk to subject concerning the laboratory or experiment. After two minutes, subject will enter the chamber, have two minutes for accommodation time, and then be tested for the second session, either with or without the noise. The only written instructions given to the subject (apart from the manufacturer's instructions) are those presented by the experimenter before the first occluded test (i.e., item # 11).

Visit 1/SF: WON Treatments (Novice and Experienced Subjects)

1. A copy of the stated purpose of the test is given to subject and is read aloud by experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. One new pair of each size V-51R plugs with manufacturer's package instructions is placed on a table in front of subject. Experimenter says, "Please read these manufacturer's instructions. You have 5 minutes to choose and fit the plugs you will use in the test." [ASL] Experimenter starts the timer for 5 minutes.
3. Once subject has read the package instructions, experimenter gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "Please try these protectors on to find the size that is best for you. This may be different for each of your ears. Begin by trying a middle or regular size and then based on the looseness or tightness of the fit, and any guidance provided in the manufacturer's instructions, proceed to larger or smaller sizes as needed." No other recommendations or physical assistance is given.
4. Subject begins fitting the different sized plugs. Experiment says, "I cannot assist you or answer any questions concerning the earplugs, but please practice inserting the plugs in both ears at this time." [ASL]
5. Subject is advised after 4 minutes to make his/her best attempt to choose and fit proper sized plugs within the next minute. After 5 minutes, or when subject indicates fitting is complete, plugs are removed by subject and placed on table. All plugs not chosen are removed from table by experimenter.
6. Experimenter tells the subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.

- f. the intercom system is always on.
 - g. the TV camera is always on.
 - h. do not forget which plug goes in which ear.
7. Subject takes plugs and the package instructions into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair, in a way that subject will not forget which plug goes in which ear.
 8. Experimenter exits chamber, closes the door, and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
 9. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
 10. When the accommodation time expires, experimenter tells subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is unoccluded).
 11. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Once you indicate that you have completed fitting the protector, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a short delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.
 12. Subject inserts plugs and indicates to experimenter when finished. After a short delay, experimenter tells subject the test is about to begin.
 13. Experimenter offers no more assistance or additional explanations nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.

14. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer printer and stores data on disk.
15. Steps 9 through 14 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the V-51R plug. Experimenter does not re-enter chamber at any time during this sequence.
16. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
17. When the testing sequence is finished, if the session is the last session in the visit, the experimenter will measure the subject's ear canals, pay, debrief, and release subject. If it is the first session, subject takes a 2 minute break outside of the chamber and then begins the next session.

Visit 1/SF: WN Treatments (Novice and Experienced Subjects)

1. A copy of the stated purpose of the test is given to subject and is read aloud by experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. One new pair of each size V-51R plugs with manufacturer's package instructions is placed on a table in front of subject. Experimenter says, "Please read these manufacturer's instructions. You have 5 minutes to choose and fit the plugs you will use in the test." [ASL] Experimenter starts the timer for 5 minutes.
3. Once subject has read the package instructions, experimenter gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "Please try these protectors on to find the size that is best for you. This may be different for each of your ears. Begin by trying a middle or regular size and then based on the looseness or tightness of the fit, and any guidance provided in the manufacturer's instructions, proceed to larger or smaller sizes as needed." No other recommendations or physical assistance is given.

4. Subject begins fitting the different sized plugs. Experiment says, "I cannot assist you or answer any questions concerning the earplugs, but please practice inserting the plugs in both ears at this time." [ASL]
5. Subject is advised after 4 minutes to make his/her best attempt to choose and fit proper sized plugs within the next minute. After 5 minutes, or when subject indicates fitting is complete, plugs are removed by subject and placed on table. All plugs not chosen are removed from table by experimenter.
6. Experimenter tells the subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on.
 - g. the TV camera is always on.
 - h. do not forget which plug goes in which ear.
7. Subject takes plugs and the package instructions into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair, in a way that subject will not forget which plug goes in which ear.
8. Experimenter exits chamber, closes the door, and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
9. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
10. When the accommodation time expires, experimenter tells subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is unoccluded).

11. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud: "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Adjust the hearing protector, using the steady noise which I will present, so that it blocks the most sound from your ears, but is still reasonably comfortable. By 'blocking the most sound' I mean that the noise you hear under the protector should be reduced to a minimum. And by 'reasonably comfortable' I mean that you should consider your ability to wear the hearing protector for normal use while engaged in noisy occupational or recreational activities. To test the fit of the hearing protector with the noise, cup your hands over your ears and listen to the noise; then, take your hands away from your ears and listen to the noise again. Adjust the hearing protector to block the sound so that the noise level differences you hear with hands cupped over your ears and hands away are as small as possible. Once you indicate that you have completed fitting the protector, the noise will be turned off, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a short delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.
12. Experimenter turns on fitting noise. Subject inserts plugs and indicates to experimenter when finished. Experimenter turns off fitting noise. After a short delay, experimenter tells subject the test is about to begin.
13. Experimenter offers no more assistance or additional explanations nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.
14. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer printer and stores data on disk.

15. Steps 9 through 14 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the V-51R plug. Experimenter does not re-enter chamber at any time during this sequence.
16. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
17. When the testing sequence is finished, if the session is the last session in the visit, the experimenter will measure the subject's ear canals, pay, debrief, and release subject. If it is the first session, subject takes a 2 minute break outside of the chamber and then begins the next session.

Visit 1/IUF: WON Treatments (Novice and Experienced Subjects)

1. A copy of the stated purpose of the test is given to subject and is read aloud by the experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. One new pair of each size of V-51R plugs with manufacturer's package instructions is placed on a table in front of subject. Experimenter says, "Please read these manufacturer's instructions. You have 7 minutes to choose and fit the plugs you will use in the test." Experimenter starts the timer for 7 minutes.
3. Once subject has read the package instructions, experimenter gives a copy of the following instructions to subject, and read them aloud (verbatim as stated in the S12/WG11 protocol): "Please try these protectors on to find the size that is best for you. This may be different for each of your ears. Begin by trying a middle or regular size and then based on the looseness or tightness of the fit, and any guidance provided in the manufacturer's instructions, proceed to larger or smaller sizes as needed."
4. Subject begins fitting the different sized plugs. Experimenter assists in selecting proper sized plugs and instructs subject on how to fit earplugs in strict accordance with the manufacturer's written instructions. Also, experimenter demonstrates and physically assists in fitting the device in accordance with the manufacturer's written

instructions. Experimenter does not augment inadequate or correct inaccurate manufacturer's instructions.

5. Subject is advised after 6 minutes to make his/her best attempt to choose and fit proper sized plugs within the next minute. After 7 minutes, or when experimenter believes subject can fit device according to manufacturer's instructions, plugs are removed by subject and place on the table. All plugs not chosen are removed from the table by experimenter.
6. Experimenter tells subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.
 - d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on.
 - g. the TV camera is always on.
 - h. do not forget which plug goes in which ear.
7. Subject takes the plugs and the package instructions into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair, in a way that subject will not forget which plug goes in which ear.
8. Experimenter exits chamber, closes the door and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
9. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
10. When the accommodation time expires, experimenter tell subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is an unoccluded).
11. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud (verbatim as stated in the S12/WG11 protocol): "After I leave the chamber I will still be

able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Once you indicate that you have completed fitting the protector, the test will begin, and you may not touch or adjust the protector until you are asked to remove it at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a short delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.

12. Subject inserts plugs and indicates to experimenter when finished. After a short delay, experimenter tells subject the test is about to begin.
13. Experimenter offers no more assistance or additional explanations nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.
14. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer and stores data on disk.
15. Steps 9 through 14 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the V-51R plug. Experimenter does not re-enter chamber at any time during this sequence.
16. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
17. When the testing sequence is finished, if the session is the last session in the visit, the experimenter will measure the subject's ear canals, pay, debrief, and release subject. If it is the first session, subject takes a 2 minute break outside of the chamber and then begins the next session.

Visit 1/IUF: WN Treatments (Novice and Experienced Subjects)

1. A copy of the stated purpose of the test is given to subject and is read aloud by the experimenter. This statement is (verbatim as stated in the S12/WG11 protocol): "The purpose of this test is to estimate the noise reduction that you would be likely to obtain while wearing this hearing protector in a noisy environment."
2. One new pair of each size of V-51R plugs with manufacturer's package instructions is placed on a table in front of subject. Experimenter says, "Please read these manufacturer's instructions. You have 7 minutes to choose and fit the plugs you will use in the test." Experimenter starts the timer for 7 minutes.
3. Once subject has read the package instructions, experimenter gives a copy of the following instructions to subject, and read them aloud (verbatim as stated in the S12/WG11 protocol): "Please try these protectors on to find the size that is best for you. This may be different for each of your ears. Begin by trying a middle or regular size and then based on the looseness or tightness of the fit, and any guidance provided in the manufacturer's instructions, proceed to larger or smaller sizes as needed."
4. Subject begins fitting the different sized plugs. Experimenter assists in selecting proper sized plugs and instructs subject on how to fit earplugs in strict accordance with the manufacturer's written instructions. Also, experimenter demonstrates and physically assists in fitting the device in accordance with the manufacturer's written instructions. Experimenter does not augment inadequate or correct inaccurate manufacturer's instructions.
5. Subject is advised after 6 minutes to make his/her best attempt to choose and fit proper sized plugs within the next minute. After 7 minutes, or when experimenter believes subject can fit device according to manufacturer's instructions, plugs are removed by subject and place on the table. All plugs not chosen are removed from the table by experimenter.
6. Experimenter tells subject the following:
 - a. the test sequence will consist of four individual tests, two with the earplugs inserted, and two with the earplugs removed.
 - b. the order of the test will be indicated.
 - c. the tests will not begin until 5 minutes after you enter the chamber and the door is closed.

- d. this time is allotted for relaxation and accommodation to the chamber.
 - e. physiological noises such as blood flow or heartbeats may be heard and should be ignored as much as possible.
 - f. the intercom system is always on.
 - g. the TV camera is always on.
 - h. do not forget which plug goes in which ear.
7. Subject takes the plugs and the package instructions into the chamber and is seated. Experimenter points out the head position indicator and the threshold response switch. Experimenter tells subject to place the earplugs and packaging on the platform beside the chair, in a way that subject will not forget which plug goes in which ear.
 8. Experimenter exits chamber, closes the door and starts the timer for 5 minutes. No other instructions are given to subject until the accommodation time expires.
 9. Experimenter checks the audiogram conditions on the computer and verifies that the video monitor is functioning properly.
 10. When the accommodation time expires, experimenter tell subject (via intercom) that the test is about to begin, to leave the earplugs and packaging on the platform (if the first test is an unoccluded).
 11. Immediately prior to the first occluded trial, experimenter enters the chamber, gives a copy of the following instructions to subject, and reads them aloud: "After I leave the chamber I will still be able to observe you by using the TV camera. Please put on the hearing protector in the way you have just learned. Adjust the hearing protector, using the steady noise which I will present, so that it blocks the most sound from your ears, but is still reasonably comfortable. By 'blocking the most sound' I mean that the noise you hear under the protector should be reduced to a minimum. And by 'reasonably comfortable' I mean that you should consider your ability to wear the hearing protector for normal use while engaged in noisy occupational or recreational activities. To test the fit of the hearing protector with the noise, cup your hands over your ears and listen to the noise; then, take your hands away from your ears and listen to the noise again. Adjust the hearing protector to block the sound so that the noise level differences you hear with hands cupped over your ears and hands away are as small as possible. Once you indicate that you have completed fitting the protector, the noise will be turned off, the test will begin, and you may not touch or adjust the protector until you are asked to remove it

at the end of the test. In the case of earplugs, if the device falls out of your ear during the test, please signal me." Experimenter then says, "You may review the manufacturer's instructions prior to fitting. After you indicate that you have finished inserting the plugs, there will be a short delay before the signals begin." [ASL] Experimenter exits chamber and closes the door, taking the copy of spoken instructions with him.

12. Experimenter turns on fitting noise. Subject inserts plugs and indicates to experimenter when finished. Experimenter turns off fitting noise. After a short delay, experimenter tells subject the test is about to begin.
13. Experimenter offers no more assistance or additional explanations nor will he enter the test chamber again until the testing of two unoccluded and two occluded thresholds is complete.
14. During each threshold determination trial, experimenter monitors video screen (to check subject) and computer screen (to check status of audiogram). At end of each trial, experimenter prints threshold table on computer and stores data on disk.
15. Steps 9 through 14 are repeated until 2 occluded and 2 unoccluded trials are completed (in predetermined order) on the V-51R plug. Experimenter does not re-enter chamber at any time during this sequence.
16. The only further instructions, given prior to each occluded trial, are to remind subject that he/she may review the manufacturer's instructions prior to refitting the plugs. Also, at the appropriate time, subject is reminded either to insert or remove the plugs.
17. When the testing sequence is finished, if the session is the last session in the visit, the experimenter will measure the subject's ear canals, pay, debrief, and release subject. If it is the first session, subject takes a 2 minute break outside of the chamber and then begins the next session.

APPENDIX E

SUBJECT'S INFORMED CONSENT

SUBJECT'S INFORMED CONSENT -- HEARING PROTECTION DEVICE STUDY

This research experiment is designed to investigate the ability of hearing protectors (earplugs) to block out sound. No loud or harmful sounds or any other dangerous situations will be present in the experiment. All of the earplugs in the study will be new and each set of plugs will only be worn by one subject.

The experiment is expected to last a minimum of two hours, but should not exceed a maximum of five hours. Please realize that your participation is voluntary, and that you may withdraw from the study at any time, thus receiving payment only for the amount of time that you have participated.

Before the experiment begins, both of your ears will be inspected with an otoscope to insure that you do not have any obstructions in your ear canals.

Next, your right and left ear hearing will be tested with very quiet tones played through a set of headphones. If your hearing ability meets the requirements of the study, you will be given several hearing tests to practice the method which will be used to indicate your ability to hear tones in the experiment.

In the experiment, your hearing ability will be tested in two conditions: (1) while wearing hearing protectors, and (2) while not wearing hearing protectors. In both conditions your hearing will be tested with very quiet pulsating tones played through a set of loudspeakers. Neither these tones nor any fitting noise will exceed 75 dBA (a safe level) for the study. You will have to be very attentive and listen carefully for these tones. Just as soon as you hear a tone, press the button on the hand switch and hold it down whenever you can hear the tone and release it when you do not hear the tone. The tones will be very faint and you will have to listen very carefully to hear them.

The tests will be conducted in a sound-proof booth with the experimenter sitting outside. The door to the booth will be shut but not locked; either you may open the door from the inside or the experimenter may open it from the outside. An intercom system will be available for your communication with the experimenter by simply talking. A closed-circuit TV system will also be used to monitor the interior of the booth.

There is no risk to your well-being posed by these hearing tests, nor are there any other known risks in this experiment. Also, realize that they are not designed to assess or diagnose any physiological or anatomical hearing disorders. The experimental

tests will only be used to determine the performance of the hearing protectors. However, if you choose, you may benefit from the study by receiving a copy of a pure tone audiogram that indicates your hearing ability at different frequencies.

Also in the experiment, there will be several measurements taken of your ears and head. These measurements include size of the ear canals, size of the outer ears, head height, length, and width. These measurements will be taken with standard professional anthropometric calipers and gauges that are only used in the research laboratory. There is no pain or danger associated with these surface measurements.

As a participant in this experiment, you have certain rights, as stated below. This sheet is intended to describe these rights to you and to obtain your written consent to participate.

- (1) You have the right to discontinue participating in the study at any time for any reason by simply informing a member of the research team.
- (2) You have the right to inspect your data and to withdraw it from the experiment if you feel that you should. In general, data are processed and analyzed after all subjects have completed the experiment. Subsequently, your data will be kept confidential by the research team. No one else will see your individual data with your name.
- (3) You have the right to be informed as to the general results of the experiment. If you wish to receive a summary of the results, include your address (four months hence) with your signature on the last page of this form. If, after receiving the summary, you would like further information, please contact the Auditory Systems Laboratory, and a more detailed report will be made available to you. To avoid biasing other potential subjects, you are requested not to discuss the study with anyone until eight months from now.
- (4) You may ask questions of the research team at any time prior to data collection. All questions will be answered to your satisfaction subject only to the constraint that an answer will not prebias the outcome of the study. If bias would occur, with your permission an answer will be delayed until after the data collection, at which time a full answer will be given.

Before you sign this form, please make sure that you understand, to your complete satisfaction, the nature of the study, and your rights as a participant. Please realize that the

results of this study will be incorporated into a master's thesis that may be published, but will in no way jeopardize the confidentiality of your individual data. If you have any questions, please ask them of the experimenter at this time. Then if you decide to participate, please sign your name below and provide your phone number so that you may be contacted for scheduling.

I have read a description of this study and understand the nature of the research and my rights as a participant. I hereby consent to participate, with the understanding that I may discontinue participation at any time if I choose to do so, being paid only for the portion of time that I spend in the study.

Signature: _____

Printed Name: _____

Date: _____

Phone: _____

Address: _____

I, the subject, do, do not (circle one) wish to receive a summary of the research results. (If the summary is desired, include address, four months, hence below).

Address: _____

REMEMBER, you are supposed to press the button (and keep it pressed) whenever you hear the tone and release it when you do not hear the tone.

The research team for this experiment consists of Mr. Michael L. Richards, graduate student in the IEOR Department, Dr. Dennis L. Price, faculty member in the IEOR Department, and Dr. John G. Casali, Director of the Auditory Systems Laboratory. They may be reached at the following address and phone number.

Auditory Systems Laboratory
Room 538 Whittemore Hall
VPI & SU
Blacksburg, VA 24061
(703) 231-9086

If you have detailed questions regarding your rights as a participant in University research, you may contact the following individual:

Dr. E. R. Stout
Chairman, University Human Subjects Committee
301 Burruss Hall
VPI & SU
Blacksburg, VA 24061
(703) 231-5281

(PLEASE TEAR OFF AND KEEP THIS PAGE FOR FUTURE REFERENCE)

APPENDIX F

**MEAN AND ANOVA SUMMARY TABLES
FOR EXPERIMENT 1**

Experiment 1. Mean Attenuations (Standard Deviations) with V-51R Pre-molded Plug

Condition	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
SF, Nov.	8.9 (7.2)	7.7 (8.1)	8.3 (7.2)	11.8 (8.7)	21.6 (8.3)	24.6 (6.2)	19.5 (6.7)	15.0 (5.7)	18.2 (6.7)
IUF, Nov.	16.9 (8.2)	17.1 (9.8)	17.8 (8.4)	19.0 (8.7)	27.5 (7.4)	30.9 (8.3)	27.0 (10.8)	34.6 (9.8)	33.6 (9.0)
SF, Exp.	17.3 (7.4)	18.0 (7.3)	19.0 (7.9)	20.9 (6.9)	28.4 (5.7)	30.1 (5.5)	28.0 (7.4)	35.5 (10.6)	33.8 (9.4)
IUF, Exp.	19.0 (10.3)	20.3 (10.2)	21.2 (10.3)	22.1 (9.5)	30.1 (7.8)	32.6 (8.3)	31.8 (9.0)	41.1 (12.4)	39.0 (10.1)

Experiment 1. Mean Attenuations (Standard Deviations) with E-A-R- Foam Plug

Condition	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
SF, Nov.	19.1 (4.8)	22.3 (5.6)	24.7 (6.1)	25.9 (4.1)	33.6 (5.1)	41.1 (4.8)	41.0 (3.9)	45.7 (7.4)	41.2 (7.8)
IUF, Nov.	28.7 (4.6)	32.5 (4.7)	36.5 (4.7)	35.8 (5.3)	36.6 (4.0)	43.2 (2.5)	43.8 (2098)	48.8 (4.6)	46.1 (4.4)
SF, Exp.	28.7 (7.1)	32.5 (5.4)	37.0 (5.2)	36.2 (6.2)	37.5 (4.4)	43.9 (2.8)	44.0 (3.7)	47.9 (3.2)	45.2 (3.6)
IUF, Exp.	29.3 (7.0)	33.5 (6.8)	38.2 (6.5)	36.9 (5.4)	37.8 (3.5)	43.6 (2.4)	44.2 (2.5)	49.1 (3.1)	45.9 (4.4)

Experiment 1 ANOVA Summary Table for Attenuation at 250 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Subjects (S)	9	225.47		
<u>Within-subjects</u>				
HPD (H)	1	4148.64	79.32	0.0001
Fit (F)	1	658.38	21.08	0.0013
Experience Level (E)	1	768.18	39.35	0.0001
HxS	9	52.30		
FxS	9	31.24		
ExS	9	19.52		
HxF	1	0.35	0.02	0.9035
HxE	1	7.02	0.13	0.7244
FxE	1	332.52	19.07	0.0018
HxFxS	9	22.59		
HxExS	9	53.04		
FxExS	9	17.44		
HxFxE	1	5.57	0.23	0.6410
<u>HxFxExS</u>	<u>9</u>	23.91		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 500 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Subjects (S)	9	226.41		
<u>Within-subjects</u>				
HPD (H)	1	6130.25	130.62	0.0001
Fit (F)	1	768.18	29.70	0.0004
Experience Level (E)	1	987.72	67.95	0.0001
HxS	9	46.93		
FxS	9	25.86		
ExS	9	14.54		
HxF	1	1.89	0.06	0.8081
HxE	1	0.01	0.00	0.9861
FxE	1	398.28	26.47	0.0006
HxFxS	9	30.23		
HxExS	9	31.36		
FxExS	9	15.05		
HxFxE	1	12.88	0.43	0.5288
<u>HxFxExS</u>	<u>9</u>	30.01		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 1000 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Subjects (S)	9	196.01		
<u>Within-subjects</u>				
HPD (H)	1	4623.84	72.20	0.0001
Fit (F)	1	456.01	31.62	0.0003
Experience Level (E)	1	690.31	38.39	0.0002
HxS	9	64.04		
FxS	9	14.42		
ExS	9	17.98		
HxF	1	6.05	0.21	0.6612
HxE	1	0.80	0.02	0.8806
FxE	1	290.32	18.64	0.0019
HxFxS	9	29.48		
HxExS	9	33.52		
FxExS	9	15.58		
HxFxE	1	13.61	0.47	0.5101
<u>HxFxExS</u>	<u>9</u>	28.94		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 2000 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Subjects (S)	9	176.71		
<u>Within-subjects</u>				
HPD (H)	1	1781.33	38.19	0.0002
Fit (F)	1	152.08	14.18	0.0044
Experience Level (E)	1	267.55	22.87	0.0010
HxS	9	46.64		
FxS	9	10.72		
ExS	9	11.70		
HxF	1	23.87	4.75	0.0573
HxE	1	22.58	1.45	0.2585
FxE	1	60.03	8.83	0.0157
HxFxS	9	5.03		
HxExS	9	15.52		
FxExS	9	6.80		
HxFxE	1	3.16	0.19	0.6719
<u>HxFxExS</u>	<u>9</u>	16.50		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 3150 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Subjects (S)	9	120.82		
<u>Within-subjects</u>				
HPD (H)	1	3588.52	81.69	0.0001
Fit (F)	1	141.51	9.53	0.0130
Experience Level (E)	1	138.34	15.87	0.0032
HxS	9	43.93		
FxS	9	14.85		
ExS	9	8.72		
HxF	1	60.55	5.37	0.0456
HxE	1	21.22	1.44	0.2605
FxE	1	50.88	2.10	0.1809
HxFxS	9	11.27		
HxExS	9	14.72		
FxExS	9	24.19		
HxFxE	1	2.24	0.21	0.6597
<u>HxFxExS</u>	<u>9</u>	10.83		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 4000 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Subjects (S)	9	167.05		
<u>Within-subjects</u>				
HPD (H)	1	5569.45	107.06	0.0001
Fit (F)	1	250.28	11.25	0.0085
Experience Level (E)	1	344.04	17.44	0.0024
HxS	9	52.02		
FxS	9	22.26		
ExS	9	19.72		
HxF	1	85.91	4.64	0.0596
HxE	1	121.28	3.32	0.1016
FxE	1	49.46	3.55	0.0920
HxFxS	9	18.50		
HxExS	9	36.48		
FxExS	9	13.92		
HxFxE	1	1.43	0.13	0.7314
<u>HxFxExS</u>	<u>9</u>	11.41		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 6300 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Subjects (S)	9	123.57		
<u>Within-subjects</u>				
HPD (H)	1	5318.69	36.21	0.0002
Fit (F)	1	1088.55	38.16	0.0002
Experience Level (E)	1	1087.08	34.07	0.0002
HxS	9	146.89		
FxS	9	28.53		
ExS	9	31.91		
HxF	1	544.45	11.44	0.0081
HxE	1	749.70	17.91	0.0022
FxE	1	314.03	11.76	0.0075
HxFxS	9	47.60		
HxExS	9	41.87		
FxExS	9	26.69		
HxFxE	1	182.71	4.40	0.0654
<u>HxFxExS</u>	<u>9</u>	41.53		
Total	79			

Experiment 1 ANOVA Summary Table for Attenuation at 8000 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Subjects (S)	9	163.90		
<u>Within-subjects</u>				
HPD (H)	1	3619.40	44.80	0.0001
Fit (F)	1	858.71	46.18	0.0001
Experience Level (E)	1	760.76	41.88	0.0001
HxS	9	80.79		
FxS	9	18.59		
ExS	9	18.17		
HxF	1	274.91	7.60	0.0222
HxE	1	371.95	11.77	0.0075
FxE	1	256.69	7.85	0.0206
HxFxS	9	36.17		
HxExS	9	31.61		
FxExS	9	32.70		
HxFxE	1	46.06	0.99	0.3456
<u>HxFxExS</u>	<u>9</u>	46.49		
Total	79			

APPENDIX G

**RTP, MEAN, AND ANOVA SUMMARY TABLES
FOR EXPERIMENT 2**

Experiment 2 Data Analysis by Randomization Test Procedure

Comparison	N^1	p^2
SF, NOV, WON - vs - IUF, NOV, WN	622	0.622
SF, NOV, WON - vs - IUF, NOV, WON	910	0.910
SF, NOV, WON - vs - SF, EXP, WON	77	0.077
SF, NOV, WON - vs - IUF, EXP, WON	123	0.123
IUF, NOV, WN - vs - IUF, NOV, WON	844	0.844
IUF, NOV, WN - vs - SF, EXP, WON	208	0.208
IUF, NOV, WN - vs - IUF, EXP, WON	334	0.334
IUF, NOV, WON - vs - SF, EXP, WON	91	0.091
IUF, NOV, WON - vs - IUF, EXP, WON	165	0.165
SF, EXP, WON - vs - IUF, EXP, WON	647	0.647

¹ N = Number of times $F_{.j} \geq F_{.0}$ for 1000 permutation cycles
where:

$F_{.j}$ = summary statistic of the nine frequency-dependent
 F statistics for the permutations where $j = 1$ to 1000;

$F_{.0}$ = summary statistic of the nine frequency-dependent
 F statistics for the actual experimental outcome.

² p = Actual significance level of comparison based on 1000
permutation cycles where 1 permutation cycle involves a
single data permutation at each of the nine test frequencies.

Experiment 2. Mean Attenuations (Standard Deviations) of Novice Subjects with V-51R

Pre-molded Plug

Condition	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
SF, Nov, WN	14.7 (12.1)	14.3 (11.8)	16.9 (13.1)	18.0 (12.1)	27.9 (7.4)	29.6 (6.8)	26.3 (8.5)	26.1 (14.8)	25.9 (15.5)
SF, Nov, WON	16.8 (12.6)	15.8 (13.4)	15.8 (13.9)	17.7 (11.7)	26.8 (7.1)	29.5 (7.2)	25.1 (8.0)	27.4 (16.2)	25.8 (15.5)
IUF, Nov, WN	16.4 (10.9)	18.1 (11.4)	19.5 (10.8)	22.3 (10.7)	29.4 (8.0)	30.9 (7.1)	27.1 (8.9)	31.6 (14.1)	29.9 (11.6)
IUF, Nov, WON	14.4 (11.3)	17.2 (11.3)	18.7 (10.9)	21.1 (11.1)	27.5 (8.1)	29.3 (6.3)	26.0 (7.5)	29.2 (15.0)	26.7 (12.3)

Experiment 2. Mean Attenuations (Standard Deviations) of Experienced Subjects with V-51R

Pre-molded Plug

Condition	Frequency (Hz)								
	125	250	500	1000	2000	3150	4000	6300	8000
SF, Exp, WN	23.7 (7.4)	24.5 (6.1)	26.8 (6.9)	26.6 (5.6)	30.7 (6.0)	33.9 (4.5)	32.3 (5.2)	38.6 (9.2)	35.1 (10.5)
SF, Exp, WON	23.9 (8.9)	25.1 (10.0)	26.3 (8.6)	26.4 (8.0)	30.9 (5.8)	33.5 (5.1)	32.3 (5.4)	38.4 (10.0)	36.3 (11.3)
IUF, Exp, WN	20.9 (4.1)	23.5 (5.5)	23.4 (6.3)	25.1 (6.3)	33.9 (6.0)	31.7 (5.3)	30.5 (8.3)	37.5 (11.3)	38.9 (6.7)
IUF, Exp, WON	19.6 (7.9)	22.2 (8.8)	23.2 (9.8)	24.2 (8.0)	33.2 (7.5)	32.2 (7.1)	30.8 (8.4)	38.9 (11.0)	38.2 (6.4)

Experiment 2 ANOVA Summary Table for Attenuation at 250 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Fit (F)	1	0.18	0.00	0.9755
Experience Level (E)	1	1195.06	6.36	0.0163
FxE	1	125.00	0.66	0.4202
Subjects (S)	36	188.02		
<u>Within-subjects</u>				
Noise (Z)	1	1.68	0.08	0.7743
ZxF	1	12.48	0.62	0.4365
ZxE	1	6.61	0.33	0.5704
ZxFxE	1	2.38	0.12	0.7331
<u>ZxS/FE</u>	<u>36</u>	20.16		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 500 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Fit (F)	1	1.65	0.01	0.9272
Experience Level (E)	1	1046.18	5.35	0.0265
FxE	1	177.31	0.91	0.3472
Subjects (S)	36	195.47		
<u>Within-subjects</u>				
Noise (Z)	1	7.88	0.41	0.5255
ZxF	1	0.47	0.02	0.8771
ZxE	1	1.95	0.10	0.7514
ZxFxE	1	0.00	0.00	0.9980
<u>ZxS/FE</u>	<u>36</u>	19.16		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 1000 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Fit (F)	1	20.60	0.13	0.7239
Experience Level (E)	1	672.80	4.14	0.0493
FxE	1	157.36	0.97	0.3318
Subjects (S)	36	162.58		
<u>Within-subjects</u>				
Noise (Z)	1	7.69	0.45	0.5060
ZxF	1	3.12	0.18	0.6712
ZxE	1	0.13	0.01	0.9314
ZxFxE	1	0.08	0.00	0.9442
<u>ZxS/FE</u>	<u>36</u>	17.04		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 2000 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Fit (F)	1	76.83	0.83	0.3696
Experience Level (E)	1	362.95	3.90	0.0560
FxE	1	12.64	0.14	0.7146
Subjects (S)	36	93.06		
<u>Within-subjects</u>				
Noise (Z)	1	15.49	2.59	0.1163
ZxF	1	3.44	0.58	0.4528
ZxE	1	7.08	1.18	0.2837
ZxFxE	1	0.03	0.01	0.9421
<u>ZxS/FE</u>	<u>36</u>	5.98		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 3150 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Fit (F)	1	7.44	0.11	0.7430
Experience Level (E)	1	181.80	2.67	0.1111
FxE	1	27.38	0.40	0.5302
Subjects (S)	36	68.15		
<u>Within-subjects</u>				
Noise (Z)	1	2.59	0.26	0.6120
ZxF	1	0.26	0.03	0.8711
ZxE	1	4.23	0.43	0.5174
ZxFxE	1	6.84	0.69	0.4112
<u>ZxS/FE</u>	<u>36</u>	9.90		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 4000 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Fit (F)	1	2.78	0.03	0.8716
Experience Level (E)	1	571.92	5.46	0.0251
FxE	1	31.13	0.30	0.5889
Subjects (S)	36	104.67		
<u>Within-subjects</u>				
Noise (Z)	1	4.37	0.36	0.5508
ZxF	1	0.19	0.02	0.9007
ZxE	1	9.18	0.76	0.3885
ZxFxE	1	0.01	0.00	0.9770
<u>ZxS/FE</u>	<u>36</u>	12.05		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 6300 Hz

Source	df	MS	F	p
<u>Between-subjects</u>				
Fit (F)	1	54.62	0.18	0.6761
Experience Level (E)	1	1910.04	6.20	0.0175
FxE	1	80.60	0.26	0.6120
Subjects (S)	36	307.91		
<u>Within-subjects</u>				
Noise (Z)	1	0.06	0.00	0.9647
ZxF	1	6.00	0.22	0.6449
ZxE	1	6.33	0.23	0.6359
ZxFxE	1	36.59	1.32	0.2585
<u>ZxS/FE</u>	<u>36</u>	27.76		
Total	79			

Experiment 2 ANOVA Summary Table for Attenuation at 8000 Hz

Source	df	MS	<i>F</i>	<i>p</i>
<u>Between-subjects</u>				
Fit (F)	1	141.25	0.56	0.4586
Experience Level (E)	1	2023.07	8.04	0.0075
FxE	1	0.82	0.00	0.9548
Subjects (S)	36	251.64		
<u>Within-subjects</u>				
Noise (Z)	1	9.18	0.45	0.5061
ZxF	1	32.90	1.62	0.2118
ZxE	1	19.11	0.94	0.3390
ZxFxE	1	1.95	0.10	0.7585
<u>ZxS/FE</u>	<u>36</u>	20.35		
Total	79			

APPENDIX H

NIOSH FIELD DATA

Sources of NIOSH Field Data:

V-51R pre-molded plugs:

National Institute for Occupational Safety and Health (NIOSH), (1978). A field investigation of noise reduction afforded by insert-type hearing protectors. NIOSH, U.S. Department of Health, Education, and Welfare, Report No. 79-115, Cincinnati, OH.

E-A-R foam plugs:

Edwards, R.G., Broderson, A.B., Green, W.W., and Lempert, B.L. (1982, April). A second field investigation of noise reduction afforded by insert-type hearing protectors (Contract No. 210-81-3001). U.S. Department of Health and Human Services, Cincinnati, OH: Center for Disease Control.

V-51R EARPLUGS

[illegible]

NOTE: -- ATTENUATION COULD NOT BE DETERMINED.
 * UNOCCLUDED THRESHOLD WAS ESTIMATED USING AVERAGE FROM OTHER TESTS.
 † OCCLUDED THRESHOLD WAS >90 DB; VALUE USED WAS 90 DB.

PLANT IV VOLUNTARY POLICY V-51R EARPLUGS

ID# D --ATTENUATION/ O.B. CENTER FREQ.(KHZ)--												ID# D --ATTENUATION/ O.B. CENTER FREQ.(KHZ)--													
Y .5 1 2 3 4 6 8 .5 .25 .12												Y .5 1 2 3 4 6 8 .5 .25 .12													
A11	1	13	14	29	31	31	12	25	17	3	2	C11	3	33	32	42	44	37	31	37	32	27	21		
	2	2	10	12	21	30	22	6	36	13	9		2	3	20	25	42	26	31	11	24	1	3	12	
	3	3	7	8	25	28	22	6	20	5	0		3	3	19	19	26	34	35	11	25	12	7	9	
	4	3	6	9	29	27	21	13	16	9	0		4	3	11	5	14	22	15	6	11	-26	-1	-13	
	5	3	1	2	17	22	20	9	16	9	8		5	3	32	38	48	44	32	15	38	29	22	26	
A21	3	10	16	30	19	15	16	22	7	9	7	C21	1	8	9	19	19	25	12	16	3	1	1	1	
	2	3	9	17	28	26	11	15	5	15	4		2	3	-7	7	20	18	10	13	15	7	3	2	
	3	3	12	12	23	17	18	21	12	8	7		3	3	4	9	30	13	15	22	19	9	9	7	
	4	3	9	21	26	23	16	9	23	11	-4		4	3	6	5	13	15	13	3	11	6	6	9	
	5	3	3	11	20	11	14	14	15	5	1		5	3	26	28	33	28	27	24	33	28	21	11	
A31	2	1	2	30	18	12	8	-4	4	1	3	C31	2	2	2	2	2	2	2	2	2	2	2	2	2
	2	3	8	11	33	23	22	9	6	1	4		2	2	-1	6	12	1	6	12	20	20	-12	-5	
	3	3	0	-9	21	15	12	2	7	0	1		3	3	1	-1	2	11	10	3	4	1	5	1	
	4	3	2	11	29	25	25	11	16	1	4		4	3	-4	-4	6	5	5	-5	-7	-7	-10	-1	
	5	3	-4	1	27	21	19	6	8	-6	1		5	3	13	-1	-4	15	16	10	12	2	8	-18	
A41	2	8	2	9	21	19	14	9	1	5	-2	C41	3	8	0	17	18	21	15	17	13	0	0	-1	
	2	2	5	4	17	32	22	9	1	-4	1		2	3	8	3	13	23	17	10	9	8	2	1	
	3	3	4	2	16	25	16	11	2	0	4		3	3	14	8	16	21	19	19	21	13	7	3	
	4	3	1	2	7	24	13	9	5	6	8		4	3	7	1	26	25	19	14	25	-1	-1	-2	
	5	3	1	0	12	23	21	7	4	4	2		5	3	1	1	9	20	16	12	19	4	4	4	
A51	2	20	25	35*	39	38	43	22	27	24	19	C51	2	26	36	47	49	45	26	43	31	21	12	12	
	2	2	8	10	24*	39*	26	18	13	1	2		2	2	27	39	37	35	22	35	27	21	18	18	
	3	3	16	26	35	30	35	23	22	18	13*		3	3	34	34	41	38	38	17	30	31	19	21*	
	4	3	15	20	32	40	30	21	20	8	10		4	3	21	23	37	41	38	21	30	22	16	2	
	5	3	30	22	39	42	33	18	17	16	7		5	3	18	24	40	41	40	18	34	20	11	8	
A61	3	30	30	46	38	42	35	30	30	23	10	C61	1	1	28	29	29	27	27	32	19	10	10	10	
	2	3	26	26	35	41	34	21	27	18	13		2	2	11	14	21	18	16	13	12	9	3	4	
	3	3	22	23	40	38	37	28	21	23	25		3	3	13	15	26	30	24	15	22	12	7	9	
	4	1	1	1	1	1	1	1	1	1	1		4	3	14	14	19	26	29	17	22	12	7	5	
	5	1	1	1	1	1	1	1	1	1	1		5	3	15	15	22	23	19	8	14	8	5	0	
A71	2	11	23	40	41	29	38	31	19	18	14	C71	2	40	33	44	36	35	20	22	36	34	28	28	
	2	2	17	25	33	40	34	27	35	18	16		2	3	22	26	32	27	27	22	28	19	19	12	
	3	3	7	22	31	34	36	41	30	18	13		3	3	20	22	32	25	17	14	38	25	15	9	
	4	3	1	18	30	34	30	40	33	16	6		4	3	22	16	34	35	39	18	25	5	2	5	
	5	3	19	32	34	39	37	44	39	16	24		5	3	7	6	24	22	26	14	16	-2	8	10	
B11	1	18	18	33	33	35	25	19	14	8	10	D11	2	5	4	17	23	17	16	29	5	4	11	11	
	2	2	11	8	17	26	22	13	10	8	2		2	2	3	9	24	23	14	18	19	3	5	0	
	3	3	9	9	25	27	23	17	22	12	9		3	3	1	5	22	20	15	7	18	2	0	3	
	4	3	6	10	24	24	19	16	10	10	-1		4	3	-3	-1	14	19	12	2	8	0	2	1	
	5	3	6	3	19	26	18	11	10	11	0		5	3	1	0	15	16	15	10	6	3	5	1	
B21	2	2	8	8	26	21	18	17	15	0	-2	D21	3	4	-4	-1	17	14	0	10	4	1	1	1	
	2	2	0	1	8	12	12	10	2	0	-2		2	3	0	-1	4	15	16	1	0	-6	-1	1	
	3	3	-1	0	19	24	21	13	9	5	4		3	3	0	3	14	14	10	16	12	3	-1	-5	
	4	3	0	1	12	17	14	15	6	0	2		4	3	-1	7	0	7	14	-2	3	2	-5	5*	
	5	3	-3	-3	5	14	11	11	10	2	-3		5	3	4	0	6	13	16	2	0	2	6	9	
B31	2	1	6	22	17	10	19	9	8	5	3	D31	2	2	13	6	11	8	10	5	7	1	1	1	
	2	2	1	7	23	22	13	26	11	3	2		2	2	5	17	16	22	24	23	13	1	-5	6	
	3	3	4	5	19	14	12	25	21	5	-1		3	3	5	17	27	25	25	20	18	2	0	-2	
	4	3	-1	2	22	21	17	23	29	4	1		4	3	31	19	29	39	41	33	31	33	28	16	
	5	3	6	15	19	16	9	25	14	6	0		5	3	4	13	22	27	24	19	13	7	2	-5	
B41	1	11	9	21	25	21	20	6	12	0	6	D41	1	3	10	8	28	27	25	35	0	10	16	16	
	2	2	33	40	30	43	47	39	35	27	20		2	2	6	12	20	14	6	-4	18	12	1	-4	
	3	3	27	35	40	49	43	36	22	29	24		3	3	7	9	4	31	30	19	30	-3	2	0	
	4	3	34	40	49	49	44	35	29	27	19		4	3	17	5	18	26	10	2	5	-1	5	-7	
	5	3	7	6	13	24	20	14	3	5	1		5	3	5	3	10	9	5	2	12	9	0	1	
B51	1	-11	0	7	9	6	-9	-6	-5	-8	-6	D51	2	-1	6	14	35	25	19	19	4	13	1	1	
	2	2	6	3	7	5	10	-2	9	-2	0		2	2	10	16	20	33	25	9	5	0	4	0	
	3	3	9	5	9	19	21	8	14	3	9		3	3	3	8	21	26	34	18	17	0	0	5*	
	4	3	6	10	15	19	11	0	-2	0	-7		4	3	1	-3*	-2	16	11	10	7*	2*	4*	0	
	5	3	2	6	18	16	16	-4	2	-2	-2		5	3	22	30	35	41	42*	--	--	--	37*	31*	
B61	1	23	29	53	35	32	20	25	16	9	10	D61	2	-2	0	10	20	28	--	16	3	-2	-1	-1	
	2	2	14	19	40	25	20	10	8	14	0		2	3	-2	1	18	22	25	19	18	0	2	9	
	3	3	2	12	29	17	16	7	0	5	2		3	3	-2	-1	9	19	24	4	9	5	15*	13	
	4	3	14	22	32	27	26	11	25	16	11		4	3	11	13	24	18	21	11	22	18	7	3	
	5	3	5	-2	13	7	-2	-9	4	-4	-5		5	3	--	--	--	--	--	--	--	--	--	--	--
B71	1	8	6	30	22	12	-1	13	2	0	0	D71	3	--	--	--	--	--	--	--	--	--	--	--	--
	2	2	3	2	4	9	4	-5	10	3	-1		2	3	0	5	13	24	15	5	13	-1	7	3	
	3	3	1	3	13	17	17	11	5	1	-1		3	3	12*	8	12								

NOTE: --, ATTENUATION COULD NOT BE DETERMINED.
 *, UNOCCLUDED THRESHOLD WAS ESTIMATED USING AVERAGE FROM OTHER TESTS.
 **, OCCLUDED THRESHOLD WAS >90 DB; VALUE USED WAS 90 DB.

PLANT V VOLUNTARY POLICY V-51R EARPLUGS

ID#	D	Y	5	1	2	3	4	6	8	5	25	12
A11	1	18	27	46	32	31	25†	31†	21	20	17	
	2	2	15	22	28	19	14	21	23†	14	19	9
	3	3	12	27	28	23	22	21†	25†	16	23	10
	4	4	25	27	34	28	29	17†	23	37	23	15
	5	5	15	30	25	24	20	22†	32†	19	24	14
A21	1	31	33	35*	37*	54	--	--	26	22	17	
	2	2	21	26	30	38	32	21	36	22	17	4
	3	3	19	17	23	32	24	28	22	22	14	12
	4	4	9	14	26	35	30	15	17	10	-1	6
	5	5	13	10	25	28	27	18	2	13	8	-1
A31	1	5	6	5	13	10	7	-4	3	3	1	
	2	2	4	7	20	14	9	8	17	2	-1	4
	3	3	-2	1	3	8	7	-4	0	0	-1	0
	4	4	-4	1	1	10	10	7	0	-6	-5	2
	5	5	3	3	6	10	-3	8	21	1	-3	5
A41	1	8	13	27	25	23	11	21	8	13	12	
	2	2	19	26	33	31	28	26	26	19	18	17
	3	3	15	20	27	28	26	25	33	19	13	13
	4	4	9	7	21	32	25	13	25	28	16	14
	5	5	-1	8	21	24	13	19	22	6	8	11
A51	1	30	31	40	43	43	54	38	30	27	22	
	2	3	17	25	26	35	42	49	30	20	20	20
	3	3	20	20	27	38	35	48	31	26	22	12
	4	4	25	26	36	33	41	50	40	27	18	12
	5	5	21	20	28	24	24	39	38	26	22	13
A61	1	30	31	40	48	44	51	47	27	26	21	
	2	2	28	22	37	49	42	59	44	29	30	22
	3	3	32	30	32	37	33	47	47	31	30	25
	4	4	45	41	54	63	69	62	55	46	40	34
	5	5	29	37	35	38	29	44	48	34	29	28
A71	1	11	8	12	20	14	8	8	-1	4	3	
	2	2	6	7	12	12	12	12	7	3	2	1
	3	3	0	3	17	21	20	10	4	-1	4	1
	4	4	8	7	23	29	24	13	14	-6	1	1
	5	5	3	4	9	17	11	10	17	-1	3	1
B11	1	11	13	23	16	14	6	7	9	4	5	
	2	2	1	5	20	18	14	6	10	3	2	1
	3	3	6	6	21	19	11	-1	9	3	-3	-2
	4	4	6	8	20	15	13	1	8	-1	-1	2
	5	5	17	16	27	29	24	20	19	7	6	2
B21	1	10	20	18	17	12	22	30	10	12	10	
	2	2	4	8	14	14	11	27	29	1	1	-1
	3	3	-1	-3	1	17	15	5	-1	0	-1	-9
	4	4	7	21	9	23	19	21	18	9	8	4
	5	5	6	6	6	16	6	29	19	6	3	5
B31	1	22	30	42	45	45	48	47	18	16	13	
	2	2	26	34	43	49	62	51	57	30	26	23
	3	3	30	40	55	47	58	57	60	35	37	28
	4	4	19	29	39	45	45	45	53	24	20	18
	5	5	24	39	41	45	58	51	53	26	22	20
B41	2	28	31	46	23	22	36	47	26	12	13	
	2	15	23	21	21	35	30	11	16	15*		
	3	16	24	33	28	26†	46	36	12	12	17	
	4	12	20	35	26	22	--	49	45	13	33	
	5	--	26	33	37	42	17	16	32	18	27	
B51	1	23	36	37	45	46†	48	58	29	30	21	
	2	2	10	8	21	28	25	37	39	11	6	3
	3	3	30	29	37	44	43†	52	51	31	31	17
	4	4	17	26	34	41	35	55	49	29	21	18
	5	5	17	25	53	46	37	57†	54	25	20	17
B61	1	5	12	26	30	30	12	5	1	0	10	
	2	2	2	5	13	16	20	8	15	-1	-7	-16
	3	4	2	1	17	27	24	9	16	7	3	21
	4	5	5	6	-1	-2	2	5	-2	2	10	-4
	5	5	0	-4	9	12	11	12	14	-1	2	3
B71	1	1	0	9	21	15	-3	14	-1	1	3	
	2	2	1	3	7	21	13	1	4	1	0	-1
	3	3	3	3	12	21	12	-4	-1	-2	0	0
	4	4	1	1	9	19	15	5	5	5	-2	-4
	5	5	1	2	12	21	16	3	10	-1	1	4

ID#	D	Y	5	1	2	3	4	6	8	5	25	12
C11	1	3	0	10	12	3	10	14	-2	-4	-8	
	2	2	2	0	15	15	9	9	8	0	-3	-2
	3	3	-4	2	11	12	7	7	13	3	-3	-3
	4	4	14	11	19	18	14	22	41	12	1	8
	5	5	-1	-1	9	11	13	4	20	1	0	-2
C21	1	24	20	31	25	33	32*	26	20	25	25	
	2	2	25	26	40	37	29	22	28	19	21	11
	3	3	12	27	35	35	41	23	18	22	22	8
	4	4	24	25	40	36	39	29	28	20	24	25
	5	5	3	12	24	29	31	22	7	10	16	20
C31	1	35	33	45	54	61	53	61	35	32	20	
	2	2	29	25	49	50	63	50	49	29	21	33
	3	3	17	26	43	33	29	25	26	26	25	20
	4	4	24	30	37	35	34	29	26	17	15	18
	5	5	15	21	29	25	28	24	29	16	11	9
C41	1	29	27	39	38	37	38	47	32	19	22	
	2	2	17	19	27	21	20	37	39	13	12	3
	3	3	15	17	26	21	26	29	30	21	16	21
	4	4	6	16	16	14	21	26	30	12	5	14
	5	5	10	13	24	27	31	38	46	9	5	3
C51	1	8	5	20	16	15	3	3	4	3	6	
	2	2	7	6	9	12	15	2	1	7	6	9
	3	3	5	7	20	24	20	8	13	4	1	9
	4	4	5	5	6	13	9	1	8	5	7	2
	5	5	-1	3	14	18	16	5	12	3	3	1
C61	1	2	9	11	-11	22	1	-4	1	-3	1	
	2	2	0	1	4	13	15	3	9	-5	-1	-5
	3	3	-1	-9	9	18	6	8	2	-3	-6	-4
	4	4	-3	-2	1	12	2	4	4	3	1	6
	5	5	-1	0	-3	12	9	7	-5	0	2	1
C71	1	2	4	2	11	18	-3	-1	3	3	3	
	2	2	3	4	12	19	12	13	3	7	11	9
	3	3	14	17	22	23	21	19	17	16	16	-9
	4	4	5	8	16	21	19	14	4	11	13	8
	5	5	0	4	8	16	11	6	-4	8	2	4
D11	1	31	37	41	38	43	25	34	29	27	23	
	2	2	4	7	21	22	14	14	21	5	-4	10
	3	3	29	31	37	38	38	16	27	25	25	18
	4	4	32	38	42	39	32	30	36	32	23	22
	5	5	16	19	26	29	27	17	22	14	7	9
D21	1	7	6	8	16	15	7	-1	5	0	8	
	2	2	1	5	11	19	13	5	8	0	3	8
	3	3	2	9	23	30	24	14	19	7	5	0
	4	4	-1	3	15	18	7	8	11	0	-7	4
	5	5	1	4	10	14	11	4	7	2	5	8
D31	1	13	19	35	30	29	19	8	13	5	5	
	2	2	19	26	42	33	38	26	19	15	17	13
	3	3	5	10	33	25	20	22	12	4	4	3
	4	4	0	6	19	21	17	15	0	3	2	1
	5	5	-1	6	29	24	24	14	5	1	0	5
D41	1	18	18	30	31	29	21	16	6	3	4	
	2	2	4	7	13	19	18	5	12	3	3	3
	3	3	7	8	19	20	14	5	7	7	-1	0
	4	4	-1	3	10	11	10	-2	23	0	3	1
	5	5	1	5	15	19	10	5	4	-3	1	3
D51	1	--	3	2	12	3	1	3	5	-11	-10	
	2	2	7	4	14	18	10	9	1	8	8	-9
	3	3	4	1	-2	1	-2	2	6	5	-2	
	4	4	1	-2	12	22	11	14	2	5	5	3
	5	5	10	4	11	14	8	-1	10	3	1	-6
D61	1	8	10	11	20	15	7	14	1	1	4	6
	2	2	1	3	12	19	12	7	17	1	11	2
	3	3	5	11	22	25	18	36	36	7	9	4
	4	4	3	2	8	9	6	8	12	0	-2	-6
	5	5	-4	-1	9	15	13	0	13	-3	-2	-7
D71	1	--	--	--	--	--	--	--	37	29	33	
	2	2	--	8	15	22	19	12	16	3	4	9

PLANT III ACOUSTICAL FOAM EARPLUGS TYPE A

ID#	D	ATTENUATION/ O.B. CENTER FREQ.(KHZ)								ID#	D	ATTENUATION/ O.B. CENTER FREQ.(KHZ)										
Y		.12	.25	.5	1	2	3	4	6	8	Y		.12	.25	.5	1	2	3	4	6	8	
A11	1	11	14	22	22	31	44	43	35	33	C11	1	-11	2	2	1	17	18	23	18	16	
	2	2	19	18	21	27	24	41	45	42		2	2	14	16	19	16	33	45	38	33	34
	3	3	-2	16	15	23	28	44	39	42		3	3	4	12	14	17	34	43	42	39	33
	4	4	18	24	22	19	25	44	38	48		4	4	10	18	19	14	33	42	46	43	26
	5	5	3	13	18	10	30	40	48	40		5	5	5	15	11	14	27	32	30	32	30
A21	1	16	10	11	16	27	29	26	43	34	C21	1	7	10	14	15	24	24	24	18	30	
	2	2	-1	7	12	9	15	29	27	25		2	2	4	10	9	9	20	26	24	23	25
	3	4	11	15	11	17	27	34	33	30		3	3	10	13	17	13	28	36	38	25	26
	4	4	9	11	14	23	30	41	43	29		4	4	9	12	15	14	27	29	28	13	37
	5	5	6	8	19	24	32	25	38	15		5	5	11	13	14	16	36	38	38	22	33
A31	1	15	20	19	21	34	48	46	41	38	C31	2	14	14	14	22	42	38	39	29	20	
	2	2	7	15	14	22	31	44	38	36		2	2	15	17	21	24	36	41	38	39	45
	3	3	17	19	18	20	31	44	38	37		3	3	10	5	13	20	35	35	31	23	21
	4	4	7	10	14	19	24	36	31	29		4	4	20	13	16	15	36	37	36	18	12
	5	5	13	10	7	13	29	35	30	24		5	5	29	30	27	20	35	31	40	38	37
A41	1	6	15	16	22	31	43	42	49	41	C41	1	13	17	17	22	34	39	46	38	29	
	2	2	12	15	19	19	22	33	39	30		2	2	8	16	17	19	33	37	43	42	41
	3	3	-5	5	10	8	9	29	26	22		3	3	14	20	14	17	36	38	44	38	37
	4	4	6	2	10	19	18	33	35	36		4	4	9	16	16	24	28	35	39	42	39
	5	5	1	14	18	18	18	27	30	16		5	5	8	14	14	22	31	43	38	27	32
A51	1	5	16	18	19	30	35	33	36	32	C51	1	4	8	9	12	21	27	19	22	34	
	2	2	13	14	24	20	32	42	36	36		2	2	4	13	20	25	32	31	24	38	55
	3	4	4	12	20	22	39	37	28	32		3	4	12	16	23	15	30	29	27	30	53
	4	3	11	15	14	22	30	35	40	38		4	3	1	-2	13	15	30	21	28	32	45
	5	5	15	17	16	21	30	38	39	39		5	5	9	3	13	17	33	38	47	43	31
A61	1	15	22	23	24	35	44	46	41	49	C61	1	13	16	19	23	24	23	30	31	29	
	2	2	17	19	25	23	32	40	40	42		2	2	8	16	7	0	17	12	10	3	15
	3	2	22	19	20	21	34	42	43	46		3	3	3	15	22	23	30	36	44	29	38
	4	3	15	15	23	26	41	46	48	54		4	4	7	2	8	11	14	19	14	12	33
	5	3	15	15	22	16	31	44	44	50		5	5	4	10	5	-2	10	10	11	8	12
A71	1	16	20	27	21	37	41	36	32	40	C71	1	21	16	25	27	37	40↑	37↑	46↑	--	--
	2	2	13	13	23	22	31	35	34	28		2	2	21	28	32	31	38	41↑	38↑	46↑	--
	3	2	14	20	27	19	31	40	39	39		3	2	13	20	29	23	36	38	42↑	38	--
	4	3	12	16	26	21	32	39	39	33		4	3	18	25	28	26	38	40	42	50	--
	5	3	13	19	26	22	35	42	39	40		5	3	21	23	32	33	34	42	45	53	--
B11	1	20	24	25	24	37	40	39↑	39↑	30↑	D11	1	6	11	14	11	27	34	23	32	25	--
	2	2	7	14	23	22	32	36	38	24		2	2	19	19	20	22	36	49	51	53	34
	3	3	17	17	16	20	37	30	30	30		3	3	12	20	17	23	34	40	46	43	41
	4	4	12	16	23	16	37	38	37↑	38↑		4	4	7	17	12	22	31	44	34	37	29
	5	5	27	20	17	15	33	25	28	28		5	5	12	9	14	21	31	40	34	48	37
B21	1	10	5	15	15	31	36	36	22	21	D21	1	17	23	27	27	32	43	42	37	38	
	2	2	3	-1	6	7	10	6	9	7		2	2	21	30	30	26	33	39	42	42	38
	3	3	-1	1	0	5	4	5	2	5		3	3	12	23	26	28	32	42	36	38	42
	4	4	11	8	10	15	23	33	34	25		4	4	15	16	20	18	26	38	37	21	21
	5	5	-10	2	2	-3	-5	10	6	-2		5	5	15	15	25	24	32	38	36	23	21
B31	1	17	22	36	33	35	51	47	49	47	D31	2	11	11	18	17	24	23	20	29	42	
	2	2	18	19	28	28	29	46	44	48		2	2	7	21	16	21	24	33	39	29	43
	3	3	18	24	31	30	33	51	43	50		3	3	-1	11	8	12	19	22	14	18	22
	4	4	25	29	29	30	31	47	49	49		4	4	2	6	10	12	14	18	18	17	18
	5	5	23	32	31	35	33	52	44	44		5	5	-2	4	1	4	10	1	2	5	3
B41	1	2	6	11	22	38	36	35	36	35	D41	1	28	19	19	28	39	41	40	29	33	
	2	2	18	16	16	27	39	43	43	44		2	2	7	21	17	16	27	44	44	42	30
	3	3	18	21	28	26	41	42	46	39		3	2	24	15	20	21	29	47	39↑	43	41
	4	4	15	19	28	26	41	40	40	45		4	3	12	19	22	20	31	42	39	48	39
	5	5	20	22	30	21	38	47	46	47		5	3	19	14	19	17	28	45	37	45	29
B51	1	12	19	21	23	39	39	44	27	33	D51	1	11	13	21	24	38	45	46	45	38	
	2	2	18	20	22	17	35	34	38	29		2	2	19	21	11	21	37	40	42	43	41
	3	3	13	18	18	23	37	42	44	31		3	3	10	17	20	25	42	46	44	38	39
	4	3	15	22	20	21	40	39	46	46		4	4	8	22	21	17	38	46	38	39	41
	5	3	10	15	24	21	36	42	42	37		5	5	15	15	20	25	40	44	40	41	47
B61	1	12	25	22	20	36	39	38	32	31	D61	1	9	21	17	25	32	37	38	26	23	
	2	2	13	21	24	20	32	41	40	32		2	2	9	9	20	18	30	42	38	37	30
	3	2	15	19	25	26	33	40	41	32		3	4	18	10	26	27	30	38	43	44	42
	4	3	4	13	9	19	30	35	32	21		4	4	17	22	19	32	31	47	49	44	41
	5	3	5	9	12	18	36	37	29	31		5	5	15	18	24	19	31	41	37	45	41
B71	1	-3	2	5	3	-3	11	6	-1	12	D71	1	15	16	21	20	28	39	40	34	34	
	2	2	9	5	8	12	22	25	23	9		2	2	4	17	13	17	28	30	30	27	36
	3	2	4	3	4	-1	13	17	-5	14		3	2	17	20	22	18	33	40	40	36	29
	4	3	13	18	18	21	38	36	22	19		4	3	13	23	24	23	33	39	40	38	43
	5	3	13	12	22	19	36	40	42	38		5	3	14	20	25	24	35	40	37	35	26

PLANT VI ACOUSTICAL FOAM EARPLUGS TYPE B

ID#	D	ATTENUATION/	O.B.	CENTER	FREQ.(KHZ)	ID#	D	ATTENUATION/	O.B.	CENTER	FREQ.(KHZ)												
Y		.12	.25	.5	1	2	3	4	6	8	Y		.12	.25	.5	1	2	3	4	6	8		
A11	1	24	30	24	27	30	42	44	43	40	C11	1	5	9	11	17	33	39	39	27	38		
	2	2	14	22	26	27	34	43	44	41		2	2	3	-3	1	6	22	34	28	17	32	
	3	3	14	27	28	25	35	41	45	39		3	3	14	0	17	19	32	40	40	35	35	
	4	4	2	23	21	23	32	42	36	41		4	4	10	10	13	18	27	45	35	32	30	
	5	5	8	17	20	24	31	33	37	40		5	5	9	14	15	19	31	38	36	35	34	
A21	1	21	30	27	31	28	40	50	35	46	C21	1	6	14	14	23	36	37	32	26	25		
	2	2	20	24	26	29	24	42	39	42		2	2	22	24	23	29	39	42	35	30	29	
	3	3	28	33	37	37	25	44	40	49		3	3	4	-8	9	14	21	32	37	22	20	
	4	4	18	24	28	31	25	46	43	51		4	4	3	14	13	19	36	42	36	25	36	
	5	5	22	30	30	19	25	40	42	38		5	5	17	16	24	25	40	53	39	36	48	
A31	1	6	-4	0	-1	10	7	16	-6	16	C31	1	10	12	17	30	43	37	29	27	36		
	2	2	6	3	13	12	19	25	27	21		2	2	14	4	19	16	24	29	30	22	31	
	3	3	-1	6	1	-9	8	17	-3	5		3	3	-9	-10	2	7	15	17	10	13		
	4	4	2	3	-2	0	-8	8	7	4		4	4	-18	-17	4	1	7	21	10	14	6	
	5	5	-14	-7	-7	8	1	17	20	6		5	5	6	1	3	5	8	14	14	17	27	
A41	1	10	15	17	20	41	45	41	42	35	C41	1	13	17	23	23	32	42	38	36	37		
	2	2	7	17	20	18	42	49	43	47		2	2	0	-5	5	3	13	24	22	14	5	
	3	3	8	15	18	21	37	38	41	46		3	3	1	-2	-1	-1	1	7	6	21	22	
	4	4	9	14	17	22	46	44	44	45		4	4	4	2	0	6	16	21	16	20	13	
	5	5	14	17	18	17	43	41	43	43		5	5	-5	10	6	5	18	16	10	16	6	
A51	1	10	16	10	16	27	40	37	37	42	C51	1	3	1	8	12	23	17	20	19	28		
	2	2	0	-1	1	-1	-3	12	0	-7		2	2	-1	-1	-2	5	8	13	16	16	14	
	3	3	4	4	5	-2	2	5	11	22		3	3	3	0	4	4	13	18	20	20	30	
	4	4	7	16	15	14	27	32	30	34		4	4	5	0	5	12	16	20	17	24	27	
	5	5	10	14	14	17	21	31	34	33		5	5	7	8	9	17	14	17	30	25	31	
A61	1	-4	-1	5	5	15	21	20	22	17	C61	1	6	4	4	3	18	16	17	5	15		
	2	2	14	14	17	18	41	35	32	33		2	2	-1	1	4	1	12	15	11	5	10	
	3	3	4	18	17	19	29	29	24	29		3	3	2	-2	2	3	10	16	17	6	14	
	4	4	5	13	0	24	31	32	29	32		4	4	0	4	5	5	21	17	14	8	13	
	5	5	14	27	32	22	43	42	43	30		5	5	0	2	6	0	13	15	11	5	11	
A71	1	13	17	13	26	41	33	37	30	35	C71	1	4	1	-1	6	14	19	14	9	-1		
	2	2	20	17	22	22	33	44	39	36		2	2	6	6	11	6	27	28	19	11	22	
	3	3	3	1	10	12	36	35	20	27		3	3	-2	2	2	1	11	15	14	12	3	
	4	4	3	14	12	15	25	34	42	42		4	4	-4	-2	-3	3	15	21	15	9	5	
	5	5	18	24	34	17	32	38	28	37		5	5	-7	1	1	5	7	11	5	2	4	
B11	2	12	17	15	12	30	41	34	24	30	D11	1	18	27	21	18	38	38	42	45	39+		
	2	2	6	14	12	17	34	31	32	34		2	2	-4	1	14	7	24	30	32	31	34+	
	3	3	15	13	17	19	32	36	33	24		3	3	0	0	1	1	17	2	20	25	22	
	4	4	0	15	13	14	33	34	30	33		4	4	9	9	16	13	26	24	26	31	28	
	5	4	-5	9	11	13	27	33	29	27		5	5	0	15	21	15	34	31	32	37	30	
B21	1	9	16	18	23	38	37	34	32	39	D21	1	6	19	20	22	30	42	34	45	31		
	2	2	13	18	18	20	38	38	33	21		2	2	7	12	27	19	34	43	42	44	25	
	3	3	10	19	22	27	43	44	44	33		3	3	13	8	6	13	30	31	33	34	26	
	4	4	10	17	22	20	34	44	40	20		4	4	12	13	21	20	31	42	38	33	17	
	5	5	8	14	22	22	37	40	37	33		5	4	8	16	16	22	28	42	36	36	30	
B31	2	1	0	3	4	17	23	4	2	5	D31	1	7	13	15	21	34	36	32	39	27		
	2	3	0	1	0	-2	2	12	9	3		2	2	4	10	16	18	36	33	31	24	39	
	3	4	-2	0	2	0	10	10	3	6		3	3	8	14	13	11	31	23	17	17	35	
	4	4	2	1	-2	-5	-1	4	3	-3		4	5	5	12	17	14	28	22	20	16	20	
	5	5	7	5	1	6	18	24	4	8+		5	5	-1	5	-12	13	36	24	23	21	31	
B41	1	25	22	19	19	27	28	29	28	--	D41	2	3	9	6	4	23	23	25	20	19		
	2	2	3	12	8	13	25	24	26	28+		2	2	-3	-6	2	-3	11	14	14	12	13	
	3	3	20	25	22	21	31+	24	23	33+		3	3	3	1	2	3	24	25	22	15	23	
	4	4	0	19	21	21	26	27	27	32+		4	4	-18	-7	0	-5	10	16	15	13	14	
	5	5	14	16	17	24	24	27	27	35		5	5	7	4	3	-7	-3	10	3	10	6	
B51	2	15	18	25	19	34	45	39	46	41	D51	1	11	13	16	22	45	34	32	31	41		
	2	2	3	4	10	13	23	29	26	28		2	2	16	12	11	26	38	40	32	28	36	
	3	3	17	14	17	26	39	35	29	31		3	3	-2	2	2	-4	8	15	11	13	12	
	4	4	11	13	12	22	32	44	38	39		4	4	12	10	16	20	37	34	26	22	34	
	5	5	10	19	16	25	38	37	28	29		5	5	4	-1	1	-2	14	18	16	4	5	
B61	1	6	7	9	13	31	28	33	37	28	D61	1	8	15	18	25	44	48	47	40	42		
	2	2	0	4	10	17	32	34	34	25		2	2	14	19	18	19	39	42	47	52	46	
	3	3	15	16	14	21	38	49	46	39		3	3	11	15	20	18	32	43	44	49	48	
	4	4	8	14	16	23	37	43	42	44		4	4	11	17	24	23	40	46	43	53	46	
	5	4	15	11	15	14	35	40	41	44		5	5	12	15	21	21	33	39	43	43	32	
B71	2	14	17	20	22	36	35	36	26	41	D71	1	6	13	12	20	21	31	35	25	27		
	2	2	-2	5	2	22	30	18	10	17		2	2	5	4	3	6	4	13	11	20	34	
	3	3	6	5	6	23	23	15	7	20		3	3	-1	4	4	13	6	25	26	16	34	
	4	4	3	-3	3	9	12	5	2	16		4	4	5	3	8	11	20	28	26	16	25	
	5	5	7	0	3	16	15	16	13	18		5	5	3	0	1	4	1	14	17	10	24	

PLANT VII ACOUSTICAL FORM EARPLUGS TYPE B

D ATTENUATION/ O.B. CENTER FREQ.(KHZ)										ID# D ATTENUATION/ O.B. CENTER FREQ.(KHZ)											
Y .12 .25 .5 1 2 3 4 6 8										Y .12 .25 .5 1 2 3 4 6 8											
A11	1	7	19	22	18	36	48	46	28	30	C11	1	10	5	2	15	19	19	19	3	25
2	2	8	-2	4	11	26	35	28	29	27	2	3	13	2	-1	2	17	17	12	9	14
3	3	4	-2	3	9	15	34	26	19	31	3	3	14	13	11	21	25	31	33	28	23
4	4	16	18	20	21	26	45	49	34	19	4	4	9	11	16	20	38	37	38	21	33
5	5	11	11	18	16	24	42	39	43	41	5	5	3	4	7	9	15	30	17	11	27
A21	2	19	0	20	23	16	38	30	23	30	C21	1	1	-2	-5	1	-5	6	-4	-4	1
2	3	1	1	4	22	30	41	32	23	17	2	1	0	-5	-2	-4	-3	-3	0	-2	0
3	4	-8	0	10	14	21	38	34	22	28	3	3	4	4	1	2	9	13	4	24	20
4	4	20	7	22	-5	14	15	21	4	14	4	4	7	3	5	5	19	20	22	26	36
5	5	-4	-8	-2	9	15	11	6	-3	9	5	5	-2	6	5	1	8	12	7	16	20
A31	1	9	17	21	21	33	51	42	41	38	C31	2	18	17	18	20	31	27	32	21	21
2	2	6	12	12	19	33	36	38	28	31	2	2	12	17	19	17	32	25	19	8	37
3	3	7	9	13	17	29	45	43	26	35	3	3	13	17	13	19	27	10	28	24	27
4	4	8	9	13	16	25	44	41	33	32	4	4	7	7	10	12	21	18	17	15	40
5	5	2	2	11	14	23	39	36	27	23	5	4	2	3	4	2	15	18	15	14	14
A41	2	6	8	4	8	19	23	18	30	32	C41	1	11	17	17	22	38	36	33	31	39
2	3	8	11	22	24	36	40	35	23	37	2	2	11	10	8	16	22	20	12	19	25
3	1	2	20	27	21	30	35	17	32	40	3	3	-1	1	-2	5	12	9	5	10	20
4	4	17	9	24	25	29	36	35	25	47	4	4	3	0	0	5	6	15	10	8	14
5	5	1	1	17	21	21	34	35	30	16	5	5	7	5	-3	10	22	13	11	24	35
A51	2	2	15	10	15	25	27	20	37	20	C51	2	4	15	19	25	32	38	31	48	34
2	2	-6	9	9	27	30	33	22	20	19	2	2	20	17	24	29	38	40	45	47	58
3	3	0	11	21	25	37	30	43	42	42	3	3	11	7	19	29	34	43	52	57	62
4	4	11	10	20	18	32	32	36	40	40	4	4	13	17	24	26	34	47	31	44	50
5	4	-7	-2	15	12	21	22	29	38	34	5	4	19	19	28	24	27	43	41	46	52
A61	1	33	13	26	25	44	38	44	25	31	C61	1	13	16	15	29	37	40	43	35	35
2	2	40	33	8	24	29	18	16	23	26	2	2	7	11	16	18	34	32	36	36	24
3	4	-3	1	15	0	27	20	10	0	3	3	3	11	11	12	14	34	40	39	29	25
4	4	10	11	21	11	26	34	37	26	37	4	4	12	11	14	19	38	40	38	25	28
5	5	23	26	-18	14	29	33	28	37	40	5	5	14	11	16	20	36	41	38	28	25
A71	2	2	16	17	22	36	37	38	25	33	C71	1	19	22	25	21	33	40	41	46	43
2	3	13	18	26	20	27	40	37	44	37	2	2	12	16	14	15	30	32	30	38	36
3	3	2	12	18	20	34	36	35	33	28	3	3	1	-1	2	0	8	15	13	15	18
4	4	12	13	16	18	31	41	37	38	38	4	4	-12	2	5	-5	7	25	20	13	16
5	5	12	22	28	20	34	47	39	42	37	5	4	-4	-1	0	-3	9	19	17	7	8
B11	1	7	-1	-3	-1	-4	10	6	-2	9	D11	1	5	1	-1	0	2	10	9	3	11
2	2	6	-2	-2	2	9	21	8	10	10	2	3	3	0	7	8	30	21	13	10	20
3	3	6	7	1	-3	-2	9	6	3	7	3	3	0	-3	-7	-2	12	14	8	1	10
4	4	-4	-10	7	-5	3	15	1	9	11	4	4	-3	1	-5	-4	7	8	5	2	11
5	5	6	-9	1	-2	3	7	6	4	25	5	5	-1	-6	-4	-6	10	10	-5	-3	0
B21	2	17	24	23	25	36	45	47	48	51	D21	1	15	18	29	28	45	50	49	28	29
2	2	10	21	27	25	36	45	41	43	35	2	3	15	15	22	25	34	39	36	24	37
3	3	5	8	22	28	31	36	39	37	31	3	1	16	22	21	25	35	52	48	43	46
4	4	14	16	17	15	29	41	42	52	49	4	4	11	23	26	27	37	33	40	38	39
5	4	3	10	20	27	32	44	46	44	53	5	4	19	22	23	21	42	40	35	32	34
B31	2	15	8	19	22	41	46	40	26	32	D31	1	8	20	18	15	20	35	36	35	33
2	3	9	12	26	27	44	44	50	45	31	2	2	17	27	24	28	38	38	37	42	28
3	4	20	17	29	27	40	40	41	48	40	3	3	9	22	27	21	38	36	41	31	35
4	4	-4	6	14	18	35	36	29	36	27	4	4	9	21	25	21	29	33	39	33	29
5	5	15	5	13	17	45	44	40	33	31	5	5	17	14	27	14	37	48	36	37	32
B41	2	-13	9	7	27	27	34	25	13	19	D41	2	10	18	25	30	35	48	53	37	31
2	3	14	16	31	17	37	35	37	50	35	2	2	10	0	14	11	27	39	35	34	30
3	4	10	15	37	15	23	30	20	19	32	3	3	11	15	23	16	34	39	38	35	32
4	4	8	4	2	9	9	16	12	17	17	4	4	7	17	15	23	20	38	34	28	14
5	4	7	7	16	26	36	34	37	33	40	5	5	8	6	0	-5	7	17	12	15	15
B51	1	13	16	17	19	33	31	24	13	31	D51	2	14	12	18	22	36	41	44	27	41
2	3	-1	2	25	17	37	29	40	34	29	2	3	7	10	16	19	44	44	44	38	37
3	3	18	1	18	12	40	33	31	30	24	3	3	8	9	16	21	35	40	38	31	30
4	4	10	8	5	6	20	25	12	12	32	4	4	9	19	18	21	37	37	40	30	34
5	5	7	8	15	12	36	28	31	21	35	5	4	7	14	23	20	32	38	34	49	41
B61	2	19	21	20	28	32	--	18	28	22	D61	2	7	9	9	13	19	27	25	--	--
2	3	0	15	16	23	35	--	14	21	34	2	2	5	18	23	24	35	46	38	--	--
3	3	7	10	19	28	34	--	19	26	25	3	3	15	22	29	23	28	46	42	--	--
4	4	26	11	15	27	35	--	23	27	33	4	4	16	23	29	26	29	48	49	--	--
5	5	4	17	21	27	38	--	20	28	33	5	4	-1	-2	13	21	20	36	36	--	--
B71	1	13	14	18	22	42	43	40	36	39	D71	2	14	16	26	19	37	45	48	37	39
2	2	6	13	19	28	39	39	40	39	38	2	2	11	11	22	17	35	42	37	31	23
3	3	13	10	19	24	35	37	39	43	41	3	3	14	-2	25	19	32	50	45	38	31
4	4	-7	14	19	21	35	39	30	33	31	4	3	3	13	20	19	34	41	37	39	33
5	4	12	17	23	23	39	39	44	40	40	5	4	14	4	14	17	36	34	37	36	38

PLANT VIII ACOUSTICAL FOAM EARPLUGS TYPE A

ID#	D	ATTENUATION/ O.B. CENTER FREQ.(KHZ)								ID#	D	ATTENUATION/ O.B. CENTER FREQ.(KHZ)									
Y		.12	.25	.5	1	2	3	4	6	8	Y		.12	.25	.5	1	2	3	4	6	8
A11	1	-1	6	11	18	36	31	33	35	30	C11	1	17	31	45	29	37	34	31	22	39
2	2	8	21	24	28	44	40	44	48	40	2	2	18	20	29	23	32	34	31	19	31
3	2	20	14	20	31	56	51	47	47	44	3	3	16	20	26	24	27	34	28	28	35
4	3	22	22	29	32	41	41	46	48	42	4	3	19	16	23	22	30	27	35	33	42
5	4	15	20	26	21	39	44	44	52	46	5	4	19	25	19	26	30	42	40	33	37
A21	1	1	4	5	4	18	24	25	16	21	C21	1	-8	0	-9	-2	14	17	18	7	13
2	2	11	21	11	19	26	42	39	35	23	2	2	-7	0	-1	5	2	8	1	-6	-2
3	2	2	8	10	21	30	30	30	28	29	3	2	-7	2	0	-1	4	0	1	-3	3
4	3	19	14	12	16	32	39	32	36	25	4	3	7	1	-4	2	-3	2	8	7	8
5	4	-8	-7	14	11	28	13	25	26	21	5	4	7	-2	6	6	-5	-3	-14	15	3
A31	1	15	17	26	25	32	50	36	37	29	C31	1	25	18	27	31	42	44	43	45	34
2	1	14	19	29	18	35	46	45	43	29	2	1	22	22	27	24	32	47	45	44	43
3	2	13	17	19	29	35	46	51	25	39	3	2	10	25	24	24	34	43	46	43	41
4	3	17	25	24	21	29	41	42	29	41	4	3	14	20	24	23	36	42	47	48	48
5	4	10	16	22	23	31	53	35	32	25	5	3	16	20	20	25	31	42	44	32	37
A41	1	15	21	30	22	35	41	37	35	31	C41	1	19	20	21	20	39	43	43	41	43
2	2	8	23	29	21	33	42	45	44	38	2	2	22	24	31	31	44	39	43	49	45
3	3	14	19	23	22	35	41	45	39	32	3	2	16	19	22	26	40	46	37	42	38
4	3	14	20	22	21	39	45	41	41	34	4	3	25	32	34	33	37	44	46	48	51
5	4	10	21	24	24	38	48	41	35	30	5	3	22	27	32	30	40	43	47	53	58
A51	1	18	25	30	36	36	49	42	45	31	C51	1	12	22	23	26	41	41	38	37	41
2	2	27	19	24	30	36	36	38	42	38	2	2	18	21	24	22	38	41	39	38	34
3	2	6	23	30	29	31	44	35	41	34	3	3	18	23	27	25	39	42	44	42	32
4	3	26	26	28	30	33	41	44	51	37	4	3	13	15	25	23	42	43	43	49	41
5	4	-2	6	16	23	28	49	40	48	2	5	4	13	21	26	31	39	41	42	42	39
A61	1	13	19	20	18	27	34	33	25	21	C61	1	2	8	14	19	36	25	28	19	28
2	2	5	9	12	14	23	32	28	17	22	2	2	11	14	13	8	27	30	21	8	29
3	2	2	0	7	12	19	26	24	21	25	3	3	13	8	10	13	18	18	9	3	16
4	3	4	6	12	15	24	33	32	32	28	4	3	13	1	-1	0	15	22	19	2	7
5	4	15	16	18	20	25	41	39	35	40	5	4	15	15	19	18	42	42	24	29	35
A71	1	2	1	1	12	22	21	10	20	23	C71	1	10	16	16	20	32	42	39	38	39
2	2	9	3	15	23	27	34	26	19	27	2	2	6	11	20	19	29	39	35	42	44
3	3	13	-7	6	14	25	26	17	21	31	3	3	6	12	17	12	28	44	40	44	47
4	3	3	2	8	9	22	23	15	22	30	4	3	5	14	9	19	27	40	32	40	50
5	4	5	11	13	19	19	21	18	20	20	5	4	14	10	9	15	29	31	24	28	37
B11	1	11	24	31	30	38	46	48	52	32	D11	1	-1	10	0	2	4	10	13	13	9
2	3	15	20	22	16	33	39	47	43	37	2	2	-4	-10	-5	-7	2	15	14	6	6
3	3	24	24	30	32	33	49	51	58	54	3	2	14	-10	7	4	-4	15	-2	-3	1
4	4	23	20	30	24	41	51	43	60	46	4	3	29	15	0	0	6	13	20	9	-1
5	4	6	14	22	18	32	43	42	37	28	5	4	31	17	-2	0	3	21	0	-3	2
B21	1	10	26	19	25	40	46	43	33	36	D21	1	-4	2	5	6	15	31	25	14	29
2	2	22	13	17	22	39	43	39	33	31	2	2	10	16	13	6	19	40	41	26	23
3	2	7	12	12	21	50	43	48	36	34	3	2	10	2	4	4	13	31	23	10	20
4	3	17	17	21	23	42	42	46	39	29	4	3	1	-7	1	2	4	26	21	9	7
5	4	8	7	14	13	30	34	35	43	34	5	4	7	8	2	1	18	30	28	14	12
B31	1	18	17	20	27	38	47	41	28	33	D31	1	0	-2	2	3	15	27	23	12	20
2	2	13	19	17	25	30	40	41	41	34	2	2	-4	6	-1	-5	1	15	21	6	10
3	3	18	30	24	27	40	41	47	36	38	3	3	2	3	4	1	10	25	21	4	11
4	3	11	12	24	23	38	34	34	32	31	4	3	5	5	12	3	13	31	30	14	6
5	4	14	15	17	20	30	40	30	31	32	5	4	6	6	6	8	8	25	19	11	13
B41	1	2	5	13	22	27	25	31	32↑	19↑	D41	1	15	13	12	20	31	40	30	35	40
2	2	13	15	13	23	42	45	50	25↑	21↑	2	2	1	8	11	21	28	35	34	32	32
3	3	14	9	15	22	31	36	37	26↑	22↑	3	3	10	13	13	18	31	37	31	21	34
4	3	5	10	8	23	29	30	36	28↑	32↑	4	3	13	18	20	15	35	41	36	37	36
5	4	7	7	8	14	29	33	32	31	20	5	4	7	10	13	22	30	33	28	16	24
B51	1	12	14	17	25	31	43	42	23	39	D51	1	27	27	30	10	25	21	23	10	21
2	1	14	21	23	28	35	42	38	36	34	2	2	16	9	18	25	28	30	35	29↑	17
3	2	0	15	16	26	36	43	38	36	41	3	3	9	8	14	25	35	41	36	20	27
4	3	16	20	20	23	33	41	47	28	36	4	3	13	14	21	11	35	34	29	9	24↑
5	4	9	12	16	24	26	37	28	17	30	5	4	18	26	19	24	38	38	38	29	26
B61	1	19	29	26	26	39	39	41	41	48↑	D61	2	17	24	23	27	34	34	32	28	22
2	2	26	31	33	36	43	35	50	55↑	34↑	2	2	13	20	21	20	33	37	32	36	41
3	2	16	27	30	30	32	34	35	40	41↑	3	3	12	22	21	29	38	36	38	38	36
4	3	11	16	22	22	32	37	44	46	37	4	3	5	10	16	22	36	35	37	36	28
5	4	26	29	29	37	33	37	44	45	35	5	4	10	18	22	20	28	31	30	37	34
B71	1	11	21	20	24	42	41	40	27	26	D71	1	15	18	17	20	27	40	33	27	32
2	2	13	14	22	25	35	47	42	40	40	2	2	21	13	16	18	28	28	39	20	41
3	3	8	8	17	17	31	37	35	33	34	3	3	13	15	11	15	34	35	32	28	35
4	3	8	16	19	22	38	37	37	30	34	4	4	9	8	15	16	25	34	30	22	36
5	4	6	26	18	20	39	35	33	26	17	5	4	9	15	13	24	36	32	30	26	24

APPENDIX I

STATISTICAL POWER ANALYSIS

Development of power estimate formula¹

Source	Deviation	Number of Observations	$\phi_{\text{effect}}^2 = \phi_z^2$
z	δ_k	(f) (e) (s')	$\frac{f e s' [\sum (\delta_k)^2]}{(z) (\sigma_{Z \times S/FE}^2)}$

where

ϕ_z^2 = Value for which the square root (ϕ_z) is used with power charts to estimate the power of the design with regard to the Noise main effect.

z = 2; number of levels for the Noise effect.

f = 2; number of levels for the Fitting Conditions effect.

e = 2; number of levels for the Experience Level effect.

s' = Sample size needed to achieve a specific level of power.

δ_k = Represents the deviation of the treatment effect mean from the true population mean at each of the nine test frequencies.

$\sigma_{Z \times S/FE}^2$ = Population error variance which is estimated by $MS_{Z \times S/FE}$ for each of the nine test frequencies.

¹ Based on formulas in Table 10-9, Keppel (1982), p. 205. Further discussion on design sensitivity and power determinations for choosing an adequate sample size can be found in Keppel, G. (1982). Design and analysis: a researcher's handbook (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall, pp. 70-75; 204-206.

Statistical Power Estimates for the Noise Main Effect of Experiment 2 Using the Observed Differences Between Treatment Means (With and Without Noise) for $s' = s = 10$ (Number of Subjects in Each Unique Treatment Cell).

	Frequency in Hz								
	125	250	500	1000	2000	3150	4000	6300	8000
$\sigma_{Z \times S/FE}^2$ (estimated by $MS_{Z \times S/FE}$)	14.53	20.16	19.16	17.04	5.98	9.90	12.05	27.76	20.35
δ_k (represented by differences in Means) ¹	0.2	0.3	0.6	0.6	0.9	0.4	0.4	0.1	0.6
ϕ_z^2	0.06	0.09	0.38	0.42	2.71	0.32	0.27	0.01	0.35
ϕ_z	0.24	0.30	0.62	0.65	1.65	0.57	0.52	0.10	0.59
Power [†] (1 - β)	< 0.30	< 0.30	< 0.30	< 0.30	~ 0.50	< 0.30	< 0.30	< 0.30	< 0.30
s' to get power = 0.90 [‡]	1925	594	141	126	20	164	200	7357	150

¹ Mean values for With and Without Noise are shown in Table 28.

[†] Power as determined from Table A-2: Power Functions for Analysis of Variance (Fixed-Effects Model) in Keppel (1982), p. 549: $df_{num.} = 1$, $df_{denom.} = (z - 1)[f e(10 - 1)] = 36$; $\alpha = 0.05$.

[‡] s' calculated by setting $\phi = 2.30$ (value at which power = 0.90 for $df_{denom.} > 60$, $\alpha = 0.05$ as determined from Table A-2 (Keppel, 1982)).

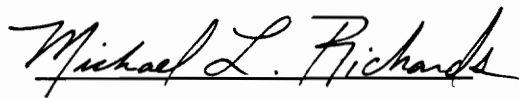
Estimates of Adequate Sample Sizes¹ to Detect a Minimum Difference of 2 dB Between Treatment Means (With and Without Noise) with Statistical Power $\cong 0.90$ for the Noise Main Effect of Experiment 2.

	Frequency in Hz								
	125	250	500	1000	2000	3150	4000	6300	8000
s'	10	14	14	12	5	8	9	18	14
ϕ_z^2	5.50	5.60	5.88	5.64	6.70	6.48	5.94	5.22	5.46
ϕ_z	2.35	2.37	2.42	2.37	2.59	2.55	2.44	2.28	2.34
$df_{\text{denom.}}$ $(z - 1)[f e (s' - 1)]$ $= 4 (s' - 1)$	36	52	52	44	16	28	32	68	52
Power ($1 - \beta$)	0.90	0.92	0.91	0.91	0.93	0.93	0.91	0.90	0.90

¹ Sample sizes were found by trial and error calculations of ϕ_z^2 equation until power levels reached approximately 0.90 as determined from Table A-2 (Keppel, 1982): $df_{\text{nom.}} = 1$, $\alpha = 0.05$, $\phi_{Z \times S/FE}^2$ estimated by $MS_{Z \times S/FE}$ at each test frequency, $\delta_k = 2.00$ for all frequencies.

VITA

Michael L. Richards, born on July 1, 1966 in Richmond, Virginia, received his B.S. in Industrial Engineering and Operations Research from Virginia Polytechnic Institute and State University (Virginia Tech) in 1988 with emphasis in safety and manufacturing. Mr. Richards was the 1988 recipient of the James L. Parker Memorial Safety Scholarship and was co-recipient of the same in 1989. He completed the M.S. at Virginia Tech in Industrial and Systems Engineering with concentrations in both human factors and safety. Mr. Richards participated in a NIOSH-funded curriculum option and worked at General Electric Drive Systems in Salem, Virginia as a human factors and safety engineer while in graduate school. He is a member of Human Factors Society, American Society of Safety Engineers, Institute of Industrial Engineers, and Society of Manufacturing Engineers.

A handwritten signature in cursive script that reads "Michael L. Richards". The signature is written in dark ink and is positioned above the printed name.

Michael L. Richards