INSTRUCTIONAL REQUIREMENTS FOR USING THE HML AND NRR METHODS FOR ESTIMATING PROTECTED EXPOSURE LEVELS UNDER HEARING PROTECTORS

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(ABSTRACT)

A study was conducted to investigate the effectiveness of different instructional tools for teaching individuals to calculate a protected hearing level given A- or C-weighted sound levels, and using the NRR and HML methods. Three instructional tools were evaluated: 1) outline instructions, 2) tabular nomogram, and 3) hypermedia computer-based instructions. Effectiveness was measured in terms of calculation time and proportion of errors made. The results yielded no statistically-significant differences between the tools. All subjects performed equally well using each tool for the NRR method, and equally poor using each tool for the HML method.

Two additional topics of investigation included a baseline of knowledge determination for hearing conservationists, and an inquiry into the subjective discrimination of various sound spectra. The baseline of knowledge determination evaluated the ability of subjects to calculate a protected hearing level, given A- and/or C-weighted sound levels and the NRR. Since professionals in this field are responsible for determining OSHA compliance, this test should have resulted in high baseline scores. However, only 50% of the

subjects could calculate a correct answer given the C-weighted sound level; only 17% could calculate a correct answer given the A-weighted level.

The spectral discrimination portion of the study evaluated the ability of an individual to subjectively classify noises as high frequency-dominated, or low-frequency-dominated. Of the 12 pink and industrial noises used, only three could be correctly identified more than 90% of the time. This suggests that subjective classifications of noises should not be relied upon.

DEDICATION

This thesis is dedicated to the memory of Mr. Rune Lundin, who contributed greatly to the field of hearing conservation through his innovation and creativity in hearing protector design while working at Bilsom AB and Peltor AB in Sweden. Rune also tirelessly served on international standards committees concerning the testing and rating of hearing protector performance. He conceived and developed the HML rating method described and evaluated herein. A strong believer in empirical research, Rune was the impetus for this project to compare his HML method to the NRR method in terms of user training needs.

William C. Thomas Jr. and John G. Casali

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INTRODUCTION

In 1981, the Environmental Protection Agency reported that more than 9 million Americans were exposed to sound levels greater than 85 dBA in a single 8-hour workday (EPA, 1981). Over time, these noise levels will rob workers of their hearing. This is an unfortunate circumstance, since noise-induced hearing loss is preventable through the use of administrative and engineering controls to reduce noise levels, and through the proper application of personal hearing protection devices (HPDs).

The effectiveness of hearing protection is a great concern in modern industry as well as in the private sector now that the leisure activities of society are becoming increasingly louder. Each of the three general types of HPDs (earplugs, earmuffs, and canal caps) offers its own specific benefits and differences in noise-attenuation qualities. That is, each type of hearing protector will reduce the various sound components in the audible range (20 to 20,000 Hz) differently from one another. Conventional earplugs, worn inserted into the ear canal, generally offer better low-frequency attenuation than earmuffs, while canal caps generally provide poorer overall attenuation than the other varieties. One goal of researchers and professionals in the field has been to summarize the attenuation (sound reduction) characteristics of HPDs with a single-value rating.

The Noise Reduction Rating (NRR) (EPA, 1979) has become the standardized single-value rating used for calculating the protected noise level of an individual wearing hearing protection in the U.S.. However, a question of accuracy in using a single-number rating method to predict protection for an entire sound spectra has been raised. Research has suggested that an alternative method, specifically the High, Medium, Low (HML) method (ISO.

1992), may be a more accurate, simplified method for calculating the protection afforded by a hearing protector.

However, the HML method is not without problems. The largest of these problems is the obtainability of the noise data. To use the HML method, A- and C-weighted sound level measurements must be performed. These weighted values are subtracted from each other to determine highness or lowness of noise spectra composition. Based on this value, two of the three (H, M, and L) ratings and the linear relationship between them are evaluated. If the C-weighted noise level is not available, a decision based on the hearing conservationist's perception of the noise spectra is used for the basis of choice between the two linear relationships. Although it requires sophisticated equipment, and is relatively more complicated to calculate than the NRR, the HML is reported by some to be a better method for a variety of reasons which are summarized later in this thesis (e.g., Lundin, 1992b). Therefore, it follows that there needs to be a way to train professional hearing conservationists to properly use the HML method.

Issues In This Study

This study investigated the two most popular hearing protection attenuation rating methods, specifically the Noise Reduction Rating (NRR) and the High, Medium, Low Rating (HML), and the abilities of trained hearing conservationists and naive users in applying the two methods to compute a protected noise level for different sound exposure situations. Three major topics were investigated. The first entailed three forms of instructional tools. Simple outline instructions utilized a "cookbook" approach to teaching the two methods:

nomogram cards provided more of a hands-on, quick-reference tabular technique; and lastly, an interactive hypermedia package provided a contemporary, computerized approach to instruction. The dependent variables of interest included calculation accuracy and speed for each of the instructional methods. Additionally, Likert ratings, as provided by the subjects, were recorded to determine different subjective responses to different aspects of each instructional tool.

A second topic of investigation was the baseline of knowledge regarding the proper use of the NRR possessed by professionals in the field of industrial hearing conservation. Since these individuals are charged with the responsibility of protecting workers' hearing, it follows that they should be able to accurately use the relatively simple NRR method without reference material (the NRR is the fundamental single-number method specified by OSHA (1983)). The dependent variables of interest for baseline NRR knowledge included calculation accuracy and speed.

The final topic of investigation concerned how accurate subjects were in performing noise spectra discriminations when relying only on auditory perception. Since the "HML-Quicky" method relies solely on subjective discrimination between noises of high and low frequency dominance, a question of interest was whether or not individuals could accurately classify given noises. A total of twelve pink (flat level by octaves) and industrial noises were presented to subjects for discrimination and classification. The dependent variable of interest in the spectral discrimination task was percent-correct identification.

HUMAN AUDITION AND HEARING LOSS: A BRIEF OVERVIEW

The Basic Hearing Mechanism

The human ear is the primary channel for receiving and transforming sound waves into nerve impulses that the brain interprets as what a human hears. Ward (1988) explains this physiology. Incoming sound waves are funneled into the earcanal by the pinna. In the canal, the wave is amplified by the inherent resonance characteristics of the canal. This is especially apparent in the 3000 to 4000 Hz range, the natural resonance frequency range of the earcanal. The waves then strike the tympanic membrane, the eardrum, at the end of the canal which sets the ossicles into motion. This is the first transformation the ear performs: the propagation of the sound is transformed from air conduction to mechanical conduction. The ossicles, having a mechanical advantage of a lever system, amplify the sound and set the fluid of the cochlea into motion via oscillation of the oval window. This is the second transformation the ear performs: bone-conducted sound is transformed into fluid-conducted sound. The excitation of the hair cells in the cochlea by the fluid movement generates the nerve impulses sent to the brain to be interpreted. Sound may also be conducted directly to the cochlea through the vibration of the skull bones. These sound paths and anatomy are shown in Figure 1.

If the sound waves incident on the ear are too intense and/or exposure is overly long, the nerves of the ear can become damaged, and their ability to receive and transform the sound waves can become impaired. This impairment can be temporary or permanent, and is referred to as noise-induced temporary

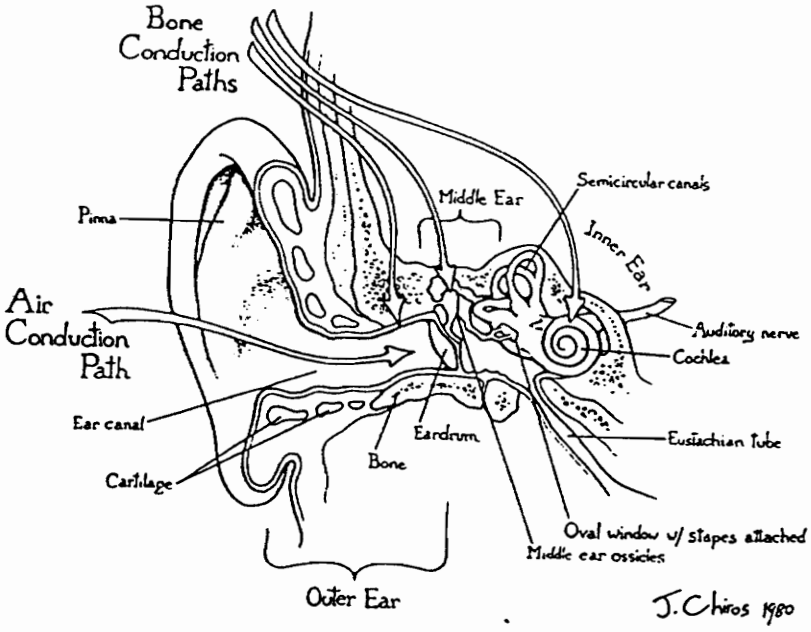

Figure 1. *Basic anatomy of the outer, middle, and inner ear with an indication of the sound path. (From Berger, 1980).*

threshold shift (NITTS), and noise-induced permanent threshold shift (NIPTS), respectively.

Noise-Induced Temporary Threshold Shift (NITTS)

Suter (1986) explains that a NITTS occurs when an individual is exposed to an intensity of noise for a period of time sufficient to fatigue the individual's ear, and to increase the individual's threshold of hearing. That is, the individual's perceptual sensitivity to the sounds of the environment will be decreased. Suter (1986) also states that if a daily temporary threshold shift is experienced for months or years, the temporary threshold shift will become a permanent threshold shift.

Noise-Induced Permanent Threshold Shift (NIPTS)

If temporary threshold shifts are exhibited over a sufficient period of time, or there is neurological damage to the cochlea as a result of acoustic trauma or disease, a permanent threshold shift can result. As the name implies, the individual's perceptual sensitivity to sound is permanently decreased. Characteristic hearing thresholds due to NIPTS are shown in Figure 2. Melnick (1979) explains that a "notch" is traditionally found at 4000 Hz as a result of neurological damage induced at that frequency by the natural resonance of the ear canal; this notch will widen with further exposure and resultant damage. As stated earlier, sounds in the 4000 Hz region are more amplified by the ear, and thus, more of a threat to hearing occurs. For reference, normal hearing is represented by a straight horizontal line at 0 dBHL.

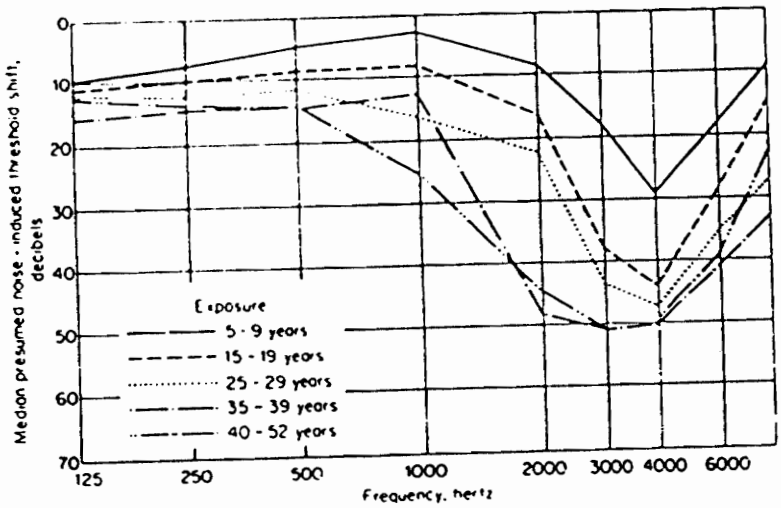

Figure 2. *Median Noise-Induced Permanent Threshold Shifts (NIPTS) for different exposure durations. (From Taylor. Pearson, Mair. and Burns, 1965).*

As NIPTS becomes more apparent, an individual's hearing loss becomes more debilitating. Gasaway (1985) presents the method of computing an individual's percent hearing loss as established by the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS). An example calculation using this procedure is seen in Table 1. The procedure begins by computing the individual's percent-impairment for each ear. The pure tone average of the individual's threshold at 500, 1000, 2000, and 3000 Hz is first calculated for each ear. A value of 25 is subtracted from each of these averages. The value of 25 is the lower bound for this calculation. This means that an individual must exhibit an average hearing loss of 25 dB for the previously-stated frequencies in order to obtain a non-zero percent hearing loss. Each of the remainders of the lower bound subtraction is then multiplied by 1.5 to take advantage of the trading relationship between the upper and lower bounds (92 and 25, respectively). That is, each decibel of hearing loss between 25 and 92 corresponds to 1.5 %. The resulting values represent the percent-impairment for each ear.

The percentages calculated above are used to determine an overall binaural percent-impairment. The smaller percentage, the percent-impairment of the better ear, is weighted by a factor of five and added to the larger percentage, the percent-impairment of the poorer ear. The average of this sum results in the overall binaural percent-impairment. This calculation provides a quantifiable value of an individual's impairment. This percentage has been used to compute the monetary amount of compensation an individual should receive as a result of a loss of hearing on the job (Gasaway, 1985).

TABLE 1

Sample Calculation of Percent Hearing Impairment (Adapted from Gasaway, 1985).

Ear =	Right				Left			
Test freq. (Hz)	500	1000	2000	3000	500	1000	2000	3000
1) Enter HL's*	20	35	35	40	15	35	50	55
2) Each ear total			135				155	
3) Divide each by 4 =			33.75				38.75	
4) Subtract			- 25				- 25	
5) Remainder =			8.75				13.75	
6) Multiply line 5 by			x 1.5				x 1.5	
7) Sum =			13.125%**				20.625**	

Line 7 represents the percent hearing impairment for each ear. The next step is to compute the binaural percent hearing impairment.

8) Enter the % hearing impairment for the better ear (smallest % value):		13.125
9) Multiply this value by 5		x 5
10) Enter result from steps 8 and 9 =		65.625
11) Enter the % hearing impairment for the poorer ear (from line 7)		20.625
12) Add values in line 10 and 11 and enter total here =		86.25
13) Divide the total on line 12 by 6	(divide by)	6
14) Enter result from dividing value in line 12 by 6 =		14.375%

This value in line 14 represents the percent of binaural impairment.

* If hearing level at any of the above test frequencies equals or exceeds 100, or exceed the maximum limits of the audiometer, then enter 100 as the value to use for the hearing level and/or if the dB hearing level is better than 0 dB (such as minus 5 or minus 10), enter 0 dB as the value to use for computation purposes

** Negative percent values are not used if encountered enter 0%

HEARING PROTECTION: A BRIEF REVIEW OF THE LITERATURE

General Types of HPDs

As previously mentioned, three general types of hearing protectors are available for use by individuals: earplugs, earmuffs, and canal caps. Earplugs are usually made of either molded plastic, malleable polyurethane or polyvinylchloride foam; waxed cotton and spun fiberglass ("ear down" or "Swedish wool") variations are also available. In any case, an earplug is inserted into the ear canal to provide protection from noise. Proper insertion is the key to experiencing the protection labeled on the package of the protector, although that level of attenuation is rarely achieved. To correctly insert an earplug, an individual must pull the pinna of the ear up and out with the opposite hand while inserting the plug as deeply as possible into the canal with the same-side hand. This action of pulling up and out of the pinna will open and straighten the canal, aiding in proper insertion. A well-fit, deeply-seated earplug can provide excellent protection, but poorly-sized or improperly-fit plugs do not.

Earmuffs are comprised of two cups that sit over an individual's ear, and are attached by a headband. The size and shape of the cups vary from protector to protector. When fitting an earmuff, it is imperative that the headband sit on the crown of the head (not along the back of the head or under the chin unless specifically designed to do so), and that the foam cushions of the cups not rest on the pinnae. The cushions are what provide the seal around the ear; excessive hair around the ear, the earstems of eyeglasses, or large ear jewelry may impair a proper seal and reduce the protection afforded by the earmuff.

Canal caps are foam or plastic pods that seat in the concha of the ear and block the entrance to the ear canal at its rim, and are held in place by a rigid

plastic or metal band that hangs under the chin, or is sometimes also worn over, or behind, the head. Canal caps are often used when an individual travels into and out of a noise environment frequently, and therefore must don and remove the protector often. Generally, canal caps provide the least amount of protection compared to earplugs and earmuffs.

As part of a hearing conservation program, hearing protectors, when properly selected and worn, can be an effective method (although considered secondary to administrative and engineering controls by the Occupational Safety and Health Administration (OSHA)) of reducing the sound levels to which an individual is exposed. OSHA regulations govern the requirements for hearing protection in occupational settings, while the Environmental Protection Agency (EPA) controls the product labeling requirement which specifies hearing protector testing standards, product rating metrics, and attenuation labeling requirements.

The protection afforded by hearing protectors is often overestimated due to a discrepancy between laboratory versus field effectiveness of HPD's. Since laboratory tests use ideal situations (experimenter fit HPD's, controlled environment, and a still subject), the protection is usually inflated over what is truly obtained while a worker is in the job environment using a comfortable fit and moving and/or talking. Researchers such as Berger (1993) have shown that between NRRs obtained in a laboratory and those in the field differ by as much as 10 to 25 dB, depending on the HPD.

Overview of OSHA Regulations

With its roots embedded in the Walsh-Healy Act of 1969, and the OSHA act of 1971, OSHA's Hearing Conservation Amendment of 1983 is the regulation

to which noise exposure limits and hearing conservation programs of modern US. industry must conform. The OSHA act (OSHA, 1971) established the following basic criteria:

1. Daily exposure for an 8-hour day is not to exceed 90 dBA Time Weighted Average (TWA) using a 5 dB trading relationship for exposure time versus dBA levels. This equals a daily noise dose of 100%.
2. Exposures to steady-state noise cannot be greater than 115 dBA.
3. Peak noise levels can not be greater than 140 dBA.

The 1983 amendment mandates the following program requirements: hearing conservation program, noise monitoring, employee notification, observation of monitoring, audiometric testing program, audiometric test requirements, hearing protectors, hearing protector attenuation, training program, access to information and training materials, recordkeeping, appendices (which contain reference tables and equations, procedures, and equipment and facility requirements), exemptions (oil and gas well drilling and servicing companies are exempt from this amendment), and startup date. The most relevant sections, to this thesis, are the following: hearing protectors (section i), hearing protector attenuation (section j), and Appendix A and B which deal with the computation of noise exposure, and the evaluation of HPD attenuation adequacy, respectively.

Overview of the 1983 amendment's section on hearing protectors (section i). This section of OSHA's 1983 amendment consists of the following five points:

1. Employers are responsible for supplying hearing protection to employees exposed to greater than or equal to 85 dBA TWA.
2. Employers are responsible for making sure that hearing protectors are worn by employees who are exposed to greater than or equal to 90 dBA TWA, or by employees who are exposed to 85 dBA TWA or above, and do not have a referenceable audiogram, or are exhibiting a standard threshold shift (STS) in hearing.
3. Employers are responsible for supplying a variety of hearing protectors from which the employee may choose.
4. Employers are responsible for training employees on the proper use and care of hearing protectors.
5. Employers are responsible for making sure that an employee is properly fitted with a hearing protector and is using it correctly.

Overview of the section on hearing protector attenuation (section j).

This section of the 1983 amendment consists of the following four points:

1. Employers are responsible for evaluating the attenuation of a hearing protector in the noise environment in which it is to be used. This section references Appendix B of the 1983 amendment; the appendix states that the Noise Reduction Rating is to be the means of hearing protector attenuation evaluation.

2. A hearing protector must provide adequate protection to reduce the 8-hour TWA exposure of an employee to less than or equal to 90 dBA.

3. For employees who exhibit a threshold shift in hearing, a hearing protector must provide adequate protection to reduce the TWA exposure to less than or equal to 85 dBA.

4. Employers are responsible for reevaluating the protection of hearing protectors when an increase in noise exposure is exhibited.

Overview of Appendix A: noise exposure computation. This appendix provides the formulae to be used by hearing conservationists when evaluating an employee's exposure to noise. Table 2 defines the reference exposure duration limits for different noise levels. The governing equation for this table is as follows:

$$T = \frac{8}{2^{(L-90)/5}}$$

Where: **T** is the allowable duration in hours for a given exposure level, **L**
L is the exposure level in dBA

An individual's daily dose is calculated using these reference durations, T, and the time they are exposed to a given noise level. The governing equation is as follows:

$$D = 100\left(\sum_{i=1}^{n} C_i/T_i\right)$$

Where **D** is the daily percentage noise dose
C_i is the time in the measured noise level in hours
T_i is the allowable duration in the specific measured noise level in hours
n is the number of different exposure durations

TABLE 2

Allowable Durations for Steady-State Noise Levels from 80 to 130 dBA (Adapted from OSHA, 1983).

A-weighted sound level	Duration, T (hours)	A-weighted sound level	Duration, T (hours)
80	32	107	0.76
81	27.9	108	0.66
82	24.3	109	0.57
83	21.1	110	0.5
84	18.4	111	0.44
85	16	112	0.38
86	13.9	113	0.33
87	12.1	114	0.29
88	10.6	115	0.25
89	9.2	116	0.22
90	8	117	0.19
91	7	118	0.16
92	6.1	119	0.14
93	5.3	120	0.125
94	4.6	121	0.11
95	4	122	0.095
96	3.5	123	0.082
97	3	124	0.072
98	2.6	125	0.063
99	2.3	126	0.054
100	2	127	0.047
101	1.7	128	0.041
102	1.5	129	0.036
103	1.3	130	0.031
104	1.1		
105	1		
106	0.87		

Each C_i/T_i represents a partial dose, the sum of an individual's partial doses for a given day is the overall daily percentage noise dose.

These equations are also applicable with the implementation of hearing protection. The noise level is effectively changed for a worker with the use of hearing protectors. Instead of using the A-weighted noise level, the protected A-weighted noise level, resulting from the use of the hearing protector, is used. The preferable methods for calculating the protected value, in the United States, use the C-weighted noise level and the Noise Reduction Rating of the hearing protector being used, or alternatively, use the octave band method. A detailed discussion of these calculations follows.

Overview of EPA Labeling Requirements

The EPA governs the regulation of the labeling requirements for hearing protectors in the United States. The requirements of a hearing protector package label are found in 40 CFR Chapter 1, Part 211, Subpart B; for the determination of the NRR rating, the regulation refers to ANSI S3.19-1974 and specifically requires that an experimenter-fit procedure (the experimenter, not the subject, fits the hearing protector in or over the subject's ears) be used to obtain optimal attenuation.

Section 211.204 outlines the physical requirements that the package label of a hearing protector must exhibit. Each section, according to 211.204-1, of the label is defined by the following:

Location	Description
A	"Noise Reduction Rating"
B	The NRR in dB as determined by the procedure outlined in ANSI S3.19-1974.
Under B	"(When used as directed)."

C	"The range of Noise Reduction Rating for existing hearing protectors is approximately 0 to 30 (higher numbers denote greater effectiveness)."
D	The hearing protector's manufacturing company name, city, and state.
E	The hearing protector's model number or kind.
F	"Federal law prohibits removal of this label prior to purchase"
G	EPA logo
H	"Label Required by US. EPA regulation 40 CFR Part 211, Subpart ----."

Figure 3 illustrates the dimensions of the label and its components. Figure 4 illustrates a sample label that has an NRR of 23 dB.

Octave Band Method of Assessing the Protected Noise Level

Although OSHA has mandated limits on the noise exposure a worker can experience, and the EPA has established the use and labeling requirements of the NRR, researchers have questioned if a single-number rating method accurately and adequately predicts the effectiveness of a hearing protector to prevent, or minimize, threshold shifts in workers' hearing (Berger, 1979, 1984; Cluff, 1986; Lempert and Fleming, 1976). In specific regard to this question of effectiveness is the noise spectra. It is questionable if a single-number rating, such as the NRR, can adequately quantify the effect of noise with a majority of energy in one or a few parts of the audible spectrum.

A majority of researchers (Berger, 1979, 1984; Cluff, 1986; Lempert and Fleming, 1976; NIOSH, 1975) agree that the most accurate procedure for determining the level of noise reaching a worker's ears is the octave band

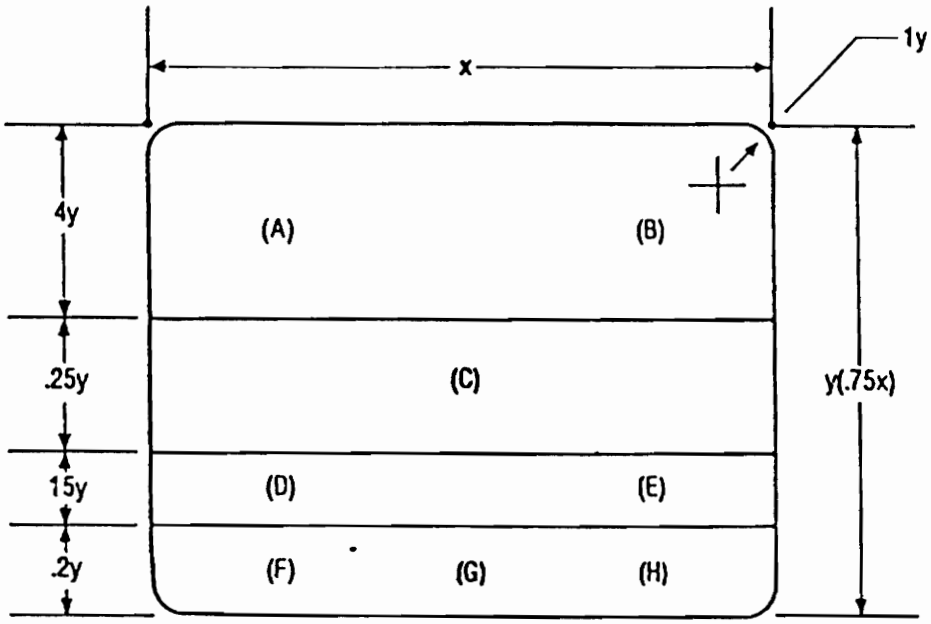

Figure 3. *EPA standard label format and dimensions (Adapted from EPA, 1979)*

NOISE
REDUCTION
RATING

23 DECIBELS

(WHEN USED AS DIRECTED)

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

ADDRESS

TYPE

Federal law prohibits
removal of this label
prior to purchase

EPA

LABEL REQUIRED BY
US EPA REGULATION
40 CFR PART 211

Figure 4. *Sample NRR label [Not to scale] (Adapted from EPA, 1979).*

method, also known as NIOSH Method Number 1, or the Long Method. This method uses octave-band analysis (i.e., the evaluation of a noise spectra by dividing it into individual octave bandwidths). To determine the protected noise level, an octave bandwidth is established by having the upper cut-off frequency be twice the lower cut-off frequency; it is defined by a doubling of frequency. It has the advantage of considering the entire noise spectrum in its calculation as well as the spectrum of attenuation of the HPD, and does not rely on a single-number wideband rating of the hearing protector.

Using octave band data to determine the protected noise level. The procedure for calculating the protected exposure level using the octave band method, as in NIOSH 76-120 (1975), is as follows:

1. Enter the ambient noise environment with an octave band analyzer.
2. Measure the ambient sound levels for the octave bands centered at the following frequencies: 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. Average the levels for 3150 and 4000 Hz and record this as the 4000 Hz level, then ignore the 3150 Hz value. Also, average the levels for 6300 and 8000 Hz and record this as the 8000 Hz level, then ignore the 6300 Hz value.
3. Apply an A-weighting to the seven remaining values (-16.1, -8.6, -3.2, 0.0, 1.2, 1.0, and -1.1 dB, respectively).
4. Perform a logarithmic sum of the weighted values from step 3 to determine the overall A-weighted unprotected sound level.

5. Measure the mean attenuation for each octave band for the hearing protector being used.

6 Determine the standard deviation of the attenuation for each of the seven center frequencies, and multiply each of these values by 2. A factor of two standard deviations is used so that 98% of the population is protected by the attenuation of the HPD.

7. Compute the protected sound level for each octave band by subtracting the mean attenuation from the unprotected A-weighted values, and adding the double-weighted standard deviation (i.e.. Step 3 - Step 5 + Step 6).

8. Compute the overall protected A-weighted sound level by performing a logarithmic sum of the values from step 7.

A numerical example of the octave band method calculation is shown in Table 3.

Evaluation of the octave band method. Researchers agree that the octave band method is the most accurate method for determining the protected sound level a worker experiences. It is also common knowledge that this method requires the use of more sophisticated equipment than does the NRR.method, including an octave band analyzer, and is laborious in its computation, namely, the logarithmic summations, the A-weighting corrections, and the multiple spectral value calculations. Additionally, it ids dependent on the noise spectrum; it cannot be pre-computed and supplied by the HPD manufacturer. It is primarily for these reasons of computational complexity and instrumentation needs that researchers have tried to develop alternative methods of computing the protected

sound level based on the octave band method; of these, the development of single-number ratings of HPDs is the most prevalent.

TABLE 3

Sample Calculation of the Protected Noise Level Using the Octave Band Method (Adapted form Berger, 1986).

Octave Band Center Frequency (Hz)	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**dBA[A]**
1. Measure sound pressure levels	85.0	87.0	90.0	90.0	85.0	82.0	80.0	
2. A-weighting correction	-16.1	-8.6	-3.2	0.0	+1.2	+1.0	-1.1	
3. A-weighted sound levels [step 1 + step 2]	68.9	78.4	86.8	90.0	86.2	83.0	78.9	93.5
4. Typical premolded earplug attenuation	27.4	26.6	27.5	27.0	32.0	46.0[B]	44.2[C]	
5. Standard deviation x 2	7.8	8.4	9.4	6.8	8.8	7.3[B]	12.8[C]	
6. Estimated protected A-weighted sound levels [step 3 - step 4 - step 5]	49.3	60.2	68.7	69.8	63.0	44.3	47.5	73.0

The estimated protection for 98% of the users in the noise environment, assuming they wear the device in the same manner as did the test subjects, and assuming they are accurately represented by the test subjects is:
93.5 - 73.0 + 20.5 dBA.

[A]Logarithmic sum of 7 octave band levels in the row.
[B]Arithmetic average of 3150 and 4000 Hz data.
[C]Arithmetic average of 6300 and 8000 Hz data.

HEARING PROTECTOR SINGLE-NUMBER RATING METHODS: A BRIEF REVIEW OF THE LITERATURE

A variety of single-number ratings have been derived to help hearing conservationists determine the protected noise level a worker experiences while wearing hearing protection. Berger (1979) provides a summary table, reproduced as Table 4, that describes some of these rating methods. For the purposes of this report, only four rating methods will be discussed in detail: NRR, HML, SNR, and SLC_{80}. The basis for this limitation of described methods is the following: relation to the octave band method, general acceptance by professional hearing conservationists and experts, and the availability of supporting literature.

Noise Reduction Rating (NRR)

The Noise Reduction Rating value was accepted by the Environmental Protection Agency (EPA) in September of 1979 as the hearing protector rating value to be used in the United States. It is required to be placed on the packaging of all hearing protectors (EPA, 1979). The NRR is generally known to be advantageous in that it is quick and easy to use.

Calculation of the NRR from HPD attenuation data. Because the EPA requires manufacturers to label their products with the NRR (in addition to the spectral mean and standard deviation data), and since it is the basis for determining a worker's protected noise exposure level, it is imperative that the value be accurately calculated. Section 211.207 of 40 CFR provides the step-by-step instructions for computing an hearing protector's NRR (EPA, 1979). The procedure is as follows:

TABLE 4

Single-Number Ratings of Hearing Protectors (From Berger, 1979).

Single Number Rating	Proposed By	Date	Weighting Network For Noise Measurement[1]	Hypothetical Noise Spectrum[2]	User Variability Correction[3]	Spectral Safety Factor[4]	Sample Calculation[5]
R	NIOSH Criteria Document	1972	dBA	Pink	10 dB[6]	—[6]	26
AES[7]	R. Camp	1972	—	—	None	—	88%
K	ANSI Z137.1 Draft 3	1973	dBA	Pink	10 dB[8]	—[8]	36
SLC[9]	J. Botsford	1973	dBC	6 typical noise spectra	Optional	—	42
Two Number Method	D. Johnson C. Nixon	1974	dBA and dBC	6 typical noise spectra	Optional	—	—
R_c	NIOSH 76-120	1975	dBC	Pink	2σ	3 dB	29
R[10]	NIOSH 76-120	1975	dBA	Pink	2σ	8.5 dB	22
P-AR[11]	J. Tobias	1975	dBC	TTN[12]	$0, 1\sigma, 2\sigma$	Accounted for by shaped spectrum	1-1-1
SLC_{80}	R. Waugh	1976	dBC	Shaped spectrum[13]	1σ	Accounted for by shaped spectrum	34
NRR[14]	EPA 40CFR Part 211	1977	dBC	Pink	2σ	3 dB	29
S	ANSI Z137.1 Draft -1979	1979	dBC	NNS[15]	2σ	4 dB	28

1 Specifies whether the single number rating is subtracted from an A or C-weighted unprotected sound level in order to arrive at the effective A-weighted exposure

2 Specifies the type of noise spectrum used for the single number calculation

3 Specifies how many standard deviations (σ) or decibels are subtracted from the mean attenuation values to account for user variability

4 Specifies how large a safety factor is incorporated to account for the difference between the actual sound spectra encountered and the hypothetical noise spectrum utilized for calculations

5 Sample calculation for currently reported E-A-R™ Plug S3 19 data (Tested 11/75)

6 This 10 dB correction included in the calculated R accounts for possible noise spectrum irregularities and noise leakage which might be caused by long hair, safety glasses, head movement, or various other factors

7 The Attenuation Efficiency Score is a relative ranking based on Fort Rucker Aero Medical Research Laboratory data. It does not yield a noise reduction figure. No device has an AES = 100%, since this would mean it had the highest attenuation ever measured at Fort Rucker at all of the test frequencies. The range of AES values for currently available devices is 2%-88%

8 Similar concept as footnote 6, *except* this correction factor is not included in K but must be subtracted from the dBA level for each calculation. Obviously the K and R (1972) factors are essentially identical

9 Sound Level Conversion

10 Note that the R value for E-A-R™ Plugs is 7 dB lower than R_c value. This reflects the extra safety factor that must be included since a dBA instead of a dBC sound level is used in the calculation

11 Protector Attenuation Rating – This, like the AES is a relative ranking. It is based on Tobias measurements of over 40 different protectors. 1 is best, 6 is worst. The three numbers represent the relative ranking with zero one standard deviation and two standard deviation corrections respectively. The best possible P-AR is 1-1-1

12 The Typical Noise is a shaped spectrum resembling pink noise, but sloping gently downwards from 63 Hz – 8 kHz.

13 Similar to TTN.

14 Noise Reduction Rating

15 Nominal Noise Spectrum is similar to TTN

1. Assume a pink noise spectrum for the test environment.
2. Calculate the C-weighted sound levels (L_C) for each of the nine octave bands centered at the following frequencies: 125, 250, 500, 1000, 2000, 3150, 4000, 6000, 8000 Hz. The values for 3150 and 6300 Hz are averaged with 4000 and 8000 Hz respectively.
3. Compute the overall C-weighted sound level by performing a logarithmic sum of the resulting seven sound levels over the resulting seven octave bands.
4. Find the A-weighted sound levels (L_A) for each of the nine octave bands. The values for 3150 and 6300 Hz are averaged with 4000 and 8000 Hz respectively.
5. Find the mean attenuation for each 1/3 octave band for the hearing protector being used.
6. Find the standard deviation of the mean attenuation for each 1/3 octave band for the hearing protector being used. Multiply each of these values by 2.
7. Compute the protected A-weighted sound level at each 1/3 octave band by subtracting the mean attenuations of the HPD from the A-weighted sound levels, and adding the double-weighted standard deviations of the mean attenuations.
8. Find the overall protected A-weighted sound level by performing a logarithmic sum of the seven protected A-weighted sound levels.

9. Calculate the NRR by subtracting the overall protected A-weighted sound level from the overall C-weighted sound level, and subtracting a correction factor for spectral uncertainty of 3 dB.

A sample calculation from Berger (1979) for the E-A-R Classic™ Polyvinyl-chloride foam plug is shown in Table 5.

Using the NRR to determine the protected noise level. The application of the NRR is exceptionally easy. To find the protected A-weighted sound level, one must first measure the C-weighted sound level of the noise environment. Then, note the NRR from the package of the hearing protector. Lastly, subtract the NRR from the C-weighted sound level (L_C) of the environment (i.e., $L_{A'} = L_C$ - NRR, where $L_{A'}$ is the protected A-weighted sound level). According to OSHA (1983) regulation 1910.95, if the dBC value cannot be obtained, the A-weighted value can be used if the NRR is first reduced by 7 (this is the same as increasing the A-weighted sound level of the environment by 7 dB). That is, $L_{A'} = L_A$ - (NRR - 7). This application is known as NIOSH Method Number 3. Additionally, the OSHA field operations manual states that the NRR should be divided by two before applying it in the calculation of the protected noise level (OSHA, 1983). OSHA recognizes that laboratory-obtained NRR values are not always experienced in the workplace; this 50% reduction is a correction factor for real-world use when comparing HPD effectiveness to noise controls.

Evaluation of the NRR. Several studies have been performed to evaluate whether or not the NRR is an effective rating method for HPD attenuation. First, a study performed by Behar (1981) compared the NRR method to the NIOSH octave band method. The study calculated the difference

TABLE 5

Sample Calculation of the NRR of Cabot Safety's E-A-R Classic™ Foam Plug (Adapted from Berger 1979).

Octave Band Frequency (Hz)	125	250	500	1000	2000	4000	8000
1. Hypothetical noise spectrum OB sound levels (pink noise)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	(level assumed is not significant)						
2. C-weighted OB sound levels unprotected ear.	99.8	100.0	100.0	100.0	99.8	99.2	97.0
3. Overall C-weighted sound level: 107.9 dBC (logarithmic sum of the seven OB sound levels in step 2.)							
4. A-weighted OB sound levels unprotected ear.	83.9	91.4	96.8	100.0	101.2	101.0	98.9
5. E-A-R Plug mean attenuation.	29.6	31.3	34.1	34.0	35.5	41.4*	39.6**
6. E-A-R Plug standard deviation x 2	6.4	6.6	4.2	4.6	5.4	3.9*	4.8**
7. Protected A-weighted OB sound levels (Step 4 - Step 5 + Step 6).	60.7	66.7	66.9	70.6	71.1	63.5	64.1
8. Overall A-weighted sound level under the protector (effective exposure): 76.0 dBA (logarithmic sum of the seven OB sound levels in step 7).							
9. NRR = Step 3 - Step 8 - 3 dB NRR = 107.9 - 76.0 - 3 = 28.9 : **29 dB**							

*Numerical average of the 3000 and 4000 Hz data

**Numerical average of the 6300 and 8000 Hz data

between the protected sound levels achieved by each of the two methods; the difference, termed E, was calculated by subtracting the protected sound level obtained using the octave band method, from the protected sound level obtained using the NRR (Behar, 1981). Behar found that the NRR-based protected sound levels were always higher than octave band-based levels. Also, the difference, E, between the two protected sound level methods depended on the noise and the protector. That is, E is noise- and protector-specific. Lastly, the difference between the two protected sound level methods was always higher for muffs than plugs.

Cluff (1986) also performed a study to determine if the NRR was reliable enough to merit a company to purchase C-weighted sound-measurement equipment. No concrete decision was reached, however. Because there was no definite understanding of "reliable enough" performance, it was decided that the NRR was most useful, and accurate, for non-V-noise spectra, where a V-noise spectra has a maximum C minus A-weighted value of less than 3.5 dB positive or negative (Cluff, 1986). Cluff's final conclusions from the 1986 study can be summarized as follows. First, the NRR is simple to use. Also, there is large variability (up to about 11 dB) in the accuracy of the NRR's attenuation estimate. Finally, the NRR works best in non-V-noise spectra ($|C - A| < 3.5$).

Lastly, Lundin (1992b) compared several rating methods to the octave band method, including the NRR. The study consisted of determining the attenuation in three noise spectral types: high, medium, and low frequency noise. Based on the underestimation of the protected level of the hearing protector (7 dB for high frequencies, 4 dB for medium frequencies, and 2 dB for low

frequencies), he concluded that the NRR "is a very poor descriptor of the octave-band method for all noises" (Lundin. 1992b. 60).

Comparison to similar methods. Two additional methods, SNR and SLC_{80}, are available to calculate a single-number rating of a hearing protector; these methods are similar in procedure to the NRR method. Although the application of the SNR and SLC_{80} is identical to the NRR (subtract the rating from the C-weighted noise level), there are some differences in the derivation of the ratings. First, both methods omit the 3 dB spectral uncertainty safety factor used in the NRR. Also, there are differences in the application of the standard deviation. Lundin (1992a) shows that a variety of standard deviations may be used for the SNR, based on the APV value (The APV calculation is discussed in the next section). On the other hand, Waugh (1984) prefers only one standard deviation for the SLC_{80}; this provides a protection rate of about 80%, and also eliminates the overprotection exhibited by the two standard deviation NRR method. The last difference occurs in the SNR method. This method includes 63 Hz in the noise spectrum, which would add additional weight to the lower frequencies which are more difficult to control for (Lundin, 1992a).

High, Medium, Low (HML) Method

The High, Medium, Low (HML) method was developed by the late Rune Lundin of Peltor AB, and prior to that Bilsom AB, hearing protector manufacturers in Sweden. This method is presently being adopted as a method for calculating the protected noise level in Europe (ISO, 1992). The HML method offers an alternative rating, called the Predicted Noise level Reduction (PNR) in dB, to the NRR which, as discussed earlier, is required in the United states by the EPA.

The underlying principle of this method is to provide an attenuation rating for noises with spectral emphasis in either the high-, medium-, or low-range of frequencies.

Calculation of the HML from HPD attenuation data. At first, the calculations that must be performed to obtain the H, M, and L values seem quite confusing, but are actually very simple once they are examined closely. Before calculation of the three ratings, Lundin (1992a) requires that two initial types of data must be used: eight reference spectra of noise, and the Assumed Protection Values (APV_f) of the hearing protector. The eight spectra can be found in Table 6; the APVs must be computed. Lundin (1992a) states the calculation of the APVs is as follows:

$$APV_f = M_f - aS_f$$

where:

f = center frequency for the octave band: 63, 125, 250, 500, 1000, 2000, 4000, 8000

M_f = mean attenuation (ref.: ISO 4869-1, 1981)

S_f = standard deviation (ref.: ISO 4869-1, 1981)

a = constant

The values for a are found in Table 7. Lundin (1992a) explains that the values for a are based on the protection performance of the hearing protector; he defines protection performance as "the percentage of situations for which the A-weighted sound pressure level effective when the hearing protector is worn is equal to or less than the predicted value...A situation is a combination of a particular individual wearing a given [HPD] in a specific noise environment" (Lundin, 1992a, p. 1).

TABLE 6

A-Weighted Octave Band SPLs, LAfi, of Eight Reference Noises Used in the Calculation of the H, M, and L Ratings (From Lundin, 1992a).

i	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	L_C-L_A*	d_i**
1	51.4	62.6	70.8	81.0	90.4	96.2	94.7	92.3	-1.2	-1.20
2	59.5	68.9	78.3	84.3	92.8	96.3	94.0	90.0	-0.5	-0.49
3	59.8	71.1	80.8	88.0	95.0	94.4	94.1	89.0	0.1	0.14
4	65.4	77.2	84.5	89.8	95.5	94.3	92.5	88.8	1.6	1.56
5	65.3	77.4	86.5	92.5	96.4	93.0	90.4	83.7	2.3	-2.98
6	70.7	82.0	89.3	93.3	95.6	93.0	90.1	83.0	4.3	-1.01
7	75.6	84.2	90.1	9..5	96.2	91.3	87.9	81.9	6.1	0.85
8	77.6	88.0	9..4	93.8	94.2	91.4	87.9	79.9	8.4	3.14

* L_C - L_A is the difference between the C-weighted and A-weighted sound levels.

** d_i is the normalized calculation constant for each reference equation.

TABLE 7

Values for Calculation Constant ***a*** to be Used in Calculating the Assumed Protection Value (APV).

Protection Performance (%)	Value of ***a***
75	0.67
80	0.84
84	1.00
85	1.04
90	1.28
95	1.64

After these initial values are obtained, the calculation of the H, M, and L values may begin. Lundin (1992a) provides the following equations for these calculations:

$$H = 0.25\sum PNR_i - 0.48\sum d_i(PNR_i) \quad \text{[Summation: } i = 1...4\text{]}$$
$$M = 0.25\sum PNR_i - 0.16\sum d_i(PNR_i) \quad \text{[Summation: } i = 5...8\text{]}$$
$$L = 0.25\sum PNR_i + 0.23\sum d_i(PNR_i) \quad \text{[Summation: } i = 5...8\text{]}$$

where:

$$PNR_i = 100 - 10\log \sum 10^{[0.1(L_{Afi} - APV_f)]} \quad \text{[Summation: } f = 63...8000 \text{ Hz]}$$

L_{Afi} and the calculation constant, d_i, (i is the reference equation number) are in Table 6. Careful calculation using these formulae will result in the H, M, and L values that are to be placed on the packaging of the hearing protector.

Using the HML to determine the protected noise level. The calculations of the protected sound level are very simple using the HML method; there are two methods that can be applied. The first method is the graphical method. Before going into the noise environment, the hearing conservationist plots the bi-linear relationship of the H, M, and L values. Behar (1990) states that on a provided graph (with the difference between the A- and C-weighted sound levels on the X-axis, and the PNR on the Y-axis), H, in PNR, is plotted in relation to the X coordinate marked -2; M at +2; and L at +10. These points are then connected to make a bi-linear relationship. Next, the conservationist measures the A- and C-weighted sound levels (L_A and L_C) in the noise environment. Some researchers feel that simultaneous readings of the sound levels are required to eliminate error introduced by time variation. However, it can be argued that if the noise is dependent on time to the extent that a few seconds make a significant difference in sound level, then a new PNR value should be

calculated anyway. Therefore, simultaneous sound level readings are not required. The A-level is subtracted from the C- level, and its position is projected up from the X-axis to the bi-linear plot. By reading over to the Y-axis from the bi-linear plot, the overall PNR for the noise environment is found. The protected sound level a worker experiences is then calculated by subtracting the PNR for the overall noise environment from the A-weighted sound level in the environment. That is, $L_{A'} = L_A - PNR$, where $L_{A'}$ is the protected A-weighted noise level.

The second method using the HML is analytical, but supplies the same PNR value; again, Behar (1990) details the procedure. This method begins by measuring the A- and C-weighted sound levels. The A-weighted level is then subtracted from the C-weighted value. If the difference is less than or equal to 2 dB, i.e. $(L_C - L_A) \leq 2$ dB, the following equation is used to find the overall PNR:

$$PNR = M - [(H - M)/4](L_C - L_A - 2)$$

If the difference is greater than 2 dB (i.e., $(L_C - L_A) > 2$ dB) the following equation is used:

$$PNR = M - [(M - L)/8](L_C - L_A - 2)$$

The difference value of 2 is the cross-over point between a HM (high-frequency-dominated) spectrum and a ML (low-frequency-dominated) spectrum. In either case, the PNR is then subtracted from the A-weighted sound level to find the protected sound level. That is, $L_{A'} = L_A - PNR$, where $L_{A'}$ is the protected A-weighted sound level.

Additionally, since the above PNR equations are linear relationships, tabular interpolation of the PNR values may also be employed. One table of

PNR values can be constructed for L_C - L_A values of less than 2, and one for greater than 2.

Evaluation of the HML. The HML is a relatively new method that merits more study in the United States. Europe is in the process of adopting this method already under ISO (1992); however, hearing conservationists in the U.S. appear to be hesitant due to a fear that the method is more complicated than the NRR method already being utilized. The question of ease of use of the HML has not been answered; however, studies have shown that the HML method out-performs the NRR method (Behar, 1990) on the basis of more accurately approximating the octave band method, which as stated earlier, is widely accepted as the most accurate method for determining protected sound levels while being too complicated to apply in the field (Lundin, 1992a, 1992b). Also, it can be observed that the HML method takes the spectrum of noise into account. That is, the NRR does not discriminate as effectively between high and low frequency noises, while the HML rating does. For these reasons, this method deserves more research attention and should be considered for adoption into regulation for hearing protector labeling and workplace noise exposure determination in the U.S..

HML-Quicky. A problem may arise with the HML method in that C- and A- weighted readings may be unattainable due to a lack of proper equipment. The HML-Quicky is a qualitative assessment method used to estimate if a selected hearing protector is adequate to be used in a given A-weighted sound environment. Peltor (1993) provides the written instructions for performing this method. These instructions are summarized as follows:

1. The first step in finding the HML-Quicky is to gather some preliminary data. The first piece of preliminary data is the A-weighted noise level for an eight-hour work period; this level will be referred to as L_8. Also needed is the desired A-weighted protected noise level; this level will be referred to as $L_{A'}$. The remaining preliminary information are the H, M, and L values; these are obtained directly from the package of the hearing protector.

2. Calculate the Predicted Noise Level Reduction (PNR) that corresponds to the selected $L_{A'}$ value by subtracting $L_{A'}$ from L_8. That is, PNR = $L_8 - L_{A'}$.

3. Evaluate the probable performance of the hearing protector. Three outcomes are possible:

   A. If the PNR is equal to or less than the smallest value of the H, M, or L values, the hearing protector is adequate to be used in the noise environment.

   B. If the PNR is more than the largest value of the H, M, or L values, the hearing protector should not be used in the noise environment; another hearing protector should be selected and retested with this procedure.

   C. If the PNR is more than the smallest value, but equal to or less than the largest value, go to step 4.

4. Listen to the noise in the environment and decide which spectra type it is: either HM or ML. Table 8 lists examples of

TABLE 8

Examples of Machinery that Produce HM and ML Noise Spectra (From Peltor, 1993).

ML	HM
Excavators	Gas cutting
Motor generators	Sugar-coating equipment
Electric smelting furnaces	Compressed air nozzles
Incinerator furnaces	Power hammers
Annealing furnaces	Rebating equipment
Blast furnaces	Bottle-filling machinery
Crushers	Polishing of castings
Compressors (piston)	Carpentry machines
Converters	Hydraulic pumps
Cupola furnaces	High pressure conveyor-fed rotary presses
Press forges	Centrifuges
Bulldozers	Injection molding machinery
Sandblasting equipment	Grinding machines
	Spinning machines
	Crocheting/knitting machinery
	Bore polishing machinery
	Mechanical looms

machines that contribute to each of these two spectra classes.

5. If the noise spectra is perceived as HM, go to step 6. If the noise spectra is perceived as ML, go to step 7.

6. Note the H and M values of the hearing protector found on the package and the calculated PNR. Again, three outcomes are possible:

   A. If the PNR is equal to or less than the smallest value of the H and M values, the hearing protector is adequate to be used in the noise environment.

   B. If the PNR is more than the largest value of the H and M values, the hearing protector should not be used in the noise environment; another hearing protector should be selected and retested with this procedure.

   C. If the PNR is larger than the smallest value of the H and M values, but equal to or less than the largest value, then the HML-Quicky method is inconclusive; use of the full HML method is required.

7. Note the M and L values of the hearing protector found on its package, and the calculated PNR. Again, three outcomes are possible.

   A. If the PNR is equal to or less than the smallest value of the M and L values, the hearing protector is adequate to be used in the noise environment.

B. If the PNR is more than the largest value of the M and L values, the hearing protector should not be used in the noise environment; another hearing protector should be selected and retested with this procedure.

C. If the PNR is greater than the smallest value, but equal to or less than the largest value of the M and L values, then the HML-Quicky method is inconclusive; use of the full HML method is required.

As can be seen, the HML-Quicky method fundamentally relies upon an individual's perception of the spectral type that the noise exhibits. Unfortunately, no quantitative data can be found to ascertain whether this judgmental procedure can be relied upon. A majority of research performed in the area of pitch discrimination has been done using pure tones, such as the landmark works of Stevens and Volkmann (1940) and Torgerson (1958), not of complex broadband noise, which constitutes most occupational exposures. However, one may draw a parallel between broadband noise discrimination and speech discrimination. Kryter (1972) explains that there are different spectra that comprise each individual's speech; furthermore, the power of a male's speech spectrum is generally in the lower frequencies while the power of a female's speech spectrum is generally in the upper frequencies. Therefore, in a loose sense, the discrimination of industrial noises can be considered to be like discriminating a male voice from a female voice.

A definite concern regarding this method is the proper classification of sound spectra. If the wrong classification is subjectively chosen, the situation may result in overprotection in the segment of the sound spectrum that the

dominant noise energy is absent, and underprotection in the segment of the sound spectrum where the dominant noise energy is present. Additionally, speech perception while wearing the ill-chosen HPD may be negatively affected. When workers cannot understand speech while wearing HPD's, they are inclined to remove them, thus nullifying any protection.

INSTRUCTION DESIGN: A BRIEF REVIEW OF THE LITERATURE

In addition to having a rating method that most accurately approximates the octave band method, hearing conservationists must be able to correctly use the method, or it is not viable. As new and better rating methods are developed, training programs and literature on their proper use need to be developed as well. Without clear and comprehensive instructions on its use, a more accurate rating method, such as the HML, will fail.

Models of Instructional Design

Friesen (1973) points out two general models in the development of instructions: development by an individual's artistic capabilities, or development by the application of a scientific systematic approach. Although both of these methods can produce effective instructional materials, the systematic approach yields quantifiable data that can be evaluated and empirically proven to be effective. Andrews and Goodson (1980, p. 2-3) cite Hayman (1974) and Logan (1976) when presenting their definition of a model of systematic instructional design: "A model is usually considered to be an abstraction and simplification of a defined referent system, presumably having some noticeable fidelity to the referent system." Andrews and Goodson (1980) continue on with providing four purposes embodied by instructional models:

1. To ameliorate the learning process and the instructional tools with the inherent characteristics of the systems approach, especially the problem-solving and feedback structure.
2. To provide an improved management scheme for the instructional design process through the systems approach.

3. To provide an improved evaluation procedure with the use of a structured systematic process.
4. To utilize theory-based design to test or construct instructional theories.

In reference to these four purposes, Gropper (1977) devised ten common tasks which all models of instructional design exhibit; Andrews and Goodson (1980) expand the list to 14 tasks. This list is found in Table 9; the authors continue by evaluating 40 well-known models of instructional design for these 14 tasks, and summarize them as shown in Table 10. Andrews and Goodson (1980) also point out that the reason that there are so many different models of instructional design is embedded in the "'not-invented-here' syndrome" (p.12). That is, developers do not reference other models before creating their own due to a sense of case-specific importance of their situation.

Selection of Instructional Model

Of the 40 previously-mentioned models of instructional development, the updated edition (3rd) of Dick and Carey (1990) has been selected to be the model which guides the development of instructions for this thesis experiment. This selection is based on the acceptance of the model by experts in the field of instructional development, and its relation to the topic under investigation. The systems approach of this model is consistent with that of the human factors engineering design process, and therefore will provide acceptable guidelines to follow. This model will be applied to the development of all three types of instruction sets which will be discussed later.

TABLE 9

Summary of the 14 Tasks Included in Models of Instructional Design (From Andrews and Goodson, 1980)

Task Number	Definition
1	Formulation of broad goals and detailed subgoals stated in observable terms
2	Development of pretest and posttest matching goals and subgoals
3	Analysis of goals and subgoals for types of skills/learning required
4	Sequencing of goals to facilitate learning
5	Characterization of the learner population "as to age, grade level, past learning history, special aptitudes or disabilities, and, not least, estimated attainment of current and prerequisite goals" (Gropper, 1977, p. 8)
6	Formulation of instructional strategy to match subject-matter and learner requirements
7	Selection of media to implement strategies
8	Development of courseware based on strategies
9	Empirical tryout of courseware with learner population, diagnosis of learning and courseware failures, and revision of courseware based on diagnosis
10	Development of materials and procedures for installing, maintaining, and periodically repairing the instructional program
11	Assessment of need, problem identification, occupational analysis, competence, or training requirements
12	Consideration of alternative solutions to instruction
13	Formulation of system and environmental descriptions and identification of constraints
14	Costing instructional programs

TABLE 10

Identification of the 14 Tasks Most Common in Models of Instructional Design (From Andrews and Goodson, 1980)

Reference for Model*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Σ
1. Army Security Agency; Legere, et al. (1966)	•	•	•	•	•	•	•	•	•		•				10
2. Atkins (1975)	•	•		•		•		•	•	•	•		•		9
3. Banathy (1968)	•	•	•	•	•	•	•		•	•		•	•	•	12
4. Bishop (1976)	•	•	•	•	•	•	•	•	•	•	•		•	•	13
5. Briggs & Wager (1979)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	14
6. Brooks, et al. (1973)	•		•		•	•	•	•	•	•	•				9
7. Burkman (1976-1978); Laugen (1979)	•	•	•	•	•	•	•	•	•	•	•		•	•	13
8. Crittendon & Massey (1978)	•	•	•		•	•		•	•	•			•	•	10
9. Davis (1977)	•		•	•	•				•	•			•		7
10. Davis & McCallon (1974)	•		•		•	•	•	•	•	•	•		•	•	11
11. Dedenick & Sturge (1975)	•	•	•	•		•		•	•	•	•				9
12. Dick & Carey (1978)	•	•	•		•	•	•	•	•		•	•			10
13. Even (1977)	•		•	•	•	•			•		•		•	•	9
14. Friesen (1973)	•	•	•	•	•	•	•	•	•	•	•	•		•	13
15. Gagne & Briggs (1974); Briggs (1975)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	14
16. Glaser (1966)	•	•	•		•	•		•	•						7
17. Gropper (1973)	•	•	•	•	•	•	•	•	•	•					10
18. Hayman (1974)	•				•			•	•	•	•	•	•	•	9
19. Interservice Procedures (1975); Branson (1978)	•	•	•	•		•	•	•	•	•	•	•	•	•	12
20. Kaufman (1972)	•	•			•	•		•	•	•	•	•	•	•	11
21. Ledford (1973)	•		•		•	•	•	•	•	•					8
22. Lee (1975)	•	•	•	•		•	•	•	•	•	•	•	•	•	13
23. Mager & Pipe (1978)	•	•	•	•	•		•	•	•	•		•	•		11
24. Maher (1978)	•				•	•	•	•	•	•			•		8
25. Merrill (1973); Merrill & Boutwell (1973)	•	•	•	•		•	•	•	•						8
26. Michigan State University; Barson (1965)	•	•				•	•	•	•						6
27. Pennington & Green (1976)	•			•	•	•			•		•		•		7
28. Penta (1973)	•	•		•			•	•	•		•	•			8
29. Roberts (1978)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	14
30. Scanland (1974)	•	•	•	•	•	•	•	•	•	•	•	•	•		13
31. Sherman (1978)	•		•		•	•			•		•	•	•		8
32. Shoemaker & Parks (1976)	•	•	•	•		•			•		•		•		8
33. Teague & Faulkner (1978)	•	•	•	•	•	•	•	•	•	•	•				11
34. Tennyson & Boutwell (1971)	•	•	•	•		•		•	•						7
35. Tosti & Ball (1969)	•				•	•		•		•					5
36. Tuckman & Edwards (1973) (cf. Davis, 1977)	•	•				•		•	•	•	•		•		8
37. Vance (1976)	•		•	•	•	•	•	•	•	•	•		•		11
38. Waldron (1973)	•	•	•			•	•	•	•	•			•	•	10
39. Wallen (1973)	•	•	•					•	•	•	•				7
40. Waters, et al. (1978)	•	•	•			•	•	•			•		•		8
Frequency	40	28	29	23	27	34	24	34	38	28	27	14	25	14	
Percentage	100	70	73	58	68	85	60	85	95	70	68	35	63	35	

*14 Tasks Most Common in Models of Instructional Design

1 = Outcome
2 = Tests
3 = Analysis
4 = Sequencing
5 = Learner Attributes
6 = Strategy
7 = Model
8 = Development
9 = Tryout/Revision
10 = Install/Maintain
11 = Need
12 = Alternatives
13 = Constraints
14 = Cost

Design of Instructions

Dick and Carey (1990) illustrate a 10-step iterative model for the design of instructional materials; this model is shown in Figure 5. As seen, the components of the model are the following: identify the instructional goals; conduct an instructional analysis; identify any entry behaviors and characteristics; write the performance objectives; develop criterion-referenced test materials; develop the intentional instructional strategy; develop and select all instructional materials; design and conduct a formative evaluation of the instructional materials; refine and revise the instructional materials; and design and conduct a summative analysis of the instructional materials. These terms are used as sub-headings in this section for the purposes of quick reference. Following this systematic instructional design methodology, an effective set of instructional materials should result.

Identify the instructional goals. A specific statement, or set of statements, are developed to define what it is that the subjects should be able to do after reading the instructional material and performing any specified tasks. This is normally a result of a needs-assessment study. Most researchers, such as Rossett (1987), recommend gathering the needs-assessment information directly from the intended users. This information is analyzed and transformed into the instructional goals. By using the obtained information, important requirements will not be omitted, and extraneous requirements will not be included. Dick and Carey (1990) also stress that this stage of the instructional design is an iterative process, and the goals should be refined and revised as necessary.

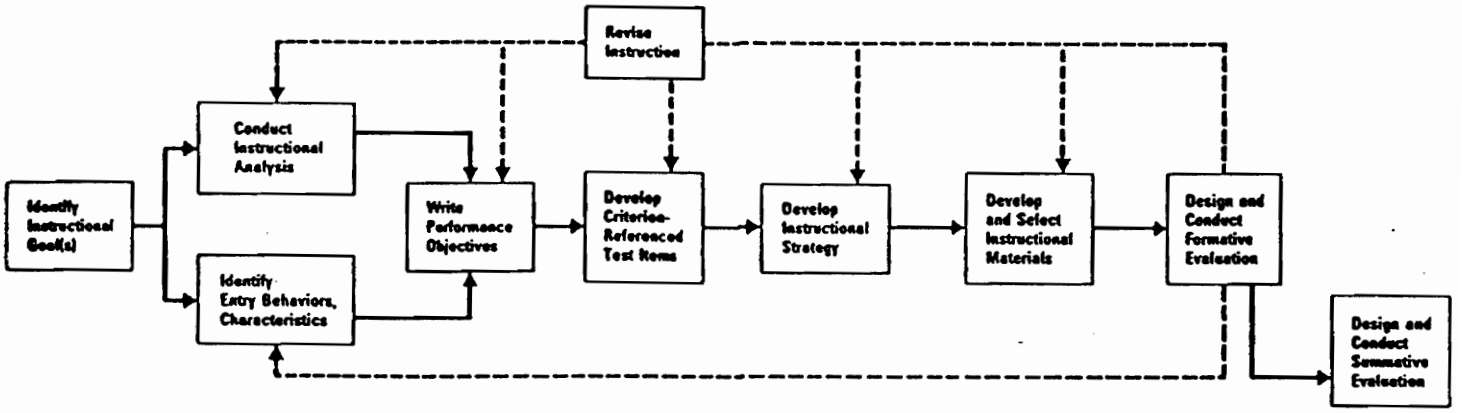

Figure 5. *Model for the systematic design of instructions (Adapted from Dick and Carey, 1990).*

Conduct an instructional analysis. This step of the instructional design process analyzes the instructional goals and determines the type of skills the subject is required to have to meet the goal. The first part of this goal-analysis process is to assign the instructional goal into one of the four domains of learning described by Gagne (1985) as the following:

1. Psychomotor Skills. In this domain, the instructional goal implies that the subject must perform some biomechanical action to fulfill the goal. Dick and Carey (1990) provide an example of learning how to operate a video camera.
2. Intellectual Skills. In this domain, the instructional goal implies that the subject must perform some cognitive or problem-solving activity to fulfill the goal. This definition is expanded to include any activity that includes the manipulation of symbols. Dick and Carey (1990) provide an example of learning how to balance a checkbook.
3. Verbal Information. In this domain, the instructional goal implies that the subject must perform a task in which information is to be presented verbally. Dick and Carey (1990) provide an example of learning to name the capitol cities of the 50 states.
4. Attitudes. In this domain the instructional goal implies that the subject must make a choice to perform a psychomotor, intellectual, or verbal skill; the choice should reflect the individual's personal beliefs. Dick and Carey (1990) provide

an example of workers choosing to become good employees.

Dick and Carey (1990) stress that the goal analysis should be focused on what the learner is to perform, and not what the learner needs to know. A flow diagram, or operational sequence diagram, will aid in this development. A completely-performed goals analysis will also result in the identification of subordinate skills, those skills that are required to perform the tasks outlined to complete the instructional goal.

Identify entry behaviors and characteristics. After the goals have been analyzed and the subordinate skills identified, Dick and Carey (1990) explain that the target population must be identified. With the target population in mind, the designer can structure the instructions around what the users already know and are experienced with (subordinate skills). These similarities in subordinate skills are what instructional designers refer to as entry behaviors.

Dick and Carey (1990) state that another important aspect to the design of instructions are an individuals' characteristics, such as reading skills and attention spans. Although individuals of a target population may have identical subordinate skills, individual differences must be taken into account. In human factors research, these characteristics can be controlled to some extent by a pre-experimental screening process.

Write the performance objectives. In this section of the instructional design, the performance objectives will be established. Dick and Carey (1990) state that a performance objective is "a detailed description of what students will be able to do when they complete a unit of instruction" (p. 105). The authors identify the components of the performance objective as the following:

1. A description of the previously-identified skills or behaviors from the instructional analysis stage.
2. A description of the conditions under which the subject will carry out the task, including what will be provided, and if any reference materials will be allowed.
3. A description of the means by which the subject's performance will be evaluated against the objective.

It is possible that these elements can be combined into one statement in the instruction design.

Develop criterion-referenced test material. In this stage of the instruction design, an evaluation method is established that directly relates the subject's performance with the performance objective; these tests are referred to as criterion-referenced tests. Dick and Carey (1990) describe the three types of criterion-referenced tests as follows:

1. Pretest. This test evaluates a subject's entry behaviors and characteristics. It follows that if the subject does not meet the criterion previously established, then the subject will probably perform poorly in the training. Dick and Carey (1990) also explain that a pretest can be used as a baseline of knowledge test. That is, an evaluation of what the subject knows prior to being exposed to the instructional material can be made.
2. Embedded Tests. Dick and Carey (1990) describe these types of tests as "a practice item with no feedback" (p. 126). The primary purpose of these tests is to provide the designer

with an informal evaluation of the subject's performance directly after finishing with the instructions.

3. Posttest. The purpose of this test is to evaluate if the subject has fulfilled the performance objective or not. Dick and Carey (1990) explain that if the subject failed to fulfill the objective, there is to be a method by which the designer can determine why and how.

Dick and Carey (1990) state that all three of these types of tests should be included in a well-designed instruction set.

Develop instructional strategy. This step in the instructional design is where the designer plans how the information will be presented to the subject; not the media used, but the order of information. Dick and Carey (1990) explain the five main parts of an instructional strategy as follows:

1. Preinstructional Activities. The preparatory procedures for a training session are just as important as the training itself. Before the actual instructions are presented to the subject, the designer performs three activities. First, the designer motivates the subject by informing them of the importance of the study. Next, the designer informs the subject of what is to occur during the training session. Finally, the designer tests the subject to determine if he/she exhibits the entry behaviors required to perform the study.
2. Information Presentation. First, the order the information is to be presented to the subject is decided. It is understandable that the subordinate skills are taught first

and then followed by the objectives. Next, the designer decides in what quantity the information will be presented at a time, and if the subject can interact with the designer during the presentation. Finally, the concepts and examples to be presented to the subject are decided upon.

3. Student Participation. At this stage of the instruction presentation, the subject practices what has been presented. Dick and Carey (1990) explain that feedback is essential at this stage. If the subject performs adequately, or inadequately, this needs to be communicated.

4. Testing. This section refers to the criterion-referenced tests previously explained.

5. Follow-Through Activities. After the subject completes the instructional training, some form of feedback should be available. Dick and Carey (1990) recommend providing correction according to the performance on the tests, as well as suggestions on how to further master the material.

Develop and select instructional materials. The purpose of this section is to establish the type of instructional materials and media that will comprise the presentation of instruction. Dick and Carey (1990) provide a set of step-by-step instructions that lead to the development of an instruction package.

The choice of media to present the material plays an important role in the communication of information. If the wrong media is chosen, it is possible that a subject will misinterpret, or completely be at a lack of understanding of, the

instructions. Reiser and Gagne (1983) have developed an algorithm for the proper selection of media; this flowchart is reproduced in Figure 6.

Design and conduct a formative evaluation. The purpose of a formative evaluation in the design of instruction material is to provide an iterative evaluation, and basis for revision. Dick and Carey (1990) explain the three stages to this evaluative procedure:

1. One-to-One Evaluation. The purpose of this phase is to correct the blatant errors and mistakes in the original instruction set through use and evaluation by representative subjects; this evaluation is an interactive process between the subject and the designer. At least three subjects are used for this phase of evaluation.
2. Small-Group Evaluation. A two-fold purpose exists for this phase of evaluation. The first is an evaluation of the results of the changes derived from the one-to-one evaluation. The second is to determine if a subject can use the instructional materials without interaction with the designer. Ideally, 8 to 20 representative subjects should be used for this phase of the evaluation.
3. Field Trial. This final phase of the formative analysis involves running the study as if it were for real; it can be considered the final dress rehearsal. It is intended that the field trial be implemented with a large group of subjects in the site of the actual experiment. Subject availability is the

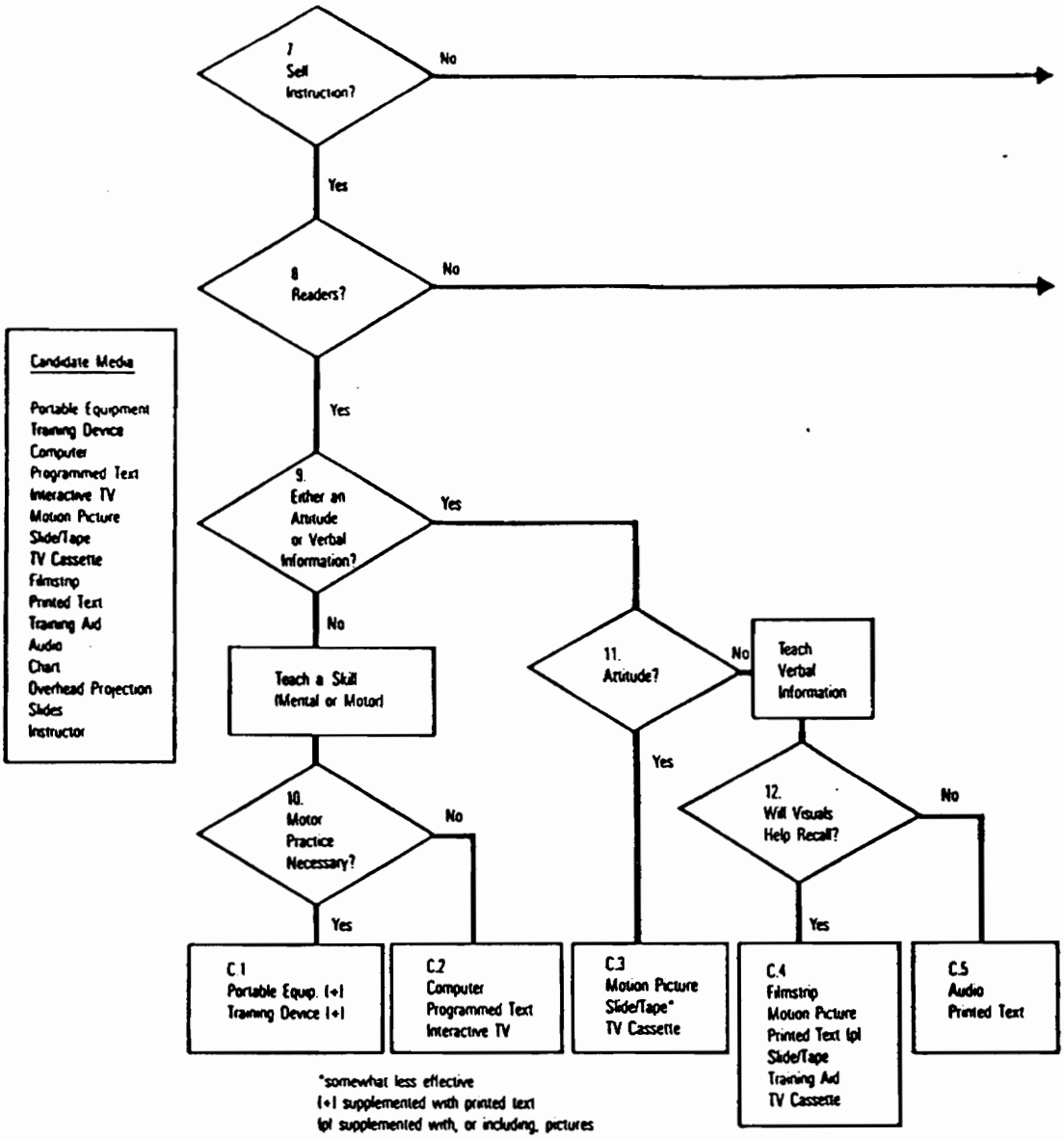

Figure 6. *Algorithm for the selection of instructional media (From Reiser and Gagne. 1983)*

largest obstacle for this phase of the instructional development.

Revise instructional materials. This iterative stage allows the designer to improve on the original design of the instructions. Dick and Carey (1990) explain that the major source of design change emanates from the three phases of the formative analysis. As was seen in Figure 6, revisions can take place at almost every stage of the instructional development; it is this property that truly makes Dick and Carey's (1990) procedure a systems approach.

Design and conduct a summative analysis. The final stage of the instructional development is the formative evaluation. Dick and Carey (1990) explain that the purpose of this stage is to thoroughly evaluate the proficiency of the instructional set with the intention of implementing or eliminating it. The two phases of the summative analysis are an expert evaluation, and a field trial. The expert evaluation provides an assessment based on the experience of the evaluator. Usually, an expert's approval will gain the respect needed by peers to implement the instructional materials. The field trial, on the other hand, provides empirical evidence that substantiates the effectiveness of an instructional tool. This type of evaluation is what is performed in human factors field research, or "proving", studies.

EXPERIMENTAL MATERIALS AND EQUIPMENT

The following provides a brief description of the apparatus used in this investigation. All equipment model numbers appear in Appendix F.

Screening Materials

Several screening tests were developed to classify subjects into experimental groups and to qualify them to participate. All screening materials appear in Appendix A. The first test was a general questionnaire that was used to classify a subject as either Novice or Hearing Conservationist (the two experimental subject groups). The qualifications for each subject group are discussed later. Individuals who displayed only partial qualification for either of these two groups were dismissed.

The second screening test examined basic mathematical and graph-reading aptitude. Since the NRR and HML methods individually require at least one of these skills, all subjects were presented with simple mathematical problems resembling those that would be asked during the experiment. It was assumed that all subjects could perform the simple math problems, but some careless errors were expected. Since it was considered likely that those making careless errors during the screening were more likely to make careless errors during testing (and such errors would likely contaminate the true differences in instructional technique effectiveness), any subject making any kind of error was excused from participating. In light of this requirement, subjects were told to check their work in detail before handing the problems back to the experimenter. Of the 52 subjects screened for this experiment, only three were excused based

on mathematical error. 11 were excused based on experience (either too much, or too little).

The last screening test, presented to Novice subjects only, served as both a check for pitch discrimination and a cursory hearing threshold qualification. In the interest of time and to obviate equipment transport to remote sites, only novice subjects participated in the spectral discrimination segment of the experiment. It was necessary to travel to employment sites to obtain experimental data from Hearing Conservationist subjects. To be granted final qualification to participate in the study, novice subjects had to demonstrate that they could accurately discriminate different pitches from one another, and possess adequate hearing to detect tones being presented by a Beltone audiometer through earphones. Tones were presented in pairs at 40 dBHL on the audiometer; this level is a rough approximation of the 40 phon curve on which different tones are judged equally loud. Subjects were asked to identify whether the first tone was of higher or lower pitch than the second tone. Tones used in the screening comparisons were 750, 1000, 2000, 4000, and 8000 Hz. If the subject could not correctly identify all of the pitch relationships, or could not hear any given tone, he/she was dismissed. However, no subjects were dismissed due to detection problems or an inability to discriminate the pitches.

Instructional Tools

Three instructional tools were developed for each of the NRR and HML methods. In order to be valid for use in a parametric experiment, the information content presented by each tool had to be almost identical. Therefore, only the instructional media (and the way each media interacted with its learner) in which

the information was presented could be different. The outline instructions were developed first, then the informational content was adapted to nomogram cards, and multimedia formats. All instructional tools used appear in Appendix B.

The basis of the information for the HML method was the outline instructions published by Peltor, *"How to choose hearing protection using the HML method"*; this also served as the outline instructions for the HML method (Peltor, 1993). It is worth noting that these instructions make provision for the case where C-weighted sound levels are not available. The nomogram card for the HML method produced by Peltor was also utilized with some modification. Although the nomogram is very complete on how to obtain the PNR value, there is no mention of how to calculate the protected noise level; therefore, this step was added. Lastly, the hypermedia package designed for the HML method was designed on Hypercard software for the Macintosh. The package used graphics, sound, text, and interactive tables to convey the HML method.

The basis of the information for the NRR method was the OSHA regulations (OSHA, 1983). Following these regulations, and using the Peltor instructions, nomogram, and hypermedia package as models, instructional tools for the NRR method were created; a separate set was made for cases when the C-weighted noise level was not available.

A pre-test of these instructional tools was used to determine the minimum amount of information required to convey the effective use of each method. Subjects representing both experimental subject groups were asked to follow the instructions for each method without assistance from the experimenter. Subjects indicated where confusion took place and what was required to clarify the method. If the suggestion could be incorporated into the method or tool without

providing more information than the other method or tools, it was added. When all pretest subjects were satisfied with the content of the instructions, the instructional tools were edited into final form.

Experimental Test Problems

A total of eight experimental test problems were developed for the study. These problems appear in Appendix C. Four problems were developed for the NRR method, and four for the HML method. In each case, two dealt with a situation where the A- and C-weighted noise levels were given, and two dealt with cases where only the A-weighted noise level was given. All numerical values for each of the problems were chosen randomly.

Additionally, four practice problems were developed to be used in tandem with the instructional tools. All numerical values for these problems were also selected at random.

Likert Scales

A series of questions on which subjects were to rate their feelings towards the evaluation, potency, activity, and understandability of the instructional tool used were developed. These scales used a nine-point continuum on which the subjects were to mark their ratings. Additionally, a final question asked that the subject respond "Yes" or "No" as to if the instructional tool was acceptable. These scales appear in Appendix D.

Sound Samples

A total of twelve sound samples were used for the spectral discrimination segment of the experiment, six of a high-medium (HM) noise class, and six of a medium-low (ML) noise class. The noise class is distinguished by its difference in C- and A-weightings. A HM noise has a difference less than or equal to 2 dB, and a ML noise has a difference greater than 2 dB. For each noise class, four sounds consisted of industrial noises recorded on cassette tape, and two were equalizer-modified pink noises. To make the industrial noise tapes, actual recordings of industrial noises were introduced into an octave band equalizer, adjusted to obtain the spectra needed, and re-recorded onto cassette tape. The noises and their C-weighted sound pressure level (L_C) minus A-weighted sound pressure level (L_A) were as follows:

HM Noise	$L_C - L_A$ (in dB)	ML Noise	$L_C - L_A$ (in dB)
Industrial 1 (I1)	-2	Industrial 8 (I8)	3
Pink 1 (P1)	-1	Pink 3 (P3)	5
Industrial 6 (I6)	-0.5	Industrial 3 (I3)	6
Industrial 7 (I7)	0.5	Industrial 5 (I5)	7
Pink 2 (P2)	1	Pink 4 (P4)	8
Industrial 4 (I4)	2	Industrial 2 (I2)	10

The graphical representations of each of these spectra are in Appendix G.

Facilities

While Hearing Conservationist subjects were permitted to perform the experiment in their places of work, Novice subjects were required to attend the experimental session in the Auditory Systems Laboratory Annex in order to complete the sound discrimination segment of the experiment. Figure 7 depicts the Annex and the arrangement of equipment in the Experimenter's and Subject's

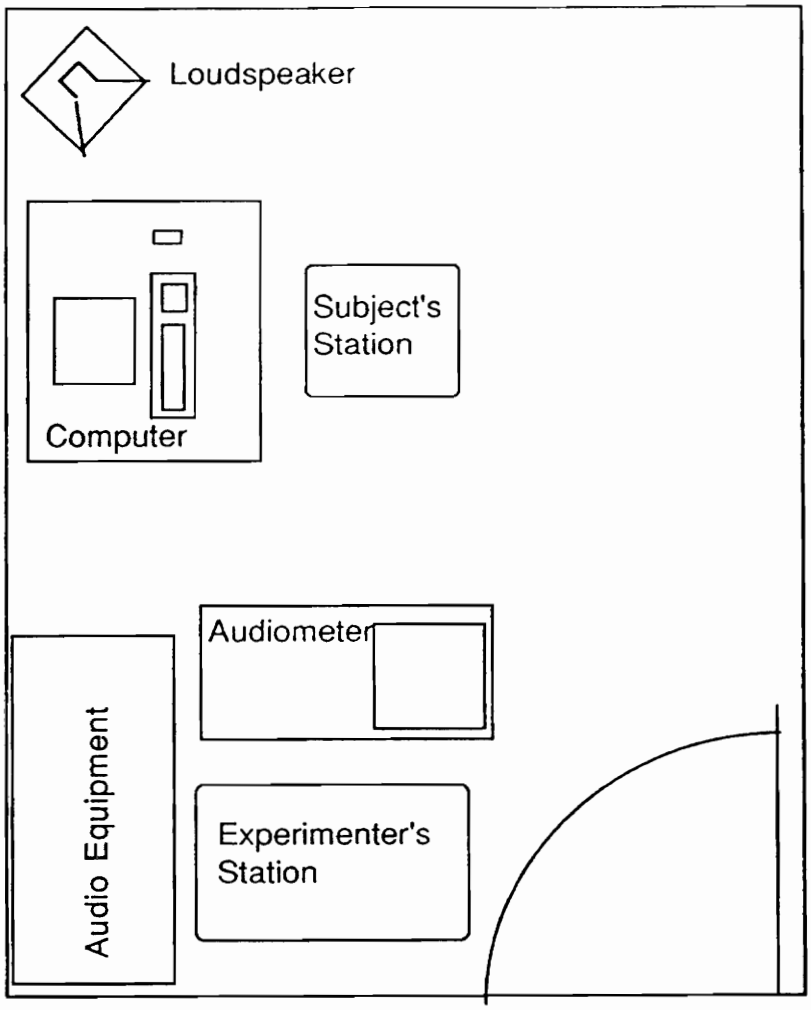

Figure 7. *Auditory Systems Laboratory Annex showing Experimenter's and Subject's stations.*

stations. The Subject station was comprised of a writing desk, a computer with mouse and keyboard, and a speaker positioned four feet from the subject's head. The Experimenter's station consisted of the audio equipment for producing the sound samples (amplifier, pre-amplifier, tapedeck, pink noise generator, two equalizers, and a selector-switch box), and an audiometer. Again, all equipment manufacturers and model numbers appear in Appendix F.

EXPERIMENTAL SUBJECTS

The following section provides a more detailed description of the subjects used in the study.

Novice

Novice subjects were those who claimed no knowledge of the NRR, and who had not covered it in any classes at Virginia Tech or at another university or shortcourse. A total of eighteen Novice subjects were used. All subjects in this category were either students of Virginia Tech or Radford University, and/or members of the Southwest Virginia community. All subjects in this category answered all mathematical screening problems correctly, and scored perfectly on the pitch discrimination screening.

Hearing Conservationist

Hearing Conservationists were subjects who claimed knowledge of the NRR and its proper use, and who had worked in the field of hearing conservation, and/or completed at least one year of education (or achieved CAOHC certification, the training which includes an emphasis on hearing conservation and protection) in preparation for a profession closely related to hearing conservation. A total of eighteen Hearing Conservationist subjects were used. All subjects in this category were recruited from either southwestern Virginia industries, the Office of Safety Programs at Virginia Tech, industrial audiology and noise consultants in southwestern Virginia, or the Department of Audiology at Radford University in Radford, Virginia. Additionally, all subjects in this category answered all mathematical screening problems correctly.

A review of the additional information questionnaires given to Hearing Conservationist subjects revealed a variety of backgrounds. Professions ranged from student (only two students were used: one in her final semester of a master's degree in audiology, and one recent master's graduate in audiology now working in industry), to industrial hygienists, to industrial nurses. Eight of the eighteen subjects were either CAOHC-certified or CAOHC course instructors. All subjects had been responsible for some form of hearing conservation function, such as the recommendation of hearing protectors, and/or the measurement of noise in industrial areas.

EXPERIMENTAL DESIGN

There were a total of four main parts to the experimental design: a baseline of knowledge determination, two complete factorial parametric designs, and a nonparametric design.

Baseline of Knowledge Determination

Hearing Conservationist subjects received a test which evaluated their basic understanding of the application of the NRR. Subjects were given two computational problems regarding the use of the NRR: one with a C-weighting provided, and one with only an A-weighting. The subjects were asked to calculate the protected noise level of a worker for both of these scenarios. For this portion of the study, no instructions or assistance were given to the subject; however, the subject was urged to perform the calculations as quickly and accurately as possible.

Dependent measure. The subjects' scratch papers for calculations were used to determine where and how the subject made an error, if any, in calculation. The dependent measures for the baseline task were problem completion time in seconds and verification of a correct answer.

Instruction Methodology Factorial Design

This segment of the experiment constituted the primary inquiry and was presented according to the three-variable, mixed-factors design illustrated in Figure 8.

Independent variables. The three independent factors were subject experience (defined earlier), instruction, and rating method.

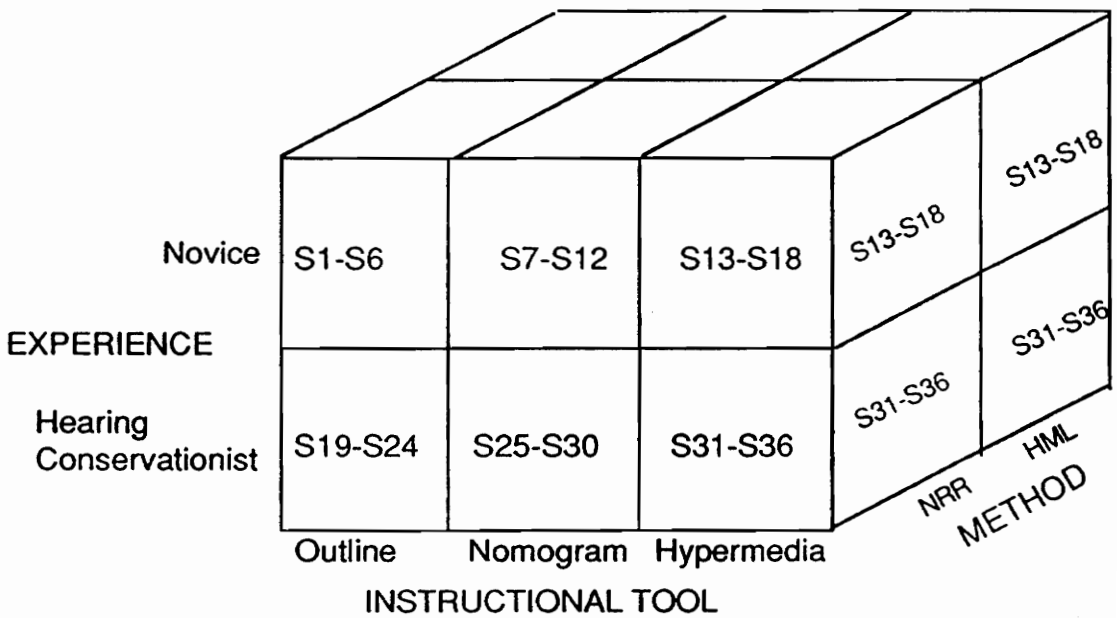

Figure 8. *Instruction Methodology factorial design.*

Instruction, a between-subjects variable with three levels, was the form of the instructional tool a subject received. Three forms of instructional tools existed: 1) a simple outline; 2) a tabular nomogram; and 3) a hypermedia package. All instructional tools appear in Appendix B.

Rating Method, the only within-subject variable, had two levels comprised of the NRR and HML methods. Each subject utilized a given instructional tool to calculate the protected noise level for different hypothetical situations using each of the two rating methods. It should be noted, however, that questions using only A-weighted levels use NIOSH method number 3 for the NRR method, and the HML-Quicky method for the HML method. These are special-case applications of the primary methods. The amount of information presented for each method was determined by a pilot study to be the minimum necessary to competently perform each method.

Dependent measures. Two dependent measures were of specific interest: percentage of errors and calculation speed. The percentage of the total number of errors (omission and commission errors) a subject could possibly make during the calculation of the protected noise level following a specified set of instructions was recorded. If the subject performed flawlessly, a zero (0) was recorded. However, if a subject did not know how to begin and conceded the task, an one (1) was recorded. Percentages were used since the total possible number of errors for each instructional tool was different; this allowed for a fair comparison. A list of possible errors for each of the four problems appears in Table 11.

The second dependent measure was calculation speed (in seconds). The subject's time to completion of a calculation was recorded (it did not matter if the

TABLE 11

Possible Errors Associated with the Four Test Problems for Each of the Three Instructional Tools.

C-weighted noise level and NRR provided

Nomogram	Outline	Hypermedia
1. Select incorrect table	1. Subtract 7 from NRR	1. Subtract 7 from NRR
2. Do not locate answer	2. Do not subtract NRR from L_C	2. Do not subtract NRR from L_C

A-weighted noise level and NRR provided

Nomogram	Outline	Hypermedia
1. Select incorrect table	1. Do not subtract 7 from NRR	1. Do not subtract 7 from NRR
2. Do not locate answer	2. Do not subtract NRR from L_A	2. Do not subtract NRR from L_A

A- and C-weighted noise levels and HML values provided

Nomogram	Outline	Hypermedia
1. Do not subtract L_A from L_C	1. Do not subtract L_A from L_C	1. Do not subtract L_A from L_C
2. Do not determine PNR	2. Do not determine PNR	2. Do not determine PNR
3. Do not use L_A	3. Do not use L_A	3. Do not use L_A
4. Do not subtract PNR from L_A	4. Do not subtract PNR from L_A	4. Do not subtract PNR from L_A

A-weighted noise level and HML values provided

Nomogram	Outline	Hypermedia
1. Do not subtract L_A from L_8. This is the PNR value	1. Do not subtract L_A from L_8. This is the PNR value	1. Do not subtract L_A from L_8. This is the PNR value
2. Do not compare PNR value to H, M, and L values	2. Do not compare PNR value to H, M, and L values	2. Do not compare PNR value to H, M, and L values
3. Do not recognize 24 > 22	3. Do not recognize 24 > 22	3. Do not recognize 24 > 22
4. Conclude adequate	4. Conclude adequate	4. Conclude adequate

answer was correct or not). Recording time started as soon as the subject was presented with the hypothetical situation to analyze; recording time ended when the subject laid down his/her pencil. If the subject conceded, the value of 3600 was recorded. This value represents an hour, in seconds, of calculation time, which was the most allowed.

Spectra Discrimination Factorial Design

This segment of the proposed experiment was the one-factor within-subjects factorial design illustrated in Figure 9.

Independent variable. The independent variable for this segment of the experiment was noise spectra. Each of the twelve spectra, as previously described, was presented to the eighteen Novice subjects for a five-second duration five times each in random order. The subject then subjectively evaluated each noise and classified it as HM or ML (high or low frequency-dominated).

Dependent variable. The dependent variable for this segment of the experiment was percent-correct identification. If a subject correctly identified a spectrum as either HM or ML, it was recorded as such. If the subject incorrectly identified the spectrum, an error was recorded.

Likert Rating Scales

After subjects finished the instructional segment of the experiment, they rated their overall satisfaction with the particular instructional tool on which they used. Subjects rated their satisfaction on the 9-point Likert scale which appears in Appendix D.

L_C - L_A Values (Corresponding to 12 Noise Spectra)

-2	-1	-0.5	0.5	1	2	3	5	6	7	8	10
S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}	S_1 - S_{18}

Figure 9. *Spectra discrimination factorial design .*

EXPERIMENTAL PROCEDURE

The following sections provide outlines of the daily preparation, and experimental session undergone by Novice and Hearing Conservationist subjects.

Daily Preparation

Before the subjects arrived, certain preparations were made. First, the experimenter gathered all forms that the subject needed, including an informed consent form. Also, after randomly selecting the instructional tool the subject was to use, random selection was employed to establish the order of methods, NRR and HML, with which the subject was presented. Additionally, all audio equipment was turned on and allowed to warm up for at least 20 minutes before the arrival of the first scheduled subject of each day. Sound levels were checked daily using a Rion octave band analyzer and microphone (see Appendix F) to ensure consistency from day to day; levels were maintained between 75 and 80 dBA at the subject's head-center position.

Experimental Session - Novice Subjects

1. Perform personal background screening test. The subject completed, by handwriting, the screening questionnaire regarding professional and educational background.
2. Perform simple mathematical screening test. The subject was given the mathematical screening problems to solve. The subject was informed to check the answers thoroughly before handing the form back to the experimenter. It was stressed to the subject that an error made during this

segment of the screening would disqualify him/her from participating any further.

3. Perform pitch discrimination screening test. Using the Beltone audiometer and earphone (see Appendix F), the following six tones were presented to the subject in the paired order illustrated on the screening form in Appendix A: 250, 750, 1000, 2000, 4000 and 8000 Hz. The attenuator dial was constantly set to 40 dBHL, and the output equalized to closely correspond to the 40 phon (equal loudness) curve. Given a pair of tones, the subject was to decide if the first was of a higher or lower pitch than the second. If a subject could not correctly identify a pitch relationship, or could not hear any given tone at the 40 dBHL level, the subject was disqualified from the experiment.

4. Review instructions and sample problems of either the NRR or HML methods using one of the three instructional tools. No assistance from the experimenter is provided. The instructional tool and order of method (NRR or HML) to be used were predetermined before the subject arrived by random assignment. The subject had a maximum of one hour to review the instructions and sample problems (and their solutions).

5. Be tested on this method with two problems with A- and C-weightings given, and two problems with only A-weightings given. A total of eight problems were actually given, however, four were used to control for the internal threat to validity known as *testing* (Goldstein, 1986). The sequence of testing was the following: C-weighted control, C-weighted test, A-weighted control, A-weighted test. An hour of calculation time was allowed for each question; the subject was told to work as quickly and as

accurately as possible. The amount of time that elapsed for each question was recorded. Recording time began when the subject was given the problem, and ended when the subject handed in the completed question. The subject was also instructed that if he/she did not have any idea about how to begin solving the problem, the word "concede" was to be written on the page. All experimental test problems appear in Appendix C.

6. Repeat steps 4 and 5 for the other method while using the same instructional tool. If the subject started with the NRR method, the HML method was now used, and vice-versa.

7. Rate satisfaction with instructional tool using Likert scales. After testing was complete, subjects were given ten 9-point Likert scales on which to rate their satisfaction with the instructional tools for the HML and NRR methods. The subjects were told to mark their rating anywhere along the scale. Lastly, a yes/no question asked for the subject's overall satisfaction with the instructional tool. These scales appear in Appendix D.

8. Perform spectral discrimination test. Subjects were asked to sit quietly and judge whether a given noise was of a HM or ML noise class. The twelve sounds were presented to the subject five times each for a five second duration in random order. Pink noises were generated by initially producing a pink noise through a noise generator, and modified to the proper L_C - L_A value through an octave-band equalizer. Each pink noise had its own equalizer which could be selected for play via a switchbox. Industrial noises were recorded on cassette tape and played for the subject via a tape deck.

Experimental Session - Hearing Conservationist Subjects

1. Perform personal background screening test. The subject was to complete the screening questionnaire regarding professional and educational background.
2. Perform simple mathematical screening test. The subject was given the mathematical screening problems to solve. The subject was told to check the answers thoroughly before handing the form back to the experimenter. It was stressed to the subject that an error made during this segment of the screening would disqualify him/her from participating any further.
3. Fill out additional background information questionnaire. Additional questions regarding the subject's professional duties, certifications and professional organization affiliations were given.
4. Determine baseline of knowledge of NRR. Two problems were given to the subject to solve without reference materials or reference instructions. One problem asked the subject to find a protected hearing level given the C-weighted sound level and NRR. The second problem asked the subject to find a protected hearing level given the A-weighed noise level and the NRR. Calculation time was recorded. The subject was instructed to write the word "concede" if he/she had no idea how to begin the problem.
5. Review instructions and sample problems of either the NRR or HML methods using one of the three instructional tools. No assistance from the experimenter is provided. The instructional tool and order of method (NRR or HML) to be used were predetermined by random assignment before the subject arrived . The subject had a maximum of one hour to review the instructions and sample problems (and their solutions).

6. Be tested on this method with two problems with A- and C-weightings given, and two problems with only A-weightings given. A total of eight problems were actually given, however, four were used to control for the internal threat to validity known as *testing* (Goldstein, 1986). The sequence of testing was the following: C-weighted control, C-weighted test, A-weighted control, A-weighted test. An hour of calculation time was allowed for each question; the subject was told to work as quickly and as accurately as possible. The amount of time elapsed for each question was recorded. Recording time began when the subject was given the problem, and ended when the subject handing in the completed question. The subject was also instructed that if he/she did not have any idea about how to begin solving the problem, the word "concede" was to be written on the page. All experimental test problems appear in Appendix C.

7. Repeat steps 5 and 6 for the other method while using the same instructional tool. If the subject started with the NRR method, the HML method was now used, and vice-versa.

8. Rate satisfaction with instructional tool using Likert scales. After testing was complete, subjects were given ten 9-point Likert scales on which to rate their satisfaction with the tools for the HML and NRR methods. The subjects were told to mark their rating anywhere along the scale. Lastly, a yes/no question asked for the subject's overall satisfaction with the instructional tool. These scales appear in Appendix D.

RESULTS AND ANALYSIS

The following section provides the data sets and analyses for all four segments of the experiment.

Baseline of Knowledge

The two computational problems regarding the proper use of the NRR in the calculation of a protected noise level that were given to the Hearing Conservationist subjects (numbers 19 - 36) appear in Appendix E. Problem 1 dealt with a situation where the C-weighted noise level and the NRR were provided; a simple subtraction would yield the answer. Problem 2 dealt with a situation where the A-weighted noise level and the NRR were provided; this requires that 7 must first be subtracted from the NRR before the result is then subtracted from the A-weighted noise level. The resulting data for this segment appear in Table 12.

From these data, the dependent measures of calculation time and percent-correct can be summarized. For Problem 1, only 50 % of the subjects calculated a correct answer; the average calculation time was 46.7 seconds. For Problem 2, only 16.7 % of the subjects calculated a correct answer; the average calculation time was 28.8 seconds. These results indicated that the hearing conservationists had a very poor knowledge of the use of the NRR for determining protected exposure levels, especially when only the A-weighted sound level was supplied.

TABLE 12

Calculation Time and Verification of a Correct Answer for the Baseline of Knowledge Test Given to Hearing Conservationist Subjects.

Subject	*Question 1	**Error Type	Time (sec)	*Question 2	**Error Type	Time (sec)
19	0	A	44	1	-	25
20	0	A	52	0	A	16
21	0	A	55	0	B	34
22	1	-	81	0	B	35
23	1	-	30	0	B	51
24	0	A	33	0	A	12
25	1	-	36	1	-	24
26	1	-	34	0	B	23
27	1	-	60	0	B	58
28	0	C	64	0	B	37
29	0	A	48	0	B,D	28
30	1	-	39	0	A	38
31	0	A	127	0	A	15
32	1	-	17	1	-	13
33	1	-	23	0	B	17
34	0	A	26	0	A	36
35	1	-	26	0	B	25
36	0	A	46	0	B	32

*Questions
1 = Correct Answer
0 = Incorrect Answer

**Error Types
A = " I don't know"
B = Did not subtract 7 from NRR given A-weighted level
C = Subtracted 7 from C-weighted level
D = Simple math error

For those who calculated a wrong answer, in Problem 1, 88.9% did not know what to do; 11.1% subtracted 7 from the C-weighted sound level. In Problem 2, 62.5% did not subtract 7 from the NRR value; 31.3% did not know what to do; and 6.2% made a simple math error.

Instructional Methodology Factorial Design

This segment of the analysis evaluated the data from the instructional segment of the experiment. Four of the eight problems were analyzed using analysis of variance (ANOVA). The other four problems were used to control any threats to validity that may have been created by the introduction of a timed test. That is, these questions, referred to as control questions in the experimental procedure, were used to familiarize the subject with the pressure of a timed test; the results were not analyzed.

C-weighted level provided, calculation time. The first analysis dealt with the calculation time, in seconds, for problems with the C-weighted noise level and the NRR, or HML values, provided. The raw data for this analysis, and the ANOVA summary table are in Tables 13 and 14, respectively.

As can be seen, the only significant factor ($p \leq 0.05$) was Method. Since only two levels of Method exist, it can be concluded that the mean calculation time (in seconds) for the HML method (693.5) is significantly longer than for the NRR method (22.94).

An F-Max test performed on this data revealed heterogeneity of variance. This is attributed to the concession value of 3600 seconds. This value was established as an apriority before data collection began. After all data was collected, however, it is seen that a better value to use would have been 300

TABLE 13

Raw Data for Test Problem with C-Weighted Sound Level Provided; Dependent Measure is Calculation Time in Seconds. Last Row in Each Cell: Mean, (Standard Deviation).*

EIM111	EIM112	EIM211	EIM212
18	80	21	51
42	133	70	3600
19	197	18	3600
69	77	14	3600
19	62	14	277
47	64	35	62
35.67, (20.72)	102.17, (53.18)	28.67, (21.69)	1865.0, (1902.31)
EIM121	EIM122	EIM221	EIM222
18	113	12	134
23	42	22	3600
20	145	17	47
25	70	14	188
33	99	38	193
19	73	13	113
23.0, (5.55)	90.33, (36.41)	19.33, (9.83)	712.5, (1415.6)
EIM131	EIM132	EIM231	EIM232
10	94	9	55
15	116	19	37
18	3600	12	3600
13	97	22	123
17	141	10	229
25	100	16	154
16.33, (5.13)	691.33, (1425.06)	14.67, (5.20)	699.67, (1422.57)

Grand Means (Standard Deviation)

Experience		Instruction			Method	
Novice	H.C.	Nomogram	Outline	Hypermedia	NRR	HML
159.8 (591.6)	556.6 (1241.4)	507.9 (1195.4)	211.3 (724.0)	355.5 (1001.0)	22.9 (14.5)	693.5 (1319.4)

* The code used in the above table corresponds to the cells of the factorial design. EIM stands for Experience, Instruction, and Method, respectively. For Experience, a 1 indicates Novice, and a 2 indicates Hearing Conservationist. For Instruction, a 1 indicates Nomogram, a 2 indicates Outline, and a 3 indicates Hypermedia. For Method, a 1 indicates NRR, and a 2 indicates HML.

TABLE 14

ANOVA Summary Table for Test Problem with C-Weighted Sound Level Provided; Dependent Measure is Calculation Time in Seconds.

Source	df	SS	MS	F	p-value
BETWEEN					
Experience, E	1	2834580.5	2834580.5	3.50	0.0710
Instruction, I	2	1055806.86	527903.431	0.65	0.5279
E x I	2	2363725.58	1181862.79	1.46	0.2480
S/EI	30	24264344.5	808811.483		
WITHIN					
Method, M	1	8093605.56	8093605.56	10.01 *	0.0036
M x E	1	2893616.06	2893616.06	3.58	0.0683
M x I	2	979496.861	489748.431	0.61	0.5523
M x E x I	2	2392500.03	1196250.01	1.48	0.2440
M x S/EI	30	24264951.5	808831.717		
TOTAL	71	69142627.4			

* Significant at $p \leq 0.05$

seconds. This value is still longer than the longest calculation time exhibited, and would have homogenized variance. However, it would be unethical to change the concession value after data collection was complete. Additionally, the significant values would not have changed if this value was used.

C-weighted level provided, percentage of errors. The second analysis dealt with the percentage of errors made for problems with the C-weighted noise level and the NRR, or HML values, provided. The raw data and ANOVA summary table for this analysis are in Tables 15 and 16, respectively.

As can be seen, the only factors of significance were Experience and Method. Again, only two levels exist for each of these factors. Therefore, the following conclusions can be made: 1) The mean number of errors (decimal equivalent of percentage) made by Hearing Conservationist subjects (0.2569) was significantly larger than the number of errors made by Novice subjects (0.0764), and 2) The number of errors made by all subjects using the HML method (0.2917) was significantly larger than the number of errors made using the NRR method (0.0417).

A-weighted level provided, calculation time. The third analysis dealt with the calculation time, in seconds, for problems with only the A-weighted noise level and the NRR, or HML values, provided. The raw data and ANOVA summary table for this analysis are in Tables 17 and 18, respectively.

As can be seen, the significant factors were Experience, Method, and their interaction. Since only two levels exist for Experience and Method, the following conclusions can be made: 1) The mean calculation time of Hearing Conservationist subjects (646.61) was significantly larger than the mean

TABLE 15

Raw Data for Test Problem with C-Weighted Sound Level Provided; Dependent Measure is Decimal Equivalent of Percent Errors. Last Row in Each Cell: Mean, (Standard Deviation).

EIM111	EIM112	EIM211	EIM212
0	0	0	0.25
0	0	0	1
0	0.5	0	1
0	0	0	1
0	0	0	0
0	0	0	0
0,(0)	0.0833, (0.2041)	0,(0)	0.5417, (0.5103)
EIM121	**EIM122**	**EIM221**	**EIM222**
0	0.5	0	0.25
0	0	0	0.5
0	0	0	1
0	0	0	0
0	0	0	0
0	0	0	0
0,(0)	0.0833, (0.2041)	0,(0)	0.2917, (0.4005)
EIM131	**EIM132**	**EIM231**	**EIM232**
0	0	1	0.25
0	0.25	0.5	0.25
0	0.25	0	0.25
0	0.25	0	1
0	1	0	0.5
0	0	0	0.5
0,(0)	0.2917, (0.368)	0.25, (0.4183)	0.4583, (0.2923)

Grand Means (Standard Deviation)

Experience		Instruction			Method	
Novice	H.C.	Nomogram	Outline	Hypermedia	NRR	HML
0.07 (0.21)	0.26 (0.38)	0.16 (0.34)	0.09 (0.24)	0.25 (0.34)	0.04 (0.18)	0.29 (0.37)

* The code used in the above table corresponds to the cells of the factorial design. EIM stands for Experience, Instruction, and Method, respectively. For Experience, a 1 indicates Novice, and a 2 indicates Hearing Conservationist. For Instruction, a 1 indicates Nomogram, a 2 indicates Outline, and a 3 indicates Hypermedia. For Method, a 1 indicates NRR, and a 2 indicates HML.

TABLE 16

ANOVA Summary Table for Test Problem with C-Weighted Sound Level Provided; Dependent Measure is Decimal Equivalent of Percent Errors.

Source	df	SS	MS	F	p-value
BETWEEN					
Experience, E	1	0.587	0.587	9.09 *	0.0052
Instruction, I	2	0.297	0.1485	2.30	0.1177
E x I	2	0.054	0.027	0.42	0.6620
S/EI	30	1.937	0.0646		
WITHIN					
Method, M	1	1.125	1.125	12.0 *	0.0016
M x E	1	0.170	0.170	1.81	0.1882
M x I	2	0.047	0.0235	0.25	0.7799
M x E x I	2	0.220	0.110	1.17	0.3232
M x S/EI	30	2.813	0.0938		
TOTAL	71	7.250			

* Significant at $p \leq 0.05$

TABLE 17

Raw Data for Test Problem with A-Weighted Sound Level Provided; Dependent Measure is Calculation Time in Seconds. Last Row in Each Cell: Mean, (Standard Deviation).

EIM111	EIM112	EIM211	EIM212
31	105	20	87
46	236	56	3600
26	126	19	3600
33	182	17	3600
22	42	16	56
50	125	23	175
34.5, (10.9)	136.0, (66.53)	25.17, (15.3)	1853.0, (1914.14)
EIM121	EIM122	EIM221	EIM222
18	51	11	24
23	63	18	3600
27	82	14	63
15	69	13	75
33	43	22	276
25	54	37	130
23.5, (6.44)	60.33, (14.0)	19.17, (9.58)	694.67, (1426.03)
EIM131	EIM132	EIM231	EIM232
24	73	8	41
8	35	10	19
18	23	24	3600
13	26	25	196
16	62	13	171
31	68	19	3600
18.33, (8.17)	47.83, (22.36)	16.5, (7.23)	1271.17, (1805.24)

Grand Means (Standard Deviation)

Experience		Instruction			Method	
Novice	H.C.	Nomogram	Outline	Hypermedia	NRR	HML
53.44 (48.71)	646.61 (1340.92)	512.21 (1193.65)	199.42 (726.45)	338.46 (1005.66)	22.89 (11.17)	677.17 (1327.06

* The code used in the above table corresponds to the cells of the factorial design. EIM stands for Experience, Instruction, and Method, respectively. For Experience, a 1 indicates Novice, and a 2 indicates Hearing Conservationist. For Instruction, a 1 indicates Nomogram, a 2 indicates Outline, and a 3 indicates Hypermedia. For Method, a 1 indicates NRR, and a 2 indicates HML.

TABLE 18

ANOVA Summary Table for Test Problem with A-Weighted Sound Level Provided; Dependent Measure is Calculation Time in Seconds.

Source	df	SS	MS	F	p-value
BETWEEN					
Experience, E	1	6333241	6333241	8.44 *	0.0068
Instruction, I	2	1178882	589441.1	0.79	0.4649
E x I	2	873537.3	436768.6	0.58	0.5648
S/EI	30	22500710	750023.7		
WITHIN					
Method, M	1	7705429	7705429	10.36 *	0.0031
M x E	1	6445247	6445247	8.67 *	0.0062
M x I	2	1111851	555925.4	0.75	0..4822
M x E x I	2	889349.4	444674.7	0.60	0.5564
M x S/EI	30	22310012	743667.1		
TOTAL	71	69348258			

* Significant at $p \leq 0.05$

calculation time of Novice subjects (53.44), and 2) The calculation time using the HML method (677.17) was significantly longer than the calculation time using the NRR method (22.89).

An additional F-Max test was performed on this data. The same results, explanations, and justifications exist for this situation as for the C-weighted situation.

The interaction of Experience and Method required a post-hoc Newman-Keuls test to evaluate differences any further. The results of this post-hoc analysis are in Table 19.

Using the code described in the table, the results are interpreted as showing that Hearing Conservationist subjects using the HML method took significantly longer to calculate their answers than Hearing Conservationist subjects using the NRR method, or Novice subjects using either method.

A-weighted level provided, percentage of errors. The fourth and final analysis dealt with the percentage of errors made for problems with only the A-weighted noise level and the NRR, or HML values, provided. The raw data and ANOVA summary table for this analysis are in Tables 20 and 21, respectively.

As can be seen, the factors of significance were Experience, Method, and their Interaction. Again for Experience and Method, only two levels exist for each of these factors; therefore, the following conclusions can be made: 1) The mean number of errors (decimal equivalent of percentage) made by Hearing Conservationist subjects (0.2083) was significantly larger than the number of errors made by Novice subjects (0.0486), and 2) The number of errors made using the HML method (0.2153) was significantly larger than the number of errors made using the NRR method (0.0694).

TABLE 19

Newman-Keuls Post-Hoc Analysis of Experience by Method Interaction (Significant Differences at $p \leq 0.05$ are in **Bold**); Dependent Measure is Calculation Time in Seconds.

*Interaction Totals (sec)	E2M1 365	E1M1 459	E1M2 1465	E2M2 22913	Rank	CD
		94	1100	**22548**	4	8111.406
			1006	**22454**	3	7372.088
				21448	2	6104.678

* The code used in the above table corresponds to the cells of the factorial design. EM stands for the Experience by Method interaction. For Experience, a 1 indicates Novice, and a 2 indicates Hearing Conservationist. For Method, a 1 indicates NRR, and a 2 indicates HML.

TABLE 20

Raw Data for Test Problem with A-Weighted Sound Level Provided; Dependent Measure is Decimal Equivalent of Percent Errors. Last Row in Each Cell: Mean, (Standard Deviation).

EIM111	EIM112	EIM211	EIM212
0	0.25	0	1
0	0.25	0	1
0	0	0.5	1
0	0	0	0
0	0	0	0
0	0	0	0
0, (0)	0.08, (0.1291)	0.0833, (0.2401)	0.5, (0.5477)
EIM121	EIM122	EIM221	EIM222
0	0	0	0.5
0	0	0	0.25
0	0	0.5	1
0	0	0	0
0	0	0	0
0	0	0	0
0, (0)	0. (0)	0.0833, (0.2401)	0.2917, (0.4005)
EIM131	EIM132	EIM231	EIM232
0	0.25	0	1
1	0	0	0.25
0	0	0.5	1
0	0	0	0
0	0	0	0
0	0	0	0
0.1667, (0.4082)	0.0417, (0.1021)	0.0833, (0.2401)	0.375, (0.4937)

Grand Means (Standard Deviation)

Experience		Instruction			Method	
Novice	H.C.	Nomogram	Outline	Hypermedia	NRR	HML
0.05 (0.18)	0.24 (0.38)	0.17 (0.34)	0.09 (0.24)	0.17 (0.34)	0.07 (0.21)	0.22 (0.37)

* The code used in the above table corresponds to the cells of the factorial design. EIM stands for Experience, Instruction, and Method, respectively. For Experience, a 1 indicates Novice, and a 2 indicates Hearing Conservationist. For Instruction, a 1 indicates Nomogram, a 2 indicates Outline, and a 3 indicates Hypermedia. For Method, a 1 indicates NRR, and a 2 indicates HML.

TABLE 21

ANOVA Summary Table for Test Problem with A-Weighted Sound Level Provided; Dependent Measure is Decimal Equivalent of Percent Errors.

Source	df	SS	MS	F	p-value
BETWEEN					
Experience, E	1	0.543	0.543	5.40 *	0.0271
Instruction, I	2	0.068	0.034	0.34	0.7157
E x I	2	0.085	0.0425	0.42	0.6590
S/EI	30	3.015	0.1005		
WITHIN					
Method, M	1	0.459	0.459	6.83 *	0.0139
M x E	1	0.542	0.542	8.06 *	0.0080
M x I	2	0.074	0.037	0.55	0.5825
M x E x I	2	0.064	0.032	0.48	0.6259
M x S/EI	30	2.017	0.0672		
TOTAL	71	6.868			

* Significant at $p \leq 0.05$

The interaction of Experience and Method required a post-hoc Newman-Keuls test to evaluate the location of differences among means. The results of this post-hoc analysis are in Table 22.

Using the same code as described earlier, this analysis shows that Hearing Conservationist subjects using the HML method made significantly more errors than those occurring in any other condition.

Spectral Discrimination

The percent-correct identification (by HM or ML noise class) of the twelve sound samples was recorded for each of the 18 Novice subjects. The raw data for this analysis appear in Table 23; a pictorial representation of the percent correct identification for each of the twelve sound samples appear in Figure 10.

An one-way ANOVA, with Spectra as the independent variable, was performed on the data to determine if any statistically significant differences existed between the percent-correct identification of the sound samples. The ANOVA summary table appears in Table 24. As can be seen, the Spectrum factor is significant. Therefore, a post-hoc Newman-Keuls test was performed to evaluate the differences among the twelve sound samples. The results of this post-hoc analysis are in Table 25.

Summarizing these results, the percent-correct identification (PCI) of I8 is significantly different from all other sound samples; the PCI of I6 is different from I2, P2, P1, I1, and P4; the PCI of I7, I3, P3, I5, and I4 is different from I2, P2, P1, I1, and P4; lastly, I2 and P2 is different from P1, I1, and P4. Stated in simpler terms, the percent-correct identification of almost every sound sample is significantly different from each other sample. Therefore, there is no trend in

TABLE 22

Newman-Keuls Post-Hoc Analysis of Experience by Method Interaction (Significant differences at $p \leq 0.05$ are in **bold**); Dependent Measure is Decimal Equivalent of Percent Error.

Interaction Totals (%)	E1M2 0.75	E1M1, E2M1 1.00	E2M2 7.00	Rank	CD
		0.25	**6.25**	3	2.217
			6.00	2	1.836

* The code used in the above table corresponds to the cells of the factorial design. EM stands for the Experience by Method interaction. For Experience, a 1 indicates Novice, and a 2 indicates Hearing Conservationist. For Method, a 1 indicates NRR, and a 2 indicates HML.

TABLE 23

Raw Data (in Percentage) for the Percent-Correct Identification of HM and ML Noise Class for the Twelve Sound Spectra. Each Cell Represents Percentage from Five Trials.

Subject	I1	P1	I6	I7	P2	I4	I8	P3	I3	I5	P4	I2
1	100	100	0	20	80	20	0	100	20	80	100	100
2	100	100	80	80	100	40	20	40	0	60	100	100
3	100	100	20	0	100	20	0	0	40	40	100	100
4	100	100	20	40	100	60	20	40	60	60	100	80
5	100	100	20	0	100	0	0	0	80	100	100	0
6	100	60	100	40	0	20	0	100	20	100	100	100
7	100	100	80	60	100	100	0	0	40	0	100	100
8	100	80	0	0	20	60	0	100	40	20	100	20
9	100	100	0	0	100	20	20	0	0	0	100	80
10	100	100	0	0	100	20	80	0	80	100	100	100
11	100	100	80	80	60	80	0	100	40	40	100	80
12	100	100	0	20	80	20	0	60	100	60	100	100
13	100	100	0	40	100	80	0	0	20	20	100	20
14	100	100	40	0	60	20	0	40	60	80	100	80
15	100	100	0	60	20	100	0	100	40	0	100	80
16	100	100	20	40	80	100	0	100	40	20	100	80
17	100	100	100	80	80	80	40	20	100	100	100	40
18	100	100	0	40	80	100	20	80	80	40	100	100
AVE	100	96.7	31.1	33.3	75.6	52.2	11.1	48.9	47.8	51.1	100	75.6

*HM Noise	$L_C - L_A$ (in dB)	ML Noise	$L_C - L_A$ (in dB)
Industrial 1 (I1)	-2	Industrial 8 (I8)	3
Pink 1 (P1)	-1	Pink 3 (P3)	5
Industrial 6 (I6)	-0.5	Industrial 3 (I3)	6
Industrial 7 (I7)	0.5	Industrial 5 (I5)	7
Pink 2 (P2)	1	Pink 4 (P4)	8
Industrial 4 (I4)	2	Industrial 2 (I2)	10

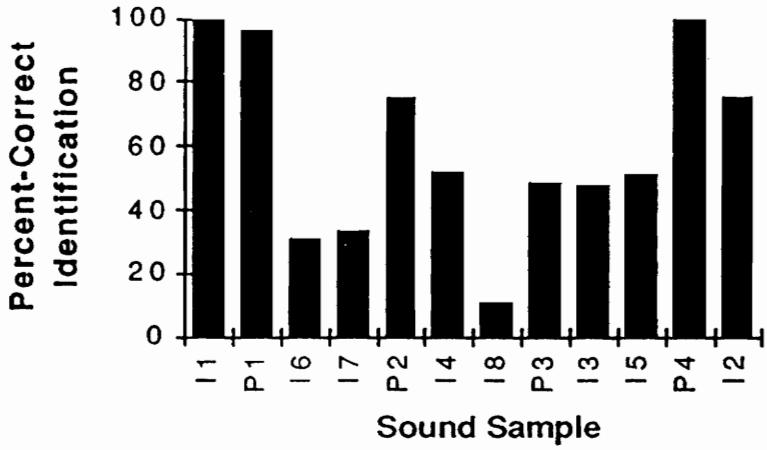

Figure 10. *Percent-correct identification of an HM or ML noise class for each of the twelve sound samples*

TABLE 24

ANOVA Summary Table for the Percent-Correct Identification of a HM or ML Noise Class for Each of the Twelve Sound Spectra.

Source	df	SS	MS	F	p-value
BETWEEN					
Subjects, S	17	18816.667			
WITHIN					
Spectra, A	11	168761.111	15341.919	18.11 *	< 0.0001
A x S	187	158405.556	847.089		
TOTAL	215	345983.333			

* Significant at $p \leq 0.05$

TABLE 25

Newman-Keuls Post-Hoc Analysis for Percent-Correct Identification of HM and ML Noise Class. (Significant Differences at $p \leq 0.05$ are in **Bold.**); Dependent Measure is Percent-Correct Identification.

Sample	I8	I6	I7	I3	P3	I5	I4	I2/P2	P1	I1/P4		
Total (%)	200	560	600	860	880	920	940	1360	1740	1800	Rank	CD
		360	**400**	**660**	**680**	**720**	**740**	**1160**	**1540**	**1600**	10	556
			40	300	320	360	380	**800**	**1180**	**1240**	9	542.1
				260	280	320	340	**760**	**1140**	**1200**	8	529.7
					20	60	80	**500**	**880**	**940**	7	514.9
						40	60	**480**	**860**	**820**	6	497.6
							20	**440**	**820**	**880**	5	476.6
								420	**800**	**860**	4	448.2
									380	**440**	3	408.7
										60	8	342

identifying any given sound as either an HM or ML. If a trend was present, correct identification of sound samples belonging to one noise class would be significantly different from those of the other class, but not from each other.

Likert Scales

A nonparametric Kruskal-Wallis One-Way ANOVA was performed on each of the ten questions of the post-test questionnaire. This test was used to determine if there were any significant differences between the ratings for each of the three instructional tools as given by each group of subjects (i.e., Novice and Hearing Conservationist data were kept and analyzed separately). However, no significant differences were found on any of the ten questions performed. Therefore, it can be concluded that both the Novice and Hearing Conservationist subjects felt there were no differences among the three instructional tools.

In regard to the final question asking for a yes/no answer for overall satisfaction, the following resulted. For novice subjects, 100% of the subjects were satisfied with all three instructional tools for the NRR method; 50% were satisfied with the hypermedia tool for the HML method, and only 17% were satisfied with both the nomograms and outline instructions for the HML method. For Hearing Conservationist subjects, again 100% were satisfied with all three tools for the NRR method; 33% were satisfied with the outline instructions, 17% with the hypermedia, and none were satisfied with the nomogram for the HML method.

CONCLUSIONS

The findings of the research described herein provide important insight into several issues concerning hearing conservation. It is clearly evident that hearing conservationists need more instruction in the use of the NRR for estimating protection levels under hearing protectors, and that the HML method can be expected to require longer time to compute, and generally have more computational errors than the NRR method. The conclusions will be discussed in terms of the three major segments of the study: 1) baseline of knowledge determination, 2) instructional methodology comparison, and 3) spectral discrimination assessment. Additionally, a "For Future Study" section provides an overview of areas that can be further investigated as a result of this thesis study.

Baseline of Knowledge Determination

The purpose of this segment of the experiment was to analyze and evaluate the ability of professionals currently in the field of hearing conservation to utilize the NRR method, a method that has appeared in OSHA regulations for more than a decade, to calculate a protected hearing level. With no prior instructions, only 50% of the Hearing Conservationist subjects were able to calculate a correct answer given the C-weighted noise level and the NRR; only slightly less than 17% were able to calculate a correct answer when the A-weighted noise level and the NRR were provided. A possible explanation for such poor performance on question 2, especially in regard to subjects not subtracting 7 from the NRR, might be attributed to the fact that instructions for using the NRR printed on HPD packaging is incorrect. The package directions

state that the NRR is to be subtracted from the A-weighted sound level. This is in direct contradiction to the OSHA regulations which require the preliminary subtraction of 7 from the NRR. Given the importance of determining an employee's protected exposure level, these high error rates are unacceptable. Perhaps emphasis needs to be placed on remedial training and re-evaluation of CAOHC certification programs, and perhaps also on the content of audiological coursework that deals with industrial hearing conservation. If hearing conservationists are to be given the responsibility of evaluating worksite noise and recommending hearing protection, every one must understand and correctly apply the fundamental concepts, in this case the NRR method, governed by OSHA. There is no excuse for hearing conservationists to not thoroughly understand the application of the NRR method. It consists of only a simple subtraction of numbers that are used every day by these professionals. Additionally, nearly all general hearing conservation texts cover the NRR method, prominently, Berger (1986) and Gasaway (1985).

Instructional Methodology Comparison

From the data analysis it is evident that none of the instructional tools performs better than the others, on a statistical basis, at instructing individuals to use the NRR or HML methods; each tool performed equally well, or equally poor, whether measured by computational errors or speed. This conclusion is also supported by the fact that subjective ratings did not reveal any significant user preference among the tools. Considering the high error rates and lack of preference among tools, it must be concluded that none of the instructional tools under investigation is adequate to instruct individuals in the HML method. Since

the information presented by each tool was the same, it can be also concluded that the media used to present the information did not affect the learning process. This means that either a new teaching strategy needs to be developed, or the HML method needs to be changed, with an emphasis on the former since the HML method, in its current form, has significant theoretical accuracy advantages over the NRR. It was observed during the course of the experiment that almost every subject asked at least one question when trying to use the HML. Since the experimenter could not give any assistance, the subject was sometimes left in a state of confusion. It is therefore suggested that perhaps an interactive lecture that could provide more information and insight into the method might be a more suitable media for instructing individuals to use the HML method. It is hypothesized that this media would result in higher accuracy, and perhaps, greater speed.

Differences between the NRR and HML methods. The NRR method scored better than the HML method in all four experimental analyses; these included the two special-case applications of the NIOSH method number 3 and the HML-Quicky where only A-weighted sound levels were provided. The method's inherent simplicity leads to quick results with little room for error. In all four experimental test question analyses, the HML method consistently scored a higher percentage of errors, and a longer calculation time. Since there are inherently more steps to the HML method, it was expected that the calculation time would be longer. On the other hand, the percentage of errors made was also larger for the HML method. It is concluded that this method is more complex to apply than the NRR method, and therefore, provides more opportunity to make an error. Since virtually all sources of error were controlled for (mathematical

ability, memorization, practice, familiarity, etc.), the inherent complexity of the HML and HML-Quicky methods, using the three tools of this experiment, must be the cause of the poor success rate.

Differences between Novice and Hearing Conservationist subjects. As a general result for the four experimental analyses, Novice subjects performed the calculations for the NRR and HML methods more accurately and more quickly. It should also be noted for the HML method that almost all Novice subjects (all except one) attempted to calculate the experimental test questions without concession; six of the Hearing Conservationist subjects (one-third of their pool) conceded. Additionally, no subjects conceded for the NRR method. It is concluded that because of the concessions made by Hearing Conservationist subjects that the calculation time in the HML method for Novice subjects was significantly shorter. It is also concluded that because Hearing Conservationist subjects were more likely to be set in their ways, this would explain their poor performance in using the HML method. Two conclusions may be drawn to explain why Novice subjects performed the NRR calculations more accurately than Hearing Conservationist subjects: 1) While Novice subjects followed the method as presented to them, Hearing Conservationist subjects tried to integrate what was being presented to them with what they already knew. Based on the Baseline of Knowledge determination, what they already knew, was wrong. 2) Hearing Conservationist subjects were less motivated to do the experiment despite all attempts by the experimenter to do so.

Spectral Discrimination Assessment

Lastly, the results of the spectral discrimination analysis were not at all favorable for the accuracy or reliability of the subjective classification of noises into high frequency-dominated (HM), or low frequency-dominated (ML) classes. Only three sound samples were correctly identified more than 90% of the time. Two of these were laboratory-generated pink noises, not the type of noises commonly found in industry. Even though a noise may be clearly biased in its spectral energy into one class, the listener may key in on another frequency component, perhaps a prominent tonal characteristic out of the bandwidth of energy bias, when making a judgment. Or, it may be the case that sufficient wideband noise masking occurs, interfering with the frequency cues necessary for pitch judgments. No matter what the perceptual explanation behind the spectral misjudgments, they lead to a conclusion that it is unwise to place any faith in subjectively classifying noises as high or low frequency-dominated, as required by the HML-Quicky method; therefore, this method simply cannot be performed reliably. For a future study, it is suggested that the just-noticeable difference threshold between the HM and ML noise classes be determined, and what reliability the identification of this limen possesses over time. However, given the results of the spectral discrimination task herein, it is important to realize that the human ear cannot substitute for a sound level meter or dosimeter, with both A- and C-weighting networks if the HML method is to be utilized.

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Appendix A

Screening Material

NAME: _____

Have you worked in the field of hearing conservation for at least one year?

YES NO

Have you been enrolled in an audiology or hearing-conservation related curriculum for at least one Year?

YES NO

Have you taken classes in any of the following topic areas at Virginia Tech or another university? Human Factors Engineering, Human Audition, Auditory Display Design Industrial Audiology, Noise Controls, Hearing Conservation.

YES NO

Are you familiar with the Noise Reduction Rating (NRR) found on hearing protector packaging, and what this rating is used for?

YES NO

Do you have any experience with hearing protection at all? If so, describe your experience in the space provided.

YES NO

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Please solve the following problems; use the space provided as scratchpaper if needed.

99 - 24 =

99 - (24 -7) =

Given the following arbitrary table of data, what is the tabled value when a = 0.05 and b = 5? _____.

When a = 0.10 and b = 1? _____.

When a = 0.025 and b = 3? _____.

	a		
b	0.10	0.05	0.025
1	3.078	6.314	12.706
2	1.886	2.920	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571

Subject Name_____

What is your job title?_____

How many years have you worked in this capacity?_____

Does you or your company evaluate the effectiveness of HPDs?_____

Does you or your company perform as hearing conservation consultants?_____

Do you perform industrial noise monitoring surveys?_____

Do you recommend an/or supply hearing protection?_____

Are you a member of NHCA?_____

Are you a member of CAOHC?_____

What is your educational background or training in hearing conservation?_____
_____
_____
_____
_____

How many professional hearing conservation conferences have you attended in the last 5 years? Please give the conference names
._____
_____
_____
_____
_____

PITCH DISCRIMINATION SCREENING
(NOVICE SUBJECTS ONLY)

Subject Name _____

Left Ear

First Tone	Second Tone	Correct	Incorrect
8000	4000		
4000	750		
2000	750		
750	8000		
750	1000		
1000	4000		
8000	1000		
2000	8000		
4000	2000		
1000	2000		

Right Ear

First Tone	Second Tone	Correct	Incorrect
8000	4000		
4000	750		
2000	750		
750	8000		
750	1000		
1000	4000		
8000	1000		
2000	8000		
4000	2000		
1000	2000		

Appendix B

Instructional Tools

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'HML Outline Instructions.....118

NRR Nomograms.....122

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How to use the NRR method

1. Measure the C-weighted (L_C) sound level of the noise environment.
2. Note the NRR from the package of the hearing protector.
3. Subtract the NRR from the C-weighted sound level to obtain the protected A-weighted hearing level. That is, $L_{A'} = L_C$ - NRR where $L_{A'}$ is the protected A-weighted noise level.

EXAMPLE

A sound level meter displays the C-weighted sound level as 99 decibels. The package label of the hearing protector states that the NRR is 29 dB. By subtracting the NRR from the C-weighted sound level, the protected A-weighted noise level is 70. 99 - 29 = 70.

<u>WHAT IF THE C-WEIGHTED SOUND LEVEL IS NOT AVAILABLE?</u>

1. Measure the A-weighted (L_A) sound level of the noise environment.
2. Note the NRR from the package of the hearing protector and subtract 7 from it.
3. Subtract the corrected NRR from the A-weighted sound level to obtain the protected A-weighted hearing level. That is, $L_{A'} = L_A$ - (NRR - 7) where $L_{A'}$ is the <u>protected</u> A-weighted noise level.

EXAMPLE

A sound level meter displays the A-weighted sound level as 97 decibels. The package label of the hearing protector states the NRR is 27 dB. Subtracting 7 from the NRR gives a corrected NRR of 20; subtracting this from the A-weighted sound level results in a protected A-weighted noise level of 77.

97 - (27 - 7) = 77.

How to use the HML method

1. Determine the actual noise level by measuring the weighted noise levels L_A and L_C.

2. Subtract L_A from L_C

3. If the difference is *less* than 2 dB, go to table 1.

If the difference is *greater* than 2 dB, go to table 2 on the next page.

Table 1, for L_C - L_A less than 2 dB

Predicted Noice level Reduction (PNR) in decibel								
H								M
40	40	40	40	40	40	40	40	40
39	39	39	39	39	39	39	39	39
38	38	38	38	38	38	38	38	38
37	37	37	37	37	37	37	37	37
36	36	36	36	36	36	36	36	36
35	35	35	35	35	35	35	35	35
34	34	34	34	34	34	34	34	34
33	33	33	33	33	33	33	33	33
32	32	32	32	32	32	32	32	32
31	31	31	31	31	31	31	31	31
30	30	30	30	30	30	30	30	30
29	29	29	29	29	29	29	29	29
28	28	28	28	28	28	28	28	28
27	27	27	27	27	27	27	27	27
26	26	26	26	26	26	26	26	26
25	25	25	25	25	25	25	25	25
24	24	24	24	24	24	24	24	24
23	23	23	23	23	23	23	23	23
22	22	22	22	22	22	22	22	22
21	21	21	21	21	21	21	21	21
20	20	20	20	20	20	20	20	20
19	19	19	19	19	19	19	19	19
18	18	18	18	18	18	18	18	18
17	17	17	17	17	17	17	17	17
16	16	16	16	16	16	16	16	16
15	15	15	15	15	15	15	15	15
14	14	14	14	14	14	14	14	14
13	13	13	13	13	13	13	13	13
12	12	12	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11
10	10	10	10	10	10	10	10	10
9	9	9	9	9	9	9	9	9
8	8	8	8	8	8	8	8	8
7	7	7	7	7	7	7	7	7
6	6	6	6	6	6	6	6	6
5	5	5	5	5	5	5	5	5
4	4	4	4	4	4	4	4	4
3	3	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0
-2,0	-1,5	-1,0	-0,5	0	0,5	1,0	1,5	2,0
($L_C - L_A$) in dB								

4. Find out the H and M values of the chosen hearing protector (marked on the packaging or in supplier's brochure or catalogue).

5. Draw a line (or place a ruler) between these H and M values (columns at far left and right).

6. Go to the bottom row and find your calculated value of L_C - L_A.

7. Draw a line from this value up to the H - M line you drew earlier.

8. Read off the value at the point where the lines cross. This value is called the PNR value (Predicted Noise level Reduction).

9. Work out the noise level that will be experienced *inside* the hearing protector by subtracting the PNR value from L_A, (i.e. L_A - PNR).

Table 2, for L_C - L_A greater than 2 dB

Predicted Noice level Reduction (PNR) in decibel																	
M								L									
40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39
38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37
36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36
35	35	35	35	35	33	35	35	35	35	35	35	35	35	35	35	35	35
34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
(L_C – L_A) in dB																	

4. Find out the M and L values of the chosen hearing protector (marked on the packaging or in supplier's brochure or catalogue).

5. Draw a line (or place a ruler) between these M and L values (columns at far left and centre). Draw your line right across the table!

6. Go to the bottom row and find your calculated value of L_C - L_A.

7. Draw a line from this value up to the M - L line you drew earlier.

8. Read off the value at the point where the lines cross. This value is called the PNR value (Predicted Noise level Reduction).

9. Work out the noise level that will be experienced *inside* the hearing protector by subtracting the PNR value from L_A, (i.e. L_A - PNR).

Noise, class ML

Excavators
Motor generators
Electric smelting furnaces
Incinerator furnaces
Annealing furnaces
Blast furnaces
Crushers
Compressors (piston)
Converters
Cupola furnaces
Press forges
Bulldozers
Sandblasting equipment

1. If PNR_{min} is equal to or less than the lowest value of M or L for the hearing protector then it provides sufficient noise reduction in the existing noise environment. The "HML-Quicky" is complete.

2. If PNR_{min} is greater than the highest value of M or L for the hearing protector then the hearing protector cannot be used in the existing noise environment. Choose another protector and repeat the "HML-Quicky".

3. If PNR_{min} is greater than the lowest value of M or L for the hearing protector but equal to or less than the highest value, then the protector may be sufficient. However, you must check using the HML method.

Noise, class HM

Gas cutting
Sugar-coating equipment
Compressed air nozzles
Power hammers
Rebating equipment
Bottle-filling machinery
Polishing of castings
Carpentry machines
Hydraulic pumps
High pressure conveyor-fed rotary presses
Injection moulding machinery
Grinding machines
Spinning machines
Crocheting/knitting machinery
Bore polishing machinery
Mechanical looms
Centrifuges

1. If PNR_{min} is equal to or less than the lowest value of H or M for the hearing protector then it provides sufficient noise reduction in the existing noise environment. The "HML- Quicky" is complete.

2. If PNR_{min} is greater than the highest value of H or M for the hearing protector then the hearing protector cannot be used in the existing noise environment. Choose a different protector and repeat the "HML-Quicky".

3. If PNR_{min} is greater than the lowest value of H or M for the hearing protector but equal to or less than the highest value, then the protector may be adequate. However, you must check using the HML method.

The "HML-Quicky" - a quick check for your chosen hearing protector.

Sometimes you only know the A-weighted noise level. In such a case you can use the "HML-Quicky" to check whether the chosen hearing protector gives adequate protection.

Always start with a hearing protector that the wearer finds acceptable. Then check it using the "HML-Quicky".

In most cases this quick check gives a clear indication whether the hearing protector is adequate or not. If not, you should use the HML method.

Step 1
- gather the data:

You need the following data:

$LA_{eq, 8h}$
The equivalent A-weighted noise level over an 8 hour period (single shift).

L_{act}
The desired A-weighted noise level when wearing hearing protection (limit is 85 dB A-weighted noise, but it is normally preferable to stay between 75-80 for safety's sake).

H, M and L values
The H, M and L values for the chosen hearing protector.

PNR_{min}
Work out the desired *minimum* noise reduction (PNR_{min}) as follows:
$LA_{eq, 8h} - L_{act} = PNR_{min}$

Step 2
- check the hearing protector:

The chosen protector gives adequate protection if...
... PNR_{min} is equal to or less than the lowest value of H, M or L for the chosen protector. The "HML Quicky" is ready.

The hearing protector does not give sufficient protection if...
... PNR_{min} is greater than the highest value of H, M or L for the chosen protector.
Choose another protector and repeat the "HML Quicky".

Step 3
- if neither conclusion in step 2 applies:

The hearing protector may give adequate protection if...
... PNR_{min} is greater than the lowest value of H, M or L for the chosen protector, but equal to or less than the highest value. Proceed as follows.

Listen to the noise and decide what "type" of noise it is by comparing with the examples in the table. Proceed as described under the chosen table.

dBC	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7
115	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108
114	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107
113	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
112	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
111	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
110	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
109	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
108	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101
107	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
106	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
105	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
104	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
103	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
102	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
101	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
100	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
99	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
98	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
97	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
96	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
95	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
94	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
93	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
92	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
91	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
90	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
89	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
88	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
87	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
86	56	67	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
85	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
84	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77
83	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
82	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
81	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
80	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73

NRR

To calculate the protected noise level, find the intersection point of the C-weighted sound level and the NRR.

Use this table when the C-weighted sound level is available

dBA	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7
115	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115
114	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
113	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113
112	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112
111	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
110	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110
109	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109
108	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108
107	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107
106	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106
105	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
104	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
103	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
102	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
101	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101
100	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
99	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
98	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
97	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
96	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
95	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
94	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
93	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
92	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
91	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
90	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
89	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
88	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88
87	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
86	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
85	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
84	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
83	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
82	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
81	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
80	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

NRR

To calculate the protected noise level, find the intersection point of the A-weighted sound level and the NRR.

Use this table when only the A-weighted sound level is available

Use this side if $L_C - L_A > 2$

Attenuation index (PNR)

M								L								
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

$(L_C - L_A)$

1. Adjust the rubber band according to the M- and L-values of the protector.
2. Find the column that corresponds to the $(L_C - L_A)$ value of the noise and read the attenuation index, PNR, of the protector where the rubber band crosses the column.
3. Calculate the protected hearing level, $L_{A'}$, by subtracting the PNR from the A-weighted sound level, L_A. That is, $L_{A'} = L_A$ - PNR.

EXAMPLE: M = 20 L =16 L_A = 92 dB and $(L_C - L_A)$ = 18. -> PNR = 12 dB.
$L_{A'}$ = 92 - 12 = 80 dB.

Use this side if $L_C - L_A \leq 2$

Attenuation Index (PNR)

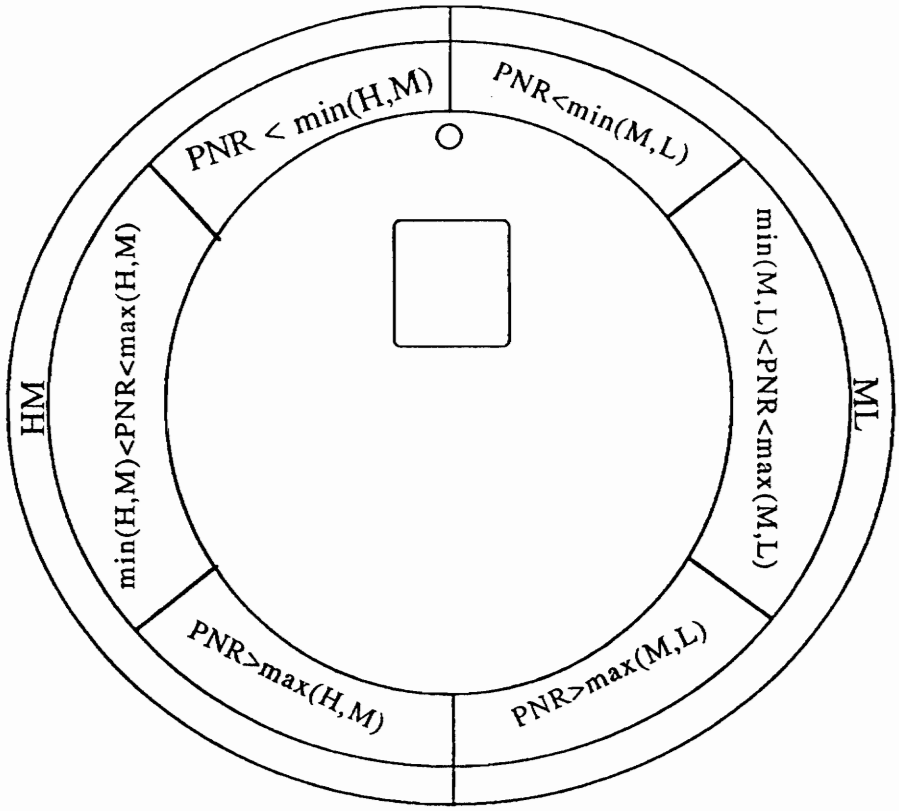
H								M
40	40	40	40	40	40	40	40	40
38	38	38	38	38	38	38	38	38
36	36	36	36	36	36	36	36	36
34	34	34	34	34	34	34	34	34
32	32	32	32	32	32	32	32	32
30	30	30	30	30	30	30	30	30
28	28	28	28	28	28	28	28	28
26	26	26	26	26	26	26	26	26
24	24	24	24	24	24	24	24	24
22	22	22	22	22	22	22	22	22
20	20	20	20	20	20	20	20	20
18	18	18	18	18	18	18	18	18
16	16	16	16	16	16	16	16	16
14	14	14	14	14	14	14	14	14
12	12	12	12	12	12	12	12	12
10	10	10	10	10	10	10	10	10
-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0

$(L_C - L_A)$

1. Adjust the rubber band according to the H- and M-values of the protector.
2. Find the column that corresponds to the $(L_C - L_A)$ value of the noise and read the attenuation index, PNR, of the protector where the rubber band crosses the column.
3. Calculate the protected hearing level, $L_{A'}$, by subtracting the PNR from the A-weighted sound level, L_A. That is, $L_{A'} = L_A$ - PNR.

EXAMPLE: H = 24 M =16 L_A = 91 dB and $(L_C - L_A) = -0.5$.
-> PNR = 21 dB. $L_{A'} = 91 - 21 = 70$ dB.

HML-Quicky Nomogram



Printed Instructions (on reverse side)

1. Calculate PNR by subtracting the desired protected noise level (L_A) from the A-weighted sound level for an 8-hour period(L_8) for the environment. PNR = L_8 - L_A

2. If the PNR is equal to or less than the smallest of the H, M, and L values, the hearing protector is **adequate for the environment**.

3. If the PNR is greater than the largest of the H, M, and L values, the hearing protector is **inadequate for the environment**. Choose a different protector and repeat this procedure.

4. If neither 2 or 3 applies, subjectively classify the environmental noise as HM (high-frequency dominated) or ML (low-frequency dominated) and use the reverse side

5. To use the wheel, align the gold dot under the condition specified for either the HM or ML noise class.

Which of the following methods will you use?

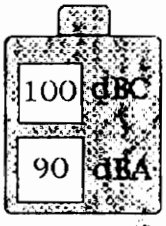
NRR | HML

Click the button of your choice.

A- and C-Weighted Sound Level

This representation of a sound level meter will be used as an example. The C-weighted sound level is termed dBC; the A-weighted level is dBA.

The sound you just heard was created by an industrial machine. The sound level meter measured the C- and A-weighted noise levels as shown.



HML Method

The High, Medium, Low (HML) method is becoming an accepted procedure for calculating the protected noise level a wearer of hearing protectors experiences. This method is based on dividing the effectiveness of a given hearing protector into three parts, corresponding to the high (H), medium (M), and low (L) frequencies of a noise environment.

Only a few pieces of information are required to use this method: simultaneous A- and C-weighted sound levels, and the H, M, and L values of the hearing protector.

First Step

We will now use the HML method to calculate the protected noise level. Once the sound levels are obtained, subtract the A-weighted sound level from the C-weighted sound level. The result of this calculation will determine which reference table to use from now on. If the difference is less than or equal to 2, Table 1 is used; if the difference is greater than 2, Table 2 is used.

For our example, dBC - dBA = 100 - 90 = 10. Since the difference is greater than 2, we would click the button for Table 2.

Table 1 (dBC - dBA ≤ 2)

Table 2 (dBC - dBA > 2)

A- and C-Weighted Sound Level

A sound level meter is used to measure the intensity (loudness) of noise in an environment. The electronics of the meter will automatically apply A- and C-weightings to the measured noise. Hearing conservationists use these weighted levels in performing the calculation of a protected noise level.

Table 1: dBC - dBA ≤ 2

Predicted Noise Level Reduction (PNR)

1. Obtain the H and M values from the packaging of the hearing protector being used. (EX:H=22,M=18)
2. Click the Draw button. Click and hold the cross sign over the H value and drag over to the M value; release the mouse button. Press Command-Tab on the keyboard before continuing.
3. Locate the dBC-dBA value (EX: 0) on the bottom of the table. Find where this column intersects the drawn line. The value at the point of intersection is the PNR for the environment. Go on.

Draw

A- and C-Weighted Sound Level

This representation of a sound level meter will be used as an example. The C-weighted sound level is termed dBC; the A-weighted level is dBA.

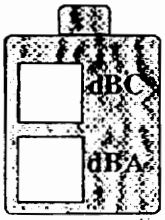


Table 2: dBC - dBA > 2

Predicted Noise Level Reduction (PNR)

1. Obtain the M and L values from the packaging of the hearing protector being used. (EX: M = 24, L = 18)
2. Click the Draw button. Click and hold the cross sign over the M value and drag over to the far right side (thick line) of the table passing through the L value; release the mouse button. Press Command-Tab on the keyboard before going on.
3. Locate the dBC-dBA value on the bottom of the table (EX: 8). Find where this column intersects the drawn line. The value at the intersection point is the PNR value for the environment. Go on.

Draw

Final Calculation

The final calculation simply involves subtracting the PNR for the environment from the A-weighted sound level. If in our example we obtained a PNR of 20, we can find the protected noise level of a worker wearing the hearing protector under investigation. Recall that for the example the A-weighted sound level was 90 dBA.

Therefore, protected noise level = dBA - PNR
= 90 - 20 = 70

Evaluation

1. If the PNR is equal to or less than the smallest value of the H, M, or L values, the hearing protector is <u>adequate for the noise environment</u> -> Click STOP

2. If the PNR is greater than the largest of the H, M, or L values, the hearing protector is <u>inadequate for the noise environment</u> -> Click STOP

3. If neither case applies, continue.

For our example, since 20 is greater than 18 but less than 24, we would continue.

What if...

What if simultaneous A- and C-weighted sound levels were not available for some reason?

The protected noise level could still be calculated by following a procedure known as the "HML-Quickly" method.

Subjective Decision

NOTE: If you are on this card, the PNR is between the highest and lowest of the H, M, and L values.

At this point, you are asked to listen to the noise and subjectively label it as HM (high-frequency dominant) or ML (low-frequency dominant). Click the appropriate button and continue.

HM High Frequency Dominant

Listen (Training Only)

ML Low-Frequency Dominant

HML-Quickly

The goal of this method is not to calculate a protected noise level for a worker wearing hearing protection, but rather to determine if a specific hearing protector is adequate for the particular environment in which it is being used.

Like the HML method, some preliminary information is required:
1. The A-weighted sound level for an 8-hour day
2. The desired A-weighted sound level for a worker wearing the hearing protector under investigation.
3. The H, M, and L values of the hearing protector.

HM Noise Class

Three outcomes are possible:

1. If the PNR is equal to or less than the lowest of the H and M values, the hearing protector is adequate for the sound environment.

2. If the PNR is greater than the highest of the H and M values, the hearing protector is inadequate for the sound environment. Choose a different protector and repeat the entire HML-Quickly procedure.

3. If the PNR is between the H and M values, the results are inconclusive.

Preliminary Calculation

A preliminary calculation is performed to determine the *minimum* PNR to correspond to the desired A-weighted sound level.

PNR = A-weighted sound level for an 8-hour day (dBA) - the desired A-weighted protected level (dBA')

In our example (recall dBA = 90, H=22, M=24, and L=18), if we want an A-weighted protected level of 70 (dBA') then the calculation is as follows: PNR = 90 - 70 = 20

ML Noise Class

Three outcomes are possible:

1. If the PNR is equal to or less than the lowest of the M and L values, the hearing protector is adequate for the sound environment.

2. If the PNR is greater than the highest of the M and L values, the hearing protector is inadequate for the sound environment. Choose a different protector and repeat the entire HML-Quickly procedure.

3. If the PNR is between the M and L values, the results are inconclusive.

Practice Question 1

Given the following information (you may wish to write these values down), calculate the protected noise level of a worker wearing a hearing protector.

H = 24
M = 16
L = 10
dBC = 100
dBA = 99
Noise is judged to be high-frequency dominated.

Go to HM Method
Go to HM Hearing
Solution

NRR Method

The Noise Reduction Rating (NRR) Method of calculating the protected noise level of a worker wearing hearing protection is very simple. Only two pieces of information, which will be discussed later, are required to perform the calculation:

1. The C-weighted sound level of the environment.
2. The NRR of the hearing protector being used.

Go Back
Next

Practice Question 1 Solution

The protected noise level is calculated as follows:

From the HM table, PNR = 18

protected noise level = dBA - PNR
= 99 - 18
= 81

If you are not correct, you should review the procedures again.

Go to HM Method

C-Weighted Sound Level

A sound level meter is used to measure the intensity (loudness) of noise in an environment. The electronics of the meter will automatically apply A- and C-weightings to the measured noise. Hearing conservationists use these weighted levels to perform the calculation of a protected noise level.

Practice Question 2

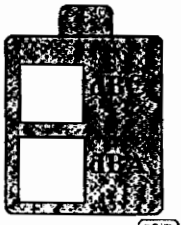
Given the following information (you may wish to write these values down), determine if the hypothetical hearing protector is adequate for the noise environment.

H = 26
M = 20
L = 14
A-weighted noise level for an 8-hour day (dBA) = 90
Desired A-weighted noise level (dBA') = 75
Noise is judged to be low-frequency dominated.

Go to HM Method
Go to HM Hearing
Solution

C-Weighted Sound Level (cont.)

This representation of a sound level meter will be used as an example. The C-weighted sound level is termed dBC; the A-weighted level is dBA.



Practice Question 2 Solution

The adequacy determination is as follows:

1. PNR = dBA - dBA' = 90 - 75 = 15

2. The noise is judged to be low-frequency dominated, and the PNR is between the highest and lowest of the H, M, and L values. Therefore, use the ML noise class decisions.

3. Since the PNR (15) is between the M and L values (20 and 14, respectively) the results are inconclusive.

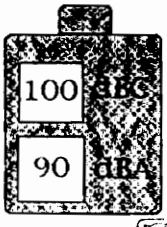
If you are not correct, you may wish to review the procedures again.

Go to HM Hearing

C-Weighted Sound Level (cont.)

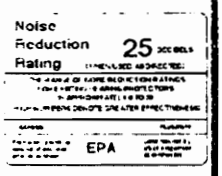
This representation of a sound level meter will be used as an example. The C-weighted sound level is termed dBC; the A-weighted level is dBA.

The sound you just heard was created by an industrial machine. The sound level meter measured the C- and A-weighted noise levels as shown.



Noise Reduction Rating (NRR)

The NRR of a hearing protector is found on the packaging label. This representation of an actual NRR label will be used as an example. Note that the NRR for this particular hearing protector is 25.



Practice Question 1

Given the following information (you may wish to write these values down), calculate the protected noise level of a worker wearing a hearing protector. You may go back and reference the procedures if needed.

dBC = 100
NRR = 27

You may use scratch paper if needed.

Review Procedures

Solution

Calculation of the Protected Noise Level

Now that we have the two required pieces of information, the C-weighted sound level and the NRR from the package label, we can calculate the protected noise level. To perform the calculation, one simply subtracts the NRR from the C-weighted sound level.

That is, Protected Noise Level = dBC - NRR

For our example,
the protected noise level = 100 - 25 = 75
That's It!!!

Practice Question 1 Solution

The protected noise level is calculated as follows:

protected noise level = dBC - NRR
= 100 - 27
= 73

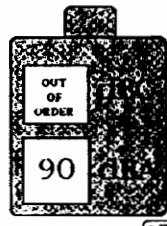
If you are not correct, you should review the procedures again.

Review Procedures

What if...

What if the C-weighted sound level was not available for some reason?

The protected noise level could still be calculated by using a simple preliminary calculation.



Practice Question 2

Given the following information (you may wish to write these values down), calculate the protected noise level of a worker wearing a hearing protector. You may go back and reference the procedures if needed.

dBA = 97
NRR = 27

You may use scratch paper if needed.

Review Procedures

Solution

(NRR - 7) Rule

When the C-weighted sound level is not available, the A-weighted sound level may be substituted, however, the NRR of the hearing protector must be penalized by seven prior to the protected noise level calculation.

That is, the protected noise level = dBA - (NRR - 7).

In our example, recall that the NRR is 25, and the A-weighted sound level is 90. Therefore, the protected noise level = 90 - (25 - 7) = 90 - 18 = 72. It is okay if the result of this calculation is not the same as the calculation using the C-weighting.

Practice Question 2 Solution

The protected noise level is calculated as follows:

protected noise level = dBA - (NRR-7)
= 97 - (27 - 7)
= 97 - 20
= 77

If you are not correct, you should review the procedures again.

Review Procedures

Appendix C

Experimental Test Problems

You enter a noise environment and measure an A-weighted sound level of 98 dBA. You note that the NRR of the hearing protector a worker would wear is 27. What is the protected noise level a worker would experience wnile wearing this hearing protector?

You enter a noise environment and measure an A-weighted sound level of 95 dBA. You note that the NRR of the hearing protector a worker would wear is 27. What is the protected noise level a worker would experience while wearing this hearing protector?

You enter a noise environment and measure a C-weighted sound level of 101 dBC. You note that the NRR of the hearing protector a worker would wear is 24. What is the protected noise level a worker would experience while wearing this hearing protector?

You enter a noise environment and measure a C-weighted sound level of 103 dBC. You note that the NRR of the hearing protector a worker would wear is 27. What is the protected noise level a worker would experience while wearing this hearing protector?

You enter a noise environment and measure the A- and C-weighted sound levels to be 96 and 98, respectively. You note that the HML values are as follows: H = 24, M = 18, and L = 10. What is the protected noise level a worker would experience while wearing this hearing protector?

You enter a noise environment and measure the A- and C-weighted sound levels to be 96 and 98, respectively. You note that the HML values are as follows: H = 28, M = 16, and L = 12. What is the protected noise level a worker would experience while wearing this hearing protector?

You measure the A-weighted sound level for an 8-hour period to be 97 dBA. You wish for the protected A-weighted level to be 75 dBA. You note that the HML values are as follows: H = 26, M = 22, and L = 12. Lastly, you judge the noise in the environment to be low-frequency dominated. Is this hearing protector adequate for this noise environment?

You measure the A-weighted sound level for an 8-hour period to be 99 dBA. You wish for the protected A-weighted level to be 75 dBA. You note that the HML values are as follows: H = 22, M = 22, and L = 8. Lastly, you judge the noise in the environment to be low-frequency dominated. Is this hearing protector adequate for this noise environment?

Appendix D

Likert Scales

POSTTEST QUESTIONNAIRE

After having completed your instructional training on the use of the NRR and HML methods of calculating a protected noise level, please rate instructional tool you were trained on using the following questions.

How would you rate the effectiveness of the instructional tool in aiding you to calculate the protected noise level using the NRR method?

Worthless Valuable

How would you rate the effectiveness of the instructional tool in aiding you to calculate the protected noise level using the HML method?

Worthless Valuable

How well does the instructional tool convey the procedures to calculate the protected noise level for the NRR method?

Weak Strong

How well does the instructional tool convey the procedures to calculate the protected noise level for the HML method?

Weak Strong

How would you rate the instructional tool's use of time in presenting the calculation procedure for the NRR method?

Slow Quick

How would you rate the instructional tool's use of time in presenting the calculation procedure for the HML method?

Slow Quick

How would you rate the understandability of the instructional tool's presentation style for the NRR method?

Complex Simple

How would you rate the understandability of the instructional tool's presentation style for the HML method?

Complex Simple

How would you rate the practicality of using the instructional tool as an on-the-job reference tool for the NRR method?

Worthless Valuable

How would you rate the practicality of using the instructional tool as an on-the-job reference tool for the HML method?

Worthless Valuable

Overall, are you satisfied with the instructional tool as a training method for the NRR method?

YES NO

If NO, why not?

_____

_____

_____

Overall, are you satisfied with the instructional tool as a training method for the HML method?

YES NO

If NO, why not?

_____

_____

_____

Appendix E

Baseline of Knowledge Problems

Baseline of Knowledge Determination

1. You enter a sound environment and measure the C-weighted sound level to be 100 dBC. You note that the NRR of a particular hearing protector is 27. What is the protected A-weighted noise level (dBA) that a worker wearing this hearing protector will experience?

2. You enter a sound environment and measure the A-weighted sound level to be 96 dBA. You note that the NRR of a particular hearing protector is 28. What is the protected A-weighted noise level (dBA) that a worker wearing this hearing protector will experience?

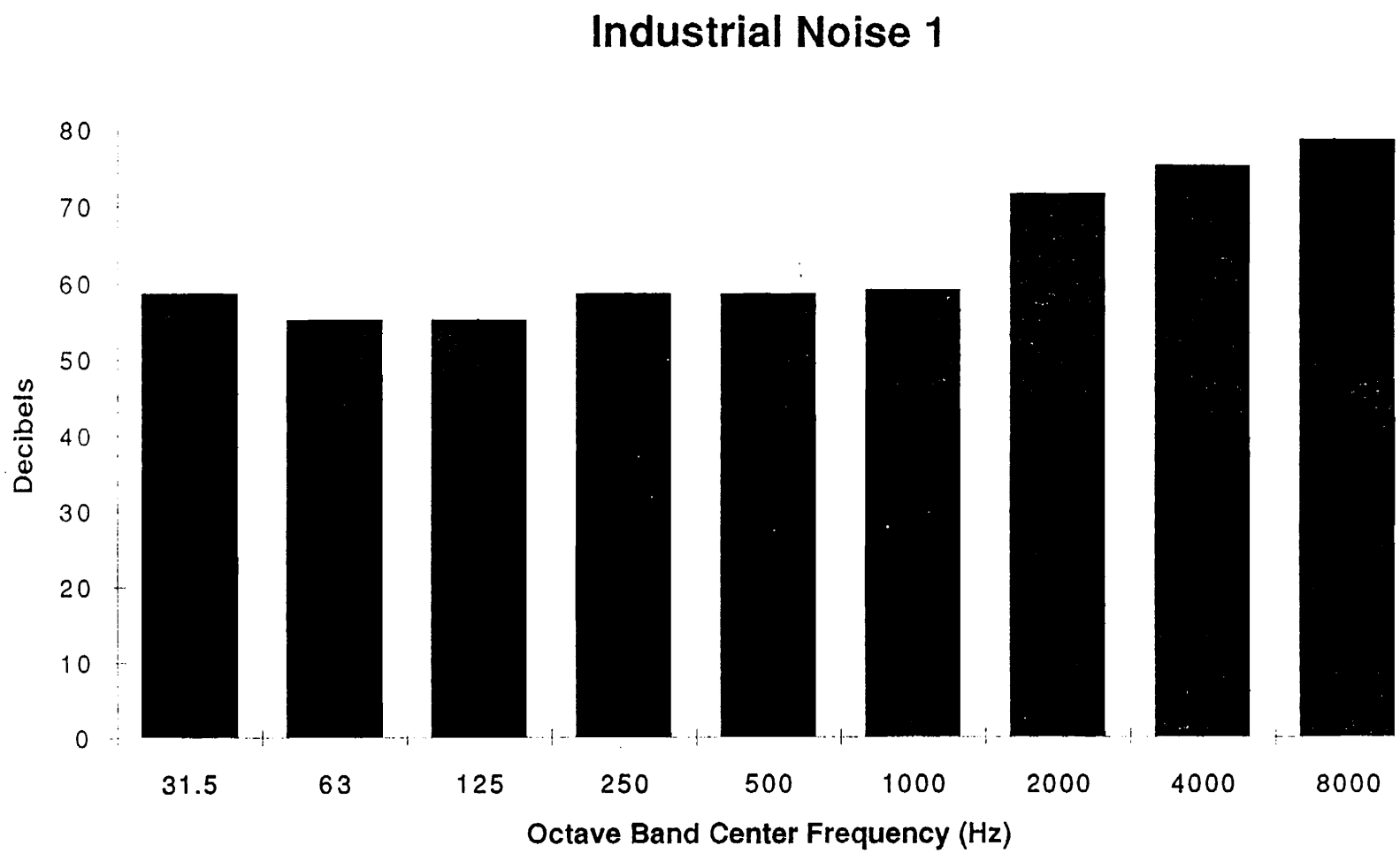
Appendix F

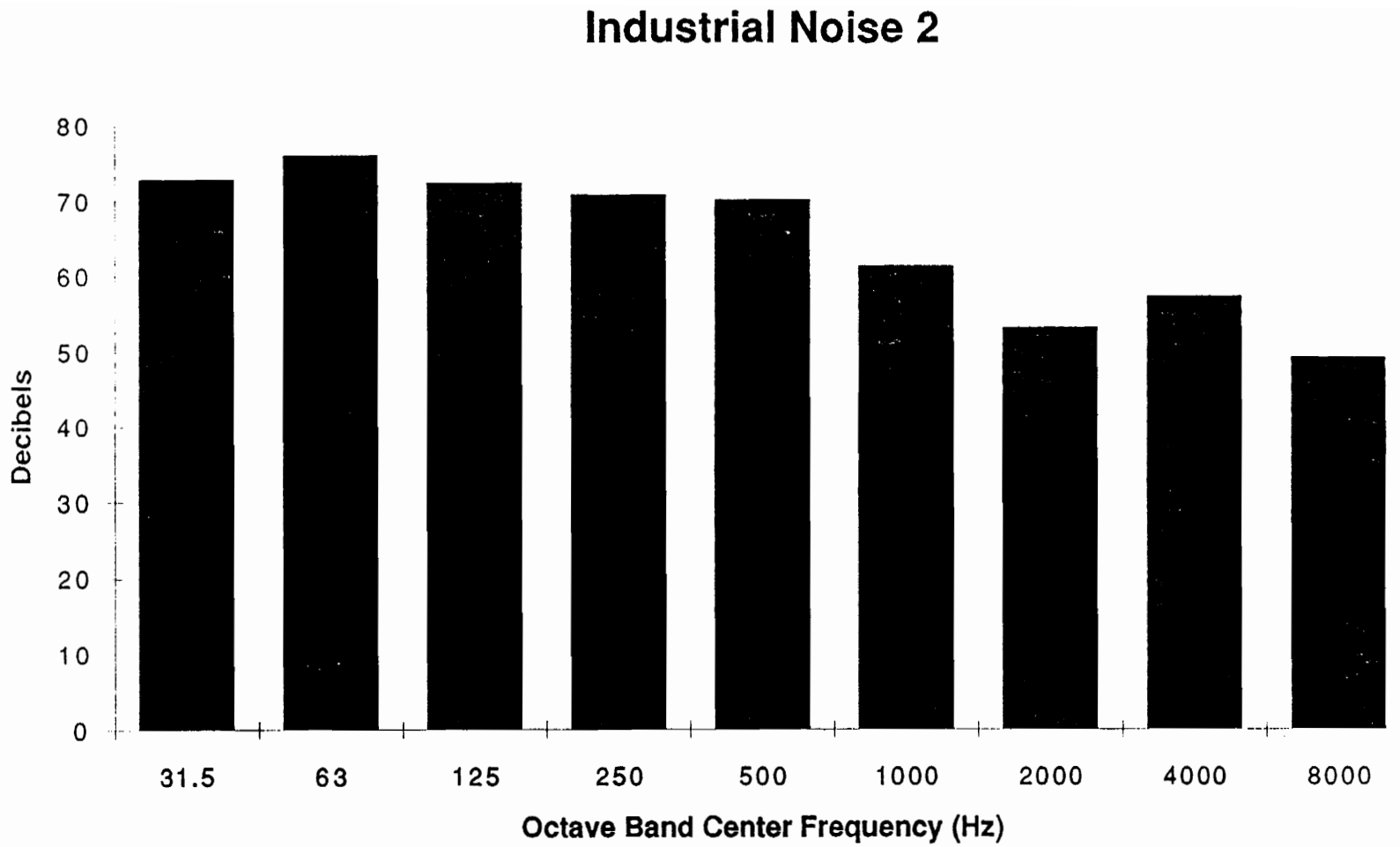
Equipment List for Experiment

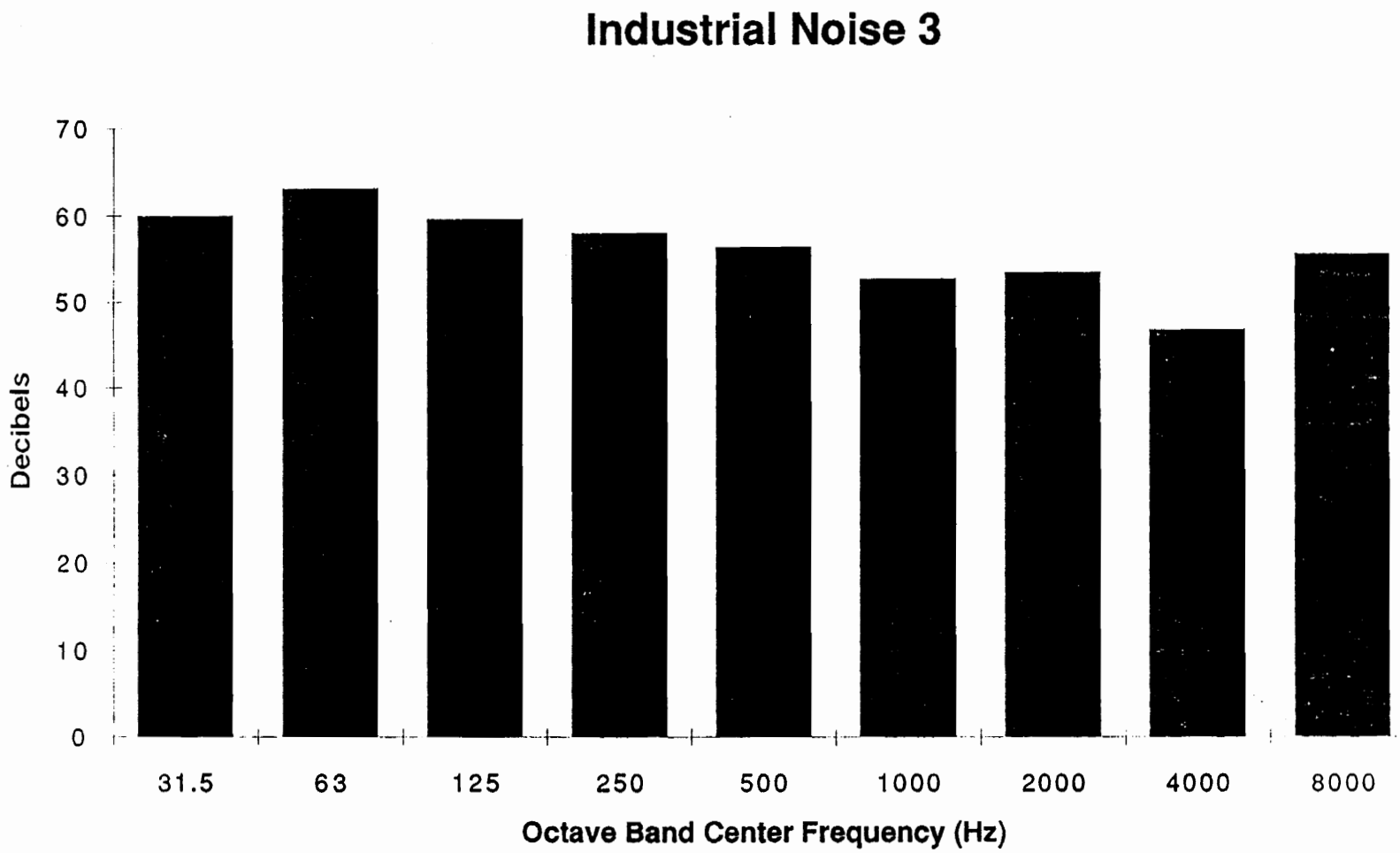
Item	Make	Model Number
Computer	Macintosh	SE 30
Pink Noise Generator	Yamaha	GE 60
Equalizer 1	Realistic	31-2020A
Equalizer 2	Realistic	31-2000A
Tape Deck	Teac	124
Amplifier	NAD	2200
Preamplifier	NAD	1020B
Speaker	Infinity	RS96
Headphone	Telephonics	2960200-3
Audiometer	Beltone	119
Octave Band Analyzer	Rion	NA-29E

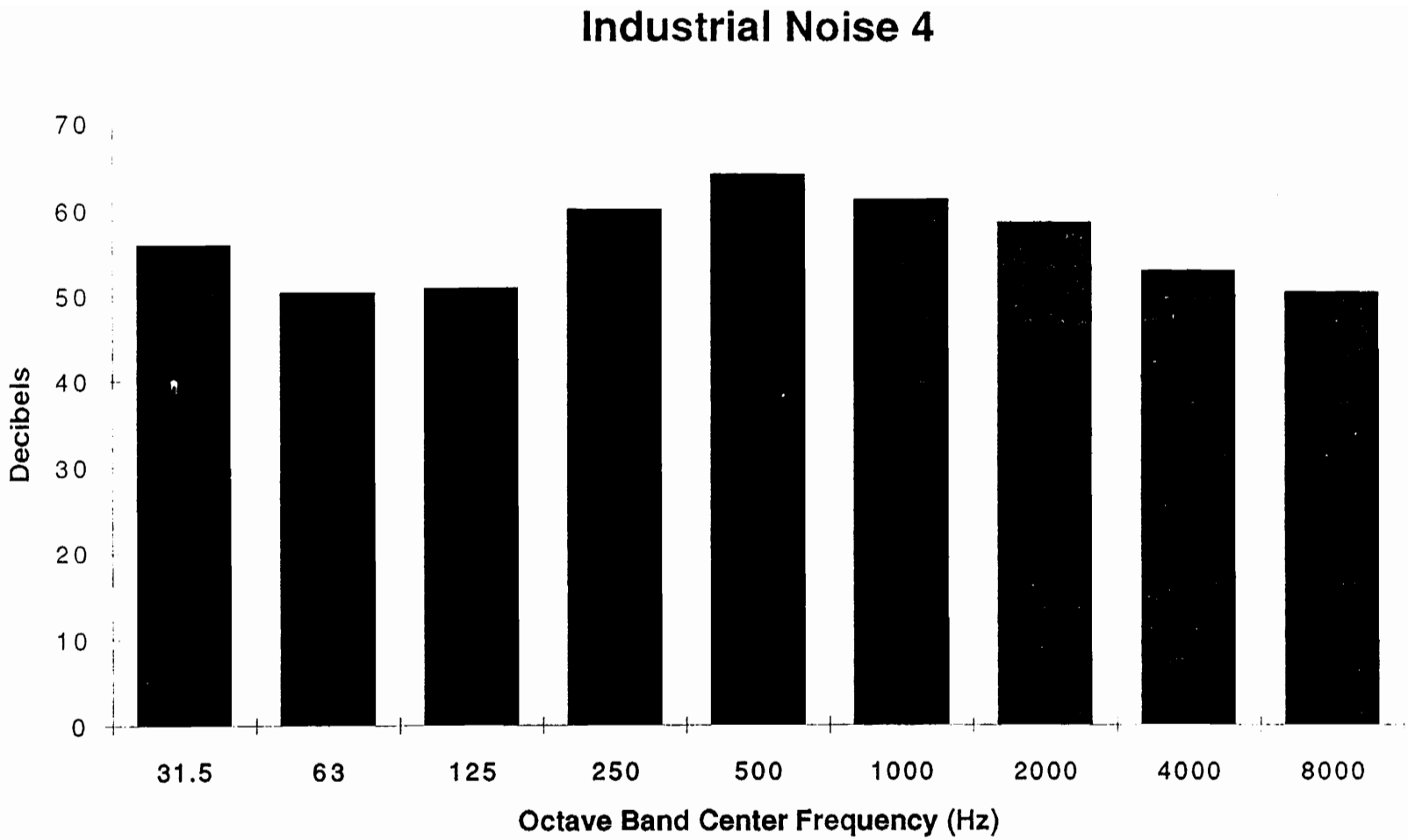
Appendix G

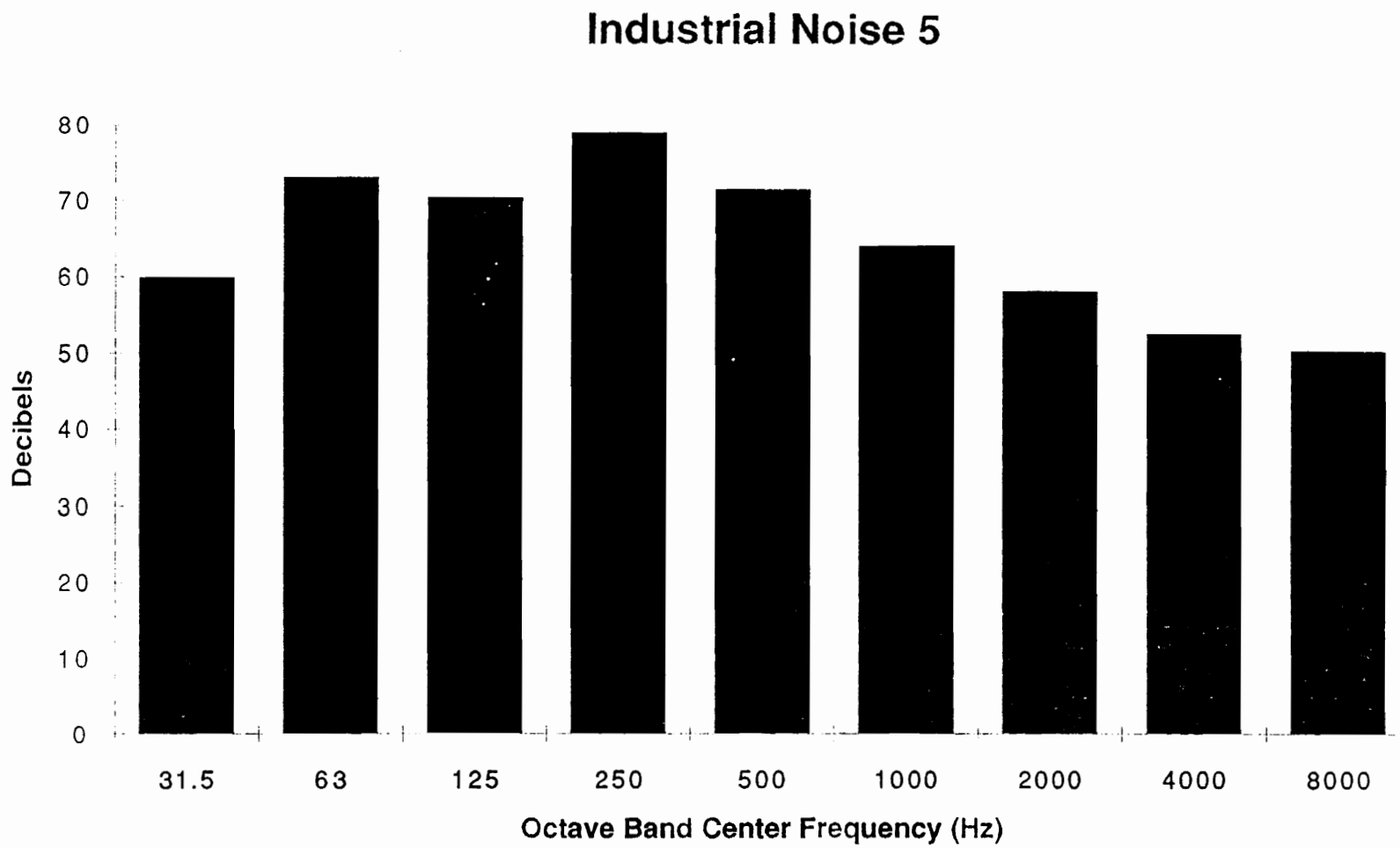
Sound Spectra

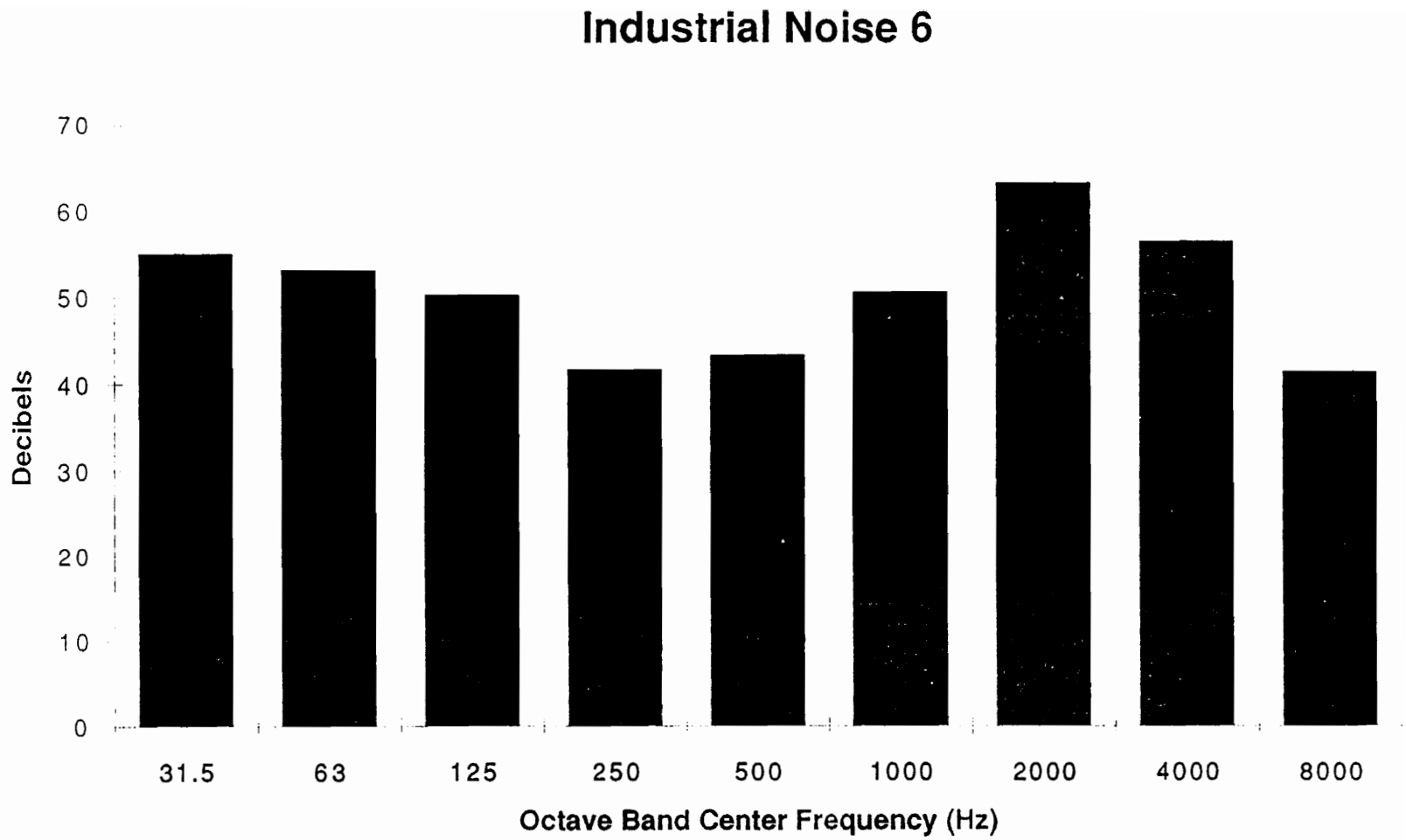

Industrial Noise 1
Decibels
80
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

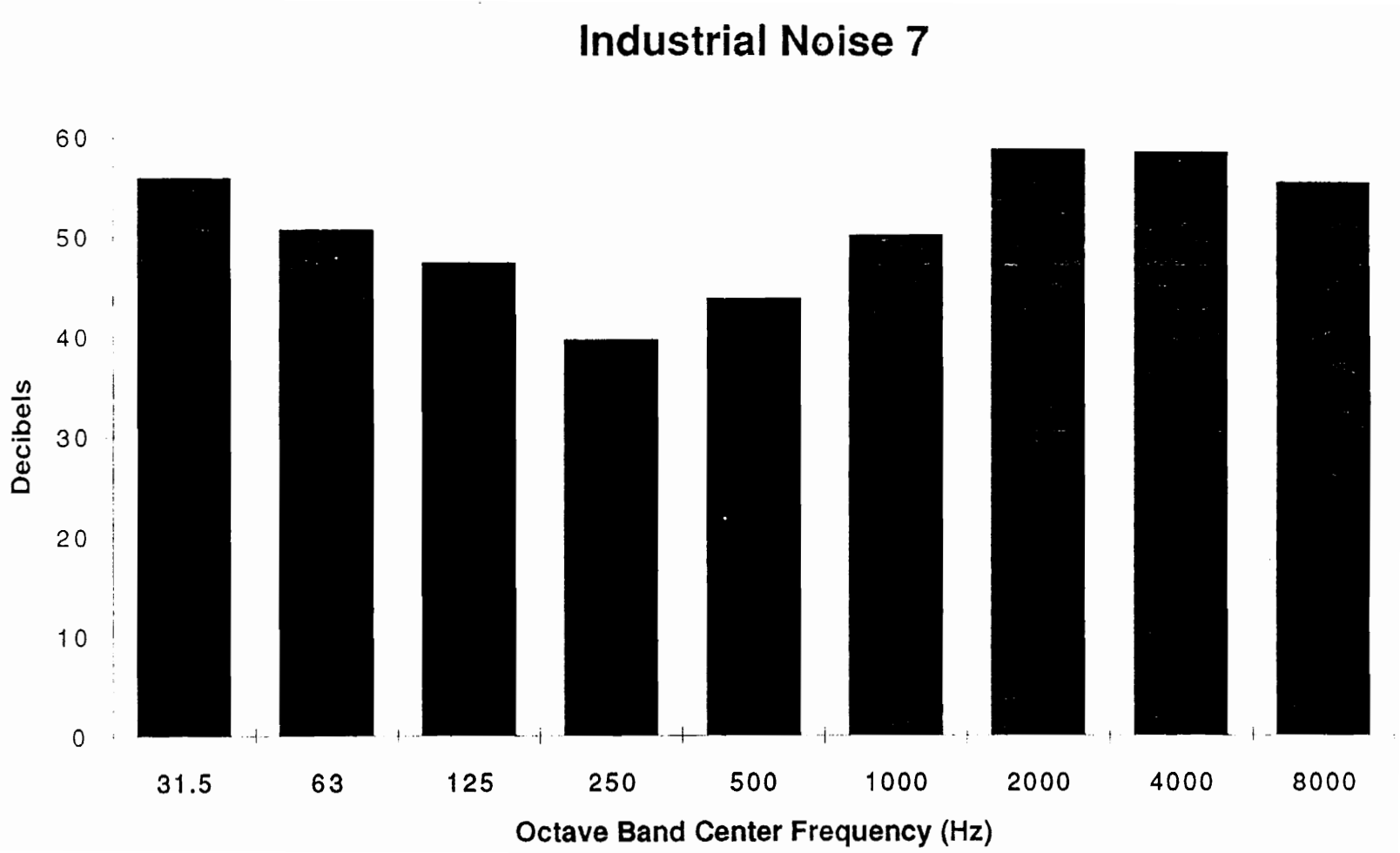

Industrial Noise 2
Decibels
80
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

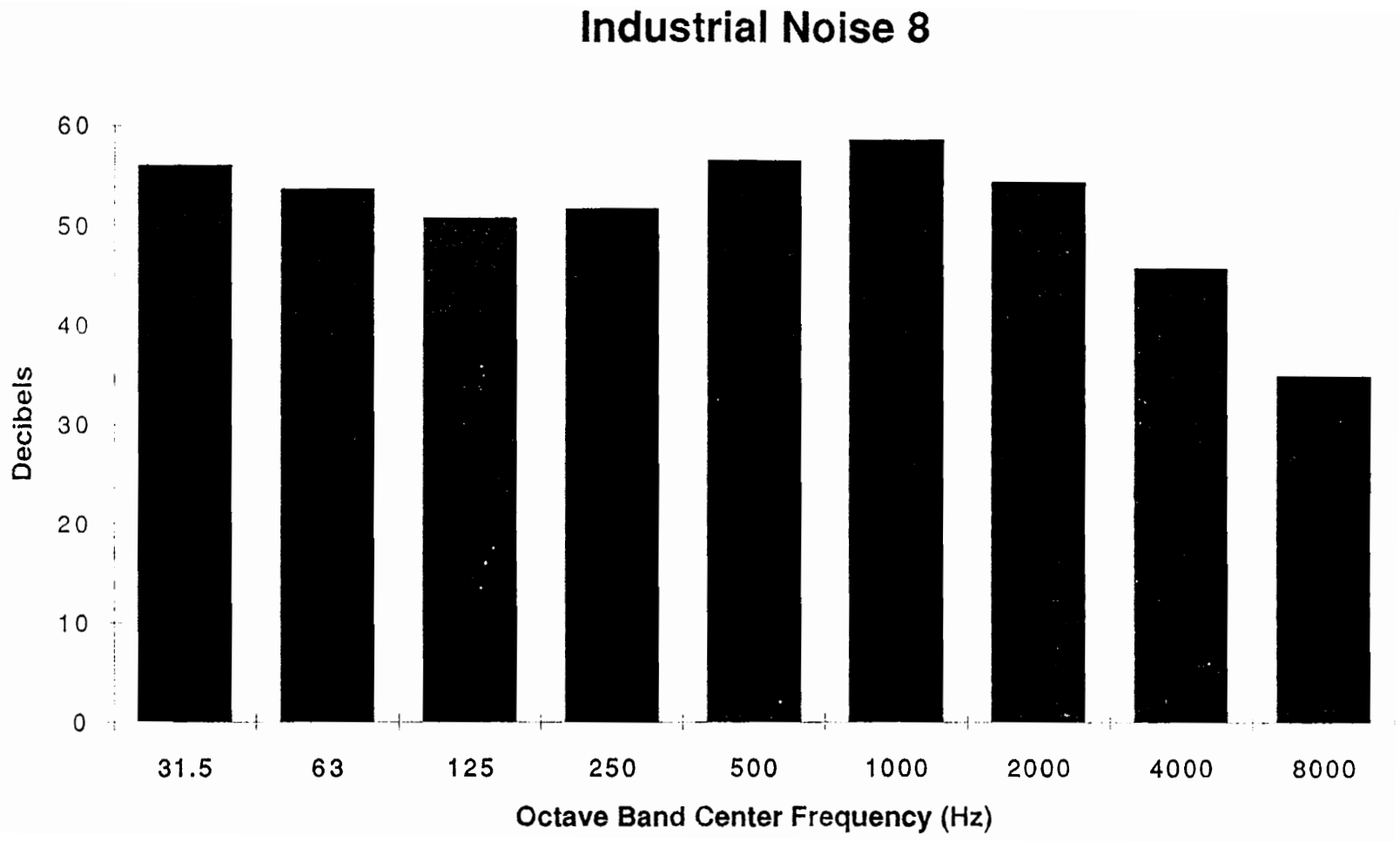

Industrial Noise 3
Decibels
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

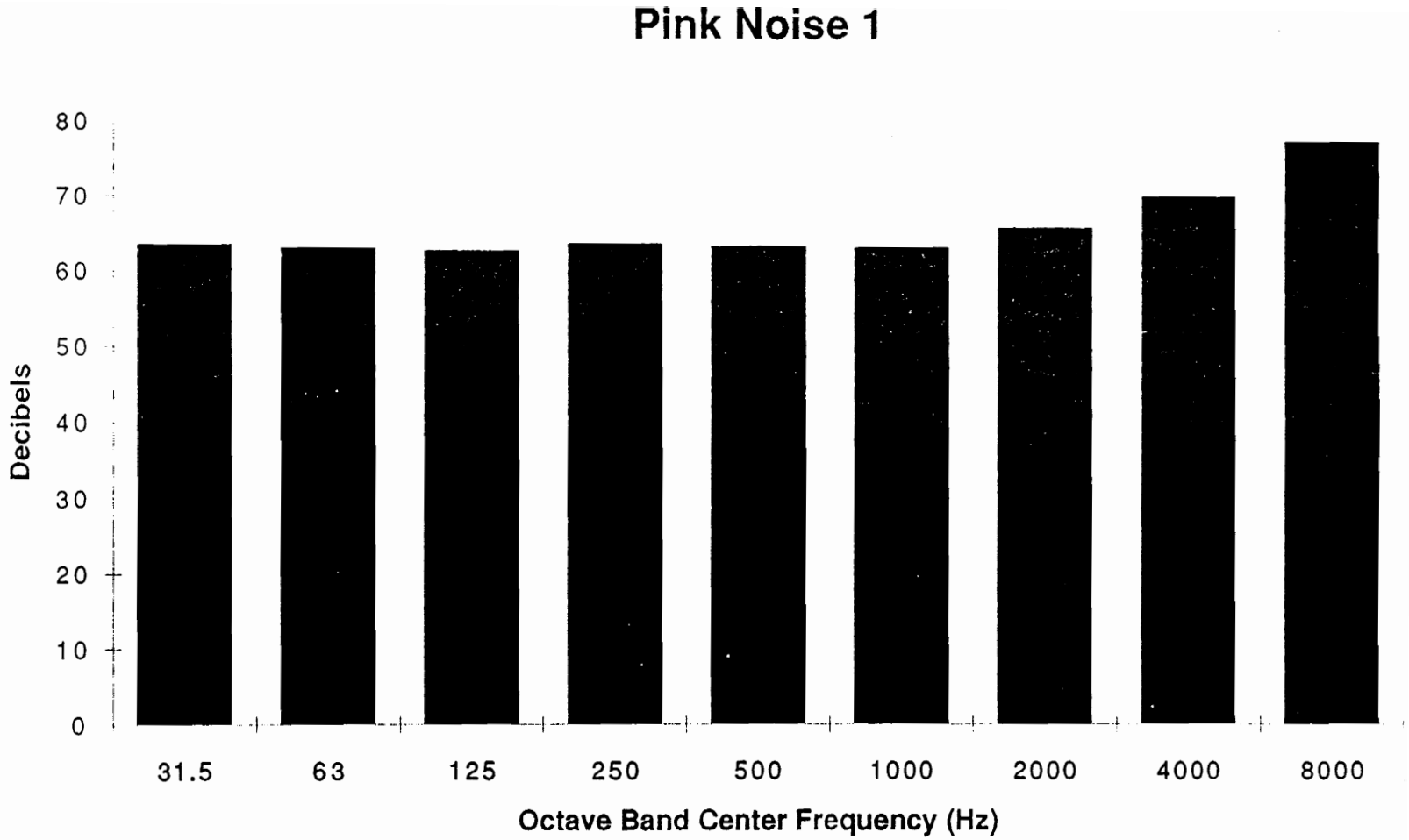

Industrial Noise 4
Decibels
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

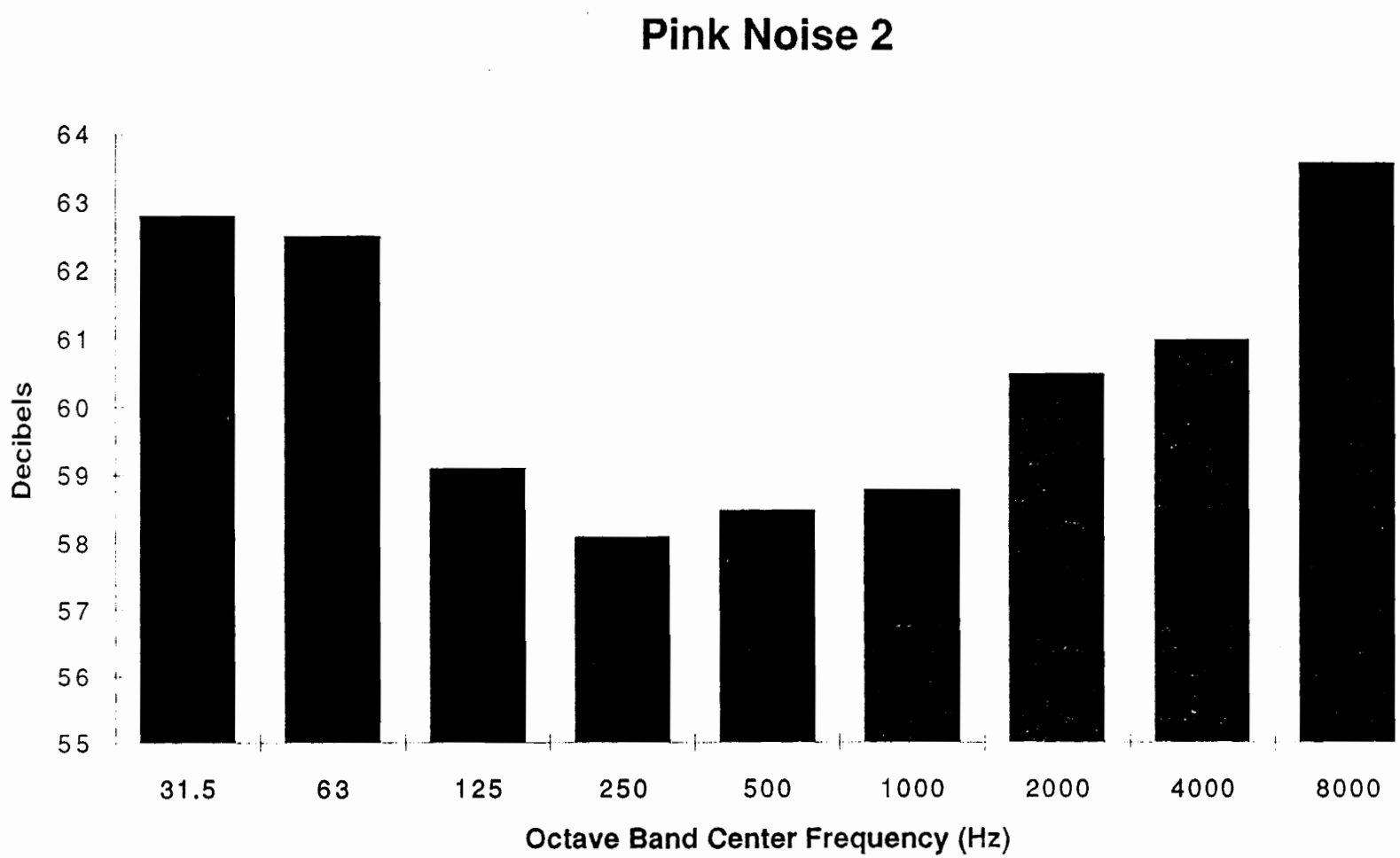

Industrial Noise 5
Decibels
80
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

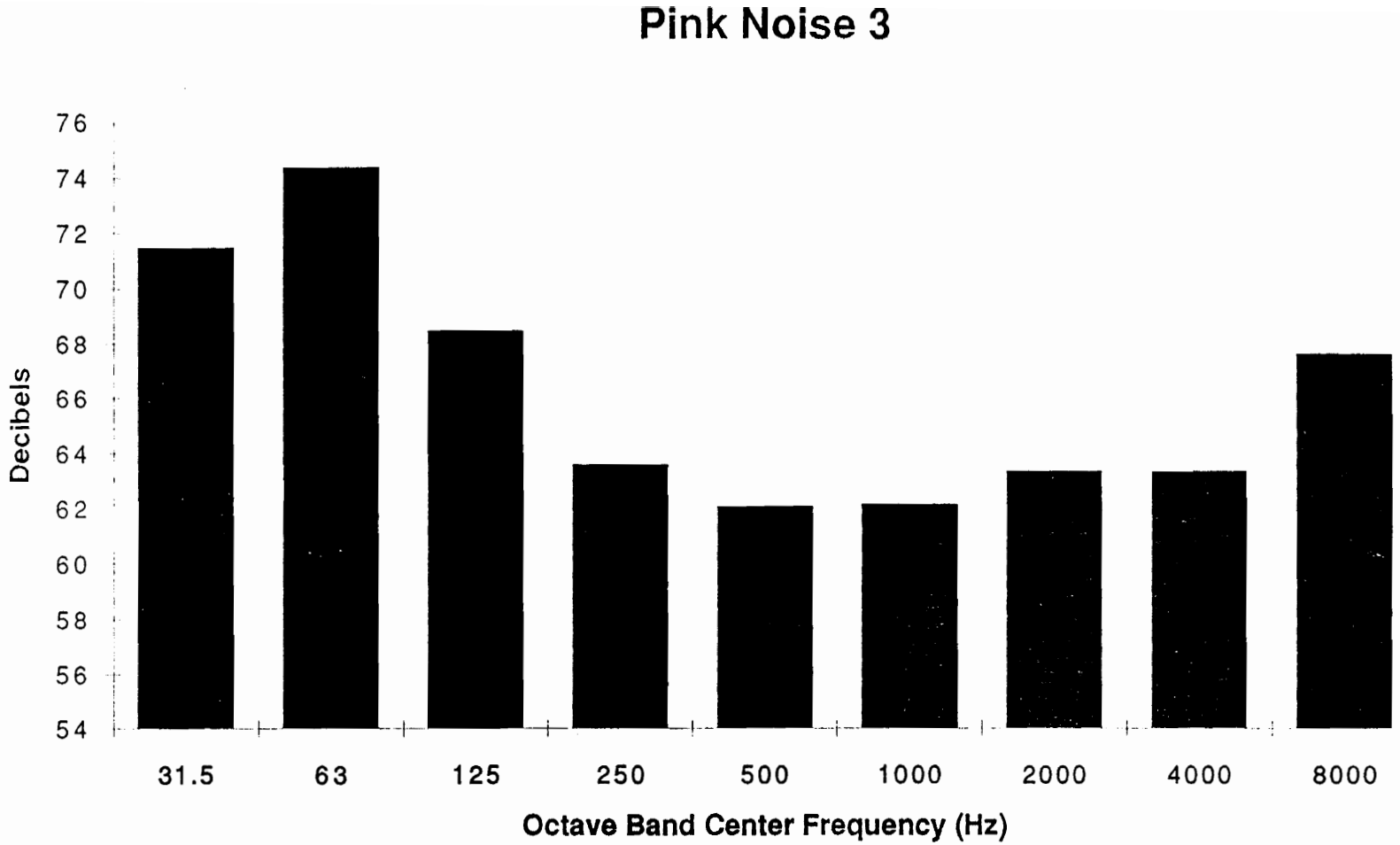

Industrial Noise 6
Decibels
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

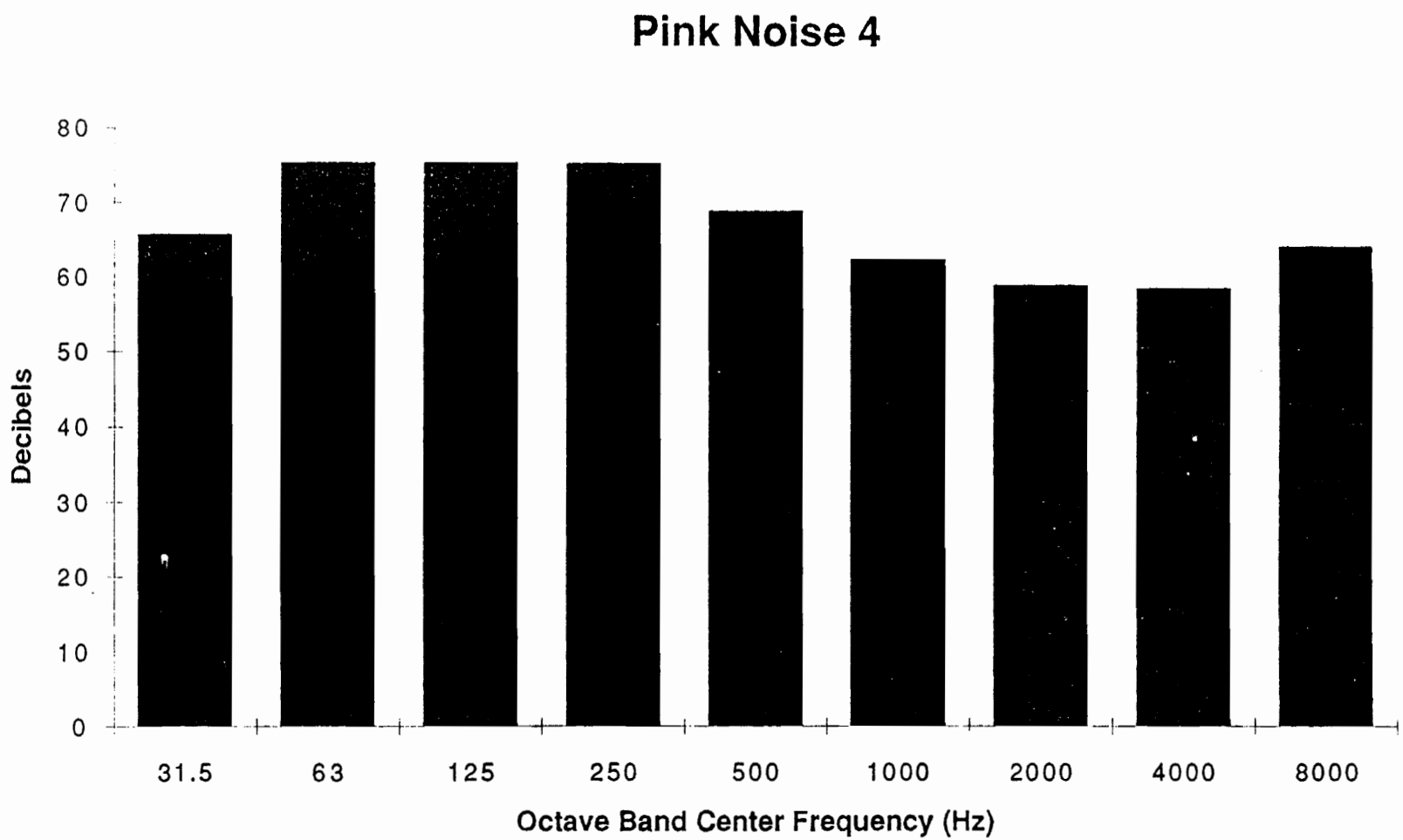

Industrial Noise 7
Decibels
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)


Industrial Noise 8
Decibels
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)


Pink Noise 1
Decibels
80
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)


Pink Noise 2
Decibels
64
63
62
61
60
59
58
57
56
55
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)


Pink Noise 3
Decibels
76
74
72
70
68
66
64
62
60
58
56
54
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)


Pink Noise 4
Decibels
80
70
60
50
40
30
20
10
0
31.5
63
125
250
500
1000
2000
4000
8000
Octave Band Center Frequency (Hz)

VITA

William C. Thomas Jr. was born January 7, 1970 in Utica, New York to William and Lorraine Thomas. At the age of seven, William and the Thomas family moved to Springfield, Virginia. Despite his visual impairment (Achromatopsia), William attended public school.

In 1988, William entered Virginia Tech in the Engineering Department. In 1993, he graduated with a Bachelor's degree in Industrial and Systems Engineering. William enrolled directly in the human factors engineering graduate program offered by the Industrial and Systems Engineering Department at Virginia Tech. William finished his Master's degree in 1995.

At the beginning of 1995, while completing his thesis, William was hired part-time as an Independent Living Coordinator by the Blue Ridge Independent Living Center. He predominantly redesigned clients' homes to be accessible to their individual disabilities. In July of 1995, William was hired by the Virginia Department for the Visually Handicapped as a Vocational Rehabilitation Counselor. His primary responsibility is to redesign worksites for blind and visually impaired clients so that they may perform their jobs effectively.