PREDICTING THE EFFECTIVENESS
OF AN AUDITORY WARNING
SIGNAL

By

LOUIS BARCLAY TRUCKS

Bachelor of Science
Auburn University
Auburn, Alabama
1939

Master of Science
University of Pittsburgh
Pittsburgh, Pennsylvania
1951

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
December, 1974

PREDICTING THE EFFECTIVENESS
OF AN AUDITORY WARNING
SIGNAL

Thesis Approved:

S. Keith Adams
Thesis Adviser

Earl J Ferguson

R F Lowery

H K Eldin

Clayton A. Morgan

N N Durham
Director of the Graduate College

PREFACE

This study is concerned with the determination of an effective auditory warning device within industrial environments. The investigation has included a survey of existing procedures for selecting warning devices, comparison of them with a survey of commercially available devices and, through psychoacoustic testing, determination of a methodology for selecting a warning device for typical industrial environments.

The author wishes to express his appreciation to his major adviser, Dr. S. Keith Adams, for his guidance and assistance throughout this study. Appreciation is also expressed to the other committee members: Dr. Wilson J. Bentley (deceased), who was a true friend, Dr. Earl Ferguson, Dr. Hamed K. Eldin, Dr. Richard L. Lowry, and Dr. Clayton M. Morgan, for their invaluable assistance and encouragement in the preparation of this manuscript. A special note of thanks to Dr. George H. Brooks and faculty of Auburn University for their encouragement and assistance throughout the study. Thanks are also extended to Dr. Saeed Maghsoodloo for his advice on statistical aspects of the study.

To Mr. Robert T. Camp, Jr., and his staff of the Army Aeromedical Research Laboratory is extended special appreciation for assistance and use of their facilities in analyzing sound characteristics of the signals.

To Mr. Robert T. Gilchrist, President of Federal Sign and Signal Corporation, appreciation is given for the use of the Selectone signal unit used in the study.

Thanks are also extended to Mrs. Sherry Shaw for her assistance in typing earlier drafts of the manuscript, and to Mrs. Margaret Estes for the excellence of the final copy and her valuable suggestions.

Finally, special gratitude is expressed to my wife Bette, and our daughters Louise, Anne, and Mary Jane for their understanding, encouragement and many sacrifices.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Of the many effects of noise on industrial environments, one which has had limited investigation is the effectiveness of audio alerting signals in the environments in which they are utilized. It is not infrequent that an alerting signal increases environmental noise. Warning signals will be sounded relatively infrequently, but it appears that a unique-characteristic signal can be discriminated and yet not increase environmental noise levels.

The U. S. Bureau of the Census, in the Statistical Abstract of the United States (1972), reports that the total number of industrial establishments is 311,140 and that these plants employ 19,323,000 workers. Most of the workers are exposed to one environmental factor which has been part of work since earliest man - noise. Noise has been defined by Burrows [32] as "that auditory stimulus or stimuli bearing no informational relationship to the presence or completion of the immediate task" (page 7). Noise annoys - that is, causes interference with work, recreation, and creates physiological and psychological conditions which may cause deleterious effects on safety, concentration, and performance of tasks. It may induce fatigue and cause hearing loss.

At a symposium on The Psychological Effects of Noise at the University of Wales in September, 1967, Dr. W. Taylor said,

> There has been since the turn of the century a steady rise in noise emission from manufacturing processes to such an

> extent that the question now arises at what level of intensity and obtrusiveness will it be necessary to call a halt, if necessary by legislation [157, page 6].

A sociological effect from hearing loss as well as a physical impairment can be the result of continual exposure to intense noise. Concern over these effects is reflected in considerable legislation enacted during the past few years, the object of which is to impose limitations of exposure to noise in industrial environments. Federal legislation has included Public Law 91-596, also called The Occupational Safety and Health Act of 1970, creation of The Environmental Protection Agency, and Public Law 92-573 which is The Consumer Product Safety Act. Each of these legislative acts or actions has specifically included references either in standards or regulations to noise exposure limitations. Public Law 91-596 standards now imposes an exposure limit of eight hours within any 24 hour period at an intensity level of 90 dBA (re 0.0002 dyne/cm^2) unless hearing protection is provided. For each increase of 5 dB of intensity, exposure time is reduced by 1/2; i.e., at 95 dB, exposure time is four hours, at 100 dB, exposure time is two hours. The Environmental Protection Agency has a primary responsibility for noise control in the community and general public sector. Coordination of research, assimilation of pertinent data, and overall responsibility for noise reduction in the total environment are the responsibility of the Environmental Protection Agency. The Consumer Product Safety Act authorizes specifications of noise standards for consumer products and has the authority to remove from the market or prohibit excessively noisy products for sale to the public.

Although workmen's compensation laws in some states now include loss of hearing as compensable, there is a strong indication in the various states and Canadian Provinces that future legislation will increase coverage and compensation. A tabulation of state changes in a three year period shows:

		1969 (63) States	1972 (6) States
Is Occupational Hearing Loss due to continuous noise exposure compensable?	Yes	37	42
	No	14	10
	Possible	2	1
Do you specify the level or type of Noise?	Yes	6	
	No	40	
	Blank	7	
Do you have any regulations regarding noise exposure?	Yes		17
	No		35
	Blank		1

Because of the increase in noise, and the concurrent habituation and acceptance of noise as a normal background, workers have tended to become less attentive to noises outside their immediate work place. In manufacturing industries, materials handling is estimated by the author to require about 85% of total employee effort. Work injury statistics for 1972* covering the following classes: manual handling of objects, falls, struck-by-falls, moving objects, and vehicles, constituted 64% of all cases reported. Inherent in materials handling is the possibility that an individual should be alerted to potential hazards arising from movement of goods over, around, or behind his workplace. In a personal communication, Dr. Allen L. Cudworth, of Liberty Mutual Insurance Company included the following sentences:

---

*Accident Facts, 1972 National Safety Council, Chicago, Ill.

> There is one situation where the noise clearly does become a causative factor in accidents and that is the situation where the workman cannot hear appropriate warning signals because of the presence of a high background noise. We've had a number of claims of this nature where people were run over or otherwise injured by trains, or other transportation vehicles because they were in the presence of sufficient noise as to mask the warning signals of the oncoming vehicle [41].

Because movement could come from any direction, some sensory cue other than vision is necessary. Based on the conditions that any alerting signal should be simple, short, evoke a reaction, and that the operator will move around at the workplace, an auditory alert warning signal (AWS) appears to be most appropriate for study of emergency or warning signals in industrial environments.

The type of noise usually considered as industrial is made up of many sounds, such as; the clang of metal falling to a concrete floor, the clatter of moving vehicles, the hiss of escaping air, the resonance induced by impact of two metal objects, the shriek of a cutting tool removing metal, the thud of a punch press closing, and the whine of hydraulic pumps. All of this cacaphony of sound is perceived by the mechanism of the human ear. This background is the noise exposure of workers who must also perform tasks, and yet be aware of moving objects in the vicinity of their work stations. In examining available auditory alert warning signals for use in industrial situations, there are many varieties, providing varying degrees of effectiveness, depending on the acoustical environment in which they are used.

The purpose of this study is to prove that within a given environment, effectiveness of auditory warning devices can be predicted. With recently developed techniques, an advance in selecting warning devices can be made. Through the developed criteria, the choice and utilization of signals in many environments will be simplified.

Past research [92] has indicated the wide use of warning horns, bells and pure tones against background noises. Past studies showed that spectrum and intensity level of signal and background were the prime factors influencing perception. Broadbent [23] as well as Burrows [32] showed that the signal information of the sound influenced the speed of response. In the industrial environment, the perception of the AWS is not the only criterion since an evoked response of looking in the direction of the danger is essential in reducing potential harm from the hazard. In Burrows' [34] study of verbal and nonverbal auditory stimuli, it was concluded that response to words was better than the response to sounds but in his experiments, channel noise (from a radio telephone) was not superimposed on the signal but was alternative. He found the shortest mean response time for the word "Fire" and the fire bell sound. It is logical to assume that a universal connotation exists among the population toward fire bells, and industrial personnel would have this same connotation. It would also appear logical to omit a fire bell from this particular study in order not to disturb the significance of that particular warning signal to which a population compatibility exists. Other forms of auditory warning signals (the siren, fog horn, starting gun) also have population compatibilities in traffic, navigating, and sports along with other activities but as a rule do not have widespread use in industrial environments.

In the preliminary design of an AWS it is necessary that an industrial operator be aware of conditions surrounding his work place which could present hazards or potential hazards while his attention is directed toward accomplishing his primary task. High priority events which could occur in the work place are:

Cranes carrying loads over his area;
Industrial vehicles delivering or removing material;
Emergency conditions of fire or imminent catastrophes;
Ladles carrying liquids or hot metals adjacent to him;
Overhead monorails or conveyors carrying material;
Boilers or pressure vessels approaching dangerous limits; or
Hydraulic pressures or temperatures approaching control limits.

Because of possible frequent occurrences of one or more of the above items, the individual must be made aware of the condition but must not be overstimulated to the point at which a startle response is evoked. Basic tenets to be specified as design parameters for the AWS include:

The signal drawing attention to the condition rapidly.
The hearer identifying the condition by visually scanning in the direction of the source of the sound.
The hearer, after visual scan, and decision and execution of action or non-action, returning to his assigned task.
The degree of urgency being indicated by the aws.

Erlick and Hunt [51] suggested grouping of priority classes for aircraft crews as:

Killer - requiring immediate attention and mandatory immediate operator response.
Warning - requiring immediate attention and immediate action.

Cautions - requiring immediate attention but no immediate action.

Status - requiring awareness of the situation.

In industrial environments, the majority of cases will fall into the above categories with a frequency inversely proportional to severity. The nature of industrial activity and work-place design is so varied that categorizing response activity is not feasible.

Auditory signals should not significantly exceed 110 dB (re .0002/dyne/cm^2) since at this level of intensity, startle effects have been noted [176]. The signal selected should be recognizable without long duration. Fitts points out:

> Audition is more nearly a continuous sense than vision, vision is basically selective and intermittant. As a consequence, audition is well adapted for the detection of warning stimuli that may arrive at any moment from one of a variety of sources whereas vision is well suited to the selection of, and concentration on, particular stimuli to the exclusiveness of others. [56, page 1314]

Van Cott and Kinkage [185] offer the following design recommendations:

1. Use sounds with frequencies greater than 500 Hz and less than 3000 Hz.
2. Use signal frequencies less than 500 Hz where signal must travel around corners.
3. Use signal frequencies different from those most intense frequencies of the noise to reduce masking.
4. Use a modulated signal to demand attention.
5. Use complex tones rather than pure sinusoidal waves.
6. Use intermittent beeps at rates of 1 to 8 beeps/sec or warbling sounds that rise or fall in pitch.

Masking of signals is a major effect of noise on man. In ANSI S1.1-1960 masking is defined as:

1. The process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound.
2. The amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound. The unit customarily used is the decibel. [4, page 46]

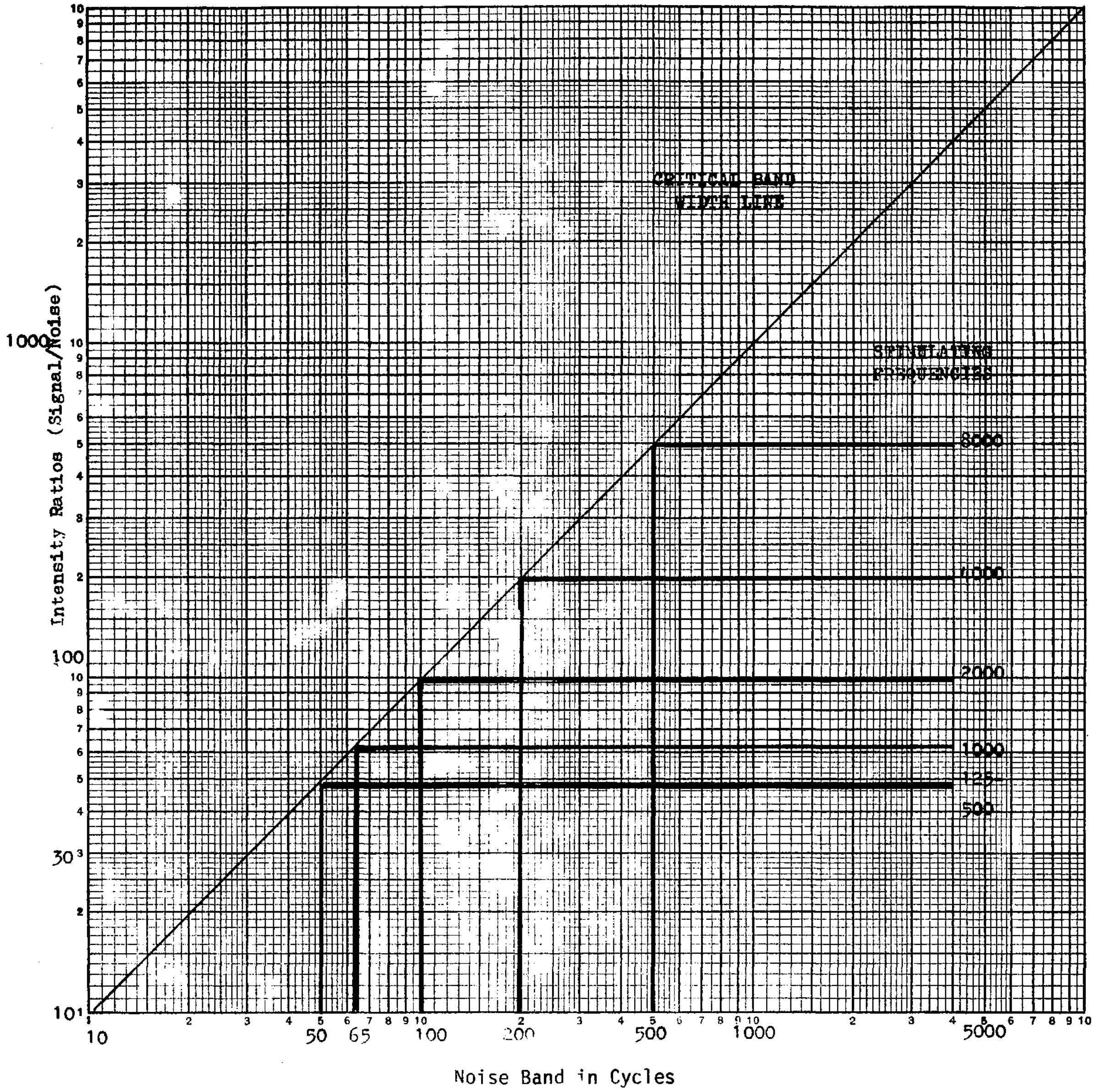
From Kryter [106] the general procedure for measuring of masking includes determination of threshold of audibility for subject in the quiet. Then, while the masking band of noise norm is presented, the subject redetermines thresholds of audibility by means of other bands of noise. The increase in level required by other bands of noise at each frequency represents the amount of masking.

An explanation of the masking phenomenon is provided by von Bekesy's Theory [161] which states that upon stimulation of the basilar membrane (organ of corti) resonance is induced on both sides of the point of stimulation but there is an assymmetrical upward spread of masking. Ehmer [49] showing curves of center frequency tone and noise wherein for tones of 500, 1000, 2000, and 4000 Hz at intensities of 60 and 80 dB SL verifies these findings.

In his classic paper, "Auditory Patterns", Fletcher [80] found that loudness corresponds to the total number of nerve impulses reaching the brain along the auditory nerve. To know that these auditory patterns correspond to what is taking place in the ear, data are drawn from masking effect of such sounds. Breadth of masking increases rapidly as the frequency of the noise doing the masking goes above 1000 Hertz. On the assumption that constant masking indicates constant stimulation along the different patches of nerves, at equal intensities for all frequencies, there is a uniform stimulation at all frequencies. However, as shown in Figure 1, the initial band-width extends from 50 cycles at frequencies of 125 to 500 Hz up to 500 cycles at frequency of 8000 Hz. In looking at the industrial environments, as compared with the selected AWS, there is evidence that at higher frequencies, that is, above 500 Hz, the masking effect will spread thus creating a more difficult task for the ear in perceiving the AWS.

In summary, the problem is to evaluate various auditory warning signals in industrial environments. The approach is to use reaction time (RT) as a criterion by which the most effective signal can be determined.

Examination and analysis of several signals and representative environments will lead to the development of a methodology by which where given a particular environment, the effectiveness of an AWS in that background can be predicted.



Adapted from: Fletcher, H. "Auditory Patterns." Rev. Mod. Physics, Vol. 12 (1940), 47-65.

Figure 1. Width of Noise Band in Cycles

CHAPTER II

ANALYSIS OF EXISTING ALERT WARNING SIGNALS

Commercially available alert warning signals (see Appendixes A and B) have as their most dominating characteristic, an intensity of the magnitude of 100 dB or more. A number of manufacturers [50] recommend a careful evaluation of the purpose for which the signal will be used; the volume and material characteristics of the area to be covered, and an analysis of the specific types of noise environments to be overcome with the signal. It is also stressed that a number of smaller signals will provide a more even and more effective blanket of sound than one high intensity unit.

In the previous chapter, the use of bells was deleted from this study because of their universal connotation of "fire" to most persons. As is shown in Appendixes A and B, the buzzers, chimes, and similar units are normally used for shift changes, lunch time or other break points during the work period and are not often used for immediate warning of approaching hazards. Burrows [32, 33, 34] has investigated a number of specific warning devices using verbal and non-verbal auditory stimuli in several backgrounds. Kryter [105] and McCann [115] along with Ouzts [125] have conducted experiments with respect to vigilance tasks in noise. In each of these cases, the objective of the study was the psycho-acoustic correlates between attention to a task while an auditory signal was sounded. This study is concerned with

applied utilization of existing signals in typical industrial environments.

A unit manufactured by Federal Sign and Signal Corporation, the Selectone, has been made available for this study. As manufactured, the unit provides any one of eight signals which can be selected for a particular environment. In the model Selectone 300 DK, circuits for all of the eight tones are in one unit with a rotatable switch whereby the desired tone may be chosen. A description of the signals is as follows:

#1	Wail	Conventional siren
#2	Yelp	Rapid siren
#3	Hi-Lo	Alternating high and low
#4	Whoop	Ascending low to high - repeated
#5	Yeow	Descending high to low - repeated
#6	Horn	Steady
#7	Beep	Slow intermittent horn - 60 cycles/minute
#8	Stutter	Rapid intermittent horn - 140 cycles/minute

A graphic representation of the signals is given in Figure 2.

Characteristics of the signals, as measured in an audiometric Testing Booth, indicate a concentration of intensity in the octave bands of 500, 1000, 2000, and 4000 Hz. The human ear is most sensitive to this middle range. For maximum discrimination of a signal in industrial noise, frequencies different from the noise are best in order to reduce masking of the noise [185].

In Tables I and II, the sound pressure levels and conversion from dB to Sones are shown. In each case, the full power output of the unit was employed in securing the data.

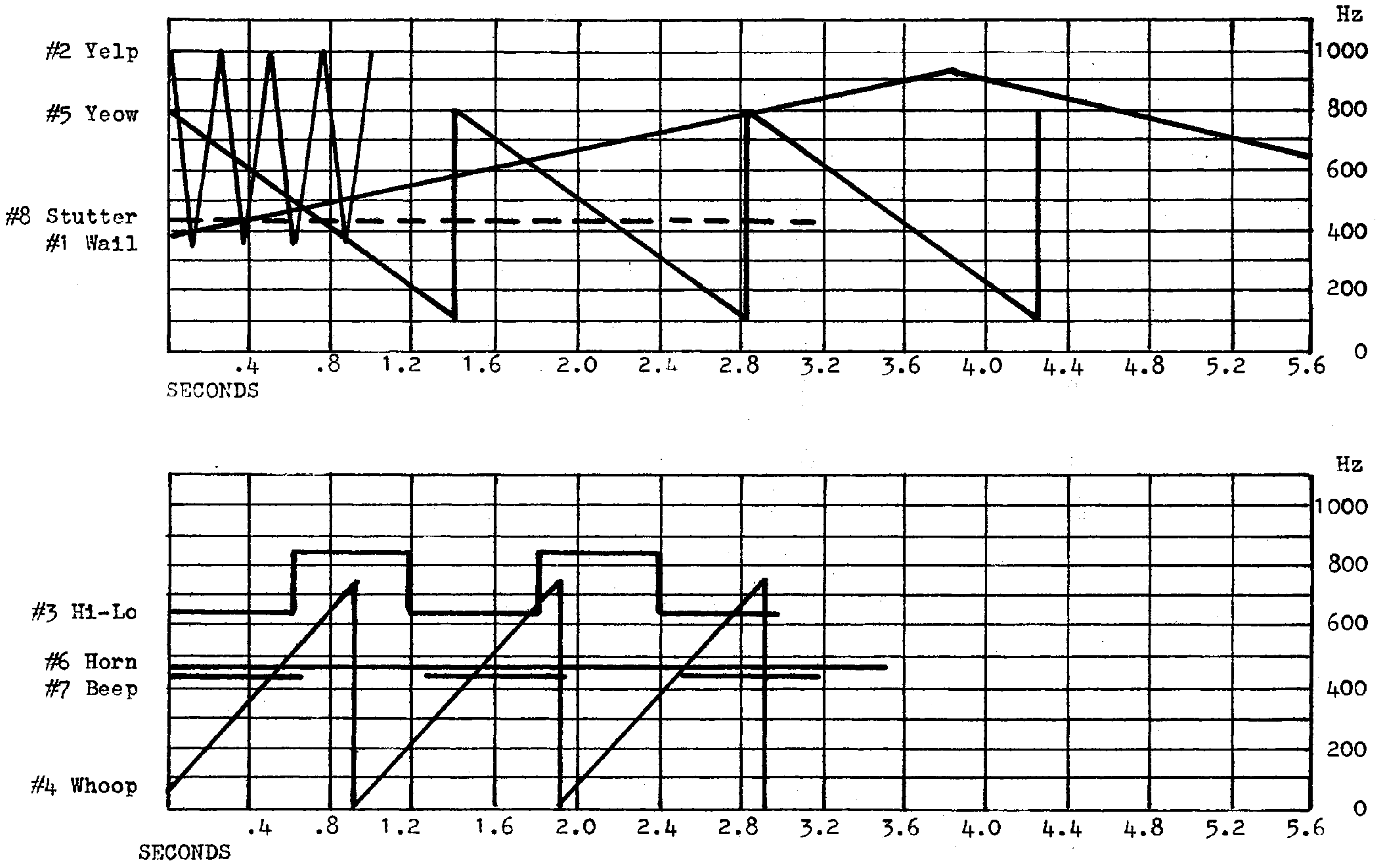


Figure 2. Selectone Signals

TABLE I

SOUND PRESSURE LEVELS OF FEDERAL SIGNAL SELECTONE 300 DK

	Sound Pressure Level, dB re .0002 dyne/cm^2											
				Octave Band Center Frequency Hz								
Signal	C Scale Level	A Scale Level	Over All Level	31.5	63	125	250	500	1K	2K	4K	8K
Wail #1	106	107	110	45	39	42	77	105	109	107	100	81
Yelp #2	107	108	109	46	43	42	72	102	103	104	98	82
Hi-Lo #3	108	109	112	46	39	30	56	99	109	106	99	83
Whoop #4	107	108	108	23	28	32	67	98	101	105	97	80
Yeow #5	108	109	109	49	48	50	63	99	98	106	97	81
Horn #6	106	107	108	45	40	39	76	99	105	99	96	81
Beep #7$^+$	108	109	110	47	42	34	71	86	108	101	91	75
Stutter #8^{++}	107	108	108	49	43	35	72	92	107	91	92	78

$^+$ Rate of signals 60/minute

$^{++}$ Rate of signals 150/minute

Equipment:

Measuring Amplifier	B&K type 2606 Serial #
Analyzer	B&K type 1613 Serial #316825
Calibrator	B&K type 4220 Serial #306336
Microphone 1",	B&K type 4145 Serial #334584

TABLE II

BAND LEVEL CONVERSION FROM FEDERAL SELECTONE 300 DK, dB TO SONES

	Band Loudness Index (Sones)							
Octave Band Center Freq.	Wail #1	Yelp #2	Hi-Lo #3	Whoop #4	Yeow #5	Horn #6	Beep #7	Stutter #8
31.5	0	.07	.07	0	.21	0	.12	.21
63	0	.21	0	0	.49	.07	.16	.21
125	.49	.49	0	0	1.13	.31	.07	.12
250	9.3	7.0	2.7	5.2	4.1	8.8	6.6	7.0
500	83.0	66.0	52.0	48.0	52.0	52.0	20.0	30.5
1K	139.0	90.0	139.0	77.0	61.0	105.0	130.0	121.0
2K	149.0	121.0	139.0	130.0	139.0	83.0	97.0	44.0
4K	113.0	97.0	105.0	90.0	90.0	83.0	56.0	61.0
8K	32.9	35.3	38.0	30.50	32.9	32.9	21.4	26.5
Sones (O.D)*	262.3	209.8	240.0	205.2	211.6	183.0	190.4	171.9
Phons (O.D)*	121	117	119	117	118	115	116	114

Calculation of Sones based on
ANSI S3.4 - 1968 and originally given by S. S. Stevens (151).

In Figures 3 through 10, a Fast Fourier Analyzer model 1923 was utilized to show the temporal aspects of each signal. Superimposed on each figure is a 1/3 octave band analysis made on a General Radio Real Time Analyzer model 1921.

The preceding data furnishes graphical representation of alert warning signals used in this study. With the exception of fire bells, these signals represent the current state-of-the-art of available equipment. With the growing emphasis on noise control, evaluation of the most effective signal for a given situation should serve to reduce the high intensities now employed to alert workers to potential hazards.

Since the study is directed toward field conditions rather than laboratory environments, the chosen noise signals, with their complex characteristics and wide usage in industrial facilities, provide general coverage of the actual problem.

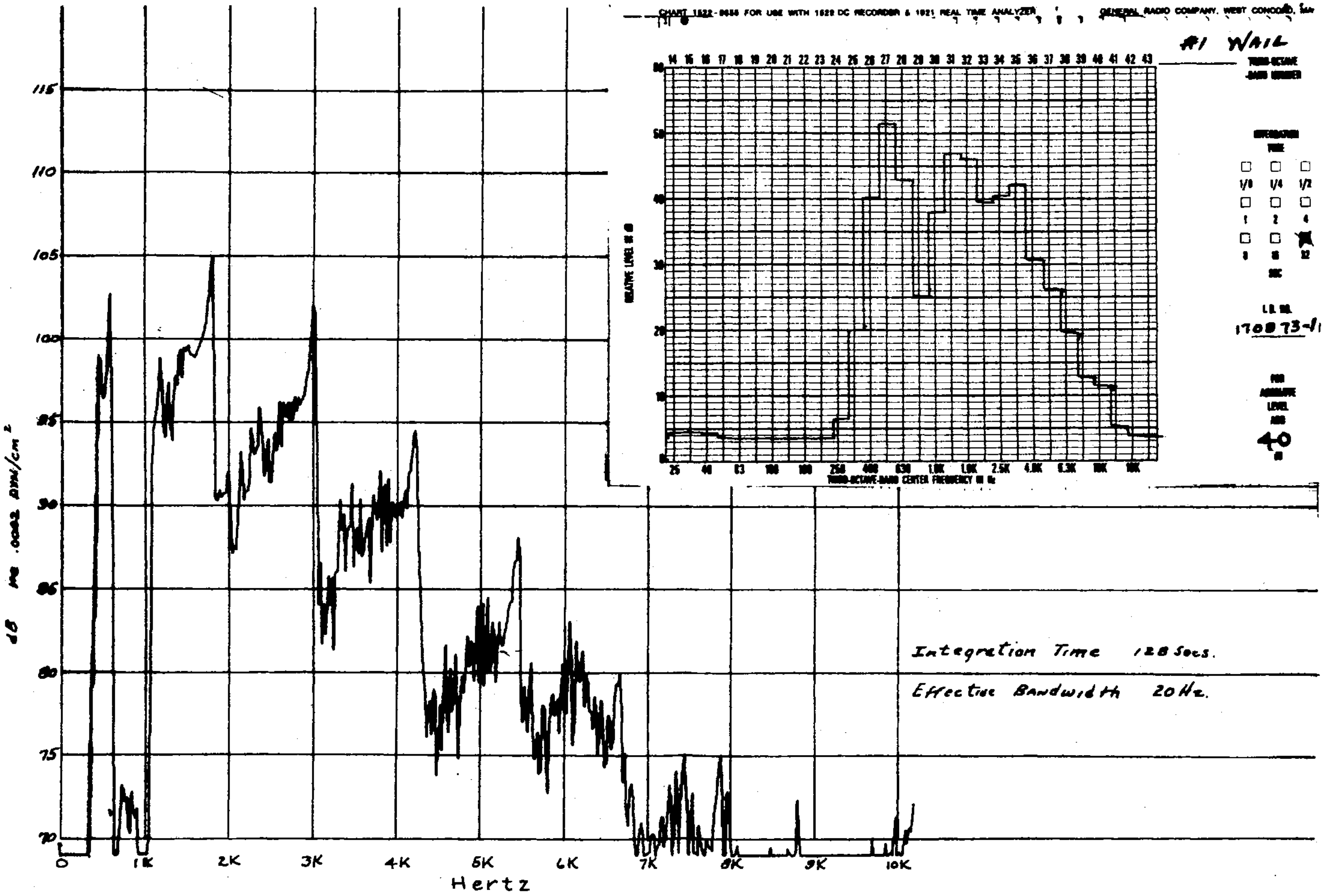


Figure 3. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #1 - Wail

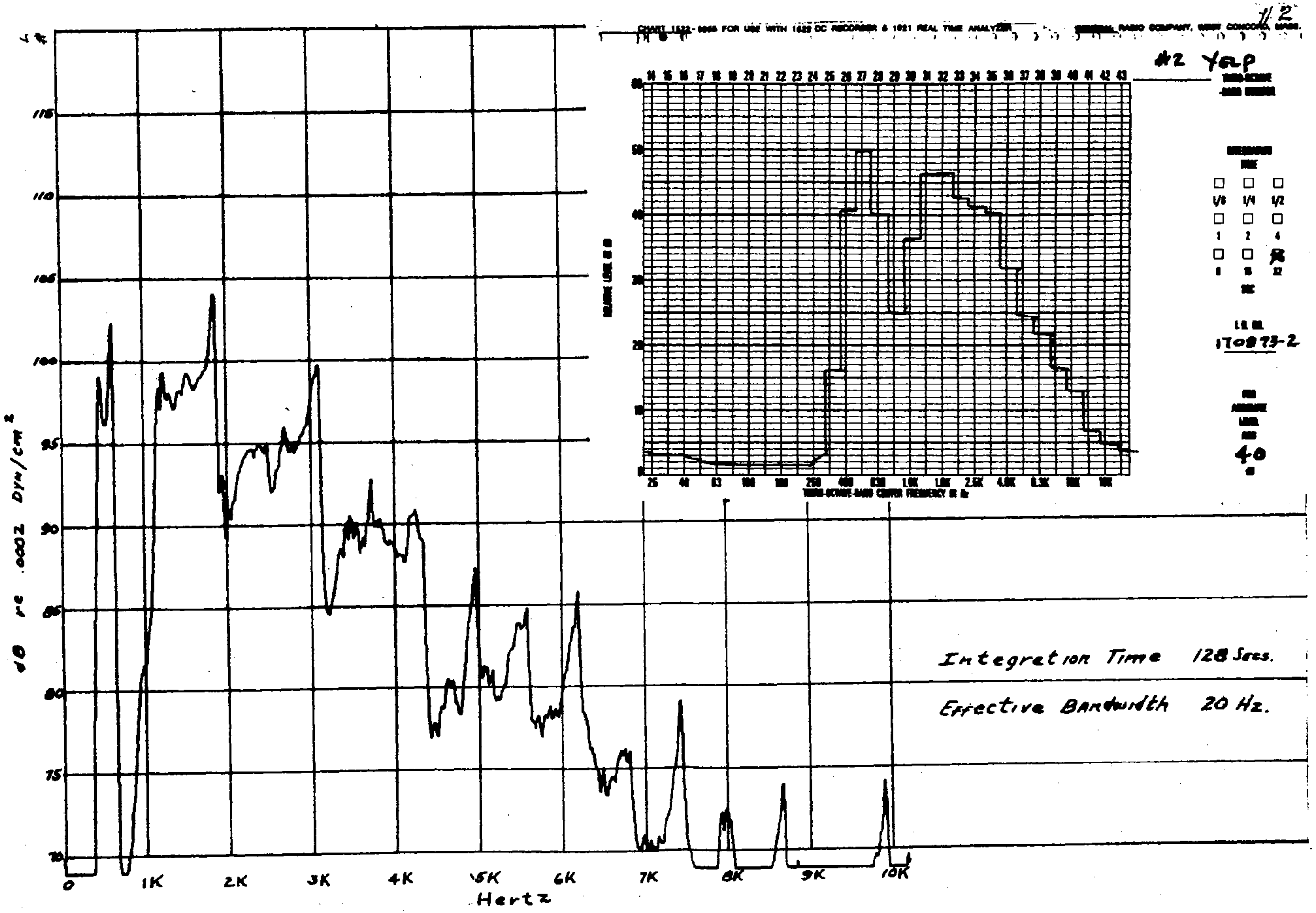


Figure 4. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #2 - Yelp

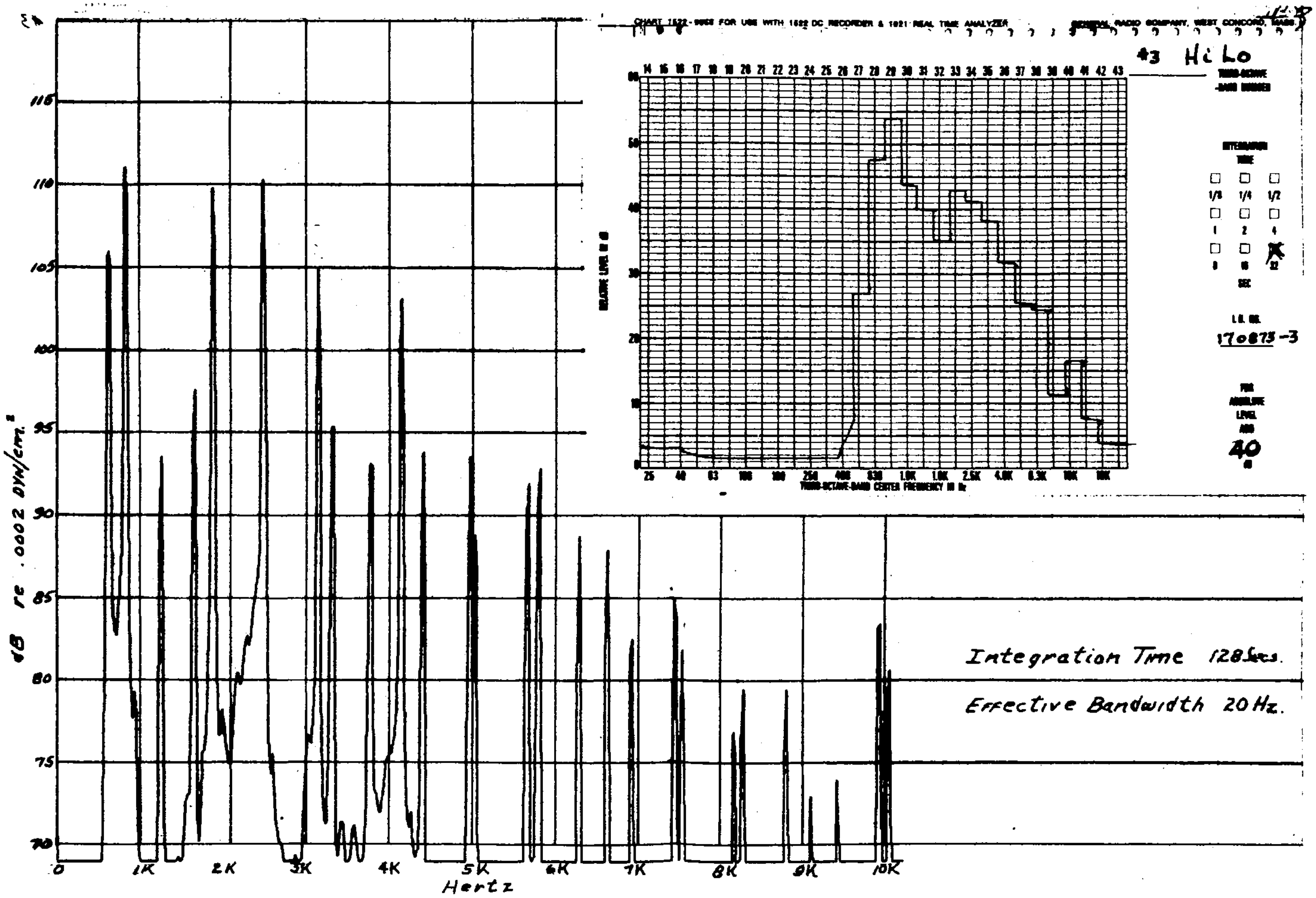


Figure 5. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #3 - Hi-Lo

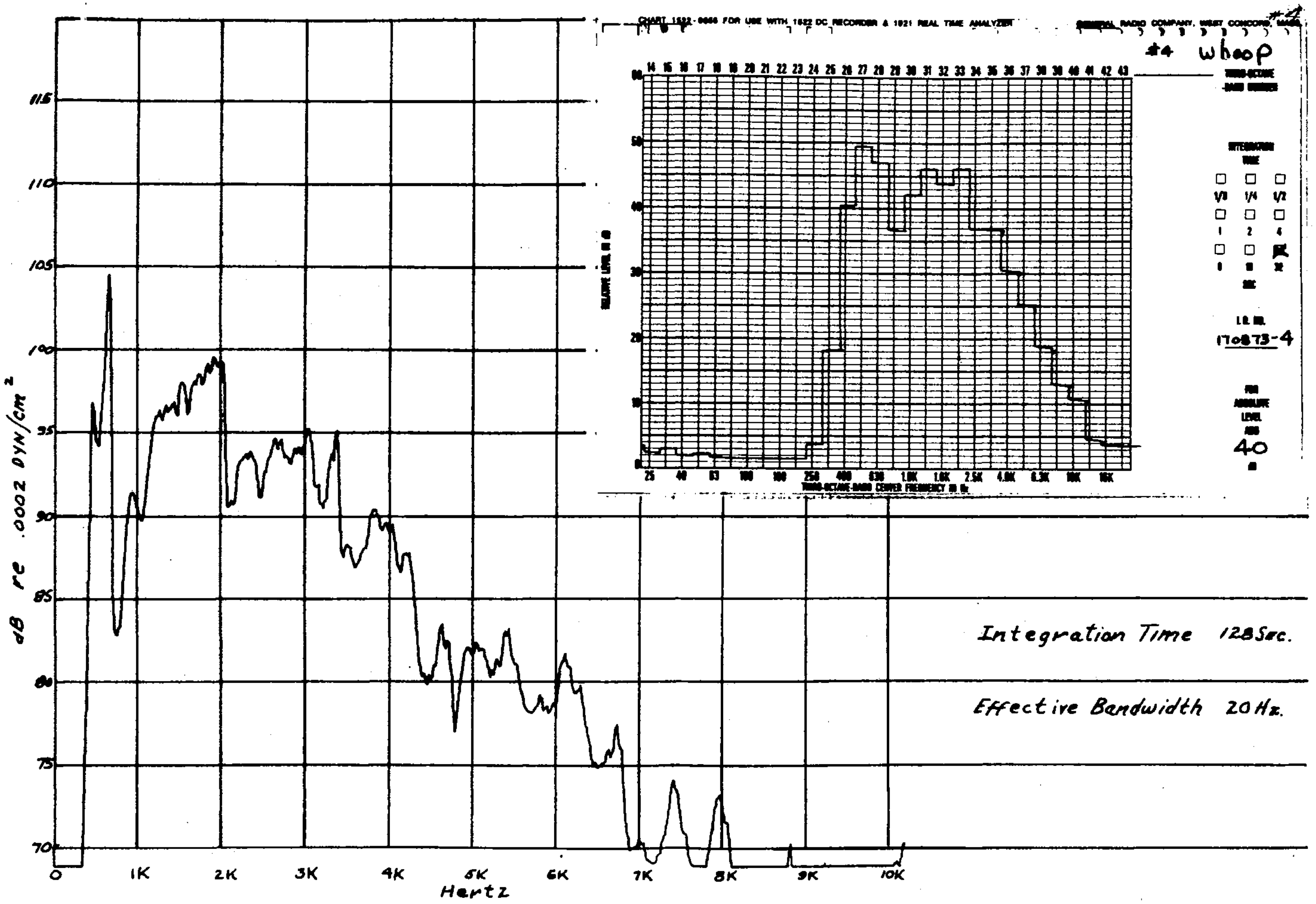
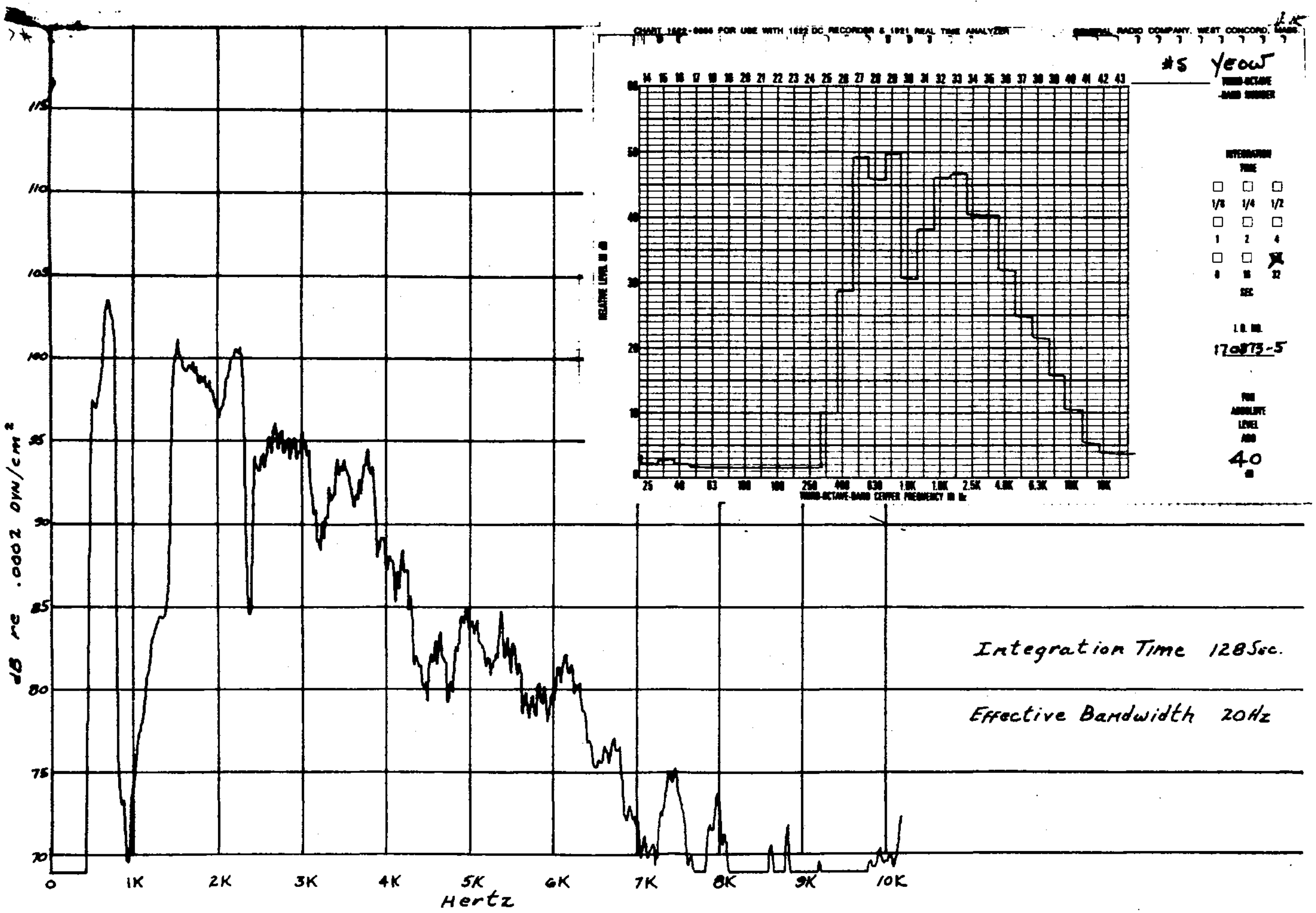


Figure 6. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #4 - Whoop



Integration Time 128 Sec.

Effective Bandwidth 20Hz

Figure 7. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #5 - Yeow

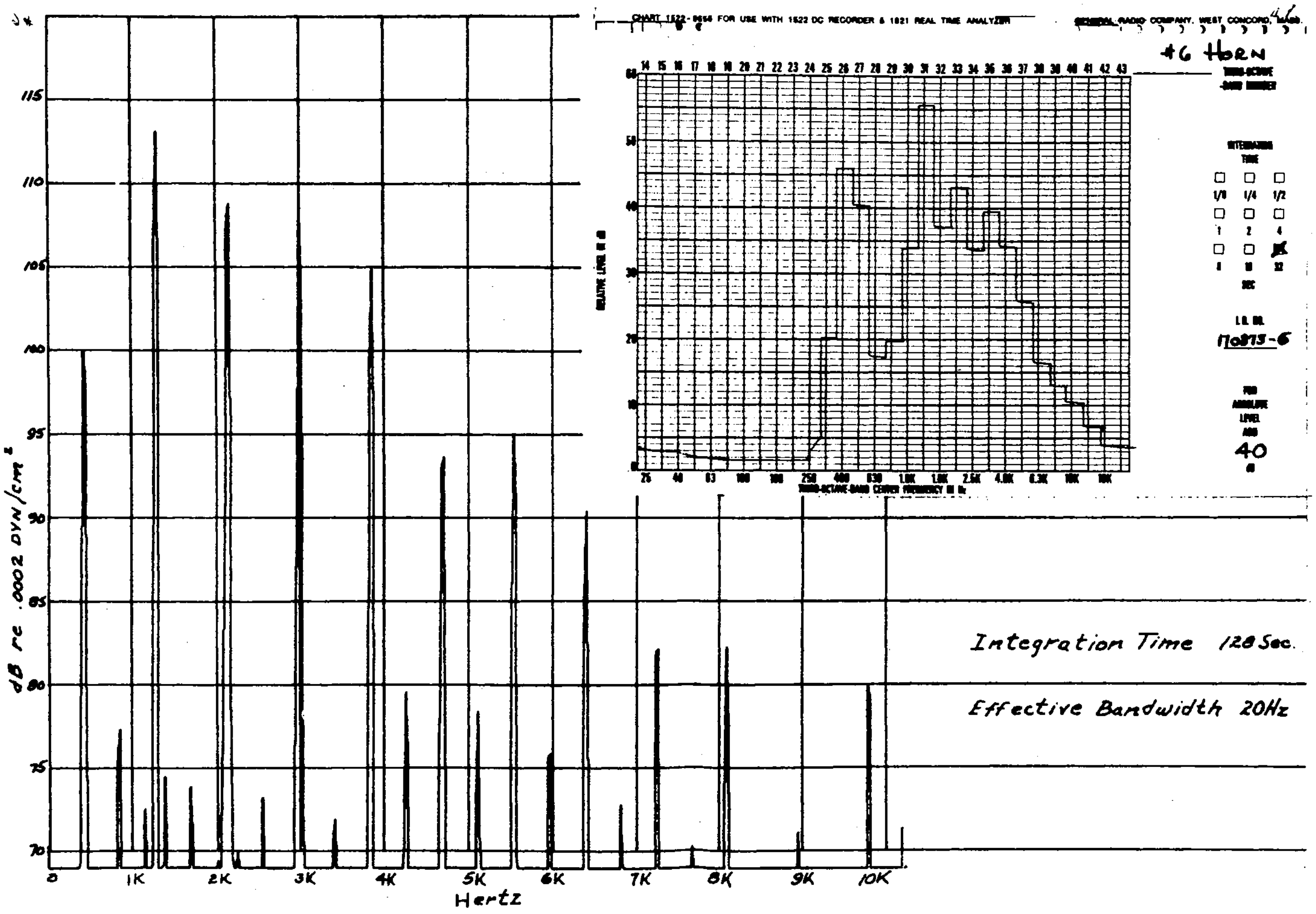


Figure 8. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #6 - Horn

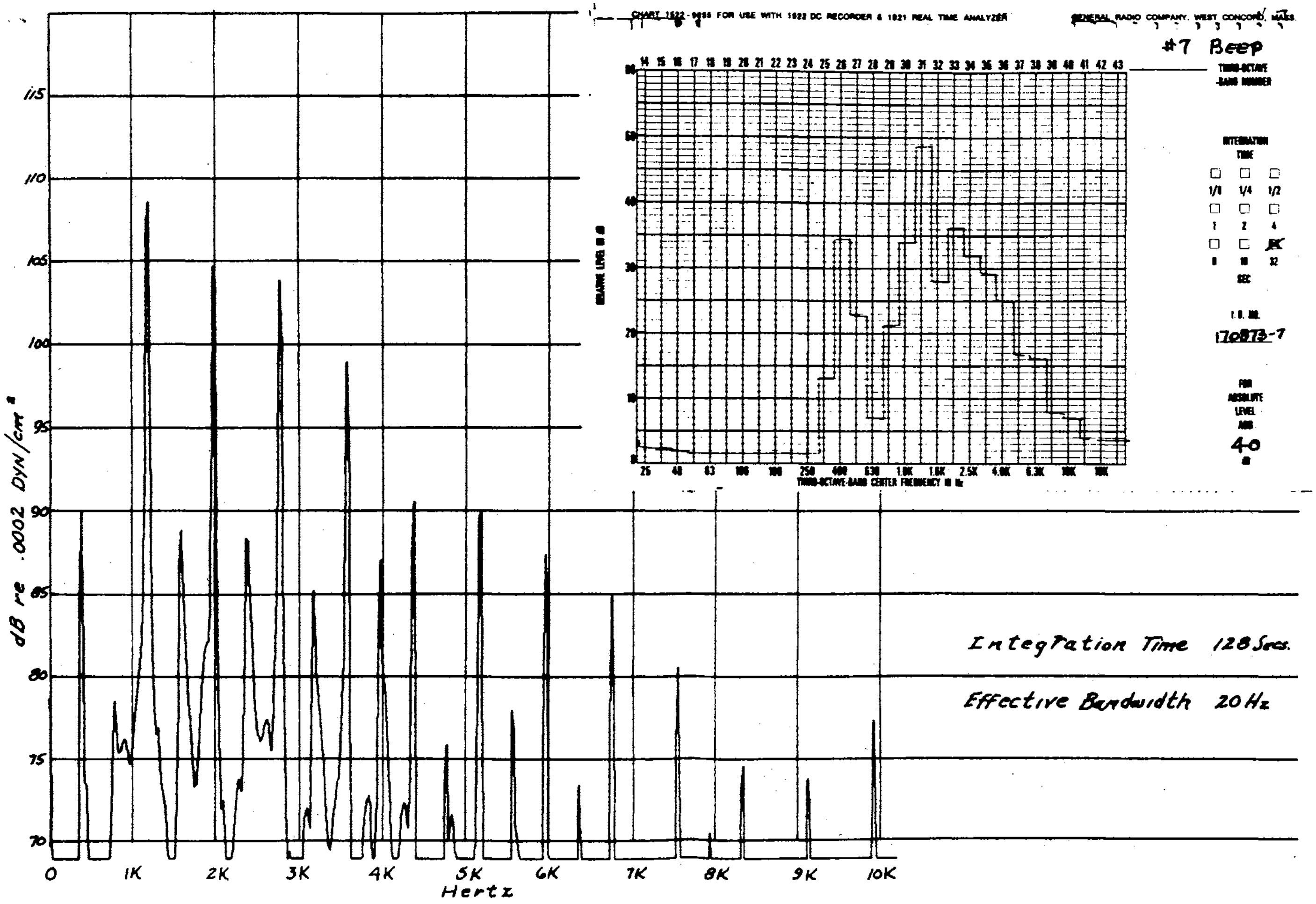


Figure 9. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #7 - Beep

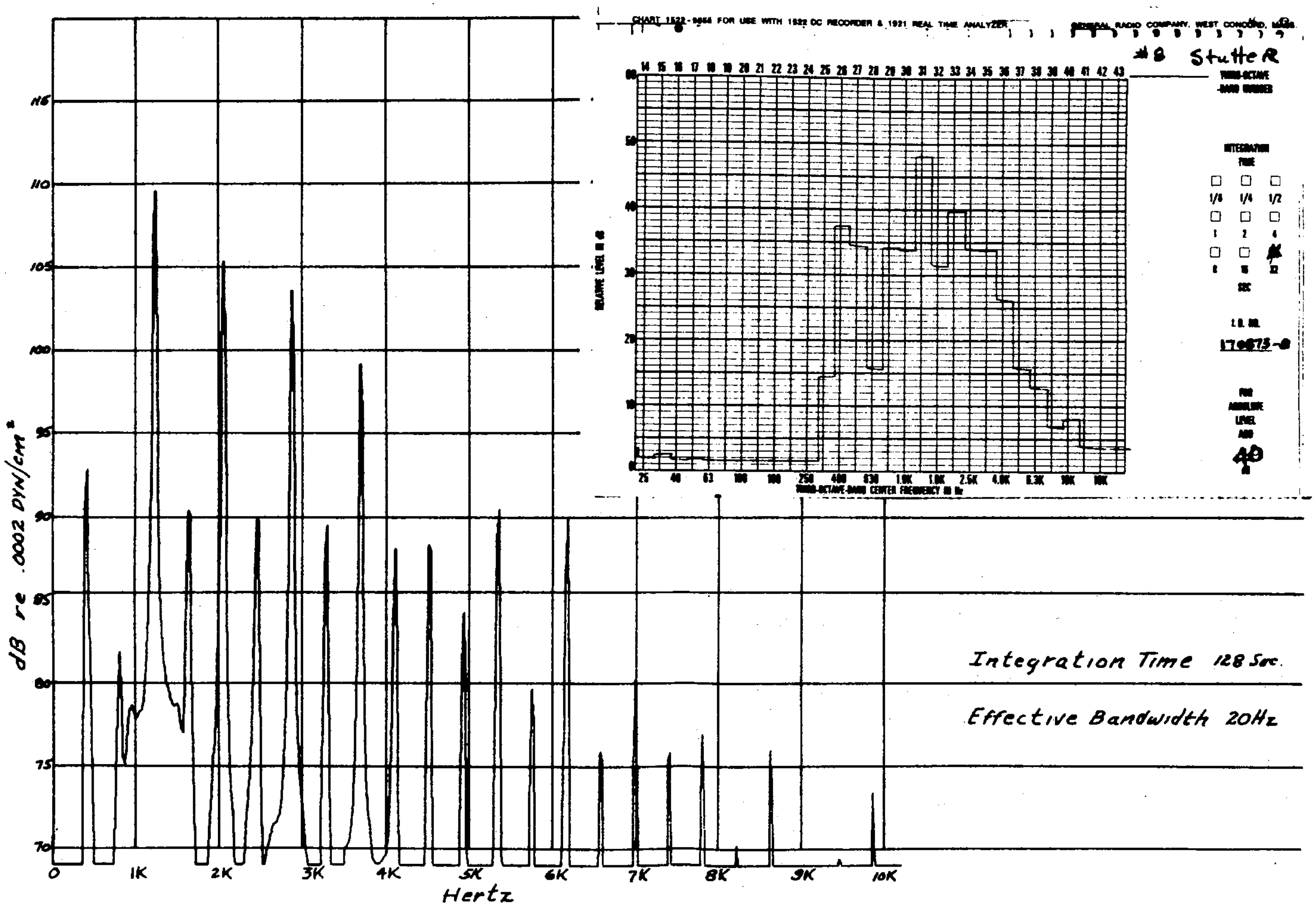


Figure 10. Frequency Plot and 1/3 Octave Band Analysis of Selectone 300 DK Signal #8 - Stutter

CHAPTER III

INDUSTRIAL ENVIRONMENTS

For an alert warning signal to be of practical significance, a representative sample of the environment used is necessary. In considering the range of extremely varied manufacturing facilities, the sound differences even in similar machines, the acoustical resonance differences in buildings, and the good or poor performance of individual operations, the composite of noise in industry is quite difficult to characterize.

Surveys of noise levels in industry indicate a great variation of sound pressure levels. In an effort to present a composite approach to industrial environments a number of studies have been made in the last 20 years. Measurements were taken by Karplus and Bonvallet [100] at about 600 locations in 40 different plants. The overall level and total loudness for each set of measurements were computed at each octave band. After appropriate conversions, the following summary of the Karplus and Bonvallet study can be made: more than 50% of the noise in surrounding areas as well as adjacent to machines was between 85-100 dB while total loudness was between 38 and 125 sones. The greatest contribution to the loudness was in the 4000 Hz band.

Another study of considerable importance was that of Yaffe and Jones [183] in which a number of manufacturing facilities in federal prisons were surveyed over a period of seven years as part of a study to evaluate hearing losses of the workers. Determinations were made of general overall sound pressure levels, octave band analyses and other measures. It was concluded that the octave band with the maximum loudness is 4000 Hertz. The number of sones varied from 36 at Leavenworth to 63 at Atlanta.

In 1968, a series of studies on industries in Oklahoma were made by the author and associates [96]. Readings were made on 1/3 octave band levels as well as overall dBA readings. Analysis of this data confirmed the findings of previous studies plus the concentration of loudness in the 500-4000 Hertz octave band.

In 1972 a study was made by Goodfriend and associates [71] for The Environmental Protection Agency. These readings were taken in 1/3 octave band levels and overall dBA sound pressure levels. There is again fundamental agreement with the previous studies.

In Table III, the data from all five studies, plus special information from certain contributing industries such as Textile and Power plants used as check references, is consolidated with respect to a weighted overall sound pressure levels per the Standard Industrial Classification (SIC).

In Table IV, a consolidation of some calculations is given from all studies by SIC codes. This verifies the concentrations of loudness in the 4000 Hz octave band. It also shows that industrial noise is concentrated between 500 and 4000 Hz, the same general bandwidth in which the human ear is most sensitive. An AWS then must compete in the area of greatest noise - with a major problem of masking as a consideration.

TABLE III

PERCENTAGES OF A WEIGHTED OVERALL SPL LEVELS BY STANDARD INDUSTRIAL CLASSIFICATIONS (SIC)

dB Range	SIC 20	SIC 22	SIC 23	SIC 24-25	SIC 26-27	SIC 28-30	SIC 31
60- 65						2	
66- 70					1		1
71- 75	9			1	3	2	
76- 80			7	1	2	8	3
81- 85	18	2	82	6	6	20	1
86- 90	23	22	7	6	23	6	40
91- 95	27	13	4	30	41	28	50
96-100	23	50		38	16	22	3
101-105		13		15	7	10	
106-110				2	1		1
111-115				1		2	
116-120							1
121-125							
126-130							
131-135							
No. Readings	22	167	26	186	93	50	190

TABLE III (Continued)

dB Range	SIC 32	SIC 33	SIC 34	SIC 35	SIC 36	SIC 37	SIC 49
60- 65							
66- 70	3		1				
71- 75		1			40		3
76- 80	6	1	3			2	1
81- 85	3	1	11	11	40	18	13
86- 90	23	10	15	20		30	13
91- 95	15	23	28	16	20	20	24
96-100	32	21	20	20		4	24
101-105	15	23	13	16		6	10
106-110		10	5	3		10	12
111-115	3	6	3	2		4	
116-120		3	1	5		2	
121-125		1				2	
126-130				5			
131-135				2		2	
No. Readings	34	68	149	61	5	50	104

TABLE IV

COMPOSITE OF SONES PER OCTAVE BANDS-- ALL SOURCES INCLUDED

	Octave Band Center Frequencies							
	63	125	250	500	1000	2000	4000	8000
SIC 20	17	30	41	40	34	34	27	25
SIC 22	20	33	55	60	52	46	55	50
SIC 23	5	12	18	17	17	20	30	32
SIC 24-25	10	20	32	46	48	47	62	58
SIC 26-27	15	26	36	43	34	35	37	33
SIC 28-30	20	26	41	50	43	46	60	70
SIC 31	17	27	32	33	34	34	37	30
SIC 32	33	50	62	72	65	80	110	90
SIC 33	29	42	57	73	79	100	140	130
SIC 34	33	31	58	90	103	110	125	110
SIC 35	9	20	36	45	43	45	56	52
SIC 36	1	7	18	17	15	12	6	4
SIC 37	50	80	125	180	180	155	150	130
SIC 39	70	57	70	80	68	79	72	70
	329	461	681	846	815	843	967	884

In selecting environments to provide typical situations found in industrial operations, many factors have to be considered. Average readings are relatively meaningless because first, decibels cannot be manipulated by simple arithmetic means. A composite of sounds would be of no value since each situation is unique. There are factors of changing speeds, the composite of operating machinery at any given time, resonance characteristics of buildings, and of major importance, the mix of jobs being performed from hour to hour in the production flow.

An approach was to select one series of environments in which intensity would be from low to high with increasing frequencies, another series in which the intensity would be from high to low with increasing frequencies, and two other environments in which are type curves from low intensity at low frequency rises in a decreasing slope to low intensity at high frequencies of 6000 to 8000 Hz. This pattern has been employed by Botsford [23] and, in a general way, by the National Institute of Occupational Safety and Health in selecting 100 of the Karplus and Bonvallet [100] noises as a fair approximation of the distribution of noise spectra and exposures for a major portion of American industry [99].

Environments chosen as representative are as follows:

Class A (#11) - Hydrogen atomic welding in a metal fabricating plant. Similar industrial noises are represented by:

Fabric cutter, garments	SIC 22
Paper folder, large sheets, noise due to worn parts	SIC 26
Pneumatic chipper, 100 psi, used on 1-3 foot castings	SIC 33
Chipping area	SIC 33
Riveting with mounted riveter jig, airplane assembly	SIC 37

Class B (#14) - Furniture factory in the areas of rough mill planers, jointers and saws. Similar industrial environments are:

Meat preparation room	SIC 20
Jointer, (16") on mill work	SIC 24
Furniture making, planers, jointers, saws	SIC 24
Printing, slotting area	SIC 26
Bloomer (Billet) mill area	SIC 33

Class C (#26) - In the spinning frame room of a textile plant, at a point between rows of spinners. The size of the room was approximately 80" x 150" with a concrete floor and no acoustic treatment on any of the walls or ceiling. Similar spectra industrial environments are:

Spinning frames	SIC 22
Reducing machines, 72 spindle	SIC 22
Preparers (for spinning)	SIC 22
Letter press, size 6/0	SIC 26
Ink mill, noise of worn parts	SIC 28

Class D (#30) - Large rotating drums in which tufting and filler materials for rugs is being dyed. The material is floating in a liquid and rotating at a relatively slow speed. Similar spectra of representative environments are:

Drum barker, tumbling logs	SIC 26
Tread tubers, making tire casings	SIC 28
Mixer, heavy chemicals	SIC 28
Clay crusher	SIC 34
Woven material washing area	SIC 22

Class E (white noise) - Generated by B&K #1402 Random Noise Generator but tape recorded from audible source. Spectra of industrial environments adjudged similar include:

Sausage kitchen	SIC 20
Furniture making, planers, shapers, molders at 15 feet from the operations	SIC 24
Cutting stone blocks, 48" saw	SIC 32
Back shear, four cutter, for 1/8" steel, operating	SIC 35

The original noises were tape recorded at the actual source and given preliminary analysis in an anechoic chamber. In the experimental data, other spectra were made in octave bands from the speaker output by a B&K #2204 sound level meter and B&K #1613 octave band analyzer at the position of the subject in the test room. On the 1" microphone a random incidence corrector was mounted. All equipment used is specified in Chapter IV. A tabulation of the sound pressure levels and conversions to sones and phons is indicated in Table V.

TABLE V

SOUND PRESSURE LEVELS AND CONVERSIONS BY BAND LEVELS FOR SELECTED ENVIRONMENTS

	Environment #11 Overall Level 93 dBA		Environment #14 Overall Level 99 dBA		Environment #26 Overall Level 94 dBA	
Octave Band Hz	Band Level dB	Band Loudness Index	Band Level dB	Band Loudness Index	Band Level dB	Band Loudness Index
31.5	56	.62	62	1.13	63	1.23
63	64	2.11	70	3.20	72	3.70
125	80	9.30	85	12.60	83	11.10
250	84	14.40	99	41.00	89	20.00
500	85	20.00	89	24.70	89	24.70
1K	89	30.50	85	23.00	86	24.70
2K	84	26.50	80	20.00	80	20.00
4K	84	32.90	70	12.60	73	15.30
8K	77	24.70	60	8.30	62	9.30
Sones Octave Diffuse		71.3		72.6		56.3
Phons Octave Diffuse		102		102		98

TABLE V (Continued)

Octave Band Hz	Environment # 30 Overall Level 97 dBA Band Level dB	Band Loudness Index	Environment - White Noise Overall Level 90 dBA Band Level dB	Band Loudness Index
31.5	69	1.96	64	1.33
63	93	17.30	74	4.30
125	91	18.70	77	7.80
250	89	20.00	84	14.40
500	78	11.80	83	16.40
1K	69	8.30	82	18.70
2K	63	7.00	82	23.00
4K	50	3.80	76	18.70
8K	48	4.10	67	12.60
Sones Octave Diffuse		41.9		51.7
Phons Octave Diffuse		94		97

Based on ANSI S3.4-1968 and originally given by Stevens (151).

CHAPTER IV

EXPERIMENTAL PROCEDURE

The purpose of the experiments was to determine the reaction time for subjects to various alert warning signals in the presence of simulated industrial environments.

Apparatus and Conditions of Experimentation: The Apparatus used in the experiments consisted of:

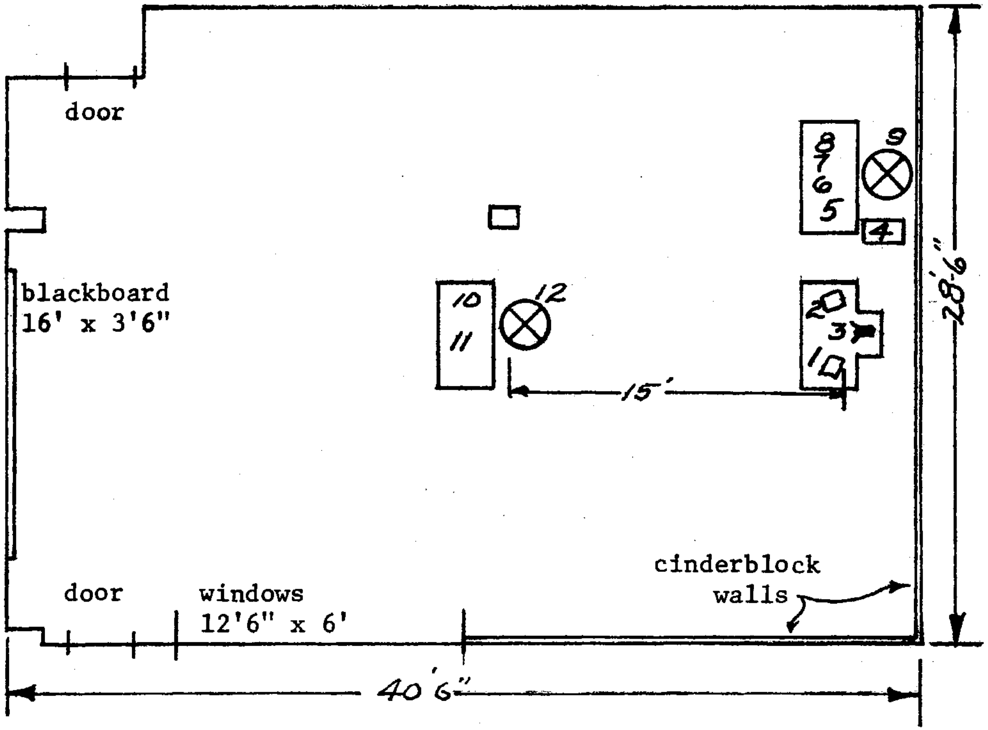
Test room. A laboratory approximately 40' x 30' x 10' height. Ceiling is concrete with open beams, floor is asphalt tile, walls are composition board except where noted on Figure 11. Remaining walls are painted cinder block. The volume of the room is 11,205 cu. ft. In the room are various tables, a table mounted conveyor belt, small bench type equipment, and material storage racks. Location of the subjects from the sound sources is 15 feet, based on the rule "a suitable distance between the noise source and the microphone is of the order of 2/3 $V^{1/3}$" [28, page 86].

Thus $\sqrt[3]{11,205} \times .66 = 15$ feet.

Ambient noise level of the test room was determined before each test and measured 39-40 dBA per the B&K 2204 sound level meter.

Equipment, Keyed to Figure 11:

1 and 2. Jensen Model 4 (8 ohms) Three way Speaker System, Serial #'s A-34912 and A-34914.



Legend

1. Jensen speaker
2. Jensen speaker
3. Selectone aws
4. Revox Tape Recorder
5. Reaction timer
6. System initiate button
7. Rheostat for aws
8. Regulated power supply
9. Experimenter
10. Response button
11. Purdue pegboard
12. Subject

Ceiling	9'10"
Floors	Asphalt tile
Walls	Composition board except where noted

Volume = 11,205 cu. ft.

Drawing scale 1/8" = 1'.

Figure 11. Test Room For Experiment

3. Selectone Demonstrator Model 300 DK made by Federal Sign and Signal Co., Blue Island, Illinois.

4. Revox Recorder, Type A77, Serial #78173, 100 watts made by Revox International, Germany.

5. Lafayette Multi-choice Reaction Timer, model 6302 BX, Serial #104420.

6. Locally assembled circuit board, including relays to initiate electronic timer on item 5 and AWS (item 3 above).

7. Rheostat - locally made to adjust intensity of AWS.

8. Lafayette Regulated Power Supply, model 83617, Serial #106968.

9. Response Key for item 5.

10. Lafayette Purdue Pegboard Unit, model 32020.

Other equipment used in preparation and operation of experiments:

B&K Impulse Precision Sound level meter Type 2204, Serial #338859.

B&K Condenser Microphone Cartridge, Type 4145, Serial #334584.

B&K Octave Filter Set, Type 1613, Serial #339438.

B&K Pistonphone Calibrator, Type 4220, Serial #347335.

Lafayette Voice Reaction Time, Model 6602A, Serial #102955.

B&K Random Noise Generator Type 1402, Serial #408445.

The experiment was conducted in the late afternoon or evening to avoid disturbing classes as well as to reduce external noise from outside the room. Figures 12 to 14 show the experimental set-up.

The two Jensen speakers are on the left and right, mounted on 1" felt pads. The AWS is located between the two speakers. Height of the unit is parallel with the head of the subjects. Both speakers are directionalized to the subject (Figure 12).

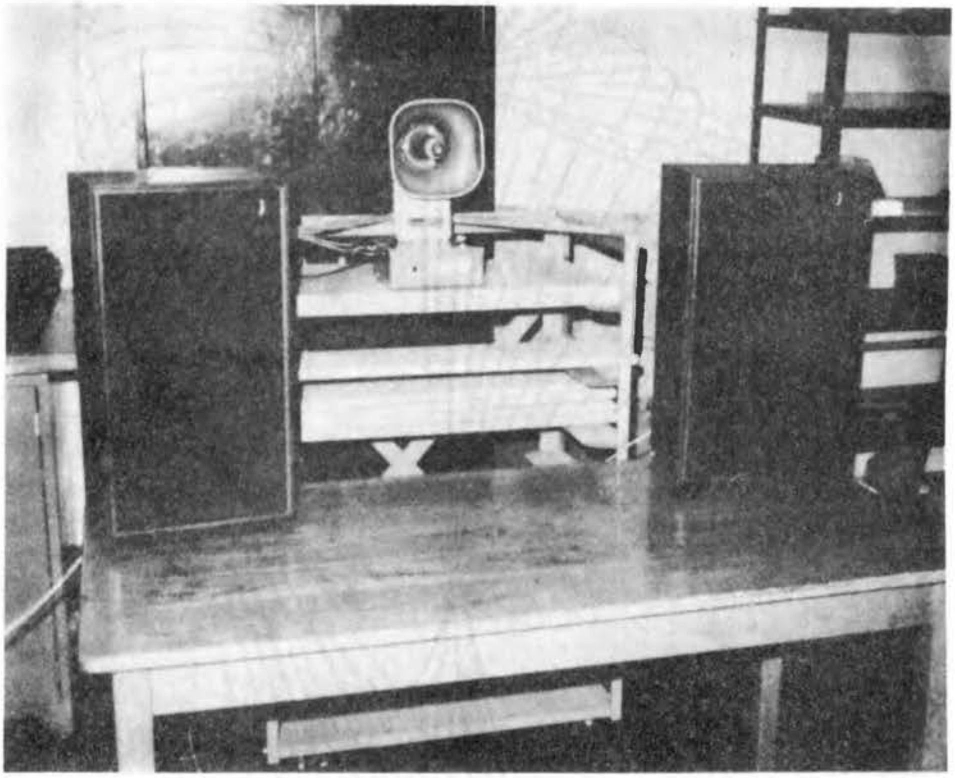


Figure 12. Environment and aws Arrangement

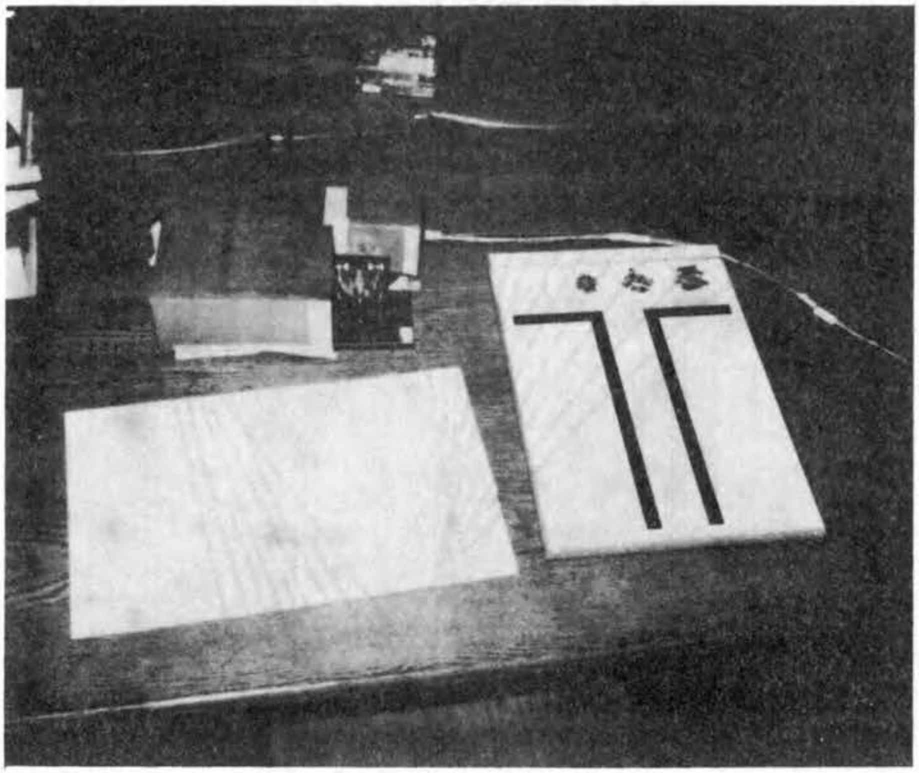


Figure 13. Position of Subject During Experiments

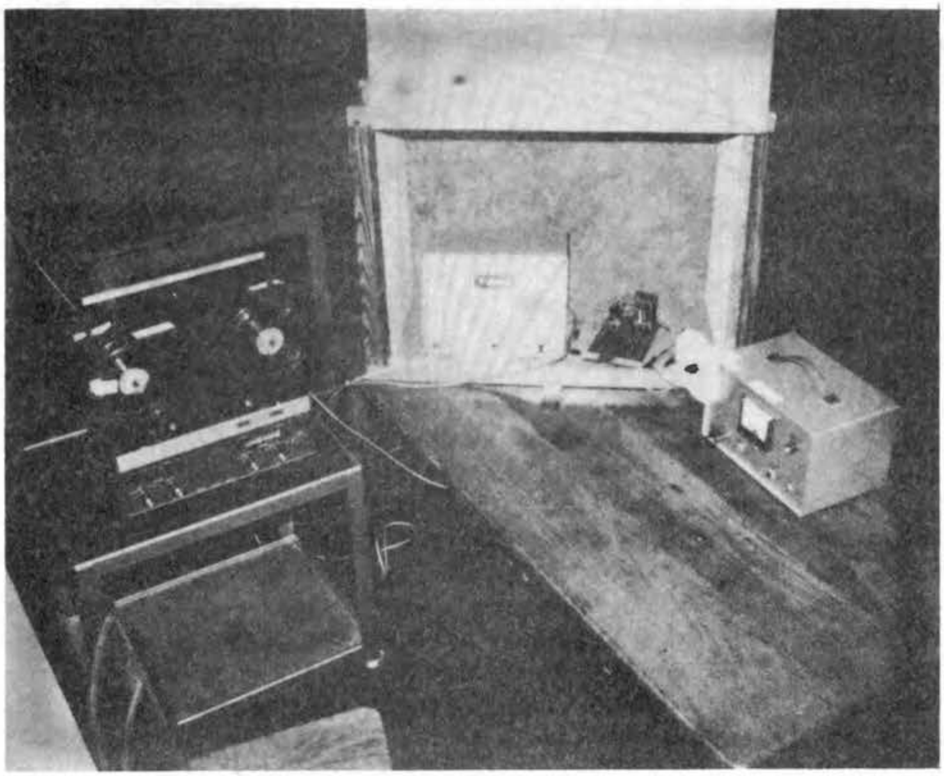


Figure 14. Experimenter's Position

The subjects faced this table, on which are situated the Purdue Pegboard unit, the response key, and a pad to record performance in inserting the pins, collars, and washers during the experiment. The sources of environment and AWS noise are located 15' to the rear of the subject (Figure 13).

In performing the experiment, at the onset of the environment noise, the subject began placing the pins, collars, and washers in sequence, in the pegboard as rapidly as possible. If the subject was right handed, the right hand placed the pins while the left hand was in close proximity to the response button, thus reducing variable movement time of the response. Although some variation existed, most subjects placed 50 pins, 42 collars, and 35 to 50 washers during the 4 minutes of each test per signal. At the conclusion of each signal, the record of placements was recorded. For each subject a practice period for familiarization with pin placement occurred before the actual test.

On the left was the Revox recorder through which the industrial environments were played using the Jensen speakers. The large box in the center contains the Lafayette Reaction Timer, with clock reading in hundredths of seconds. To the right of the timer is the circuit board, including the system initiate button. Outside the box is the power supply unit. On the left of the power supply unit is the locally made rheostat (in 20 major divisions) to control the intensity of the AWS (see Table VI). There is no audible transfer of the equipment operation noise to the subject since the wooden box is lined with 1" fiberglass mats.

Test Procedure:

1. Set recorder to position for desired environmental background

2. Choose appropriate signal on AWS unit.

3. Adjust rheostat for AWS to desired intensity. The dial has previously been calibrated (see Table VI) at the position of the subject in the test room. An octave band analysis of the AWS in the test room is shown in Table VII.

4. Initiate environment by tape recorder.

5. S begins to place pins in pegboard.

6. Initiate AWS and clock simultaneously by system initiate button.

7. Upon perception, S pushes response button, thus stopping timer and AWS.

8. Block of 5 readings made on each intensity of each signal. Intensity of signal is varied by block-up and down method, i.e., highest intensity on first block, lowest intensity on second block, then alternately next highest and lowest intensities, thus converging toward center of intensities by alternating high and low.

At conclusion of each signal test, S records amount of pins, collars, and washers placed during test.

In every case, exposure to environment and AWS was limited to one complete run of eight signals per day to avoid threshold shift of subject.

All subjects were given audiometric tests at the Auburn Speech and Hearing Clinic. A list of subjects with details of each audiogram is given in Appendix D.

TABLE VI

FEDERAL SELECTONE RHEOSTAT SETTINGS IN dBA

Rheostat	Signal							
Setting	#1	#2	#3	#4	#5	#6	#7	#8
20	104.	104	107	104	106	100	102	103
19	98	98	100	100	101	98	97	101
18.75	93	92	96	93	94	90	90	92
18.50	89.5	87.5	91	88.5	90	87	87	89
18.25	87.5	85.5	89	86	87.5	86	85	87.5
18.00	84	82	85	83	86	85.5	83	86
17.5	83	81	84	82	82	81	79.5	80.5
17.0	81	79	82	80	81	80	77.5	79
16	78	76	81	76.5	77	76	75	74.5
15	76	74	78	74.5	75.5	76	73	74
14	74	72.5	77	72.5	73.5	74	72	72
13	73	71	76	71	72.5	73	71	70
12	71.5	70	74	70.5	71	70	70	68
11	70	68.5	73	69	70	70	68	67
10	69.5	67.5	72	68	69	69	66	65
9	68.5	66.5	71	67	68	68	65	64
8	68	66	70	66.5	67	67	65	64
7								
6	67	65	68	65	66	66	64	65
5								
4								
3	66	63	65	64	65	65	63	62.5
2								
1	65	62	63	63	64	64	62	62

aws is 15' to rear of subject in test chamber. Reading made with B&K #2204 S.L.M. #338859 using 1" microphone B&K 4145 #334584 with random incidence corrector.

TABLE VII

OCTAVE BAND ANALYSIS OF ALERT WARNING SIGNALS IN TEST ROOM

Signal	Sones Octave Diffuse	Octave Bands								
		31.5	63	125	250	500	1K	2K	4K	8K
2	77.26	53	55	64	67	92	87	91	83	68
1	82.92	54	54	55.5	70	95	89.5	91	84	67
7	84.09	53	52	54	73	85	96	90	83	69
8	104.73	62	64	64	76	91	97	94	88	73
6	128.73	44	43	43	75	93	102	90	87	79
4	145.00	66	67	69	75	102	97	99	89	76
5	145.01	64	65	64	67	102	96	99	90	77
3	161.03	64	61	62	69	102	97	102	87	80

CHAPTER V

EXPERIMENT AND RESULTS

The data collection portion of the study was conducted over a six month period. The subjects, as indicated in Appendix D, were given an audiometric test prior to their use in the tests. Selection of subjects was based on their prior experience in industry while cooperative education students or from summer employment.

Tests were made in the late afternoons and early evening hours to avoid noise sources other than those established by the experiments. Use of an anechoic chamber was ruled out because actual industrial environments have very similar characteristics to the test chamber as indicated in Figure 11. Each subject was questioned regarding his noise exposure the preceding twenty-four hours prior to the tests and in every case, no excessive exposures had been experienced. Each subject was instructed as to procedures of the Purdue peg-board test and, prior to the first test being administered, was given a practice period of fifteen minutes to become familiar with the task.

In each test, a close record was kept of the number of pins, collars, and washers placed on the board. This information was examined with respect to the actual testing time. Results indicated a consistency among subjects, as well as a good effort in maintaining attention to the task and not anticipating the signal. A thorough explanation was given as to the objective of the test and each subject instructed "when you hear the signal press the reaction button as rapidly as possible." Attitude of the subjects toward performance on the tests was excellent.

A study was made of octave band or 1/3 octave band environmental spectrums as recorded in thirty-two manufacturing establishments in Oklahoma and Alabama. From these studies as well as a review of other environmental data [100, 183, 71] five environments were selected as representative of industrial noises (see Figures 28 through 32).

The recorded data (see Table IX, Appendix E) reflects a rank order in reaction time for each signal in each environment. As the study progressed, it appeared that the tabulated data did not conform to established knowledge in psychoacoustics [5, 12, 28, 39, 55, 73, 80, 106, 154, 162, 175]. It was obvious that some major element had been overlooked. A special study was made of onset time of each signal by use of a Fast Fourier Transform analyzer. The results indicated that onset time of each signal varied considerably therefore the originally recorded reaction times should be adjusted.

The Fast Fourier Transform (FFT) computer unit plotted in units of .0125 seconds, a series of 10,240 impulse per second from each signal. The signal was located in an adjacent room. The plots showed peaks of intensity for each signal per various time units. Simultaneously on an oscilloscope, a photograph was made of time intervals of zero to one second and a second photograph was made of the chosen interval of interest which provided a more exact placement of onset of the signal. Figures 15 through 22 indicate the oscilloscope photographs for each signal. For each figure, the ordinate scale is signal intensity, which was held constant for all signals.

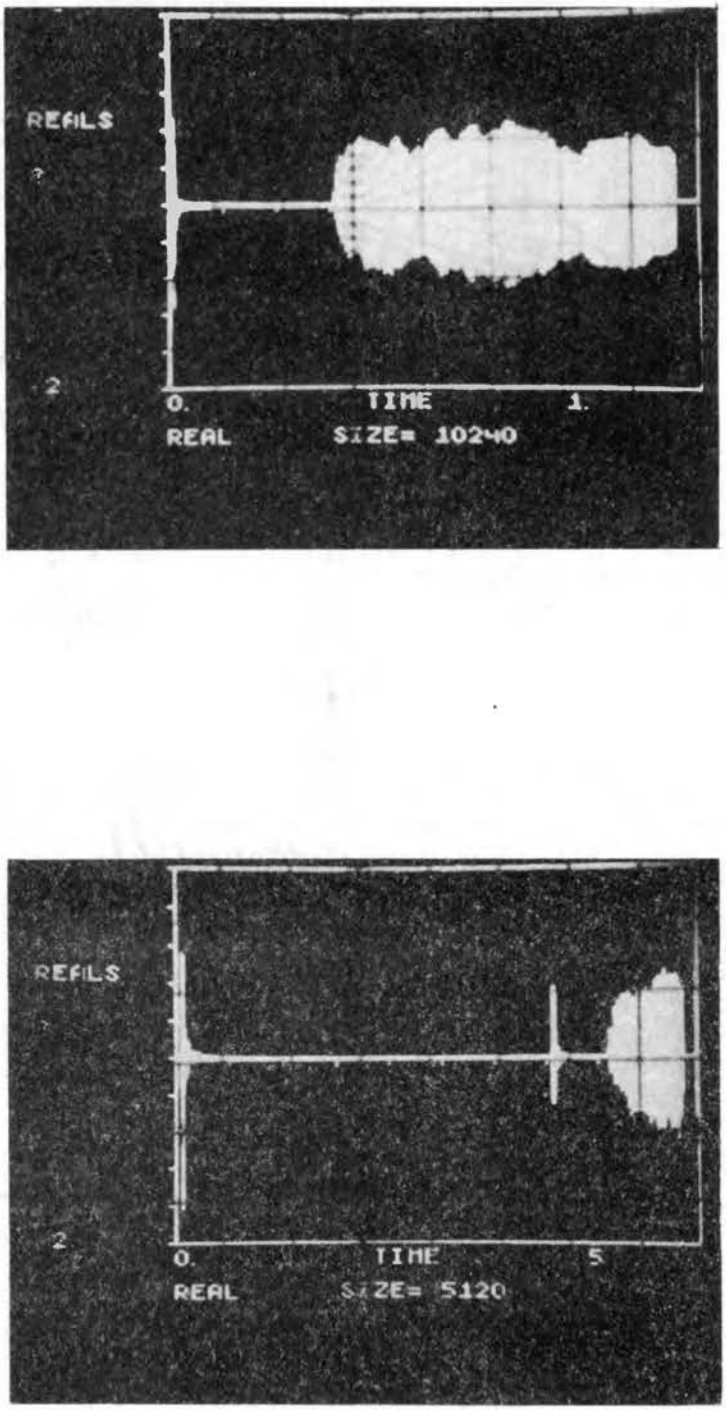


Figure 15. Onset Time for Signal #1

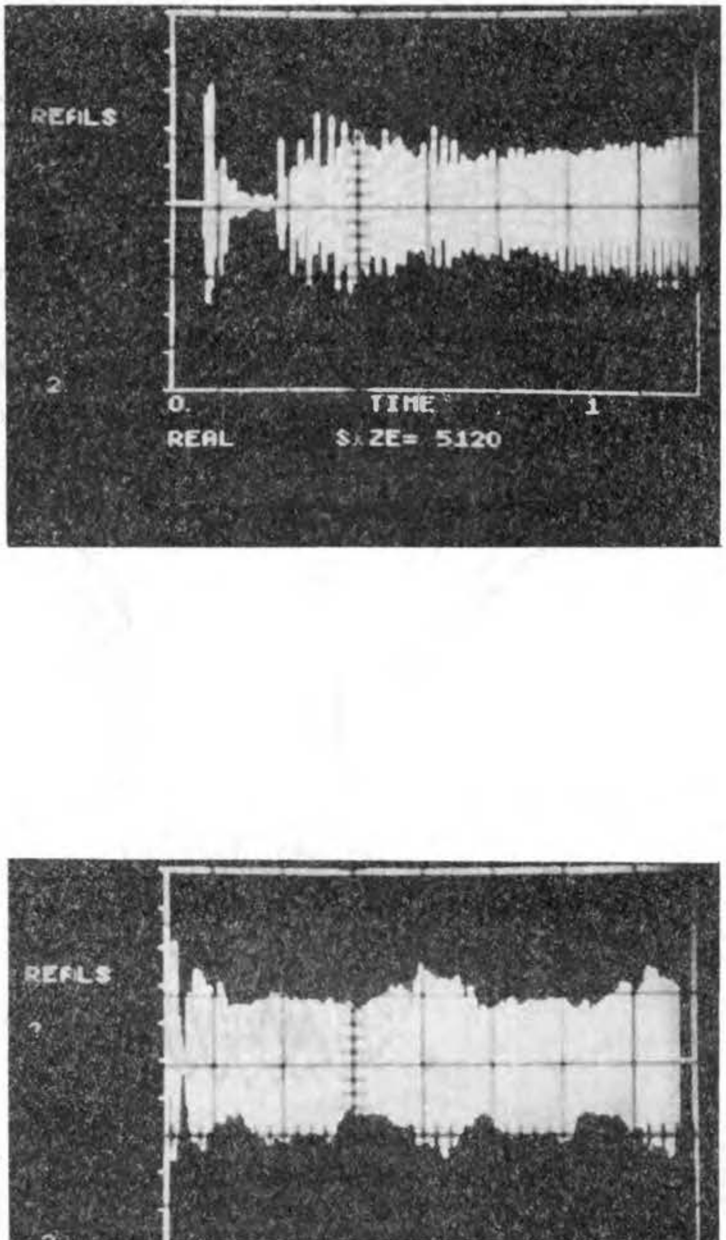
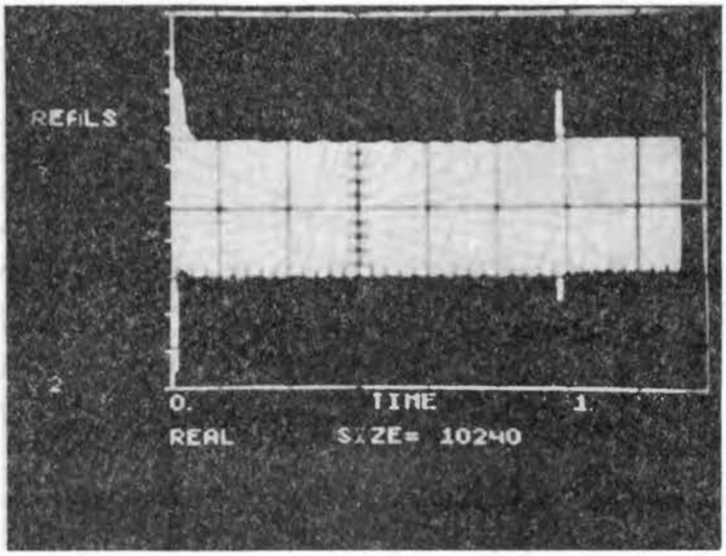


Figure 16. Onset Time for Signal #2



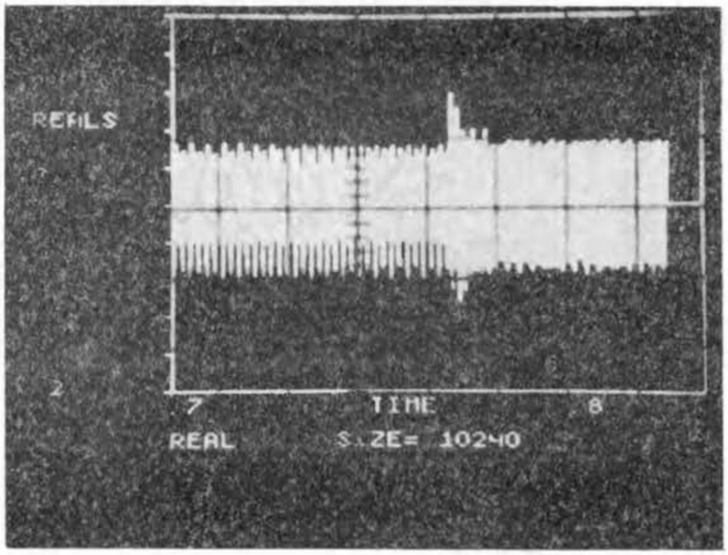


Figure 17. Onset Time for Signal #3

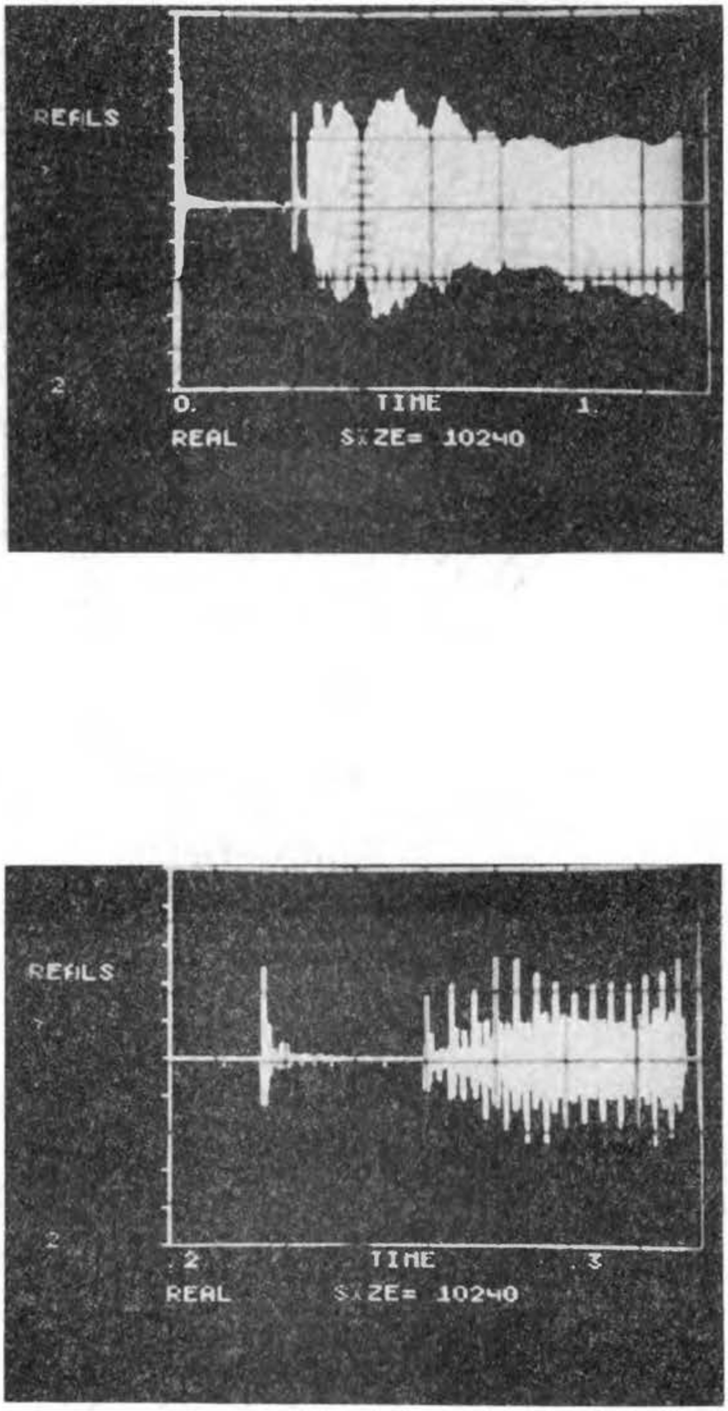
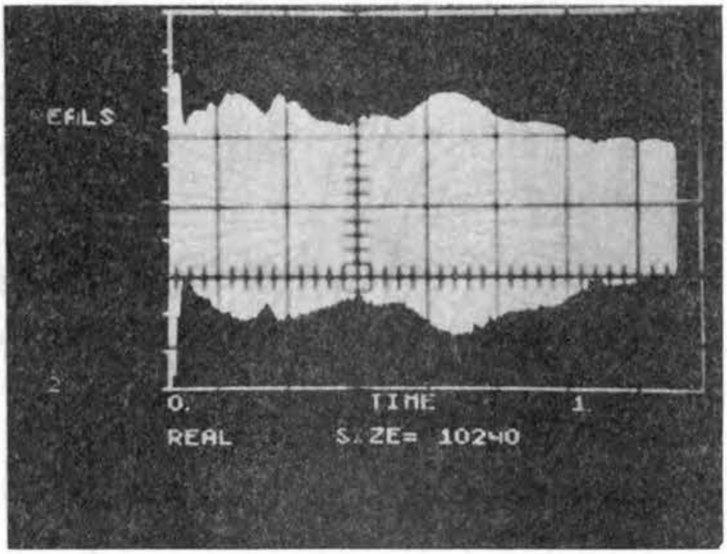


Figure 18. Onset Time for Signal #4



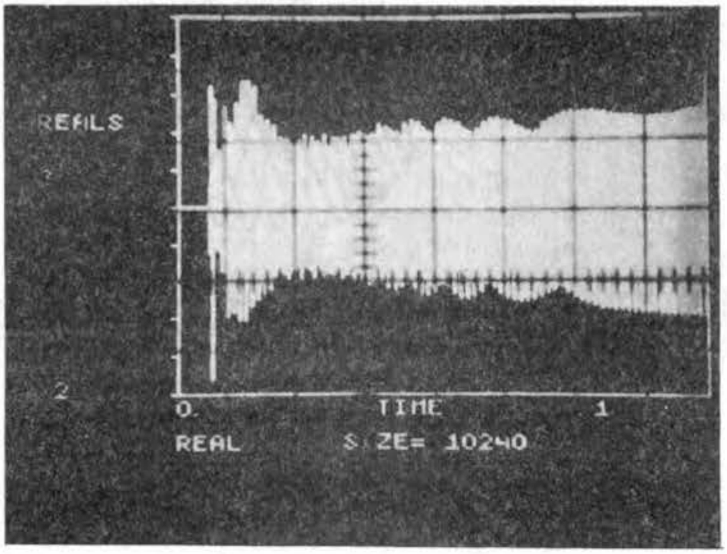


Figure 19. Onset Time for Signal #5

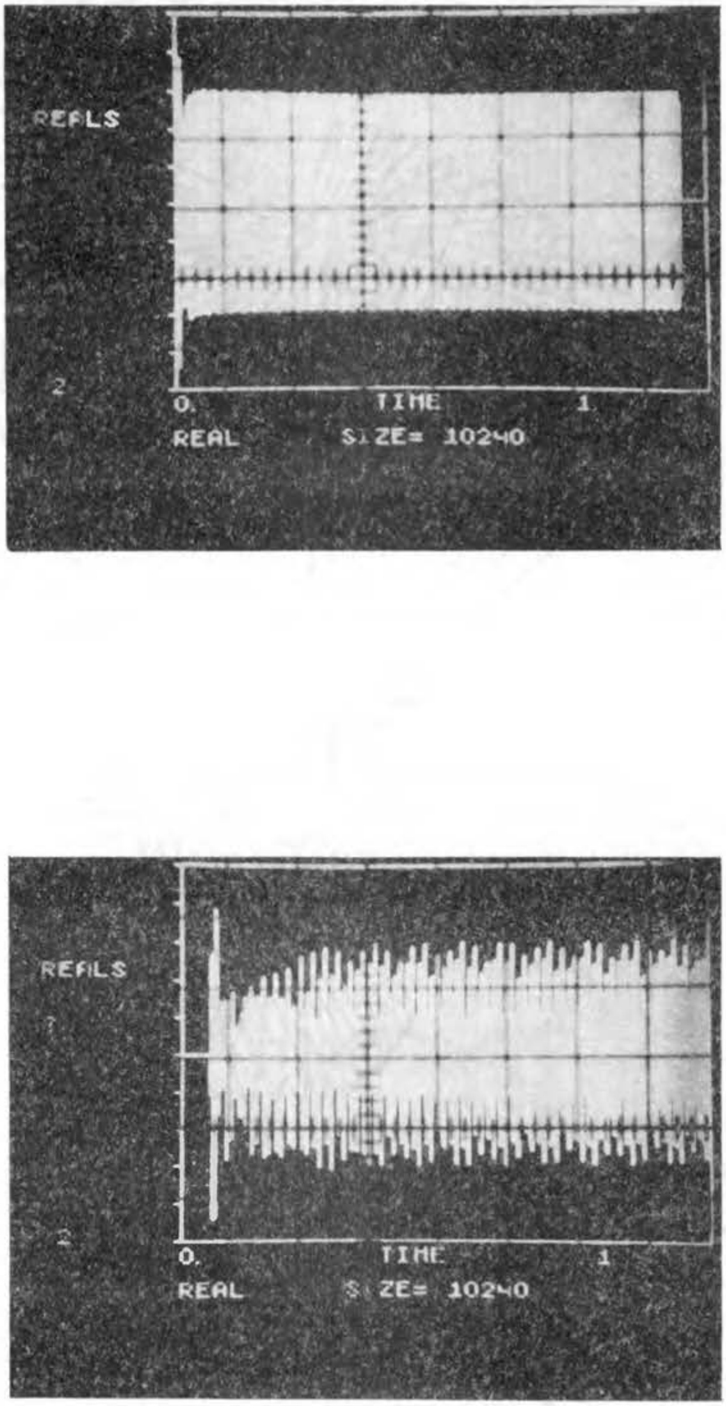


Figure 20. Onset Time for Signal #6

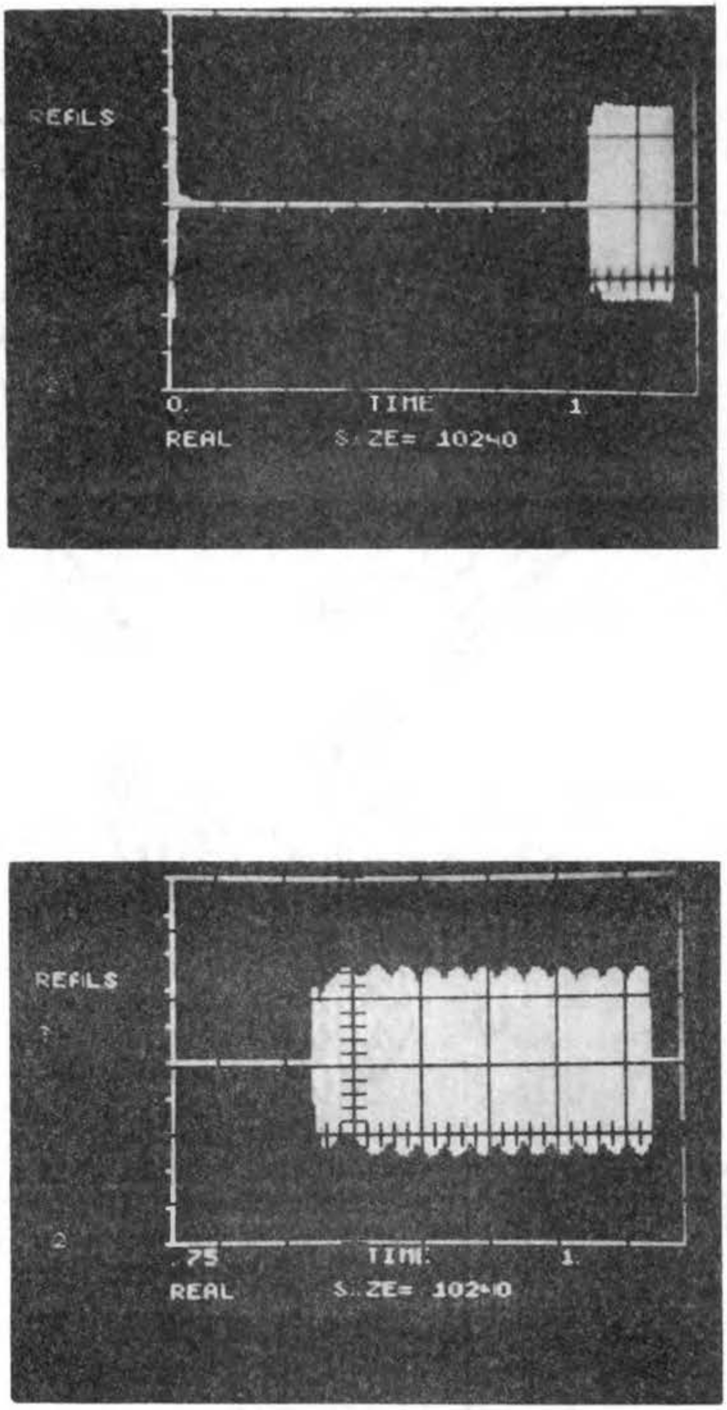


Figure 21. Onset Time for Signal #7

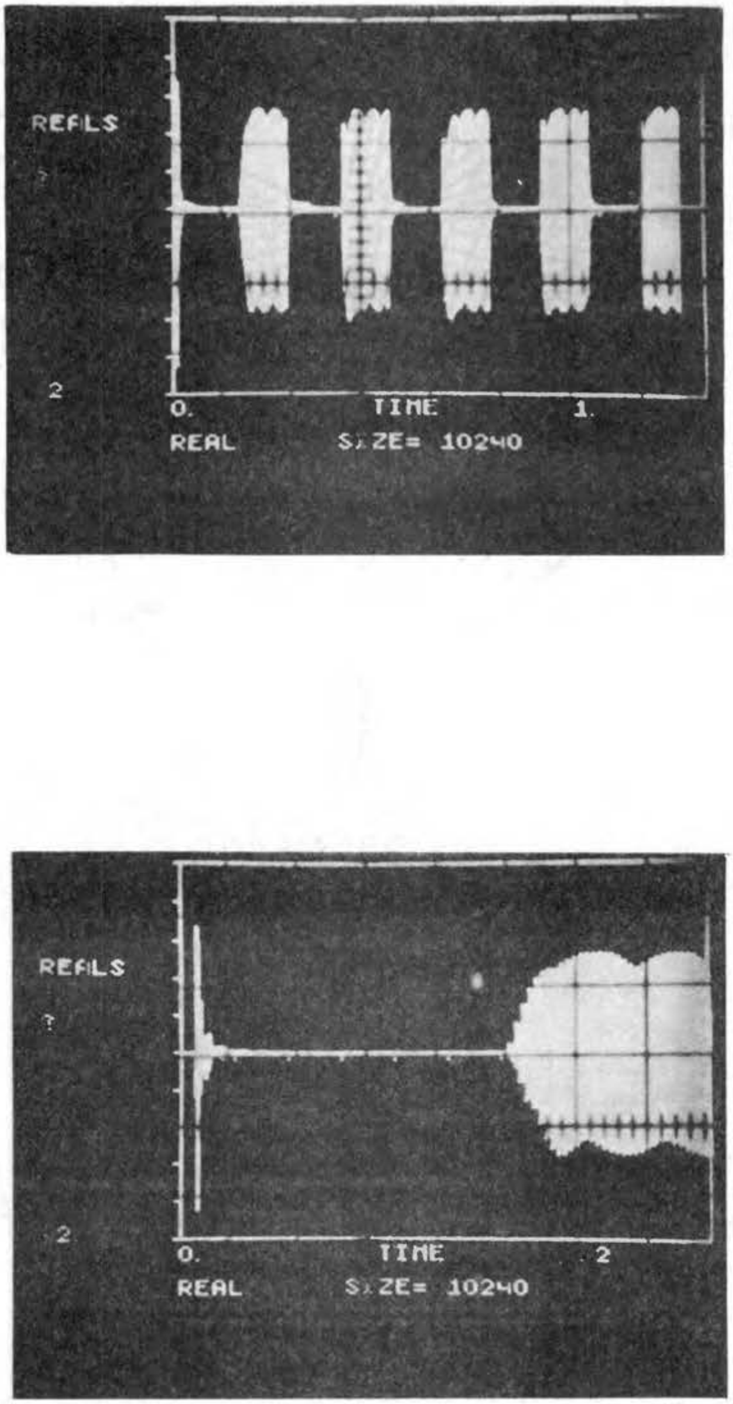


Figure 22. Onset Time for Signal #8

Onset times for each signal, subtracted from the data of Table IX, are indicated in the Data Summary, Table XI in Appendix E. The adjusted mean reaction times shown indicate confirmations of general psychoacoustics knowledge for reaction time increases with decreases in intensity. Figures 23 through 27, showing reaction time versus intensity, confirm the relationship.

Variations of the reaction times for preferred signals calculated on the basis of a 95% confidence interval yield, at $x = \bar{x}$:

	LCL	Mean R.T. Value	UCL
For Environment A (#11) Signal 7	.176	.290	.453
For Environment B (#14) Signal 5	.329	.350	.376
For Environment C (#26) Signal 5	.352	.380	.409
For Environment D (#30) Signal 7	.250	.260	.307
For Environment E (W.N.) Signal 5	.385	.422	.495

An anova was not conducted because it only would have indicated an increase in reaction time for a decrease in intensity of signal.

A contributed program in BASIC, REGCOR A404-36054A, title "Regression/Correlation", was used to perform regression and correlation analyses on the series of observations. The program used the method of least squares to fit an exponential curve to the values of reaction time observed at selected values of signal intensity. Sample size for each correlation study was eight pairs of readings. The program is shown in Appendix G.

A sample run of the program on data for Environment A (#11), Signal 1, yields:

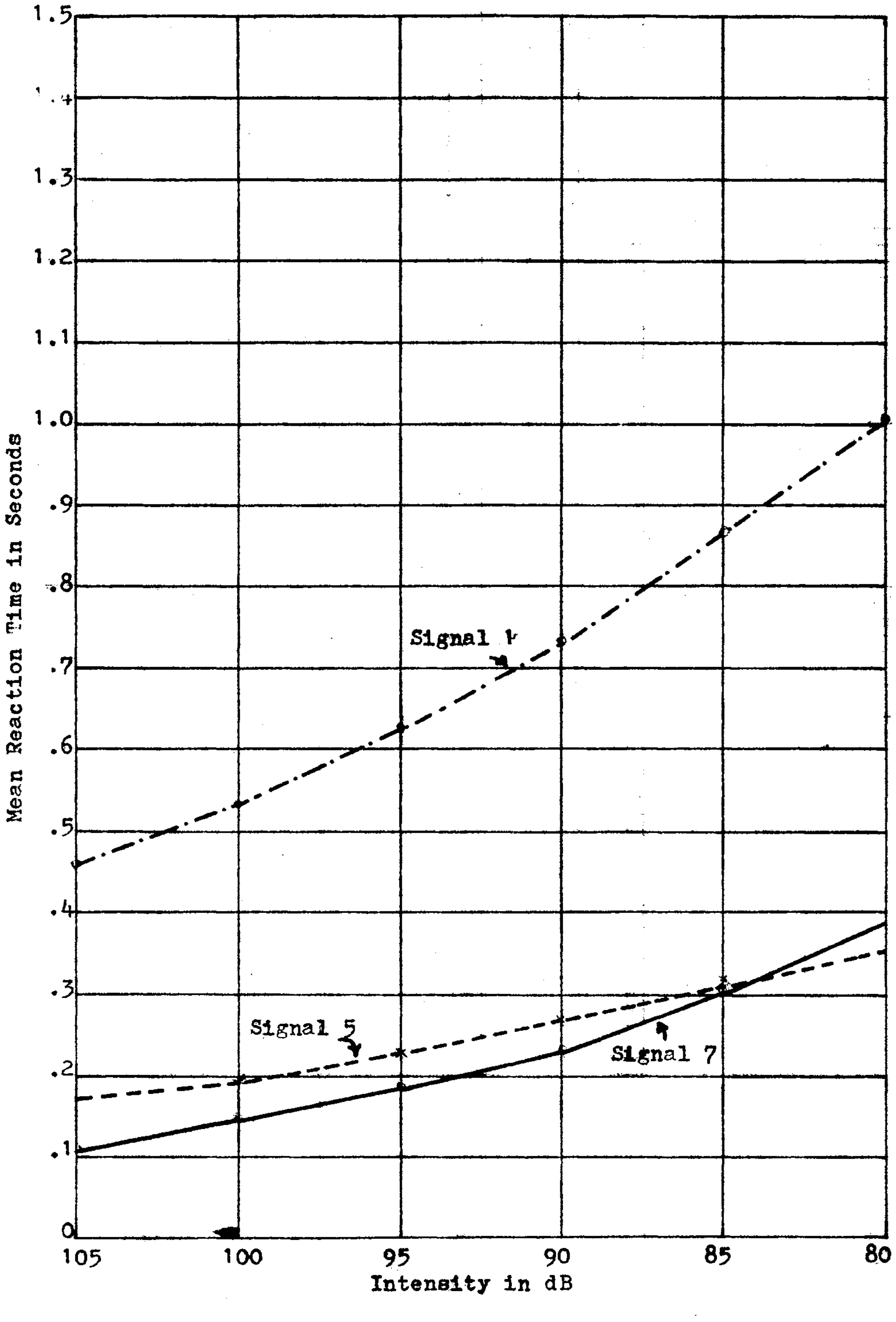


Figure 23. Mean Reaction Time vs. Intensity, Environment #11

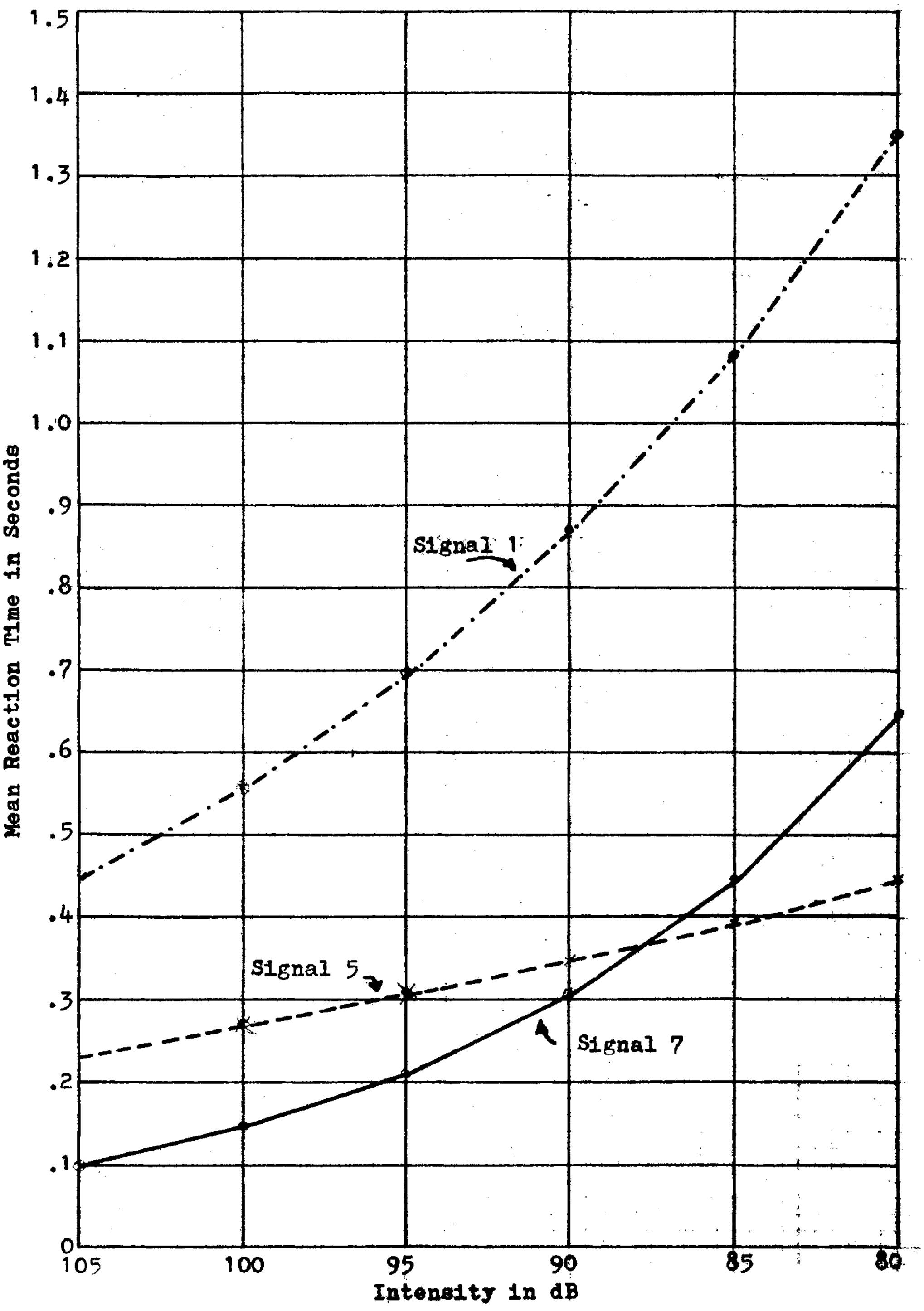


Figure 24. Mean Reaction Time vs. Intensity, Environment #14

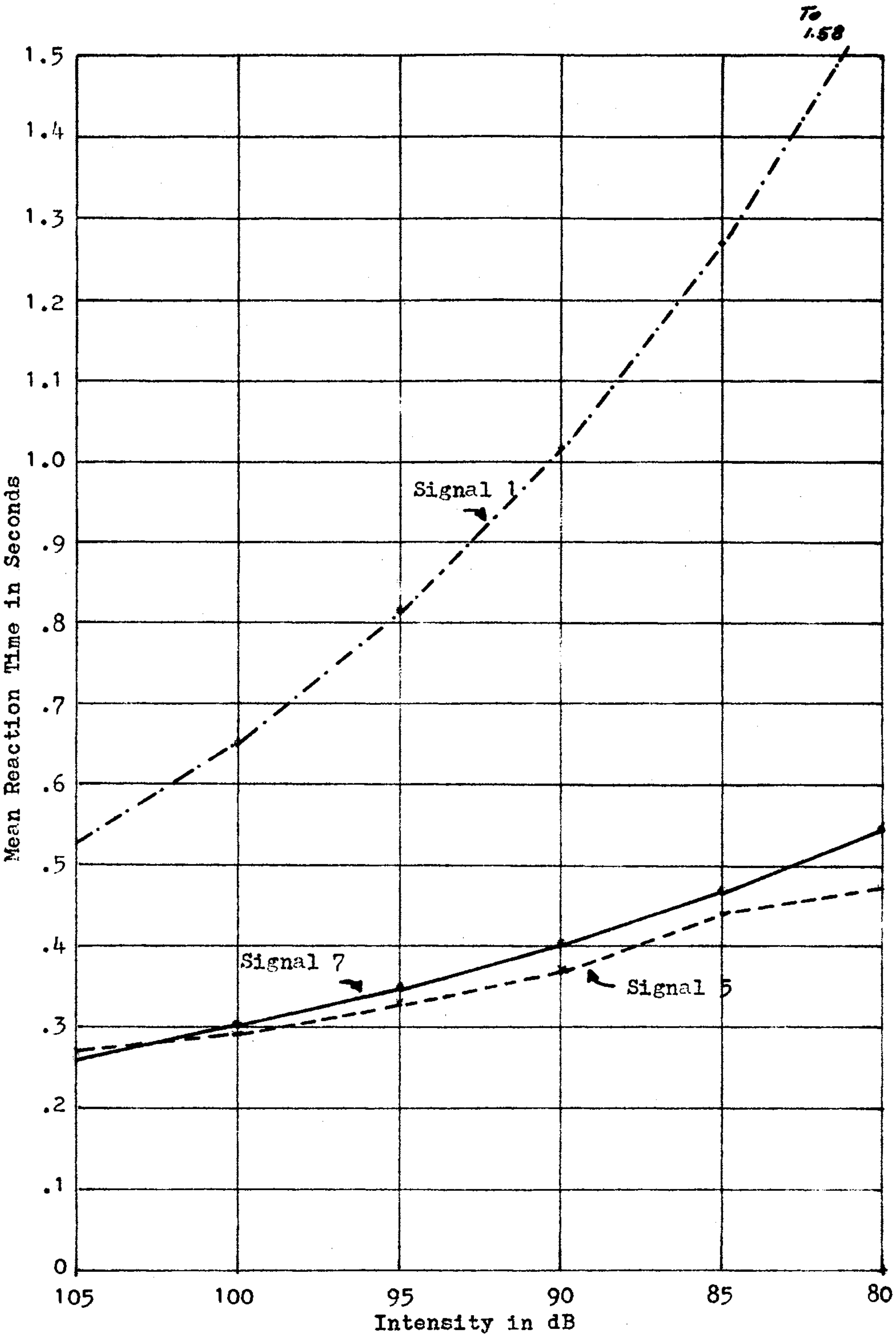


Figure 25. Mean Reaction Time vs. Intensity, Environment #26

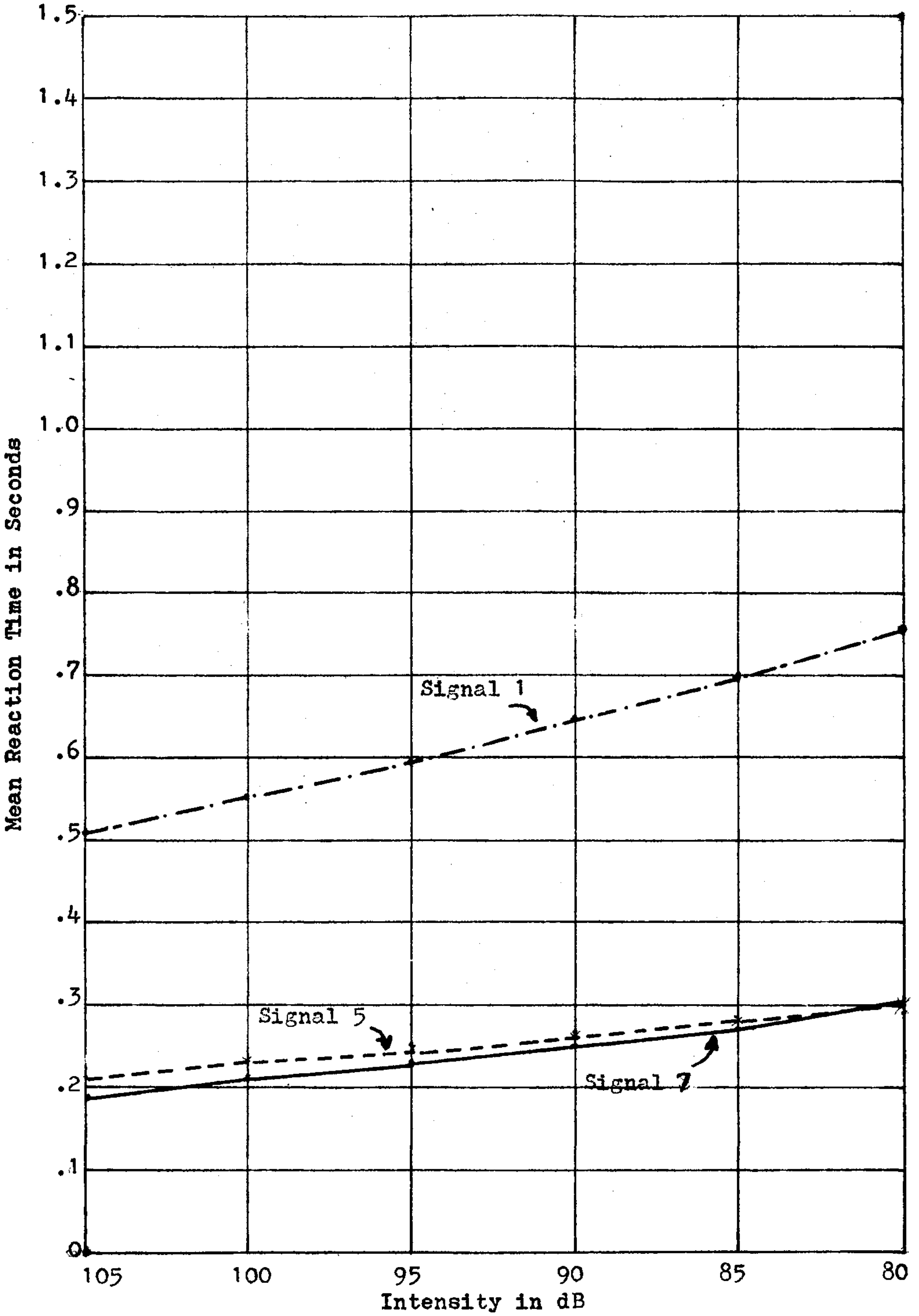


Figure 26. Mean Reaction Time vs. Intensity, Environment #30

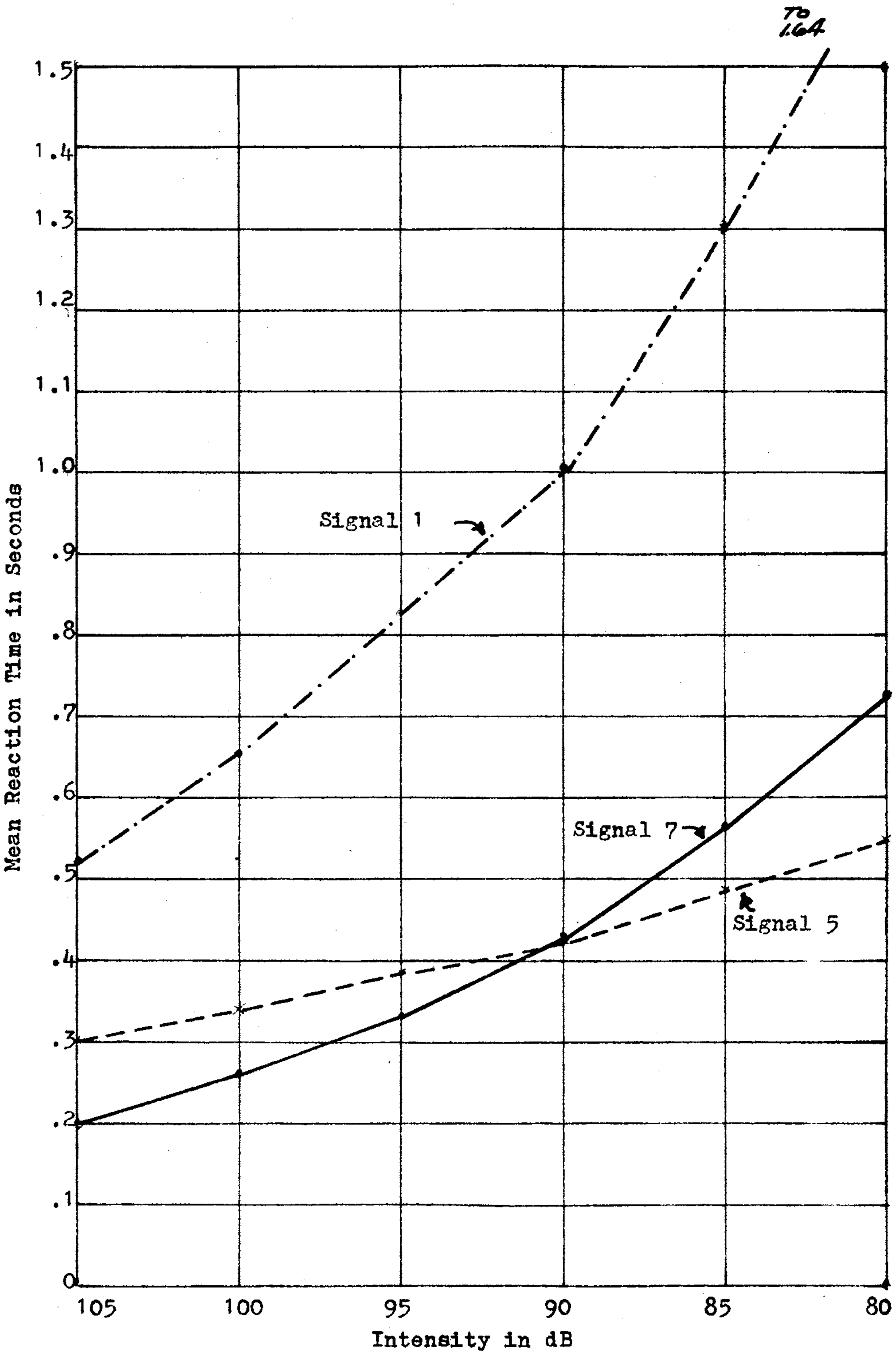


Figure 27. Mean Reaction Time vs. Intensity, Environment White Noise

Correlation coefficient $r = .867$

Regression equation, $y = e^{2.609-.0324x}$, where x is intensity.

Since it was expected that the reaction time was a decreasing function of the intensity, a one-tailed test at the 5% level of significance was conducted. Denoting the population correlation by ρ (rho), the null hypothesis was $H_0:\rho = 0$ versus the alternate $H_1:\rho < 0$. The random variable $Z = \frac{1}{2} \ell_n \frac{1+r}{1-r}$ where r is the sample correlation coefficient, normally distributed with mean $\mu_Z = \frac{1}{2} \ell_n \frac{1+\rho}{1-\rho}$ and variance $\sigma_Z^2 = \frac{1}{n-3}$. Therefore under the null hypothesis $\mu_Z = 0$, and the critical region for Z at the 5% level becomes $[-1, -1.645/\sqrt{n-3}]$, where -1.645 is the five percentage point of a standard normal deviate. Since the sample sizes for most experiments were eight, this critical region for Z was converted to the 5% critical region for r and the result was (-1, -.6265).

$$\frac{1}{2} \ell_n = \frac{1+r_u}{1-r_u} = - \frac{1.645}{\sqrt{n-3}}$$

$$\ell_n = \frac{1+r_u}{1-r_u} = - \frac{3.290}{\sqrt{5}} = - \frac{3.290}{2.236} = - 1.4712$$

$$\frac{1+r_u}{1-r_u} = e^{-1.4712} = .22965$$

$$1 + r = .22965 - .22965 r_u$$

$$1.22965 r_u = - .77035$$

$$r_u = - .6265$$

The significance of a sample point can now be determined by comparing the observed r with - .6265. If $r < .6265$, H_0 is rejected at the 5%; otherwise H_0 cannot be rejected.

The sample correlation coefficients were significant at the 5% level except for Environment A (#11), Signal 7, by Subject B. A malfunction of the equipment might have caused the erroneous reading.

A computer program, made on the HP2000E in BASIC was written to calculate response time by intensity using the regression equations developed by the REGCOR program, is shown in Appendix G.

CHAPTER VI

FINDINGS

Results of the study support the hypothesis that a preferred signal can be selected for a particular environment. The suggested procedure is:

1. An octave band analysis must be made of the environment in question. In some noises, a preponderence of energy lies in the lower frequencies, while in others it lies in middle and high frequency ranges. In Appendix F, the annoyance of higher frequency energy is shown to be greater than equivalent energy in lower frequencies. In Figure 1, Chapter I, the increased spread of masking is greater in higher frequencies. Therefore spectral compositions of the noise is of significant importance to ascertain the category classification of an environment.

2. Industrial environments fall into a series of patterns which are represented by the studies made by references 100, 96, 183, and 71. Classification of a particular environment into one of five classes, A through E, as indicated in Figures 28 through 32 provides a determination of the appropriate regression equation to be used in later calculations.

3. Obtain an octave band analysis of the signals to be considered. Energy concentration by frequency indicates the extent of masking or non-masking of the signal with respect to the environment.

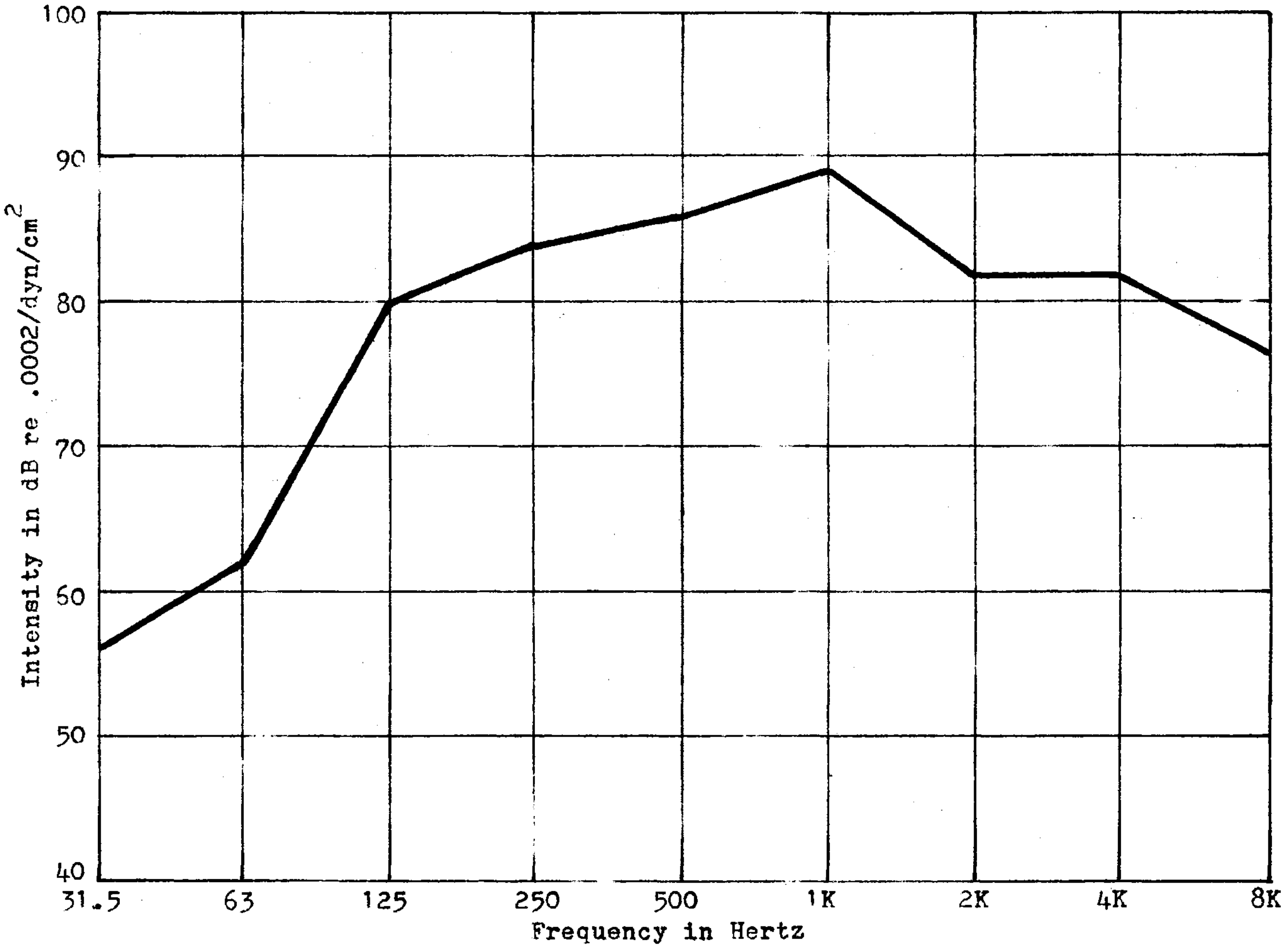


Figure 28. Environment # 11, Class A

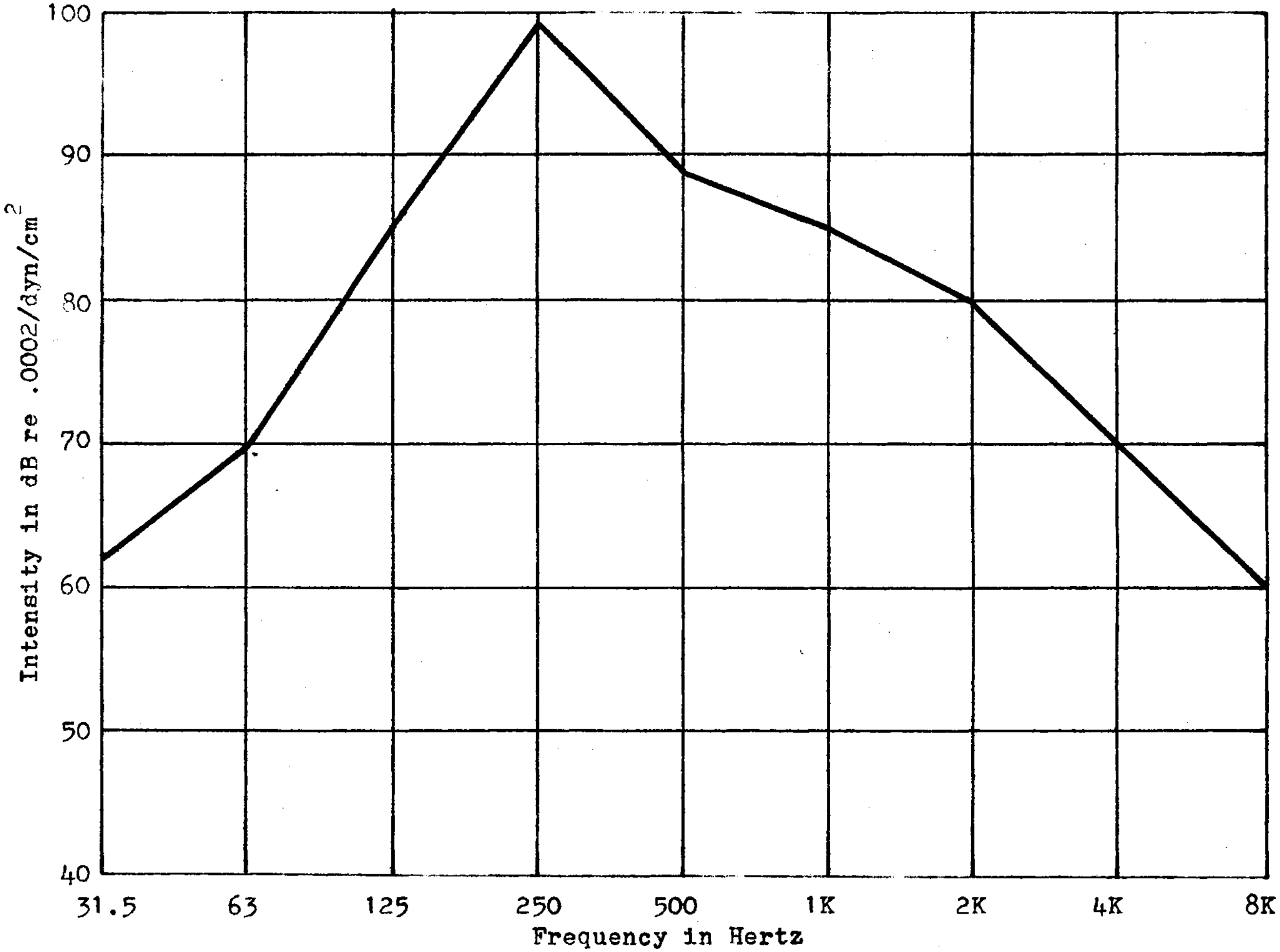


Figure 29. Environment #14, Class B

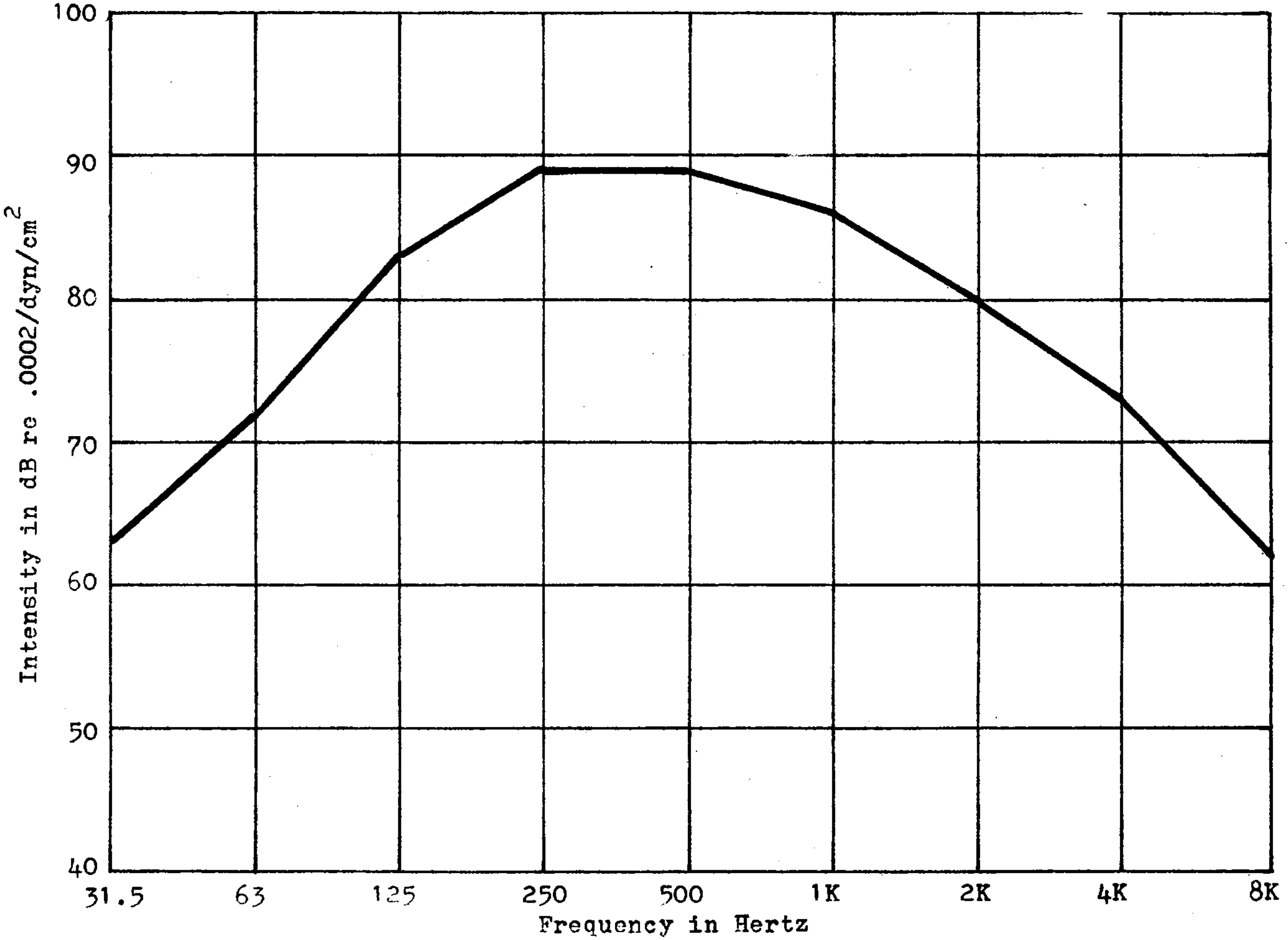


Figure 30. Environment #26, Class C

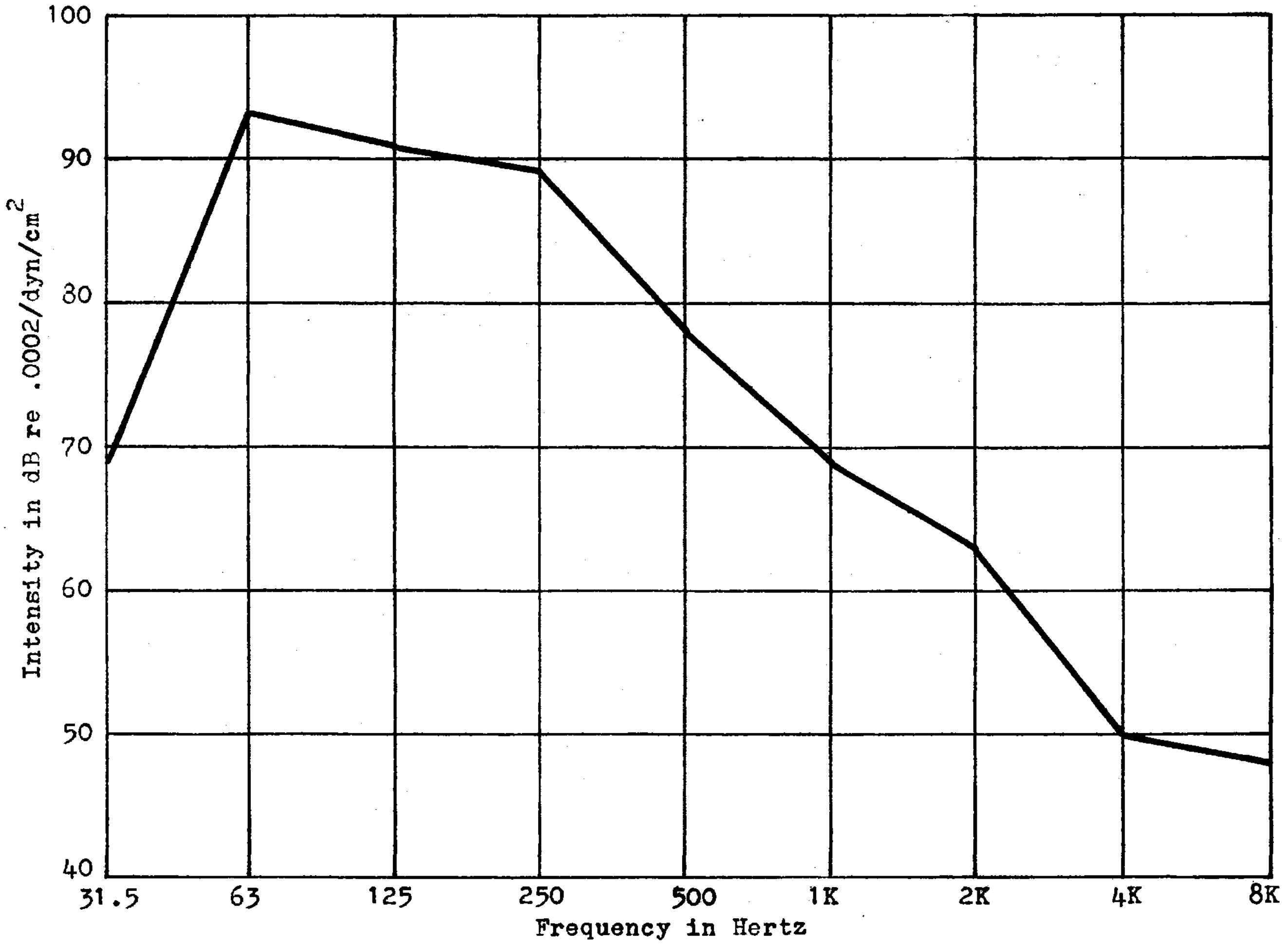


Figure 31. Environment # 30, Class D

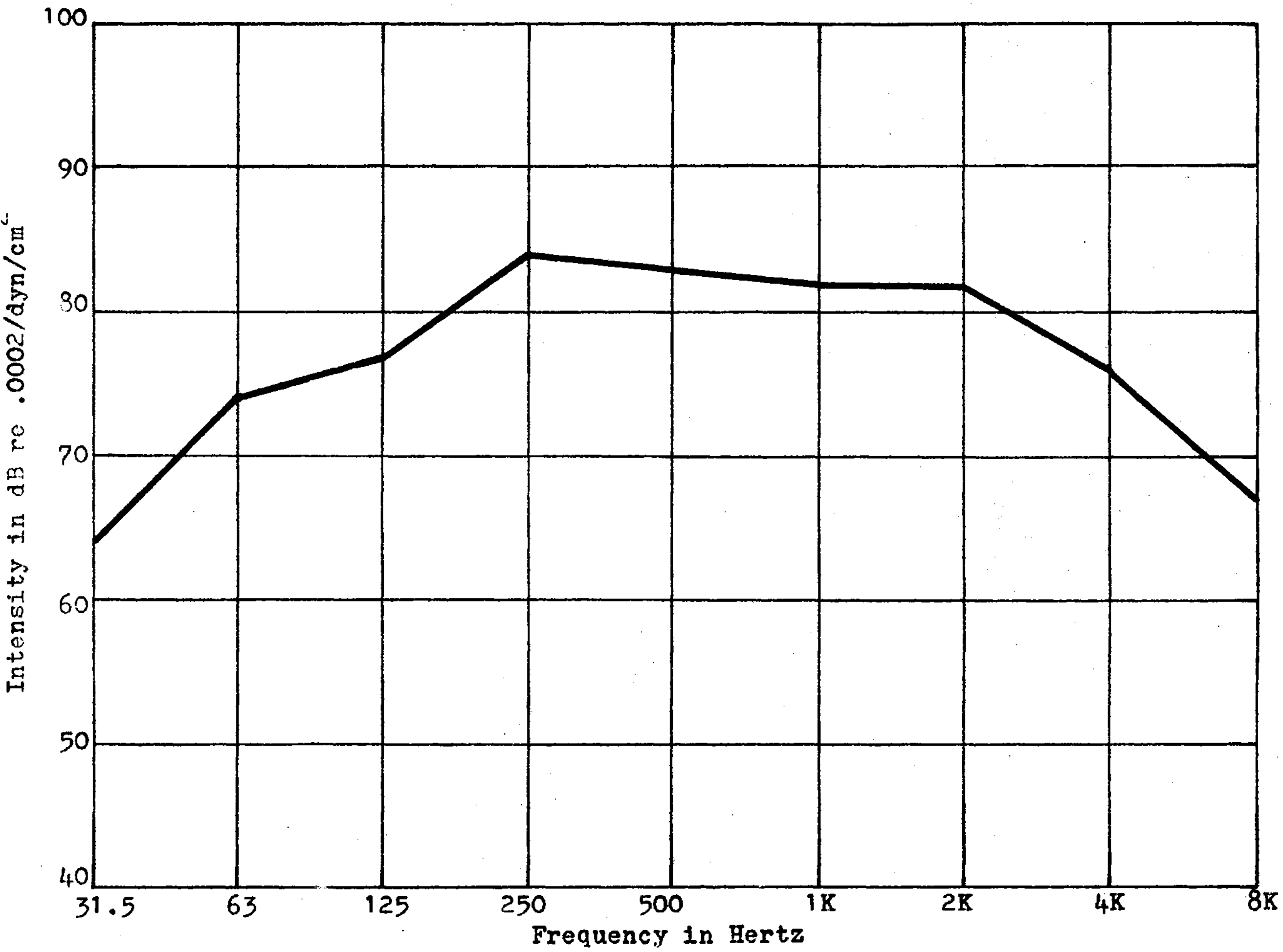


Figure 32. Environment White Noise, Class E

"Noises that include a wide range of frequencies will correspondingly be effective in masking over a wide-frequency range" [129, page 36].

4. Calculate the signal-noise ratio of each octave band center of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. Octave bands as indicated are the area of greatest sensitivity for sensory perception.

5. Multiply each S/N ratio by reaction time (from regression equations, Table VIII) at environment intensity per octave band to obtain octave number. The experimental results showed a major factor in the rapid discrimination of a signal is the relationship of the signal to the background. When the two (signal/noise) are widely separated (with limits of ±20 dB) a more rapid discrimination takes place. Multiplying the two levels to reinforce the relationship provides a more positive difference.

6. Sum the octave numbers to arrive at a selector factor. The summations by which the energy in each octave band can be consolidated, provides a single factor for selection of one signal in preference to another.

The terms, octave number, and selector factor, are created to use in this methodology. They are not designed to have unit designations and only represent their own arithmetic value.

7. Select the selector factor with the smallest numerical value as a preferred signal to be used in the environment, in parallel with the procedure for determining communication criteria in noise for speech. The lowest factor will provide the most effective noise criteria.

The entire methodology as evolved in this study is somewhat parallel to the procedures as suggested by Karl Kryter [184] with respect to acoustical noise criteria (NCA). In the procedure for NCA of an environment, a measurement of background noise in octave bands is the first step. Then, a plot of the octave band spectrum on a worksheet which parallels the selected environments for industrial noises as indicated in Figures 28 through 32. A final selection for the most desirable communication environment is that one with the lowest NCA. The choice of the numerically smallest selector factor also indicates more effective discrimination of an AWS.

In employing the derived methodology a series of recommendations are as follows:

Step one. Information can be secured from a sound level meter with an integral octave band recorder. An alternative procedure is to record the actual environment on tape and analyze it later by use of an octave band analyzer. However, extreme care must be exercised in choice of a recorder to assure faithful reproduction and also the conditions under which the playback is made.

Step two. Typical classes of environments are:

Class A (#11): rising (20-40%) intensity to a peak at central frequencies of 500, 1000, and 2000 Hz, then a slow (15 to 30%) intensity decrease to 8000 Hz.

Class B (#14 in this study): rapidly rising (45-60%) to a peak intensity at 250 Hz, then reasonably consistent decrease in intensity of 5 to 8 dB per octave.

Class C (#26 in this study): slow rise (15-20%) in intensity to 250 Hz, then level or slow decrease to 2000 Hz then rapid decrease to 8000 Hz.

Class D (#30 in this study): initial intensity high at low frequency then rapid decrease in intensity at the rate of 8 to 10 dB per octave band to 8000 Hz.

Class E (white noise): relatively level in primary frequencies of 250 to 2000 Hertz then drop of 6 to 8 dB for 400 to 8000 Hz.

Step three can be measured by a sound level meter with an octave band analyzer or secured from the manufacturer of the signal being considered.

Step four is calculated from data obtained in steps one and three above.

Step five is calculated from the regression equation for the preferred signal. Table VIII provides the constants and variables for all of the signals used in this study.

Step six is the summation of the octave numbers.

Example: For signals in Environment Class B the sum of octave numbers are:

Signal	Sum of Octave Numbers
1	11.017
2	8.933
3	7.354
4	9.628
5	3.568
6	11.379
7	6.844
8	8.311

In step seven, one selects the smallest numerical value. In decreasing sequence, preferred signals are #5, 7, 3, 8, 2, 4, 1, 6.

TABLE VIII

REGRESSION EQUATIONS

Environ.	Class A	Class B	Class C	Class D	Class E
Signal 1	$e^{2.609-.0324x}$	$e^{3.861-.0445x}$	$e^{4.014-.0444x}$	$e^{.979-.0157x}$	$e^{4.196-.0462x}$
2	$e^{3.943-.0557x}$	$e^{5.114-.0649x}$	$e^{2.971-.0412x}$	$e^{.273-.0172x}$	$e^{6.147-.0727x}$
3	$e^{1.325-.0265x}$	$e^{3.714-.0495x}$	$e^{2.706-.038x}$	$e^{-.149-.0129x}$	$e^{2.702-.0378x}$
4	$e^{6.467-.0846x}$	$e^{4.532-.057x}$	$e^{5.414-.0653x}$	$e^{.422-.0191x}$	$e^{5.895-.0713x}$
5	$e^{1.43-.0308x}$	$e^{1.174-.0248x}$	$e^{1.12-.0233x}$	$e^{-.0749-.0141x}$	$e^{1.322-.024x}$
6	$e^{2.493-.0397x}$	$e^{6.229-.0788x}$	$e^{2.262-.035x}$	$e^{-.0951-.0134x}$	$e^{6.678-.0807x}$
7	$e^{3.003-.0494x}$	$e^{5.511-.0744x}$	$e^{1.762-.0296x}$	$e^{-.274-.0117x}$	$e^{3.824-.0517x}$
8	$e^{5.422-.0724x}$	$e^{4.629-.0549x}$	$e^{4.449-.0583x}$	$e^{.1955-.0173x}$	$e^{5.448-.067x}$

Reaction Time = $e^{\text{constant - variable (environment intensity at each octave in dB)}}$.

$$RT = e^{(c-v*I)}$$

Example:
C = 2.609
V = .0324
I = 80dB

$RT = e^{(2.609-.0324(80))}$
$= e^{(.017)}$
RT = 1.017 called octave numbers

A copy of the computer program to calculate step six above is given in Appendix G.

Based on the environments as utilized in this study, and with the signals as chosen to be representative of commercially available units, it is concluded that in specified environments, the preferred signals are as follows:

	Preferred Rank							
	1st	2nd	3rd	4th	5th	6th	7th	8th
	Preferred Signal Number							
Environment A (#11)	7	5	3	6	2	8	4	1
Environment B (#14)	5	7	3	8	2	4	1	6
Environment C (#26)	5	7	6	2	3	8	4	1
Environment D (#30)	7	5	3	6	8	2	4	1
Environment E (W.N.)	5	7	3	8	4	6	2	1

CHAPTER VII

CONCLUSIONS AND FUTURE RESEARCH AREAS

Results of the study indicate the following:

1. As intensity of a signal decreases, there is an increase in reaction time. The limits of this statement are from intensities of 105 to 80 dB, and reaction times from .0120 to 1.4 seconds.

2. Signals of unique characteristics with respect to signal/noise ratio determine one's ability to recognize the signal contrasted with noises. Signal five has a high onset intensity and very rapid decrease in frequency. Signal seven has a series of intermittent beeps (two to three cycles per second). In each case, these are unique signals as compared to typical noises encountered in industrial environments. These findings agree with those of Deathrage "To demand attention - modulate signal to give intermittent 'beeps' or modulate frequency to make pitch rise and fall at rate of about 1-3 cps" [184, page 126].

3. A signal of slow modulation (number 1) and one of rapid modulation (number 2) are not of adequate uniqueness from typical industrial noises to be readily discriminable.

4. As a possible effect causing the variance in the reaction time of various signals, inhibition in the central nervous system could be the factor (see Appendix F). Since white noise contains a wide spectrum of frequencies, and by verbal comment of the subjects was more annoying than other environments, a considerable variance in reaction time at the

lower intensities is apparent. Von Bekesy [161] provides an explanation of this as the occurrence of a phenomenon causing a momentary lack of consciousness at intervals of .8 to 1.2 seconds where the subject is continuously concentrating on a tone. The net effect is for the subject to have momentary reductions in the magnitude of sensations.

5. Although signals five and seven are most effective and signal one is least effective in most all environments, the other five signals not shown in Figures 23 through 28 fall between the drawn curves. A specific rank is indicated by the results but when each signal is plotted on a background of the environments by octave bands, many difficult questions can be raised as to an explanation of each curve. The writer does not believe this study has the depth to answer these questions.

6. In summary, the results of this study indicate an extension of prior research using pure tones and white noise into a test employing a complex signal in an actual industrial environment. This fact opens many questions which can only be investigated by future research.

Future Research

Many variables such as effects of heat stress, fatigue, and mental attitudes of workers under noise stress have not been pursued in this study. The effects of a moving signal in a noise background are likely to be worthy of investigation. The general question of spatial localization of sound sources with complex sounds could refine the results of the present study.

One experiment not suggested is to repeat the experiment with employees wearing hearing protection devices. As the present items on the market attenuate high frequency sounds, it appears that substantial effects would be the same as in the present experiment.

A SELECTED BIBLIOGRAPHY

1. Adams, S. K., and L. B. Trucks. "An Analysis of Auditory Warning Device Signals in the Presence of Industrial Environments." Unpublished report. May 1969.

2. Alexander, Milton, and L. L. Laubach. "Anthropometry of the Human Ear." AMRL-TR-67-203, Wright Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratories, Aerospace Medical Division Air Force Systems Command, January, 1968.

3. Alpaugh, E. L. "Procedures of a Sound Survey." National Safety News, Vol. 99, No. 1 (January, 1969), pp. 65-73.

4. ANSI S1.11. Appendix A. New York, N. Y.: American National Standards Institute, 1966.

5. Antinoro, Frank, and Paul H. Skinner. "The Effects of Frequency on the Auditory Evoked Response." Journal of Auditory Research, Vol. 8, No. 2 (April, 1968), p. 119.

6. American Academy of Ophthalmology and Otolaryngology. Guide for Conservation of Hearing in Noise. Revised 1969. Aram Glorig, Field Coordinator AAOO, Committee on Conservation of Hearing. American Academy of Ophthalmology and Otolaryngology, Rochester, Minnesota.

7. American Industrial Hygiene Association. Industrial Noise Manual, 2nd Edition. American Industrial Hygiene Associations, 1966.

8. Azrin, Nathan H. "Some Effects of Noise on Human Behavior." Journal of Experimental Analysis of Behavior (April, 1958), p. 9.

9. Bailey, J. Ronald. Textile Industry Noise Control Guidelines. Unpublished, Letter Ala. Text. Mfg. Assoc. to Chairman ATMA Safety Committee, September 14, 1972.

10. Baron, Robert Alex. The Tyranny of Noise. New York: St. Martin's Press, 1970.

11. Bartlett, Frederick Charles. The Problem of Noise. Cambridge, England: The University Press, 1934.

12. Bartlett, F. C., and K. G. Pollack. "Two Studies in the Psychological Effects of Noise." British Journal of Industrial Health Research Board, Report 65 (1932), pp. 29-33.

13. Behar, A. "Noise in the Textile Industry (Spanish)." Galaxia, Vol. 8, No. 5 (Oct., 1970), pp. 25-30.

14. Benox Report. "Biological Effects of Noise, Exploratory." Contract No. N6 orio20, Task Order 44, Office of Naval Research, NR 144079. Chicago, Ill.: University of Chicago, 1953.

15. Beranek, Leo L. "Noise." Scientific American, Vol. 215, No. 6 (Dec., 1966), pp. 66-76.

16. Beranek, Leo L. Noise Reduction. New York: McGraw Hill, 1960.

17. Beranek, Leo L., and Laymon N. Miller. "The Anatomy of Noise." Machine Design, Vol. 39, No. 21 (Sept. 14, 1967), pp. 174-183.

18. Berland, Theodore. The Fight for Quiet. Englewood Cliffs, N.Y.: Prentice-Hall, 1970.

19. Berry, R. C., and G. Patrick Nerbonne. "A Comparison of the Masking Functions of Speech Modulated and White Noise." Journal of Auditory Research, Vol. 11, No. 3 (July, 1971), p. 248.

20. Blackwell, P. J., and J. A. Belt. "Effect of Differential Levels of Ambient Noise on Vigilence Performance." Perceptual and Motor Skills, Vol. 32, No. 3 (June, 1971), p. 734.

21. Bode, John. "Sketch of Terminal Analog Speech Synthesizer and Howler." Informal Notes and Personal Communication, March, 1973.

22. Bonvallet, G. L. "The Measurement of Industrial Noise." Industrial Hygiene Quarterly, Vol. 13, No. 3 (Sept., 1952), pp. 136-157.

23. Botsford, James H. "Current Trends in Hearing Damage Risk Criteria." Sound and Vibration, Vol. 4, No. 4 (April, 1970), pp. 16-19.

24. Broadbent, D. E., and E. A. L. Little. "Effects of Noise Reduction in a Work Situation." Occupational Psychology (April, 1960), pp. 133-140.

25. Broadbent, D. E. "Effects of Noise on an Intellectual Task." Journal of Acoustical Society of America, Vol. 30, No. 9 (1958), pp. 824-827.

26. Broadbent, D. E. "Attention and the Perception of Speech." Scientific American, Vol. 206, No. 4 (April, 1962), pp. 143-151.

27. Broadbent, D. E. "Noise Paced Performance and Vigilance Tasks." British Journal of Psychology, Vol. XLIV, Part 4 (1953), pp. 295-302.

28. Broch, Jens Trampe. Acoustics Noise Measurement. 2nd Edition. So Borg, Denmark: Bruel & Kjaer, January, 1971.

29. Broker, Earl W. "Personal Ear Protection." National Safety News, Vol. 99, No. 3 (March, 1969), pp. 64-75.

30. Bruce, Robert D. "Noise Control for Punch Presses." Paper presented at 21st Tech. Conference of American Metal Stamping Assoc. N. Y. City, April 1, 1970.

31. Burns, William. Noise and Man. London: John Murray, 1968.

32. Burrows, Alan A. Aircraft Warning Systems, Argument, Evidence, and Design. 15th Technical Conference, Lucerne, International Air Transport Assoc., 1963, pp. 1-13.

33. Burrows, A., and H. K. Ford. "Sounds as Warnings in Aircraft." Flying Personnel Research Committee Report #966, Air Ministry, London, 1956.

34. Burrows, Alan A. "Choice Response in Quiet and Loaded Channels with Verbal and Non-Verbal Auditory Stimuli." Human Factors, Vol. 4, No. 4 (August, 1962), pp. 187-191.

35. Campbell, R. A., and E. Z. Lasley. "Adaptive Threshold Procedures, BUDTIF." Journal of Acoustical Society of America, Vol. 35 (1968), pp. 537-541.

36. Campbell, R. A. "Detection of a Noise Signal of Varying Duration." Journal of Acoustical Society of America, Vol. 35 (1963), pp. 1732-1736.

37. Crombie, A. C. "Early Concepts of the Senses and the Mind." Scientific American, Vol. 210, No. 5 (May, 1964), pp. 108-116.

38. Cohen, Alexander. "Effect of Noise on Psychological State." American Society of Safety Engineers, Vol. 14, No. 4 (April, 1969), pp. 11-15.

39. Cohen, Alexander. "Environmental Noise Problems in Broad Perspective." Personal Communication from author, May, 1969.

40. Corso, John F. The Experimental Psychology of Sensory Behavior. New York, N. Y.: Holt, Rinehart, and Winston, pp. 219-245 and Chapter XI.

41. Cudworth, Allen L. "Compensation Claims for Hearing Losses Due to Noisy Equipment." Personal Communication - June 4, 1971.

42. Cudworth, Allen L. Personal Communication. June 19, 1974.

43. Davis, R. C., A. M. Buchwald, and R. W. Frankman. "Autonomic and Muscular Responses and Their Reaction to Simple Stimuli." Psychological Monographs, Vol. 69, No. 405 (1955), pp. 1-71.

44. Dirks, Donald D., and Jane Chandler. "Effects of Intensity Level on Threshold Shifts Produced by Pulsed and Continuous Maskers." Journal of Acoustical Society of America, Vol. 37 (1965), p. 1180.

45. Dittrich, F. L., and R. C. Extermann. Biophysics of the Ear. Springfield, Ill.: Charles C. Thomas, 1963, pp. 148-161.

46. Diehl, G. M. "Think Quiet." Special Reprint from "Compressed Air." Ingersol Rand Corp. (1971), pp. 1-32.

47. Donley, Ray. "Acoustical Term Definitions." Personal Communication - May, 1973.

48. Eames, B. L., D. Hamernik, D. Henderson, and A. Feldman. Role of the Middle Ear in Acoustic Trauma From Impulses. Rockville, Md.: Accession No. 0421, Grant OH00364, OEA, NIOSH.

49. Ehmer, Richard H. "Masking by Tones vs. Noise Bands." Journal of the Acoustical Society of America, Vol. 31, No 9 (Sept., 1959), pp. 1253-1256.

50. Bulletins 100 and 102, Federal Sign and Signal Corp., Printed June, 1971, pp. 1-8.

51. Erlick and Hunt. "Evaluating Audio Warning Displays for Weapon Systems." WADC Technical Report 57-222. Wright Air Development Commission, Wright Air Depot, Ohio, 1957.

52. Erulkar, S. D. "Comparative Aspects of Spatial Localization of Sound." Physiological Reviews, Vol. 52, No. 1 (Jan., 1972), pp. 237-347.

53. Eschenbrenner, A. John, Jr. "Effects of Intermittent Noise on the Performance of a Complex Psychomotor Task." Human Factors, Vol. 13, No. 1 (1971), pp. 59-63.

54. Faulkner, Lynn L. "Sound Measurement and Analysis." Personal Communication - Received August, 1973.

55. Finkelman, Jay M., and David C. Glass. An Information Processing Evaluation of the Effect of Environmental Noise Upon Human Performance. Personal Communication - May, 1971.

56. Fitts, P. M. Handbook of Experimental Psychology. Ed., S. S. Stevens. New York: John Wiley, 1951.

57. Fleshler, Morton. "Adequate Acoustic Stimulus for Startle Reaction in the Rat." Journal of Comparative and Physiological Psychology, Vol. 60, No. 2 (1965), pp. 200-207.

58. Fletcher, J. L., and Arthur J. Riopelle. "Protective Effect of the Acoustic Reflex for Impulsive Noises." Journal of Acoustical Society of America, Vol. 32, No. 3 (March, 1960), pp. 401-404.

59. Fletcher, John L., and Adrian B. Cairns. "Recovery from Impulse Noise Induced Acoustic Trauma." Journal of Auditory Research, Vol. 7, No. 1 (January, 1967), pp. 35-39.

60. Fletcher, John L. "Pure Tone Thresholds Following Stimulation by Narrow Band Filtered Noise." Psychological Monographs, Vol. 71, No. 4 (1957), pp. 1-13.

61. Fletcher, Harvey. Speech and Hearing in Communication. 2nd Edition. New York: Van Nostrand, 1953.

62. Forster, R. S. "The Control of Noise." Symposium No. 12, National Physical Laboratory, June 1961. Her Majesty's Stationery Office, London (1962), pp. 26-28.

63. Fox, Meyer S. "Hearing Loss Statutes." National Safety News, Vol. 105, No. 2 (Feb., 1972), pp. 50-56.

64. Gjaevenes, Kjell, and Thorleif Schoel. "Masking of Speech by 'White' and 'Pink' Wide-Band Noise." Journal of Auditory Research, Vol. 7, No. 1 (Jan., 1967), pp. 31-34.

65. Glorig, Aram. "Noise is Blamed for Many Things." Paper presented at American Medical Association's Sixth Congress on Environmental Health, April 18-19, 1969, in Chicago, Illinois.

66. Glorig, Aram. "Noise - Exposure - Facts and Myths." Transactions of American Academy of Ophthalmology and Otolarynology (Nov/Dec., 1971), pp. 1264-1272.

67. Glorig, Aram, W. Dixon Ward, and James Nixon. "Damage Risk Criteria and Noise Induced Hearing Loss." Archives of Otolarynology, Vol. 74 (Oct., 1961), pp. 413-423.

68. Glorig, Aram. "Noise and Your Ear." From Series - Modern Monographs in Industrial Medicine. Editor in Chief, Anthony J. Lanza. New York and London: Grune and Stratton, 1958, pp. 109-111.

69. Glorig, Aram. Audiometry Principles and Practices. Baltimore: The Williams and Watkins Company, 1965.

70. Glorig, Aram. "Non Auditory Effects of Noise Exposure." Sound and Vibration, Vol. 5, No. 5 (May, 1971), pp. 28-30.

71. Goodfriend, L. S. Associates. "Noise From Industrial Plants." Prepared by L. S. Goodfriend Associates under Contract 68-04-0044 for the U. S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D. C.

72. Green, David M. "Additivity of Masking." Journal of Acoustical Society of America, Vol. 41, No. 6 (Jan., 1967), pp. 1517-1524.

73. Green, David M. "Psychoacoustics and Detection Theory." Journal of Acoustical Society of America, Vol. 32, No. 10 (Oct., 1960), pp. 1189-1203.

74. Guilford, J. P. Psychometric Methods. N. Y.: McGraw-Hill Book Co., 1954.

75. Gulian, Edith. "Auditory Vigilance Under Noise Conditions: Psychophysiological Correlations." Studia Psychologica, Vol. XIII, No. 2 (1971), pp. 114-119.

76. Handley, John M. "How to Slash the Cost of Noise - A Practical Plan." Reprint from Environmental Control and Safety Management. Industrial Acoustics Company, IAC Bulletin No. 600006.0, 1971.

77. Hamernik, R. P., D. Henderson, D. S. Dosanjh, and R. Sitler. "Impulse Noise: Some Electrophysiological and Anatomical Effects." Accession No. 0420, Grant No. OH 00364. OEA, NIOSH, Rockville, Md., 1971.

78. Hamernik, R. P., D. Henderson, and R. W. Sitler. "Cochlear Degeneration Following Impulse Noise Exposure." Accession No. 0429, Grant No. OH 00364. OEA, NIOSH, Rockville, Md.

79. Harris, Cyril M. Handbook of Noise Control. N. Y.: McGraw-Hill Book Co., 1957.

80. Harris, J. Donald. Editor. "Forty Germinal Papers in Human Hearing." Journal of Auditory Research (1969).

81. Henderson, D., R. P. Hamernik, and R. W. Sitler. "Audiometric and Histological Effects of Exposure to 40 u-sec High Level Impulses." Accession No. 0426, Grant No. OH 00364. OEA, NIOSH, Rockville, Md.

82. Henderson, D., R. P. Hamernik, and R. Sitler. "Audiometric and Anatomical Correlates of Impulse Noise Exposure." Accession No. 0424, Grant No. OH 00364. OEA, NIOSH, Rockville, Md.

83. Henderson, D., R. P. Hamernik, C. Woodford, R. W. Sitler, and R. Salvi. "Evoked Response Audibility Curve of the Chinchilla." Accession No. 0423, Grant No. OH 00364. OEA, NIOSH, Rockville, Md.

84. Henderson, D., R. P. Hamernik, and R. W. Sitler. "A Comparison Between Hair Cell Losses and Permanent Threshold Shifts Produced by Three Levels of Impulse Noise." Accession No. 0428, Grant No. OH 00364. OEA, NIOSH, Rockville, Md.

85. Hermann, Edward R. "Ear Anatomy and Effects of Noise." *National Safety News*, Vol. 99, No 2 (Feb., 1969), pp. 64-73.

86. Hirschorn, Martin. "The 90 dB A Guideline for Noise Control Engineering." *Sound and Vibration*, Vol. 4, No. 4 (April, 1970), pp. 266-29.

87. Hockett, Charles D. "The Origin of Speech." *Scientific American*, Vol. 203, No. 3 (Sept., 1960), pp. 88-96.

88. Hoffman, H. S., and M. Fleshler. "Startle Reaction: Modification by Background Acoustic Stimulate." *Science*, Vol. 141 (Nov., 1963), pp. 928-930.

89. Hoffman, Howard, and John L. Searle. "Acoustic and Temporal Factors in the Evocation of Startle." *The Journal of the Acoustical Society of America*, Vol. 43 (Nov., 1968), pp. 269-282.

90. Hofman, Mark A., and N. W. Heimstra. "Tracking Performance with Visual, Auditory, or Electrocutaneous Displays." *Human Factors*, Vol. 14, No. 2 (1972), pp. 131-138.

91. Hosey, Andrew D., and Charles H. Powell. "Industrial Noise, A Guide to its Evaluation and Control." U. S. Dept. of HEW, Public Health Service Publication #1572, May 1972, U. S. Government Printing Office, Washington, D. C., 1967.

92. Houston, R. C., and R. Y. Walker. "The Evaluation of Auditory Warning Signals for Aircraft." Technical Report No. 5762, Hq. Air Command, Wright Patterson AFB, Ohio, June, 1949.

93. Hunter, Joseph Lawrence. *Acoustics*. Englewood Cliffs, N. J.: Prentice Hall, 1957.

94. Hurley, William. "Noise - A New Focus for Government and Industry." Presented at Meeting - National Council on Noise Abatement, Washington, D. C., February, 1969, pp. 1-40.

95. Ihde, W. "Instruments & Techniques of Sound Measurement." *National Safety News*, Vol. 98, No. 6 (Dec., 1968), pp. 64-73.

96. Imhoff, John, and L. B. Trucks. "A Representative Sample of Industrial Environmental Noise." Unpublished - Special Report to Dr. S. K. Adams. Oklahoma State University (Fall, 1969).

97. Jerison, Harry J., and Shelley Wing. "Effects of Noise and Fatigue on a Complex Vigilance Task." WADC Technical Report 57-14. ASTIA Document No. AD110700, Jan. 1957.

98. Jerison, J. H. "Performance on a Simple Vigilance Task in Noise and Quiet." Journal of the Acoustical Society of America, Vol. 29, No. 11, pp. 1163-1165.

99. Johnson, D. L., and Charles W. Nixon. "Simplified Methods for Estimating Hearing Protector Performance." Sound and Vibrations, Vol. 8, No. 6 (June, 1974), pp. 20-27.

100. Karplus, H. B., and G. L. Bonvallet. "A Noise Survey of Manufacturing Industries." Industrial Hygiene Quarterly, Vol. 14 (Dec., 1953), pp. 235-263.

101. Kerr, Willard A. "Accident Proneness of Factory Departments." Journal of Applied Psychology, Vol. 34 (1950), pp. 167-170.

102. Knowles, W. B., W. J. Burger, M. B. Mitchell, D. T. Hanifan, and J. W. Wulfeck. "Models, Measures, and Judgements in System Design." Human Factors, Vol. 11, No. 6 (1969), pp. 577-590.

103. Kling, J. W., and Lorrin A. Riggs, and Seventeen Contributors. Experimental Psychology. London: Methuen & Co., Ltd., 1971.

104. Kryter, K. D. "Concepts of Perceived Noisiness, Their Implementation and Application." The Journal of the Acoustical Society of America, Vol. 43, No. 2 (1968), pp. 344-361.

105. Kryter, Karl D. "Performance Tests in Noise." Stanford Research Institute. Unpublished Draft - Personal Communication from Karl D. Kryter. Stanford Research Institute. June 1, 1973.

106. Kryter, Karl D. The Effects of Noise on Man. N. Y.: Academic Press, 1970.

107. Laird, Donald A. "The Effect of Noise." Journal of the Acoustical Society of America, Vol. 1 (1929), pp. 256-262.

108. Lahey, James W. "Problem Solving and Decision Making." National Safety News, Part I, Vol. 98, No. 6 (Dec., 1968); and Part II, Vol. 99, No. 1 (Jan., 1969), pp. 64-65.

109. Lenhardt, M. L. "Effects of Frequency Transitions on Auditory Averaged Evoked Response." (Dissertation submitted to Dept. of Habilitative Sciences, Florida State University, March, 1970.)

110. Lillywhite, C. W. "The Intelligibility of Voice Communications While Wearing Gas Masks." From Autonetics, A Division of North American Rockwell Corp., Anaheim, Calif., T9-2401/501.

111. Loeb, Michel. "Psychophysical Correlated of Intratympanic Reflex Action." USA Med. Research Laboratory, *Psychological Bulletin*, Vol. 61, No. 2 (1964), pp. 140-152.

112. Loeb, Michel, and John L. Fletcher. "Impulse Duration and Temporary Threshold Shift." *Journal of the Acoustical Society of America*, Vol. 44, No. 1 (1968). American Institute of Physics, Washington, D. C., pp. 353.

113. Loeb, M., and A. J. Riopelle. "Influence of Load Contralateral Stimulation on the Threshold and Perceived Loudness of Low Frequency Tones." *Journal of the Acoustic Society of America*, Vol. 32, No. 5 (May, 1960), pp. 602-610.

114. McBain, W. N. "Noise, the Arousal Hypothesis and Monotonous Work." *Journal of Applied Psychology*, Vol. 45, No. 5 (Oct., 1961), pp. 309-317.

115. McCann, Patrick H. "The Effects of Ambient Noise on Vigilance Performance." *Human Factors*, Vol. 11, No. 3 (1969), pp. 251-256.

116. Mintz, F., and F. G. Tyzzer. "A Loudness Chart for Octave Band Data on Complex Sounds." *Journal of the Acoustic Society of America*, Vol. 24, No. 1 (Jan., 1952), pp. 80-82.

117. Mitchell, Larry D., and Gerald A. Lynch. "Origins of Noise." *Machine Design*, Vol. 41, No. 10 (May, 1969), pp. 175-178.

118. Nakamura, Shiro, and Yoshio Katano. "Relationship Between Temporary Threshold Shift and Duration of Noise Exposure." *Journal of Auditory Research*, Vol. 7, No. 4 (Oct., 1967), pp. 401-408.

119. National Bureau of Standards Under Interagency Agreement. *The Economic Impact of Noise*. U. S. Environmental Protection Agency Office of Noise Abatement and Control, NTID300.14, Dec. 31, 1971.

120. "Noise References." (Unpublished paper from Acoustics Laboratory, Oklahoma State University, School of Mechanical and Aerospace Engineering by Richard Lowry.)

121. Editorial. "Noise and Its Control." *Sound*, Vol. 2, No. 5 Sept.-Oct., 1963), p. 4.

122. Olishifski, Julian B. "An Industrial Hearing Conservation Program." *National Safety News*, Vol. 97, No. 2 (Aug., 1968), pp. 64-70.

123. Oppenheim, Arthur, and Seymour Wasserman. "Understanding Acoustic Enclosure Systems." Reprint of Article in "Electronic Industries," by IAC Bulletin No. 6.0001.0. Industrial Acoustics Company, N. Y., N. Y., 1970.

124. Olson, Harry Ferdinand. Acoustical Engineering. Princeton, N.J.: Van Nostrand, 1957.

125. Ouzts, James W. "Auditory Temporary Threshold Shift Following Exposure to High-Intensity and Variable-Peaked Farm Machinery Noise." Journal of Acoustic Research, Vol. 9, No. 1 (Jan., 1969), pp. 64-69.

126. Palmer, John M., and Dominic A. LaRusso. Anatomy for Speech and Hearing. New York: Harper and Row, 1965, pp. 157-167.

127. Parker, B. T., R. W. Habersat, and J. Tiffin. "Visual Performance and Accident Frequency." Journal of Applied Psychology, Vol. 33, (1949), p. 499.

128. Pearson, K. W., R. D. Horonjeff, and D. E. Bishop. "The Noisiness of Tones Plus Noise." NASA Report NASA CR-117, Washington, D. C., August, 1968.

129. Peterson, A. P. G., and Ervin E. Gross. Handbook of Noise Measurement. Seventh Edition. Concord, Mass.: General Radio, 1972.

130. Plath, D. W. "Acoustical Noise Tests of PVD Alarm." UAFB. Autonetics, Division of North American Aviation T8-3048/501. No. Am. Aviation, Inc., Dec., 1968.

131. Plutchik, R. "The Effects of High-Intensity Intermittent Sound on Performance, Feeling, and Physiology." Psychological Bulletin, Vol. 56 (1969), pp. 131-151.

132. Pickett, J. M. "Message Constraints, A Neglected Factor in Predicting Industrial Speech Communication." ASHA Reports, Vol. 11, No. 4 (1969), ASHA, Danville, Ill., pp. 121-128.

133. Powell, P., M. Hale, J. Martin, and M. Simon, et al. "2000 Accidents, A Shop Floor Study of Their Causes Based on 42 Months' Continuous Observation." National Institute of Industrial Psychology, London, England.

134. Purswell, J. L., and H. C. Aulwurm. A Study of Emergency Vehicle Auditory Warning Signals. (Unpublished M.S. Thesis, Main Library, University of Oklahoma, Norman, Oklahoma, 1971.)

135. Rappaport, Maurice, and H. Kenneth Hopkins. "Signal Detection and Chlorpromazine." Human Factors, Vol. 13, No. 4 (1971), pp. 387-390.

136. Raytheon Service Company. "Industrial Noise and Worker Medical, Absence, and Accident Records." RR-17, June 1972. Prepared by Raytheon Service Co., 12 Second Avenue, Burlington, Mass. 01803. For the National Institute for Occupational Safety and Health, U. S. Dept. of Health, Education, and Welfare.

137. Robinson, D. W. *General Problems of the Control of Noise.* Symposium No. 12 - National Physical Laboratory, London, Her Majesty's Stationery Office, 1962, pp. 5-17.

138. Roeser, Ross J., and Lloyd L. Price. "Effects of Habituation on the Auditory Evoked Response." *Journal of Acoustic Research*, Vol. 9, No. 4 (Oct., 1969), p. 306.

139. Rosenzweig, Mark R. "Auditory Localization." *Scientific American*, Vol. 205, No. 4 (Oct., 1961), pp. 132-142.

140. Salvi, R. J., D. Henderson, and R. P. Hamernik. "Cochlear Nucleus Neurons Response to TTS Producing Noise." Accession No. 422, Grant No. OH 00364, OEA, NIOSH, Rockville, Md.

141. Sataloff, Joseph. *Industrial Deafness.* N. Y.: McGraw-Hill, 1957.

142. Scott, T. H., in J. A. Adams and J. P. Frarckmann. "Theories of Vigilance." *Psychological Bulletin*, Vol. 59 (1962), pp. 257-272.

143. Sergeev, S., and V. Sergeev. "Music Versus Noise (Muzyka Protn Suma - Russian)." Abstract from *Occupational Safety and Health Abstracts*, Vol. 8, No. 10 (1970), p. 587.

144. Sias, Douglas. "How to Reduce the Noise Hazard." *Mechanical Engineering*, Vol. 88, No. 10 (Oct., 1966), p. 26.

145. Simon, J. Richard, and James A. Chisman. "Protection Against Impulse - Type Industrial Noise by Utilizing the Acoustic Reflex." *Journal of Applied Psychology*, Vol. 45 (1960), pp. 402-407.

146. Sitler, R., D. Henderson, and R. P. Hamernik. "The Temporary and Permanent Threshold Shifts Produced by Three Levels of Impulse Noise." Accession No. 0427, Grant No. OH 00364, OEA, NIOSH, Rockville, Md.

147. Sonn, Martin . "Psychoacoustical Terminology." Raytheon Company, Submarine Signal Division, Portsmouth, R. I. 02871, 1969.

148. Sperry Rand. *Sound Advice.* Troy, Michigan: Vickers Division of Sperry Rand Corp., 1971.

149. Stevens, Stanley Smith, and Fred Warshofsky. *Sound and Hearing.* New York: Time, Inc., 1965.

150. Stevens, S. S., and Hallowell Davis. *Hearing.* New York: John Wiley and Sons, 1938.

151. Stevens, S. S. "Procedure for Calculating Loudness: Mark VI." *Journal of the Acoustical Society of America*, Vol. 33, No. 11 (November, 1961), pp. 1577-1585.

152. Stevens, S. S. "On the Psychophysical Law." Psychological Review, Vol. 64, No. 3 (May, 1957), pp. 153-181. American Psychological Assoc., Inc., Washington, D. C.

153. Stevens, S. S. Editor. From Fitts' Handbook of Experimental Psychology. New York - London: John Wiley and Sons, Inc., 1951.

154. Surry, Jean. An Annotated Bibliography for Industrial Accident Research and Related Fields. Toronto, Canada: Ontario Dept. of Labor, April, 1969.

155. Surry, Jean. Industrial Accident Research: A Human Engineering Appraisal. Toronto, Canada: Ontario Dept. of Labor, June, 1969.

156. Thompson, Richard F. Foundations of Physiological Psychology. New York, Evanston, and London: Harper and Row, 1967.

157. Taylor, W. Proceedings of the Symposium on the Psychological Effects of Noise Held at University of Wales. Cardiff, September, 1967.

158. Teichner, W. H., E. Arees, and R. Reilly. "Noise and Human Performance, A Physchophysiological Approach." Ergonomics, Vol. 6, No. 1 (1963), pp. 83-97. Taylor & Francis, Ltd., London.

159. Underwriters Laboratories. Fire Protection Equipment List. Chicago, Ill.: Underwriters Laboratory, Inc., Jan., 1974.

160. Underwood, B. J. Psychological Research. N. Y.: Appleton-Century-Crofts, Inc., 1957.

161. von Bekesy, Georg. Sensory Inhibition. Princeton, N. J.: Princeton University Press, 1967.

162. von Bekesy, Georg. Experiments in Hearing. Translated and edited by E. G. Wever. New York: McGraw-Hill Book Company, Inc., 1960.

163. von Bekesy, Georg. "The Ear." Scientific American, Vol. 197, No. 2 (August, 1957), pp. 66-76.

164. Walker, R. P., C. C. Bagwell, Jr., and E. J. Bernet. "Preliminary Report on Noise in the Textile Industry." Institute Project No. 82, February 1, 1968. Unpublished. Institute of Textile Technology, Charlottesville, Virginia.

165. Walkush, T. J., and J. E. Baker. "Pure Tone Warning Signals in Industrial Noise." (Unpublished - Special Report to Dr. S. K. Adams, Oklahoma State University, May, 1970.)

166. Ward, W. Dixon. "Effect of Temporal Spacing on Temporary Threshold Shift From Impulses." Journal of Acoustical Society of America, Vol. 34, No. 9 (Sept., 1962), pp. 1230-1232.

167. Ward, W. D., A. Glorig, and D. L. Sklat. "Dependence of Temporary Threshold Shift at 4kc on Intensity and Time." Journal of Acoustical Society of America, Vol. 30 (1958), pp. 944-954.

168. Warner, Harold D. "Effects of Intermittent Noise on Human Target Detection." Human Factors, Vol. 11, No. 3 (1969), pp. 245-250. Baltimore, Md.: Johns Hopkins Press.

169. Warner, H. D., and Norman W. Heimstra. "Effects of Noise Intensity on Visual Target - Detection Performance." Human Factors, Vol. 14, No. 2 (1972), pp. 181-185.

170. Warrick, M. J., A. W. Kibler, and Donald A. Topmiller. "Response Time to Unexpected Stimuli." Human Factors, Vol. 7, No. 1 (Feb., 1965), pp. 81-86.

171. Wasserman, Seymour, and Arthur Oppenheim. "How Acoustical Enclosures Muffle Plant Noises." Reprint from Plant Engineering by IAC Bulletin No. 6.0002.0 Industrial Acoustics Company, New York, N. Y.

172. Wenner, Adrian M. "Sound Communication in Honeybees." Scientific American, Vol. 210, No. 4 (April, 1964), pp. 116-124.

173. Wever, Ernest Glen, and Merle Lawrence. Physiological Acoustics. Princeton: Princeton University Press, 1954.

174. Wever, Ernest Glen. Theory of Hearing. New York: John Wiley and Sons, Inc.

175. Woodhead, M. Effects of Bursts of Loud Noise on A Continual Visual Task. R. N. P. 57/891. London: Royal Navy, 1957.

176. Woodhead, M. "Effect of Bursts of Noise on An Arithmetic Task." American Journal of Psychology, Vol. 77, No. 4 (1964), pp. 627-633.

177. Woodhead, M. "Effect of Brief Loud Noise on Decision-Making." Journal of Acoustical Society of America, Vol. 31, No. 10 (1959), p. 1329. American Institute of Physics, Washington, D. C.

178. Woodson, Wesley E., and Donald W. Conover. Human Engineering Guide for Equipment Designers. Excerpt from Chapter 4, pp. 7-26 and 35. Berkeley-Los Angeles: University of California Press, 1964.

179. Wright, Samson. *Applied Physiology*. Eleventh Edition. Part VI. "The Special Senses 55 the Ear." N. Y., Toronto: Oxford University Press, 1965, pp. 315-321.

180. Wrightman, Frederick L., and David M. Green. "The Perception of Pitch." *American Scientist*, Vol. 62 (March-April, 1974), pp. 208-215.

181. Wyman, Charles W. "Administration and Human Relations Aspects." *National Safety News*, Vol. 99, No. 5 (May, 1969), pp. 63-75.

182. Yaffe, Charles D., and Herbert H. Jones. "Noise and Hearing." Public Health Service Publication No. 850. U. S. Dept. of Health Education and Welfare, Public Health Service, Division of Occupational Health, U. S. Government Printing Office, Washington, D. C., 1961.

183. Young, I. M., and C. H. Wenner. "Effects of Masking Noise on the SISI Test." *Journal of Auditory Research*, Vol. 8, No. 3 (July, 1968), pp. 331-338.

184. Van Cott, Harold P., and Robert G. Kinkade. "Human Engineering Guide to Equipment Design." Revised Edition, 1972. Sponsored by Joint Army-Navy-Air Force Steering Committee. U. S. Govt., U. S. Govt. Printing Office, Washington, D. C.

APPENDIX A

COMMERCIALLY AVAILABLE WARNING SIGNALS

COMMERCIALLY AVAILABLE WARNING SIGNALS
(based on available literature from manufacturers)

Name of Unit	Code No. of Manufacturer	Ratings as given
Vibrating Horn	9	100 dB at 10'
Vibrating Horn 31-41 (w/grille)	22	101 dB at 10'
Vibrating Horn 32-42 (w/single projector)	22	101 dB at 10'
Vibrating Horn 33-43 (w/double projector)	22	98 dB at 10'
Motor driven Sirens	9	110 dB at 10'
Motor driven Horn 20	22	103 dB at 10'
Motor driven Howlers (single projector)	9	110 dB at 10'
Motor driven Howlers (double projector)	9	106 dB at 10'
Motor driven Howlers (Heavy duty-single projector)	9	97 dB at 10'
Motor driven Howlers (Heavy duty-double projector)	9	95 dB at 10'
Motor driven Howlers (Heavy duty-grille front)	9	92 dB at 10'
Buzzers	9	89 dB at 10'
Electric Signal Horns model 20 (motor driven mechanical)	22	103 dB at 10'
Electric Signal Horns model 60 (two projectors)	22	100 dB at 10'
Electric Signal Horns model 31X (diaphragm grille)		101 dB at 10'
Electric Signal Horns model 32X (horn)	22	102 dB at 10'
Electric Signal Horns model 33X (dual horn)	22	99 dB at 10'
Electric Signal Horns model 53 (resonating w/13" projector)	22	104 dB at 10'
Electric Signal Horns model 55 (resonating w/24" projector)	22	105 dB at 10'
Electric Signal Horns model 350 (grille)		100 dB at 10'
Electric Signal Horns model 351 (single projector)		101 dB at 10'
Electric Signal Horns model 352 (dual projector)		98 dB at 10'
BELLS		
10" Single stroke and vibrating	9	106 dB
Single stroke	16	92 dB at 10' 335 Hz

Name of Unit	Code No. of Manufacturer	Ratings as given
Electric trumpet horns	Sparton	
Model 243	Sparton	130 dB at 4" 480 Hz
Model 244 and 362	Sparton	130 dB at 4" 400 Hz
Model 363	Sparton	130 dB at 4" 340 Hz
Model 364	Sparton	130 dB at 4" 270 Hz
Model U-70	Sparton	130 dB at 4" 523 Hz
Air Horns	Sparton	
Model 277 (matched pair)	Sparton	137 dB at 4" 385 & 505 Hz
Model 275 (matched pair)	Sparton	137 dB at 4" 320 & 385 Hz
Model 176C (single)	Sparton	126 dB at 4" 208 Hz
Model 555C (with compressor)	Sparton	125 dB at 4" 410 & 450 Hz

Name of Unit	Code No. of Manufacturer	Ratings as given
BELLS		
10" Vibrating	16	98 dB at 10'
Vibratone	22	102 dB at 10'
8" not available		
6" Single stroke and vibrating	9	101 dB
Single stroke	16	86 dB at 10' 585 Hz
Vibratone	22	100 dB at 10'
4" Single stroke and vibrating	9	96 dB
Vibrating	16	88 dB at 10'
Vibratone	22	98 dB at 10'

Although these are not normally used in industry, they provide additional information:

Automotive horns	Sparton	
S-500	Sparton	133 dB at 4" 314 Hz
S-570 low	Sparton	137 dB at 4" 312 Hz
S-570 high	Sparton	133 dB at 4" 390 Hz
U-34 low	Sparton	125 dB at 4" 360 Hz
U-34 high	Sparton	125 dB at 4" 450 Hz
U-1 and U-2	Sparton	130 dB at 4" 420 Hz
S-1 and S-2	Sparton	133 dB at 4" 270 Hz

APPENDIX B

AUDIBLE SIGNAL APPLIANCES

AUDIBLE SIGNAL APPLIANCES (3801 AO) ULSZ

Source: Underwriters Laboratories Inc.
Fire Protection Equipment List, January 1974, pp. 86-94

Note: Manufacturers identification numbers are as numbered by writer.

BELLS

Single stroke, Sizes not given numbers 6, 8, 9, 11, 16, 19, 23, 25, 26, 28, 30, 34, 35, 38, 42, 49, 50, 52, 55, 58, 60, 61.

Single stroke, Sizes

4" numbers 7, 21, 22, 41, 47, 53, 67.

6" numbers 1, 7, 18, 21, 22, 36, 41, 46, 47, 53, 57, 67.

8" numbers 1, 5, 7, 18, 21, 22, 36, 41, 46, 47, 53, 57, 67.

10" numbers 1, 5, 7, 18, 21, 22, 36, 41, 46, 47, 53, 57, 67.

12" numbers 1, 5, 7, 21, 22, 36, 41, 67.

Controlled stroke vibrating, 6", 8", 10", 12" number 42.

Vibrating, sizes not given numbers 6, 8, 9, 11, 16, 17, 23, 24, 26, 27, 28, 29, 30, 32, 33, 34, 35, 38, 39, 42, 43, 44, 45, 49, 52, 54, 55, 56, 58, 59, 60, 61, 62, 63, 64, 66.

Vibrating, Sizes

4" numbers 1, 21, 25, 41, 47, 50, 51, 53, 67.

6" numbers 1, 18, 21, 22, 25, 36, 41, 46, 47, 48, 50, 51, 53, 57, 67.

8" numbers 1, 2, 3, 14, 18, 21, 22, 25, 31, 36, 37, 41, 46, 47, 48, 51, 53, 57, 67.

10" numbers 1, 2, 3, 14, 18, 21, 22, 25, 31, 36, 37, 41, 46, 47, 48, 50, 51, 53, 57, 67.

12" numbers 1, 21, 22, 36, 41, 67.

Vibrating contactless 4", 6", 8", 10", 12" numbers 7, 15, 42, 51.

Vibrating, contact 4", 6", 8", 10", 12" numbers 7, 13, 51, 65.

Vibrating, polarized 4", 6", 8", 10", 12" numbers 7, 22, 45, 55, 58.

Electronic vibrating number 16.

Electro mechanical number 28.

BUZZERS

No other description numbers 5, 6, 16, 21, 28, 33, 36, 46, 47, 55, 57, 58, 63.

Vibrating numbers 8, 9, 32, 49, 61.

CHIMES

No other description numbers 6, 7, 15, 18, 20, 21, 22, 25, 26, 28, 32, 42, 52, 55, 58, 60, 67.

Vibrating number 7.

Single stroke numbers 11, 16.

HORNS

No other description numbers 5, 16, 21, 25, 26, 36, 40, 55, 58, 67.

Diaphragm numbers 16, 63.

Electronic numbers 22, 45.

Motor driven numbers 8, 9, 49, 61.

Resonating numbers 7, 22, 42.

Vibrating numbers 7, 8, 9, 10, 11, 12, 18, 22, 32, 41, 42, 49, 50, 55, 57, 58, 61, 62.

Vibrating polarized numbers 22, 45, 55, 58.

HORN-SIREN COMBINATION

Number 16.

SIRENS

Indoor use numbers 2, 4, 16, 18, 21, 22, 64.

Motor driven, outdoor use numbers 8, 9, 49, 61.

WHISTLES

Number 7.

APPENDIX C

METHOD OF CALCULATING LOUDNESS

Method to be used in Calculating Loudness

Yaffe (1961) made his analysis of sound on the octave band filter set based on ANSI Z-24.10 - 1953. He calculated the sones based on Stevens, S. S. "Calculations of the Loudness of Complex Noise," Journal of Acoustic Society of America, Vol. 28, No. 5, September 1956, p. 824. Two conversions of the data are necessary to bring it to the approach used in this study, which is based on the "new" octave bands as specified in ANSI S1.11 - 1966 and Stevens, S. S., Procedure for Calculating Loudness: Mark VI, Journal of the Acoustic Society of America, Vol. 33, No. 11, Nov. 1961, pp. 1577-1585.

As an example, in Table 2, page 8 of the Yaffe and Jones Report, we see the following:

	No. of Analyses	Percentile	Unit	Octave Bands 20 75	75 150	100 300	300 600	600 1200	1200 2400	2400 4800	4800 10,000	Overall
Weave	18	Median	dB	90	89	92	94	96	96	92	86	103
			Sones	15	22	36	46	52	58	63	52	147

		63	125	250	500	1000	2000	4000	8000	
To Convert	dB	90.	88.8	92.7	94.5	96.5	96	91	84.6	103
Weave	Band level index (Sones) (See below for conversion)	13.6	16.1	26.1	36.7	54	66	56	43	139.6

Octave Band No.	Octave Band Hz	Band Level dB	Band Loudness Index	
18	63	90	13.6	
21	125	88.8	16.1	
24	250	92.7	26.1	
27	500	94.5	36.7	
30	1000	96.5	54	
33	2000	96	66	$= S_m$
36	4000	91	56	
39	8000	84.6	43	

E band loudness index 311.5 x .3 = 93.45

S_m = max. band loudness index = 66 x .7 = 46.2

139.6 Sones (OD)

or computed loudness level = 111 Phons (OD)

OD = Octave Diffuse

APPENDIX D

AUDIOLOGICAL RECORDS

SUBJECTS

A. H. B., Age 25, Environments: White Noise

Audiometric Record: Right Ear Normal

Left Ear Mild Loss at 4K and 8K

B. R. C., Age 21, Environments: #11, 14, 26

Audiometric Record: Right Ear Normal

Left Ear Normal

C. K. D., Age 23, Environments: White Noise

Audiometric Record: Right Ear Normal

Left Ear Mild Loss at 4K

D. D. D., Age 54, Environments: #14, 26

Audiometric Record: Right Ear Mild to moderate loss at 4K and 8K

Left Ear Mild loss at 4K and 8K

E. J. H., Age 22, Environments: #14, 26, 30

Audiometric Record: Right Ear Normal

Left Ear Normal

F. J. L., Age 22, Environments: #11, 26, 30

Audiometric Record: Right Ear Normal

Left Ear Normal

G. C. O., Age 22, Environments: #30

Audiometric Record: Right ear Essentially normal

Left Ear Essentially normal

H. R. T., Age 22, Environments: #14, 26, White Noise

Audiometric Record: Right Ear Normal

Left Ear Normal

Classifications of Hearing Loss as used by the Speech and Hearing Clinic, Auburn University

Hearing Threshold level in decibels

From 0 to -10	Normal
From -10 to -25	Essentially normal
From -26 to -40	Mild loss
From -41 to -65	Moderate loss
From -66 to -90	Severe
Below -90	Profound

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

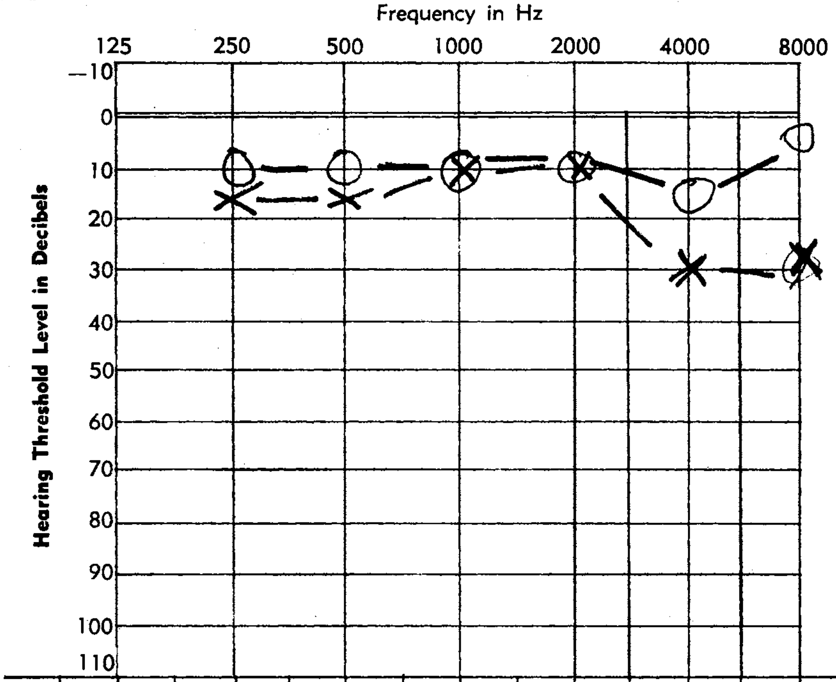
AUDIOLOGICAL RECORD

File Number A Date 8-[illegible]-71 Age 35 DOB Examiner

Name H.B. Referral Source

Address

Weber



Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	☐
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used 1701. Grayson-Stadtler

Masking for Speech [illegible]

Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

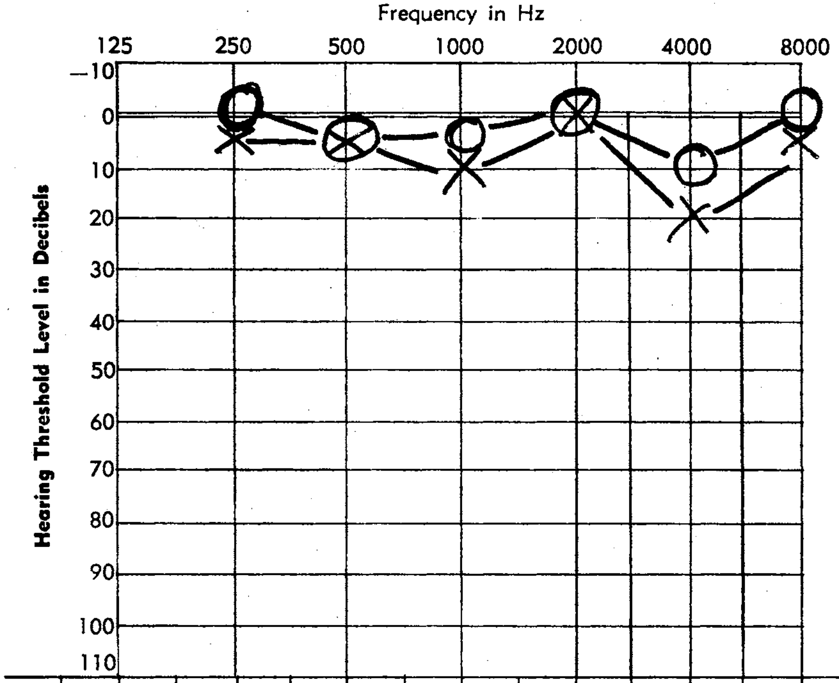
AUDIOLOGICAL RECORD

File Number B Date 1 August 1972 Age 21 DOB 6-1-52 Examiner

Name R.C. Referral Source

Address

Weber



Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	☐
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used 1701 Grayson Stadtler

Masking for Speech None

Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

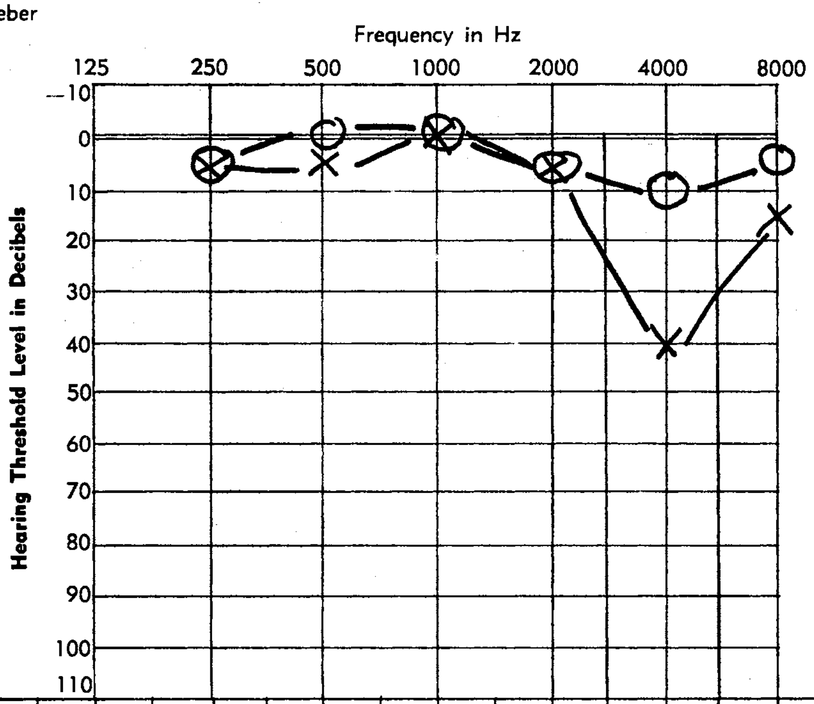
AUDIOLOGICAL RECORD

File Number C Date 8-9-74 Age 23 DOB 10-6-50 Examiner

Name K.D. Referral Source

Address

Weber



Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	□
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used GRASON STATLER 1701

Masking for Speech

Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

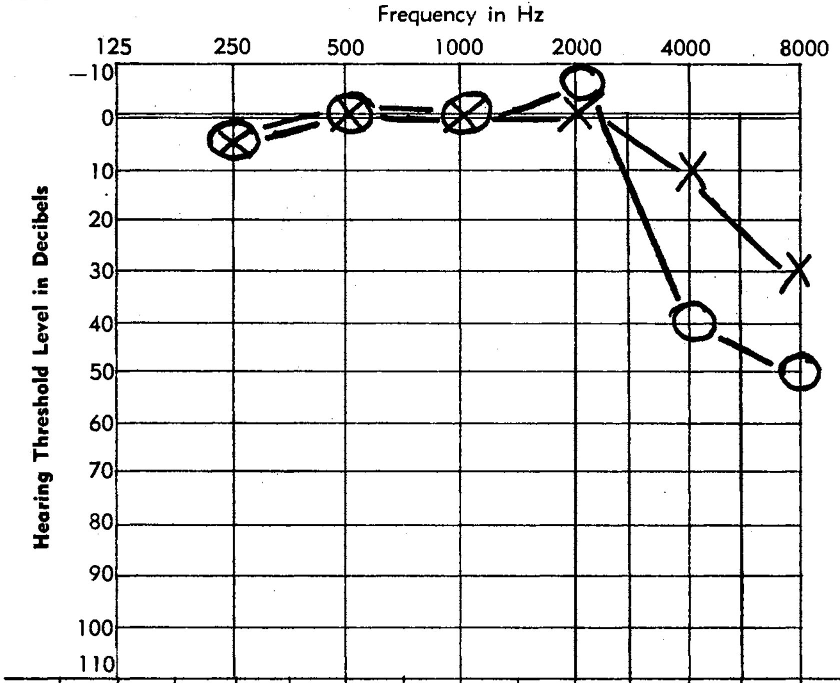
AUDIOLOGICAL RECORD

File Number D Date 8/1/74 Age 54 DOB ____ Examiner ____

Name D.D. Referral Source ____

Address ____

Weber



Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	□
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:
Good

A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used 1701 Grayson Stadler

Masking for Speech None

Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

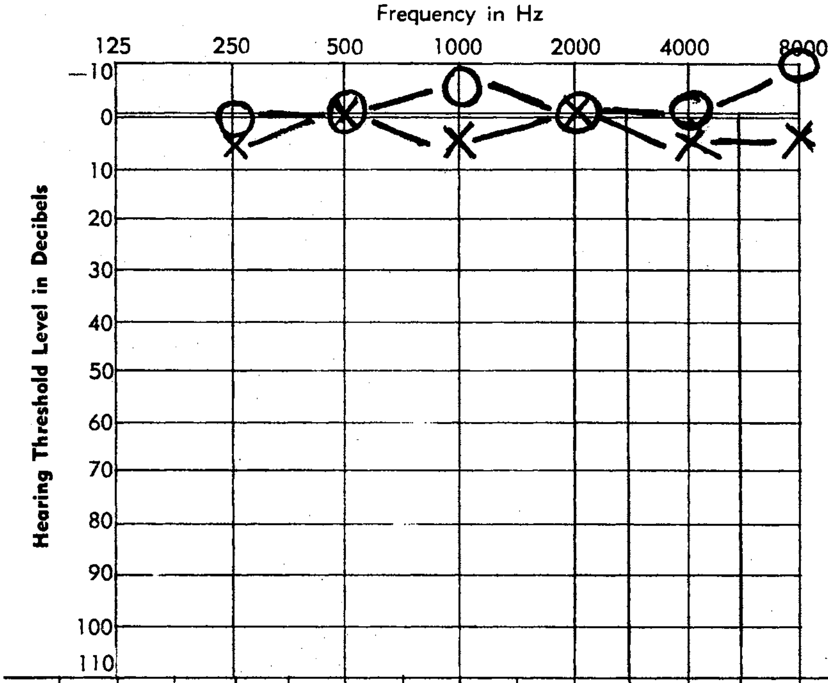
AUDIOLOGICAL RECORD

File Number E Date 8-2-74 Age 22 DOB 5-12-52 Examiner

Name J.H. Referral Source

Address

Weber



A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	□
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used G-S. 1701

Masking for Speech None

Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY

1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

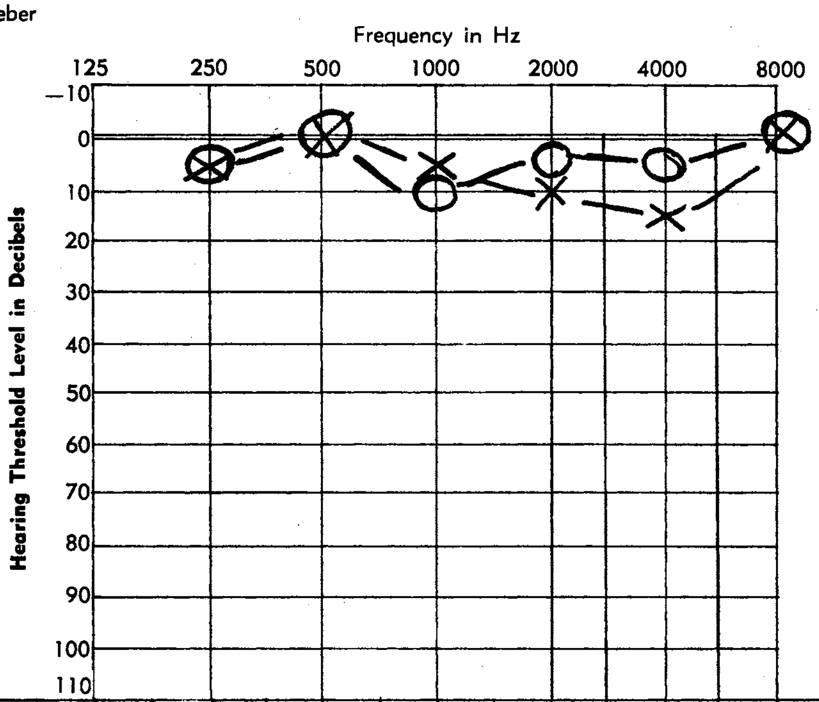
AUDIOLOGICAL RECORD

File Number F. Date 8-5-74 Age 22 DOB ____ Examiner ____

Name J.L. Referral Source ____

Address ____

Weber



Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	□
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

	Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones					
SRT					
HL for Sp. Discrim.					
Sp. Discrim.					

		Right Ear	Left Ear
Bekesy			
Tone Decay	500		
	1K		
	2K		
	4K		
SISI	500		
	1K		
	2K		
	4K		

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used 1701 Grayson Stadtler

Masking for Speech None

Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

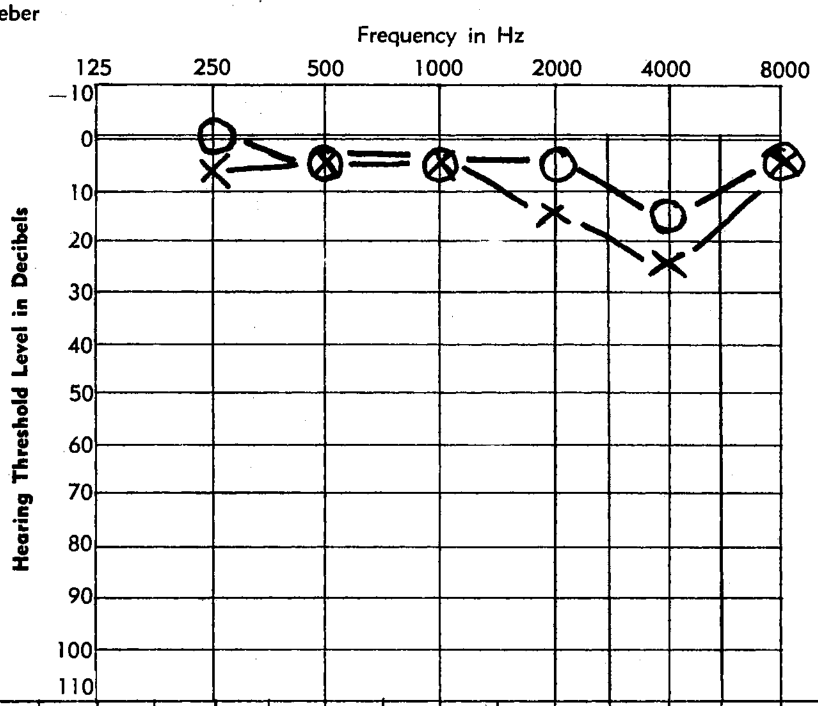
AUDIOLOGICAL RECORD

File Number G Date 6/11/74 Age 22 DOB ____ Examiner ____

Name C.O. Referral Source ____

Address ____

Weber



Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	□
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used 1701 Grayson-Stadler

Masking for Speech None

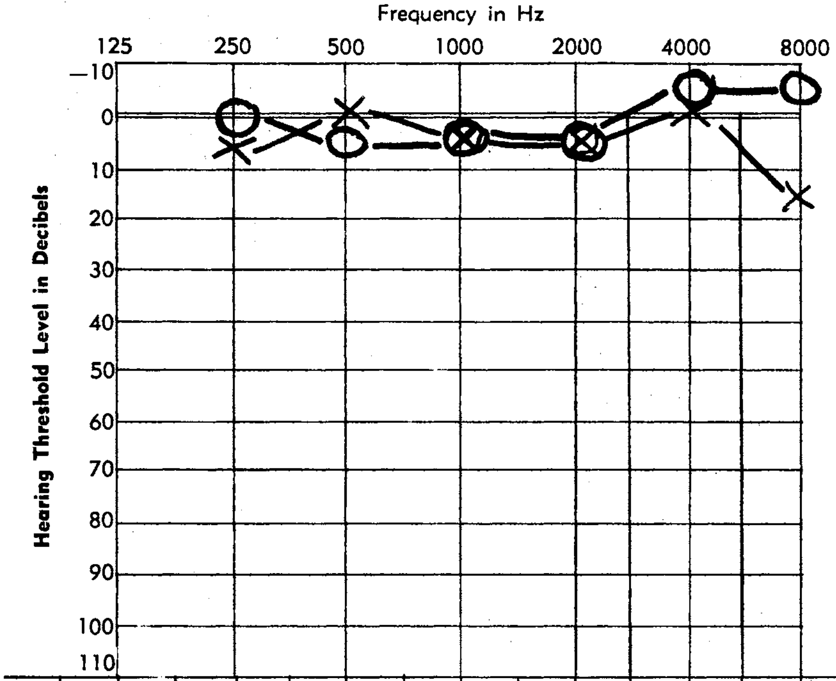
Remarks:

Sandra Clark
Audiologist

SPEECH & HEARING CLINIC
AUBURN UNIVERSITY
1199 Haley Center — Auburn, Alabama
Phone: 205/826-5545

AUDIOLOGICAL RECORD

File Number H Date 1 Aug 74 Age 22 DOB ________ Examiner ________
Name R.T. ________ Referral Source ________
Address ________
Weber



A/C B/C	L	R	L	R	L	R	L	R	L	R	L	R	L	R	A/C B/C

Effective Masking Re OdB HL

Key to Audiogram

Ear	R	L
A/C	O	X
A/C Masked	Δ	□
B/C	>	<
B/C Masked	⊳	⊲
Color	Red	Blue

NR—No Response
DNT—Did Not Test
CNT—Could Not Test
SAT—Speech Awareness Threshold
EM—Effective Masking
HL—Hearing Level
SL—Sensation Level

Test Reliability:

		Right Ear	Left Ear	Sound Field	With Pt. Aid RE	With Pt. Aid LE
Hearing Loss Pure Tones						
SRT						
HL for Sp. Discrim.						
Sp. Discrim.						
Bekesy						
Tone Decay	500					
	1K					
	2K					
	4K					
SISI	500					
	1K					
	2K					
	4K					

Reference Levels Used: ANSI (ISO-1964)

Audiometer Used 1701 Grayson Stadler

Masking for Speech None

Remarks:

Sandra Clark
Audiologist

APPENDIX E

DATA

TABLE IX

ORIGINAL RAW DATA

Environment #11

	Rheostat Settings								Errors	Correlation Coefficient
	20	19	18.75	18.5	18	17.5	17	16		
Signal #1										
dB	104	98	93	89.5	84	83	81	78		
Average	.501	.585	.751	.803	.778	1.184	.873	1.208		.867076
S_s B	.448	.582	.748	.870	.774	1.176	1.058	1.316		.920392
S_s F	.554	.588	.754	.736	.782	1.192	.688	1.100		.724782
Signal #2										
dB	104	98	92	87.5	82	81	79	76		
Average	.175	.245	.343	.294	.336	.549	.776	1.049		.808632
S_s B	.192	.224	.312	.282	.406	.552	.828	1.506		.752213
S_s F	.158	.266	.374	.306	.266	.546	.724	.592		.793419
Signal #3										
dB	107	100	96	91	85	84	82	81		
Average	.212	.298	.309	.324	.347	.329	.400	.622		.738699
S_s B	.152	.280	.236	.328	.322	.366	.290	.934		.603624
S_s F	.272	.316	.382	.320	.372	.292	.510	.310		.431744
Signal #4										
dB	104	100	93	88.5	83	82	80	76.5		
Average	.263	.465	.493	.608	.663	1.73	.687	.931		.630972
S_s B	.266	.456	.574	.524	.666	2.01	.678	.890		.551345
S_s F	.260	.474	.412	.692	.660	1.45	.696	.972		.725003

TABLE IX (Continued)

Environment #11

	Rheostat Settings									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #5										
dB	106	101	94	90	86	82	81	77		
Average	.177	.187	.243	.271	.249	.320	.345	.473		.892764
S_s B	.132	.156	.240	.276	.226	.328	.432	-		.888569
S_s F	.222	.218	.246	.266	.272	.312	.258	.473		.730975
Signal #6										
dB	100	98	90	87	85.5	81	80	76		
Average	.245	.285	.307	.375	.291	.689	.458	.646		.810876
S_s B	.200	.268	.290	.322	.280	.536	.442	.722		.852516
S_s F	.290	.302	.324	.428	.302	.842	.474	.571		.678657
Signal #7										
dB	102	97	90	87	83	79.5	77.5	75		
Average	.927	.952	1.093	1.132	1.102	1.971	1.114	1.084		.46104
S_s B	.932	.960	1.070	1.106	1.162	2.792	1.112	-		.516298
S_s F	.922	.944	1.116	1.158	1.042	1.150	1.116	1.084		.738474
Signal #8										
dB	103	101	92	89	86	80.5	79	74.5		
Average	.240	.353	.372	.447	.408	1.258	.483	1.848		.738691
S_s B	.244	.416	.362	.440	.454	.908	.472	-		.674358
S_s F	.236	.290	.382	.454	.362	1.608	.494	1.848		.735191

TABLE IX (Continued)

Environment #11

	Rheostat Settings									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
	Rank Order in Reaction Time									
1	2	5	5	5	5	5	5	5		
2	5	2	6	2	6	3	3	3		
3	3	6	3	3	2	2	6	6		
4	8	3	2	6	3	6	8	4		
5	6	8	8	8	8	1	4	2		
6	4	4	4	4	4	8	2	7		
7	1	1	1	1	1	4	1	1		
8	7	7	7	7	7	7	7	8		
	Octave Band									
Octave	31.5	63	125	250	500	1K	2K	4K	8K	
dB	56	64	80	84	86	89	84	84	77	

TABLE IX (Continued)

Environment #14

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #1										
dB	104	98	93	89.5	84	83	81	78		
Average	.606	.605	.751	.836	.844	1.146	1.395	2.142		.802125
S_s D	.596	.402	.768	.840	.786	1.060	1.320	-		.827494
S_s E	.666	.620	.718	.850	.916	1.024	1.160	1.498	3	.87729
S_s B	.548	.672	.730	.808	.944	1.225	1.532	3.356	0	.722409
S_s H	.614	.726	.788	.846	.728	1.278	1.568	1.574	0	.815253
Signal #2										
dB	104	98	92	87.5	82	81	79	76		
Average	.280	.303	.362	.397	.470	.866	1.010	2.448		.697245
S_s D	.338	.344	.390	.414	.462	.732	1.502	-	0	.661082
S_s E	.284	.298	.346	.390	.474	.472	.486	2.522	0	.557448
S_s B	.256	.256	.360	.392	.414	1.694	-	-	0	.619908
S_s H	.240	.312	.350	.396	.530	.566	1.044	2.344	0	.687568
Signal #3										
dB	107	100	96	91	85	84	82	81		
Average	.258	.274	.335	.346	.389	.689	.820	1.081		.797427
S_s D	.312	.320	.355	.373	.482	.860	.985	-	0	.79465[illegible]
S_s E	.250	.238	.398	.390	.410	.522	.434	1.118	0	.658049
S_s B	.230	.240	.282	.316	.280	.806	1.356	1.252	0	.747421
S_s H	.240	.298	.306	.306	.384	.568	.506	.874	3	.766017

TABLE IX (Continued)

Environment #14

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #4										
dB	104	100	93	88.5	83	82	80	76.5		
Average	.524	.535	.599	.667	.823	1.028	1.402	1.849		.833445
S_s D	.573	.636	.654	.701	1.04	1.082	1.126	-	0	.917499
S_s E	.564	.408	.482	.560	.750	.776	.936	1.674	0	.745937
S_s B	.472	.526	.616	.700	.756	1.365	2.406	-	0	.722465
S_s H	.486	.570	.645	.708	.746	.890	1.138	2.024	2	.75692
Signal #5										
dB	106	101	94	90	86	82	81	77		
Average	.243	.282	.313	.334	.332	.457	.456	.503		.937829
S_s D	.246	.274	.316	.358	.366	.442	.528	-	0	.926471
S_s E	.298	.344	.356	.354	.294	.542	.384	.380	3	.513299
S_s B	.156	.242	.278	.298	.310	.456	.482	.508	0	.9502
S_s H	.274	.268	.300	.324	.356	.388	.428	.620	1	.829683
Signal #6										
dB	100	98	90	87	85.5	81	80	76		
Average	.270	.307	.309	.347	.389	.676	1.125	2.462		.731265
S_s D	.330	.330	.352	.354	.388	.432	.466	-	0	.892938
S_s E	.272	.298	.330	.418	.434	.450	.474	.297	0	.596051
S_s B	.224	.282	.290	.306	.360	.708	.808	1.954	0	.749676
S_s H	.252	.318	.262	.308	.374	1.114	.275	-	3	.659861

TABLE IX (Continued)

Environment #14

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #7										
dB	102	97	90	87	83	79.5	77.5	75		
Average	.953	.999	1.096	1.188	1.229	1.271	1.816	2.004		.842203
S_s D	1.060	1.208	1.254	1.252	1.306	1.476	1.336	-	0	.89226
S_s E	.864	.924	1.066	1.226	1.236	1.324	1.60	2.12	0	.869974
S_s B	.890	.936	1.030	1.168	1.216	1.080	2.91	-	0	.623571
S_s H	.998	.926	1.032	1.106	1.158	1.202	1.416	1.888	3	.789601
Signal #8										
dB	103	101	92	89	86	80.5	79	74.5		
Average	.363	.413	.483	.535	.559	.755	1.232	1.756		.832036
S_s D	.398	.410	.466	-	.521	.570	.596	-	0	.986665
S_s E	.356	.434	.576	.522	.600	.704	.832	2.13	0	.727466
S_s B	.360	.380	.420	.474	.556	1.060	2.678	-	0	.698639
S_s H	.338	.428	.470	.610	-	.686	.822	1.382	0	.859434

Rank Order in Reaction Time

1	5	3	6	5	5	5	5	5	
2	3	5	5	3	3	6	3	3	
3	6	2	3	6	6	3	2	8	
4	2	6	2	2	2	8	6	4	
5	8	8	8	8	8	2	8	7	
6	4	4	4	4	4	4	1	1	
7	1	1	1	1	1	1	4	2	2
8	7	7	7	7	7	7	7	6	

TABLE IX (Continued)

Environment #14

	Octave Band								
Octave	31.5	63	125	250	500	1K	2K	4K	8K
dB	62	70	85	99	89	85	80	70	60

TABLE IX (Continued)

Environment #26

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #1										
dB	104	98	93	89.5	84	83	81	78		
Average	.691	.749	.942	.882	.991	1.186	1.637	2.782		.746451
S_s F	.696	.716	1.090	.852	1.032	-	1.686	2.782	0	.789022
S_s H	.744	.748	1.064	.976	.995	1.204	1.674	-	0	.801427
S_s E	.604	.746	.794	.866	.973	1.234	1.552	-	3	.872872
S_s B	.718	.785	.820	.832	.962	1.120	-	-	0	.892084
Signal #2										
dB	104	98	92	87.5	82	81	79	76		
Average	.319	.363	.441	.399	.563	.661	.830	1.151		.835685
S_s F	.357	.342	.568	.418	.554	.902	1.148	1.151	2	.834371
S_s H	.258	.326	-	.346	.446	.420	.850	-	0	.704341
S_s E	.335	.350	.322	.390	-	-	.492	-	0	.84018
S_s B	.326	.432	.434	.442	.690	-	-	-	0	.863244
Signal #3										
dB	107	100	96	91	85	84	82	81		
Average	.331	.320	.364	.403	.410	.599	.768	1.059		.752211
S_s F	.304	.284	.402	.488	.474	.554	.624	1.288	3	.694241
S_s H	.320	.295	.310	.326	.366	.584	1.008	-	0	.663517
S_s E	.370	.350	.382	.412	.368	.658	.672	.830	2	.744683
S_s B	.330	.350	.360	.386	.430	-	-	-	0	.970503

TABLE IX (Continued)

Environment #26

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #4										
dB	104	100	93	88.5	83	82	80	76.5		
Average	.528	.594	.628	.725	.887	1.242	1.582	2.590		.793238
S_s F	.668	.760	-	.862	1.22	1.545	2.00	2.590	0	.850991
S_s H	.470	.546	.583	.596	.752	1.250	1.145	-	0	.820468
S_s E	.530	.520	.650	.698	.690	.930	1.60	-	2	.719847
S_s B	.444	.548	.650	.745	-	-	-	-	0	.994424
Signal #5										
dB	106	101	94	90	86	82	81	77		
Average	.267	.327	.314	.375	.394	.421	.507	.558		.922245
S_s F	.288	.402	-	.438	.478	-	.416	.574	1	.848016
S_s H	.236	.280	.292	.300	.376	.494	.446	.478	0	.927992
S_s E	.261	.296	.290	.290	.336	.364	.432	.622	0	.778804
S_s B	.282	.328	.360	.472	.384	.406	.735	-	0	.713521
Signal #6										
dB	100	98	90	87	85.5	81	80	76		
Average	.315	.340	.346	.395	.442	.623	.592	.726		.910656
S_s F	.358	.454	-	.330	.424	.556	.610	.726	0	.746051
S_s H	.242	.248	.294	.330	.388	.510	.560	-	0	.920014
S_s E	.305	.288	.362	.466	.378	.472	.606	-	0	.874894
S_s B	.354	.368	.383	.452	.578	.952	-	-	0	.801419

TABLE IX (Continued)

Environment #26

	Rheostat Settings									Correlation Coefficient
	20	19	18.75	18.5	18	17.5	17	16	Errors	
Signal #7										
dB	102	97	90	87	83	79.5	77.5	75		
Average	1.109	1.157	1.187	1.227	1.292	1.378	1.476	1.427		.947272
S_s F	1.034	1.09	-	1.21	1.164	1.238	1.250	1.398	0	.911939
S_s H	1.122	-	1.214	1.270	1.354	1.380	1.486	1.456	0	.964066
S_s E	1.192	1.156	1.168	1.230	1.374	1.506	1.680	-	0	.839079
S_s B	1.088	1.226	1.180	1.196	1.274	1.388	1.486	-	0	.86871
Signal #8										
dB	103	101	92	89	86	80.5	79	74.5		
Average	.381	.382	.451	.487	.598	.907	.964	1.607		.861408
S_s F	.414	.366	.440	.470	.618	.652	.670	1.314	0	.794356
S_s H	.274	.374	.428	.482	.514	.874	1.258	1.900	0	.85087
S_s E	.418	.394	.462	-	.604	1.127	-	-	1	.848268
S_s B	.418	.392	.474	.508	.654	.974	-	-	0	.86693

Rank Order in Reaction Time

1	5	3	5	5	5	5	5	5
2	6	5	6	6	3	3	6	6
3	2	6	3	2	6	6	3	3
4	3	2	2	3	2	2	2	2
5	8	8	8	8	8	8	8	7
6	4	4	4	4	4	1	7	8
7	1	1	1	1	1	4	4	4
8	7	7	7	7	7	7	1	1

TABLE IX (Continued)

Environment #26

	Octave Band								
Octave	31.5	63	125	250	500	1K	2K	4K	8K
dB	63	72	83	89	89	86	80	73	62

TABLE IX (Continued)

Environment #30

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #1										
dB	104	98	93	89.5	84	83	81	78		
Average	.602	.535	.691	.694	.659	.739	.765	.920		.821361
S_s G	.686	.652	.778	.836	.714	.720	.880	.920	0	.688684
S_s F	.670	.594	.696	.772	.692	.766	.772	-	0	.696976
S_s E	.450	.360	.598	.474	.572	.732	.644	-	0	.769371
Signal #2										
dB	104	98	92	87.5	82	81	79	76		
Average	.219	.257	.275	.285	.337	.372	.336	.334		.928223
S_s G	.284	.278	.332	.334	.424	.442	.436	.340	0	.772466
S_s F	.166	.282	.216	.232	.270	.206	.235	.286	0	.462528
S_s E	.206	.210	.276	.290	.316	.468	.338	.376	0	.83289
Signal #3										
dB	107	100	96	91	85	84	82	81		.774009
Average	.224	.225	.255	.249	.331	.321	.258	.302		.777844
S_s G	.240	.292	.278	.304	.336	.418	.294	.302	0	.619467
S_s F	.220	.160	.246	.224	.328	.274	.250	-	0	.655896
S_s E	.212	.224	.240	.218	.330	.270	.230	-	0	.562044
Signal #4										
dB	104	100	93	88.5	83	82	80	76.5		
Average	.407	.437	.465	.493	.497	.564	.557	.558		.955102
S_s G	.444	.486	.506	.542	.578	.604	.582	.558	0	.918182
S_s F	.415	.482	.416	.448	.442	.512	.490	-	0	.529721
S_s E	.362	.342	.474	.488	.472	.576	.598	-	0	.917689

TABLE IX (Continued)

Environment #30

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #5										
dB	106	101	94	90	86	82	81	77		
Average	.210	.217	.262	.283	.292	.306	.285	.305		.951869
S_s G	.204	.302	.274	.390	.370	.440	.362	.282	1	.603366
S_s F	.178	.192	.258	.190	.276	.254	.244	-	0	.717685
S_s E	.188	.156	.254	.270	.230	.224	.248	.328	0	.745025
Signal #6										
dB	100	98	90	87	85.5	81	80	76		
Average	.227	.263	.287	.316	.317	.253	.291	.382		.69199
S_s G	.276	.302	.360	.366	.376	.272	.360	.468	0	.626086
S_s F	.222	.250	.222	.263	.232	.226	.240	-	0	5.14616E-02
S_s E	.182	.238	.278	.318	.344	.262	.272	.296	0	.622541
Signal #7										
dB	102	97	90	87	83	79.5	77.5	75		
Average	1.058	1.034	1.084	1.067	1.118	1.131	1.122	1.110		.861795
S_s G	1.066	1.096	1.250	1.132	1.200	1.234	1.162	-	0	.674445
S_s F	1.114	1.006	.988	1.026	1.010	1.042	1.104	1.056	0	2.11749E-02
S_s E	.994	1.000	1.014	1.044	1.144	1.118	1.100	1.164	0	.900787
Signal #8										
dB	103	101	92	89	86	80.5	79	74.5		
Average	.287	.363	.366	.418	.422	.430	.389	.448		.83749
S_s G	.382	.468	.416	.494	.508	.498	.430	.472	0	.461163
S_s F	.254	.258	.328	.348	.400	.334	.378	-	0	.851877
S_s E	.224	.362	.354	.412	.358	.458	.360	.424	0	.715352

TABLE IX (Continued)

Environment #30

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
	Rank Order in Reaction Time									
1	5	5	3	3	5	6	3	3		
2	2	3	5	5	6	5	5	5		
3	3	2	2	2	3	3	6	2		
4	6	6	6	6	2	2	2	6		
5	8	8	8	8	8	8	8	8		
6	4	4	4	4	4	4	4	4		
7	1	1	1	1	1	1	1	1		
8	7	7	7	7	7	7	7	7		

Octave Band

Octave	31.5	63	125	250	500	1K	2K	4K	8K
dB	69	93	91	89	78	69	63	50	48

TABLE IX (Continued)

Environment #White Noise @ 90 dBA

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #1										
dB	104	98	93	89.5	84	83	81	78		
Average	.712	.715	.815	.941	1.133	1.393	1.902	2.250		.86263
S_s C	.544	.568	.704	.914	1.140	-	-	-	0	.947343
S_s H	.608	.814	.828	.918	1.128	1.53	1.723	-	0	.893317
S_s A	.986	.762	.914	.992	1.132	1.256	2.080	2.250	2	.76406
Signal #2										
dB	104	98	92	87.5	82	81	79	76		
Average	.331	.400	.453	.667	.813	2.948	-	-		.663407
S_s C	.252	.322	.424	.508	.766	-	-	-	0	.955143
S_s H	.318	.340	.452	.590	.816	2.820	-	-	0	.670302
S_s A	.424	.538	.482	.902	.856	3.076	-	-	2	.659185
Signal #3										
dB	107	100	96	91	85	84	82	81		
Average	.308	.327	.371	.436	.464	.543	.690	1.063		.762389
S_s C	.276	.272	.338	.396	.402	.518	.650	.840	0	.822402
S_s H	.288	.330	.366	.434	.398	.516	.648	1.110	0	.705919
S_s A	.362	.380	.410	.480	.592	.594	.772	1.240	0	.755174
Signal #4										
dB	104	100	93	88.5	83	82	80	76.5		
Average	.472	.539	.623	.699	.965	1.330	1.715	2.092		.876104
S_s C	.418	.542	.618	.704	.818	1.060	1.738	2.134	0	.830212
S_s H	.512	.494	.578	.684	1.212	1.556	1.776	2.192	0	.899745
S_s A	.486	.580	.674	.708	.864	1.374	1.632	1.950	2	.867496

TABLE IX (Continued)

Environment #White Noise @ 90 dBA

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
Signal #5										
dB	106	101	94	90	86	82	81	77		
Average	.330	.327	.383	.444	.429	.471	.484	.779		.803168
S_s C	.285	.264	.310	.350	.386	.426	.446	.616	0	.881332
S_s H	.356	.362	.500	.554	.453	.492	.512	1.154	0	.66451
S_s A	.348	.356	.340	.428	.448	.494	.494	.568	0	.924733
Signal #6										
dB	100	98	90	87	85.5	81	80	76		
Average	.295	.362	.423	.497	.680	1.238	1.852	1.790		.868989
S_s C	.258	.320	.338	.362	.852	.815	-	-	0	.791934
S_s H	.290	.348	.436	.510	.532	1.840	2.710	-	0	.768267
S_s A	.338	.418	.496	.620	.658	1.060	.994	1.790	0	.870442
Signal #7										
dB	102	97	90	87	83	79.5	77.5	75		
Average	1.128	1.096	1.186	1.236	1.320	1.473	1.699	2.189		.817062
S_s C	.982	1.076	1.138	1.170	1.278	1.695	2.146	3.12	0	.79280
S_s H	1.252	1.108	1.142	1.208	1.304	1.376	1.466	1.534	0	.799534
S_s A	1.150	1.104	1.280	1.330	1.378	1.348	1.484	1.914	0	.819161
Signal #8										
dB	103	101	92	89	86	80.5	79	74.5		
Average	.365	.442	.517	.569	.761	1.122	1.509	1.858		.905489
S_s C	.306	.328	.420	.522	.938	.912	-	-	0	.893458
S_s H	.390	.554	.564	.594	.656	1.824	1.862	2.375	0	.874948
S_s A	.400	.444	.568	.592	.688	.630	1.156	1.340	1	.852779

TABLE IX (Continued)

Environment #White Noise @ 90 dBA

	Rheostat Setting									
	20	19	18.75	18.5	18	17.5	17	16	Errors	Correlation Coefficient
	Rank Order in Reaction Time									
1	6	5	3	3	5	5	5	5		
2	3	3	5	5	3	3	3	3		
3	5	6	6	6	6	8	8	6		
4	2	2	2	8	8	6	7	8		
5	8	8	8	2	2	4	4	4		
6	4	4	4	4	4	1	6	7		
7	1	1	1	1	1	7	1	1		
8	7	7	7	7	7	2	2	2		
	Octave Band									
Octave	31.5	63	125	250	500	1K	2K	4K	8K	
dB	64	74	77	84	83	82	82	76	67	

TABLE X

FALSE REACTIONS OR ERRORS IN EXPERIMENTAL DATA

	Environments					
Signals	#11	#14	#26	#30	White Noise	Total
1	0	E-3	E-3	0	A-2	8
2	0		F-2	0	A-2	4
3	0	H-3	E-2 F-3	0	0	8
4	0	H-2	E-2	0	A-2	6
5	F-1	E-3 H-1	F-1	G-1	0	7
6	B-1	H-3	0	0	0	4
7	0	H-3	0	0	0	3
8	0	0	E-1	0	A-1	2
	2	18	14	1	7	42
No. of Total Trials	640	1280	1280	960	960	
%	0.31	1.40	1.09	0.10	0.72	

Overall percentage 42/5760 = .0072 or .72%.

TABLE XI

DATA SUMMARY (WITH ONSET TIME SUBTRACTED)

Signal #1 (onset .035 sec. delay)

Intensity		104	98	93	89.5	84	83	81	78	Std. Dev.	Corr. Coeff.	Regression Equation
Mean		.587	.603	.755	.796	1.002	1.095	1.279	1.825	.413	.872	3.526 - .0405x
Envir.	#11	.466	.55	.716	.768	.743	1.149	.838	1.173	.253	.867	2.609 - .0324x
	#14	.571	.57	.716	.801	.809	1.111	1.36	2.107	.52	.802	3.861 - .0445x
	#26	.656	.714	.907	.847	.956	1.151	1.602	2.747	.642	.746	4.014 - .0444x
	#30	.567	.50	.656	.659	.624	.704	.73	.885	.115	.821	.979 - .0157x
	W.N.	.677	.68	.780	.906	1.098	1.358	1.867	2.215	.575	.862	4.196 - .0462x

Signal #2 (onset .006 sec. delay)

Intensity		104	98	92	87.5	82	81	79	76			
Mean		.259	.308	.369	.402	.498	1.073	.732	1.241	.369	.813	3.975 - .0528x
Envir.	#11	.169	.239	.337	.288	.330	.543	.77	1.043	.301	.808	3.943 - .0557x
	#14	.274	.297	.356	.391	.464	.86	1.004	2.442	.730	.697	5.114 - .0649x
	#26	.313	.357	.435	.393	.557	.655	.824	1.145	.283	.835	2.971 - .0412x
	#30	.213	.251	.269	.279	.331	.366	.33	.328	.051	.928	.273 - .0172x
	W.N.	.325	.394	.447	.661	.807	2.942	—	—	1.002	.663	6.197 - .0727z

TABLE XI (Continued)

Signal #3 (onset - no change)

Intensity	107	100	96	91	85	84	82	81	Std. Dev.	Corr. Coeff.	Regression Equation
Mean	.267	.289	.327	.352	.388	.496	.587	.825	.188	.795	$e^{2.356 - .036x}$
Envir. #11	.212	.298	.309	.324	.347	.329	.400	.622	.120	.738	$e^{1.325 - .0265x}$
#14	.258	.274	.335	.346	.389	.689	.820	1.081	.303	.797	$e^{3.714 - .0495x}$
#26	.331	.320	.364	.403	.410	.599	.768	1.059	.263	.752	$e^{2.706 - .038x}$
#30	.224	.225	.255	.249	.331	.321	.258	.302	.042	.774	$e^{-.149 - .0129x}$
W.N.	.308	.327	.371	.436	.464	.543	.690	1.063	.250	.762	$e^{2.702 - .0378x}$

Signal #4 (onset .215 sec. delay)

Intensity	104	100	93	88.5	83	82	80	76.5			
Mean	.224	.299	.347	.423	.552	.964	.974	1.379	.412	.877	4.903 - .0625x
Envir. #11	.048	.250	.278	.393	.448	1.515	.472	.716	.448	.630	6.467 - .0846x
#14	.309	.335	.384	.452	.608	.813	1.187	1.634	.474	.831	4.532 - .057x
#26	.313	.379	.413	.51	.672	1.027	1.367	2.375	.703	.793	5.414 - .0653x
#30	.192	.255	.25	.278	.282	.349	.342	.343	.055	.919	.422 - .0191x
W.N.	.257	.324	.408	.484	.750	1.115	1.50	1.877	.599	.876	5.895 - .0713x

TABLE XI (Continued)

Signal #5 (onset .006 sec. delay)

Intensity	106	101	94	90	86	82	81	77	Std. Dev.	Corr. Coeff.	Regression Equation
Mean	.239	.262	.297	.335	.333	.389	.409	.518	.0898	.926	1.050 - .0238x
Envir. #11	.171	.181	.237	.265	.243	.314	.339	.467	.0961	.892	1.430 - .0308x
#14	.237	.276	.307	.328	.326	.451	.45	.497	.094	.937	1.174 - .0248x
#26	.261	.321	.308	.369	.388	.415	.501	.552	.098	.922	1.120 - .0233x
#30	.204	.211	.256	.277	.286	.30	.279	.299	.037	.951	-.0749 - .0141x
W.N.	.324	.321	.377	.438	.423	.465	.478	.773	.143	.803	1.322 - .024x

Signal #6 (onset .006 sec. delay)

Intensity	100	98	90	87	85.5	81	80	76			
Mean	.264	.305	.328	.38	.418	.69	.858	1.195	.331	.860	4.428 - .0591x
Envir. #11	.239	.279	.301	.369	.285	.683	.452	.64	.170	.810	2.493 - .0397x
#14	.264	.301	.303	.341	.383	.67	1.119	2.456	.754	.731	6.229 - .0788x
#26	.309	.334	.34	.389	.436	.617	.586	.72	.154	.910	2.262 - .035x
#30	.221	.257	.281	.31	.311	.247	.285	.376	.0476	.691	-.0951 - .0134x
W.N.	.289	.356	.417	.491	.674	1.232	1.846	1.784	.644	.868	6.678 - .0807x

TABLE XI (Continued)

Signal #7 (onset .813 sec. delay)

Intensity	102	97	90	87	83	79.5	77.5	75	**Std. Dev.**	**Corr. Coeff.**	**Regression Equation**
Mean	.222	.235	.316	.357	.399	.632	.632	.75	.201	.930	3.174 - .0472x
Envir. #11	.114	.139	.280	.319	.289	1.158	.301	.271	.331	.461	3.003 - .0494x
#14	.140	.186	.283	.375	.416	.458	1.003	1.191	.383	.842	5.511 - .0744x
#26	.296	.344	.374	.414	.479	.565	.663	.614	.133	.947	1.762 - .0296x
#30	.245	.221	.271	.254	.305	.318	.309	.297	.035	.861	-.274 - .0117x
W.N.	.315	.283	.373	.423	.507	.660	.886	1.376	.370	.817	3.824 - .0517x

Signal #8 (onset .12 sec. delay)

Intensity	103	101	92	89	86	80.5	79	74.5			
Mean	.207	.271	.318	.371	.43	.774	.795	1.383	.395	.873	4.542 - .0601x
Envir. #11	.120	.233	.252	.327	.288	1.138	.363	1.728	.568	.738	5.422 - .0724x
#14	.243	.293	.363	.415	.439	.635	1.112	1.636	.487	.832	4.629 - .0599x
#26	.261	.262	.331	.367	.478	.787	.844	1.487	.422	.861	4.449 - .0583x
#30	.167	.243	.246	.298	.302	.310	.269	.328	.0516	.837	.1955 - .0173x
W.N.	.245	.322	.397	.449	.641	1.002	1.389	1.738	.548	.905	5.448 - .0672x

APPENDIX F

ANATOMY OF THE HUMAN EAR

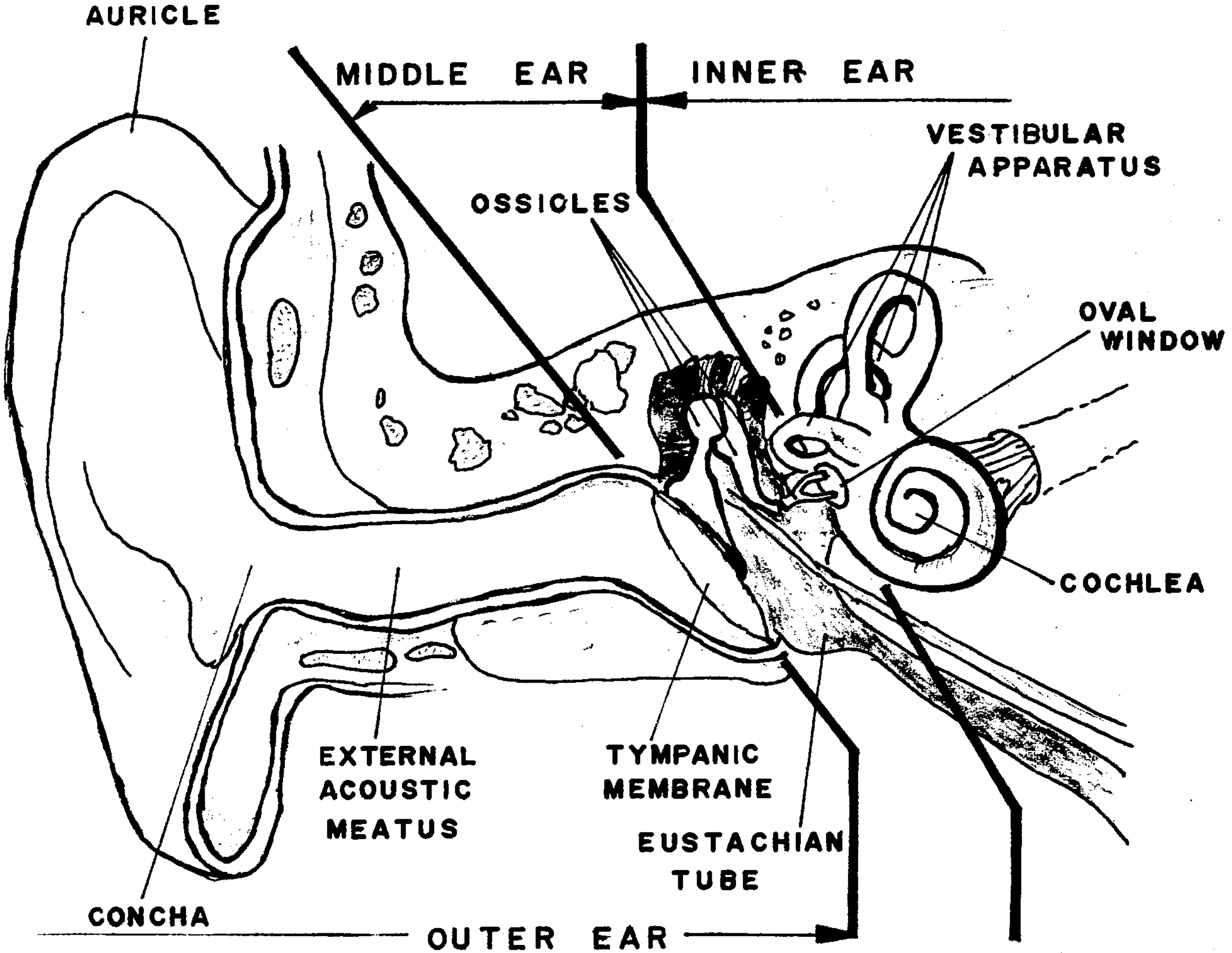
Anatomy of the human ear can be separated into three major sub parts, the outer ear, the middle ear, and the inner ear. Figure 33 indicates the complete ear with this triparte breakdown.

The outer ear provides for the original receptions of sound. As sound travels through air, the movement of the molecules create a series of waves of pressure. These waves, upon striking the auricle, are somewhat concentrated by the concave contours of the ear and directed into the concha thereby into the passageway of the external acoustic meatus. Dimensions of the auricle differ for each person but one study [2] provides these sizes:

Length	from 53.8 to 79.7 mm;	95% percentile	74.8 mm
Breadth	from 27.4 to 42.8 mm;	95% percentile	39.4 mm

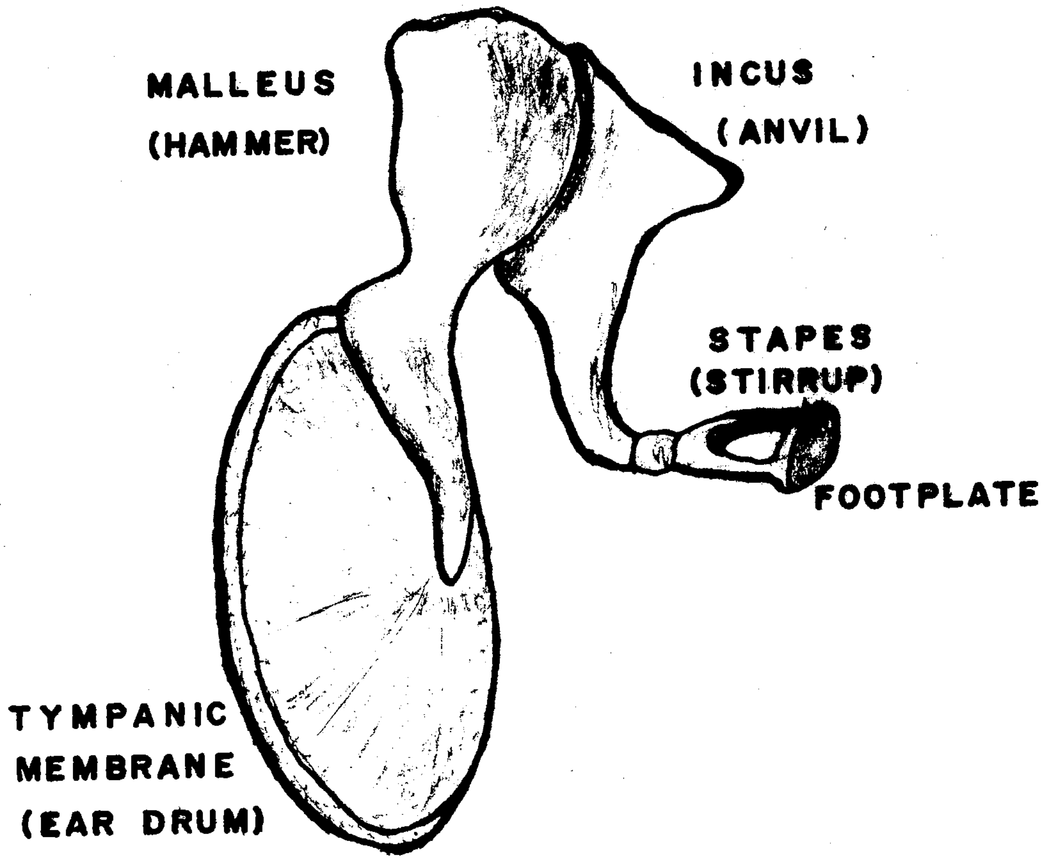
Diameter of the external acoustic meatus ranges from 4 mm to 10 mm while the length is approximately 25 mm. Walls of the meatus are thick hairless skin which secrete small quantities of cerumen, a water proof wax-like material. The dividing line between the outer and middle ear is the tympanic membrane which stretches across the meatus, and seals the passage against outside air or foreign material.

The tympanic membrane (ear drum) is multilayer connective tissue covered with skin on the outside and mucuous membrane on the inside. The ear drum is the shape of a shallow funnel with the apex of the funnel (umbo) pointing inwards. Attached to the funnel is one part of the malleus (manubrium), part of the ossicles chain making up the middle ear. The ossicles consist of three bones which act as an impedance matching device, either damping or amplifying vibrations of the tympanic membrane in transmitting sound energy to the oval window at the beginning of the inner ear. The first and largest bone in the ossicles (Figure 34)



Source: Palmer and LaRusso. Anatomy for Speech and Hearing. Harper and Row Publishers.

Figure 33. Auditory Apparatus



Source: von Bekesy. "The Ear." Scientific American (August 1957).

Figure 34. Ossicles

is called the malleus (hammer) and by a projection of the malleus called the manubrium, is directly connected to the tympanic membrane. Through a multi-directional knee action type socket, the incus (anvil) is moved by the malleus, and in turn moves the stapes (stirrup) forward or backward in a horizontal plane at the oval window. The inner ear is filled with air and under changing pressure conditions can exert differing pressures on the tympanic membrane, occasionally creating pain to the individual. The Eustachian (auditory) tube which connects to the throat relieves this pressure upon normal and swallowing actions. Muscles involved are the stapedius and the tensor tympani. Upon contraction the tensor tympani pulls the manubrium of the malleus thus increasing the tautness of the ear drum. Loud sounds reflexly excite the tensor tympani and stapedius and as indicated above, the increased tautness provides a damping effect to protect the ear drum. The stapedius muscle is in the neck of the stapes and upon activation, vibrates the stapes at the oval window, thus transferring acoustic energy to the fluid medium of the inner ear. Other ligaments which provide suspensions of the ossicles in the middle ear are; three of the malleus, posterior ligament of the incus, ligament between malleus and drum membrane, and the annular ligament of the stapes.

The inner ear (Figure 35) contains the sensory perception areas of the organ of hearing and is sketched in diagrammatic form in Figures 36 and 37. It is fluid filled and has as the key element the cochlea, a tube coiled (2 1/2 turns) around a central bony pillar. At the lower end, two apertures are present, the oval window and the round window. The oval window is a diaphragm connected to the stapes of the middle ear and as the stapes moves in and out, this movement creates variations in

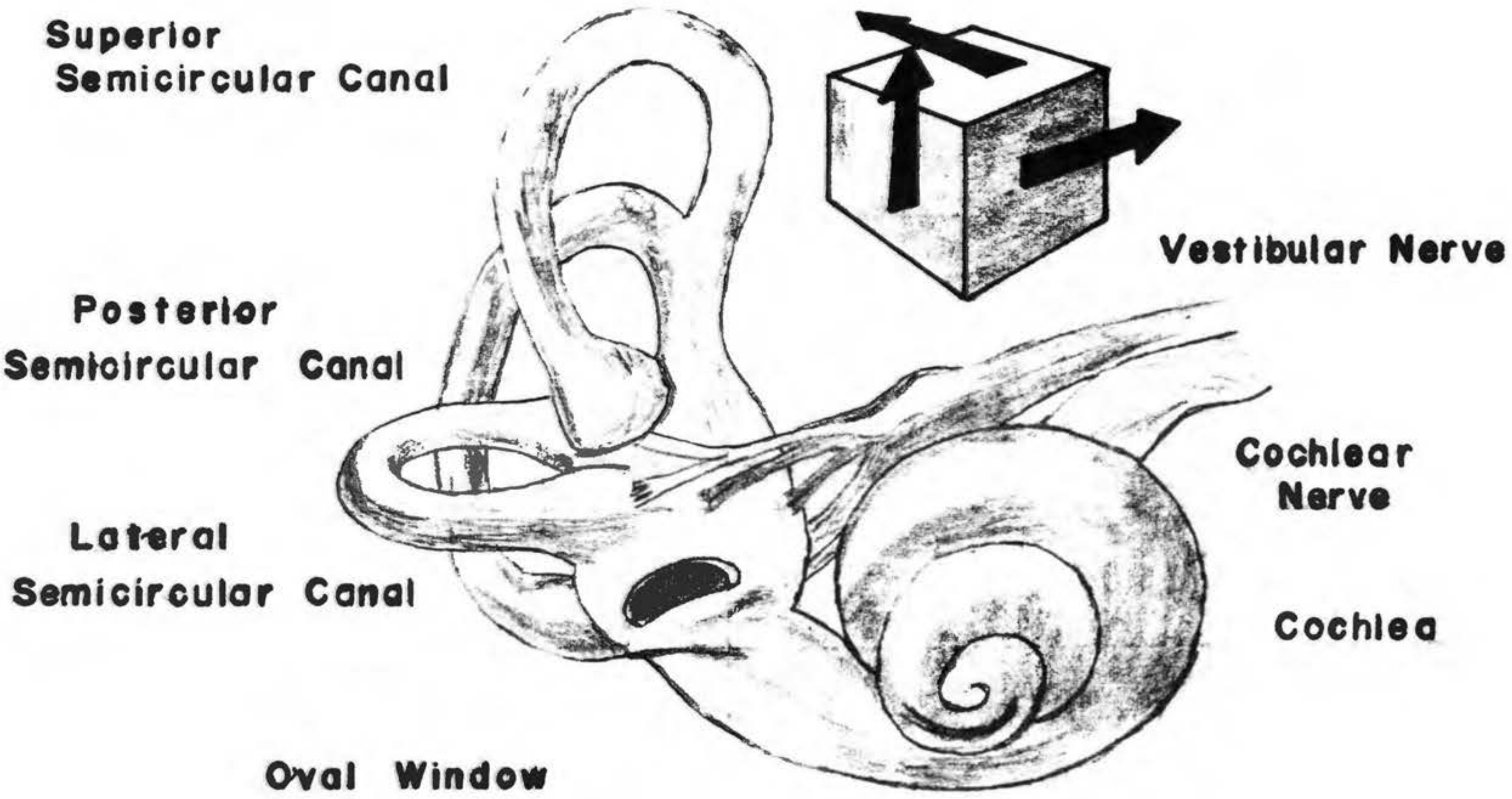


Figure 35. Inner Ear

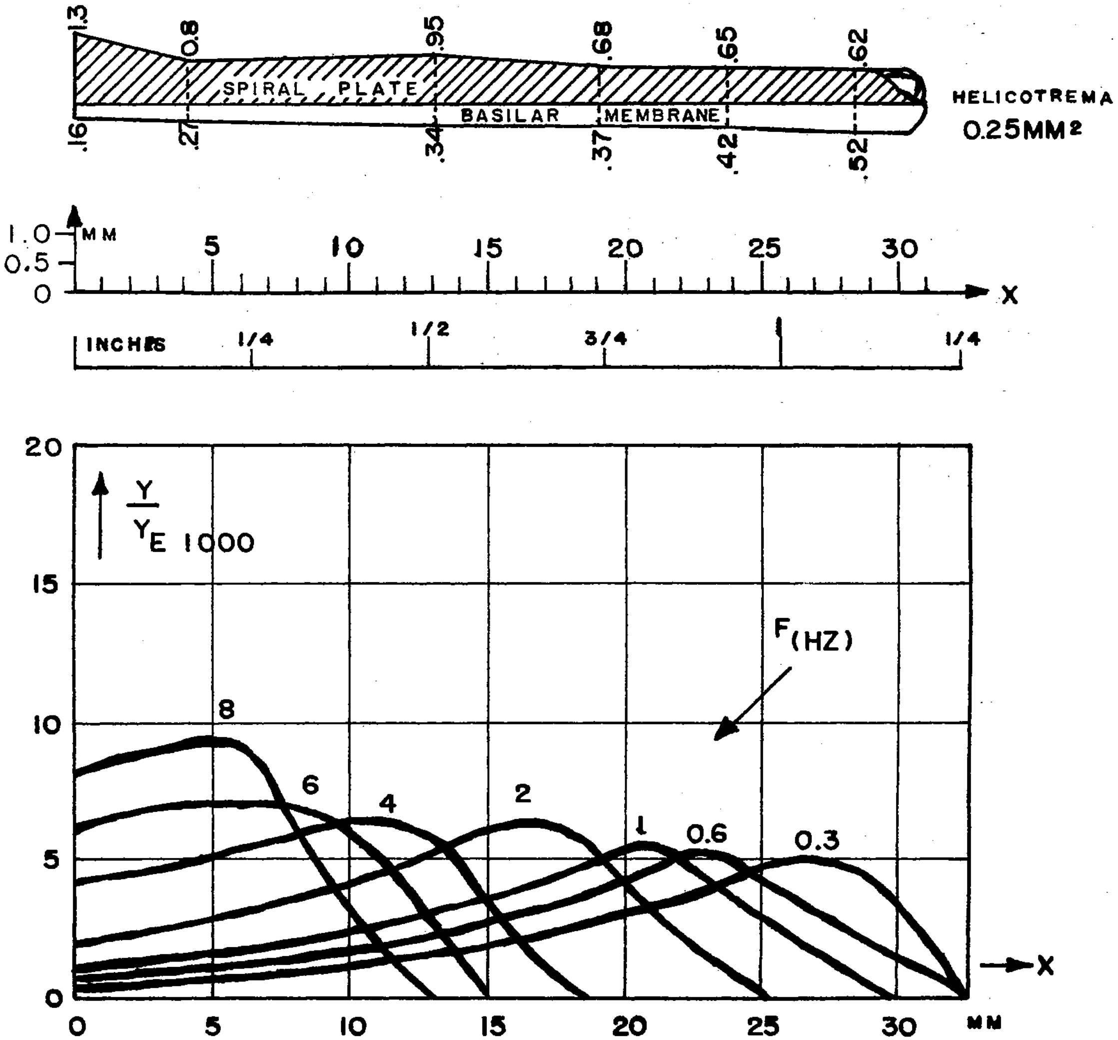


Figure 36. Stimulation Areas on Organ of Corti by Frequencies

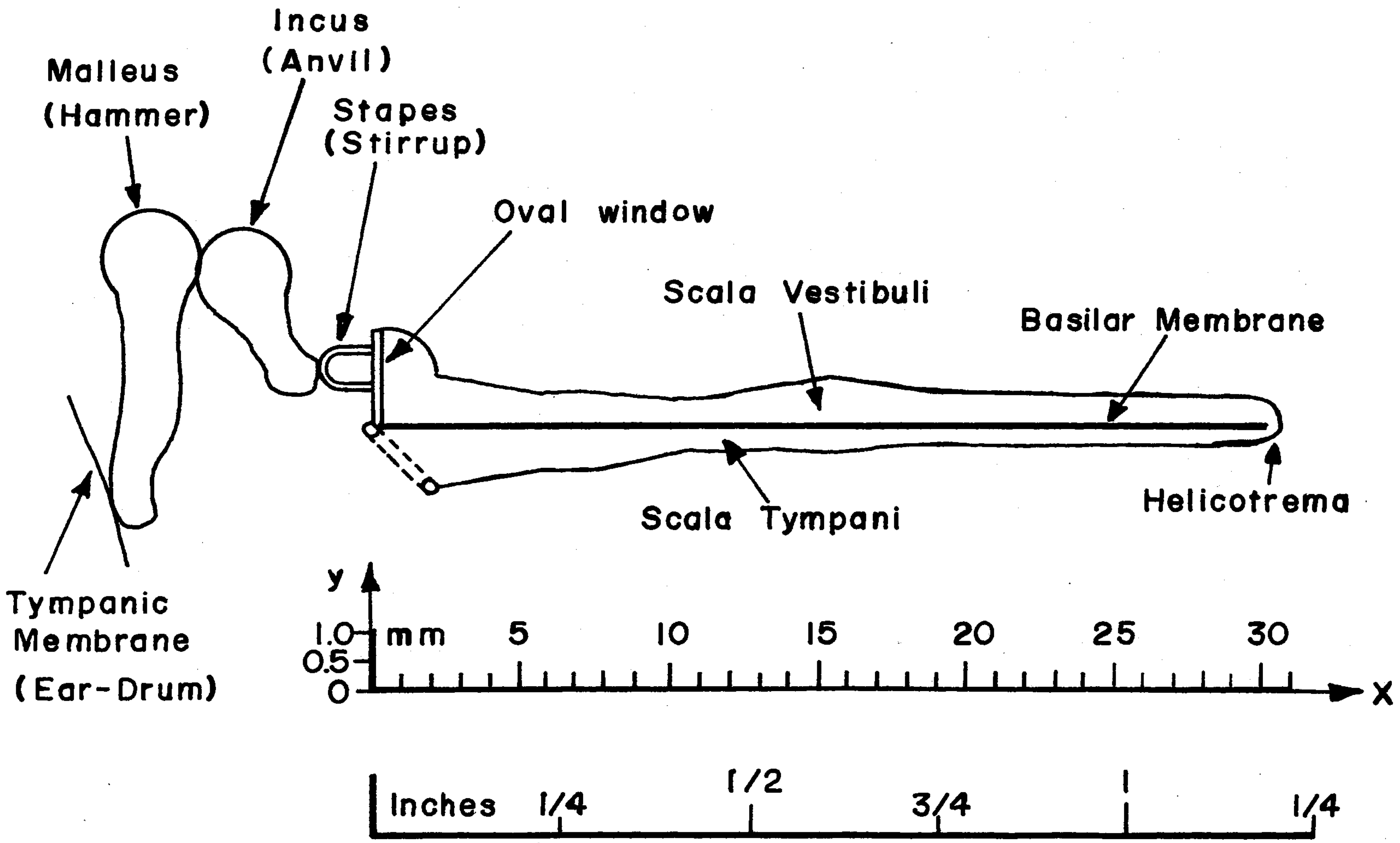


Figure 37. Cochlea in Diagrammatic Form

pressure behind the window in the perilymph fluid of the scala vestibuli. This pressure carries movement of the liquid and as it moves toward the apex of the cochlea, it goes toward the helicotroma. The helicotroma is a connection between the scala vestibuli and the scala tympani. The pressure then transmits by hydraulic laws to an area located below the oval window, the round window. The round window bulges and thus permits the movement to be damped. As the original sound vibrations come through the ossicles and move the stapes up or down at the oval window, this pressure is transferred by a downward movement of the basilar membrane, tectorial hairs along the organ of corti (an organ supported by the basilar membrane) are stimulated and produce neural impulses which proceed to the cerebral cortex and the sensation of hearing occurs.

The cochlea is a tube composed of smaller internal tubes. The internal tubes are the scala vestibuli (vestibular canal), the scala media, and the scala tympani. Each unit is filled with a liquid, the scala vestibuli and the scala tympani have perilymph, while the scala media is filled with endolymph. Between scala media and scala tympani is the cochlea duct, and between two membranes, the basilar and tectorial, is the organ of Corti. A bony spiral lamina supports the organ of Corti and inside the organ are internal hair cells (3500); external to the outer support rod are four hair cells which have a total of 20,000 hairs.

As the shearing force, from movement of the perilymph of the scala tympani caused by the oval window being pushed inward, moves across the basilar membrane, the cell hairs are stimulated and produce a DC potential alteration. This alteration is innervated by fibers of the auditory nerve, whose cell bodies lie in the spiral ganglion embedded in the skull.

APPENDIX G

COMPUTER PROGRAMS

COMPUTER PROGRAM REGCOR

A404-36054A REGRESSION/CORRELATION

```
10  REMARK -- REGRESSION AND CORRELATION PROGRAM
11  DIM A[50],B[50],X[50],Y[50]
20  REMARK -- READ DATA
21  GOSUB 200
30  REMARK -- REGRESS VARIABLE 2 ON VARIABLE 1
31  FOR I=1 TO N
32  LET A[I]=X[I]
33  LET B[I]=Y[I]
34  NEXT I
35  GOSUB 500
40  REMARK -- PRINT AVERAGE AND STANDARD DEVIATIONS
41  PRINT
42  PRINT "THE AVERAGE VALUE OF VARIABLE 1 IS",A1
43  PRINT "THE AVERAGE VALUE OF VARIABLE 2 IS",A2
44  PRINT "THE STANDARD DEVIATION OF VARIABLE 1 IS",D1
45  PRINT "THE STANDARD DEVIATION OF VARIABLE 2 IS",D2
46  PRINT "THE CORRELATION COEFFICIENT BETWEEN VARIABLES 1 AND 2 IS",C9
47  LET A9=A2
50  PRINT
51  PRINT "EQUATION 1"
52  PRINT "VARIABLE 2 =",I9,"       +",S9,"* VARIABLE 1"
53  PRINT P9,"PERCENT OF THE VARIANCE IN VARIABLE 2 EXPLAINED"
54  PRINT
60  REMARK -- REGRESS VARIABLE 2 ON LOG OF VARIABLE 1
61  FOR I=1 TO N
62  IF X[I] <= 0 THEN 80
63  LET A[I]=LOG(X[I])
64  NEXT I
65  GOSUB 500
66  PRINT "EQUATION 2"
67  PRINT "VARIABLE 2 =",I9,"       +",S9,"*LOG OF VAR 1 "
68  PRINT P9,"PERCENT OF THE VARIANCE IN VARIABLE 2 EXPLAINED "
69  PRINT
80  REMARK -- REGRESS LOG OF VAR 2 ON VAR 1
81  FOR I=1 TO N
82  LET A[I]=X[I]
83  IF Y[I] <= 0 THEN 20
84  LET B[I]=LOG(Y[I])
85  NEXT I
86  GOSUB 500
87  GOSUB 600
```

Continued

```
88   PRINT "EQUATION 3"
89   PRINT "LOG(VAR 2) =",I9,"    +",S9,"* VARIABLE 1"
90   PRINT "ALTERNATE FORM --"
91   PRINT "VARIABLE2 ="EXP(I9),"     *"EXP(S9),"↑VAR 1"
92   PRINT P9,"PERCENT OF THE VARIANCE IN VARIABLE 2 EXPLAINED "
93   PRINT
100  REMARK -- REGRESS LOG OF VAR 2 ON LOG OF VAR 1
101  FOR I=1 TO N
102  IF A[I] <= 0 THEN 20
103  LET A[I]=LOG(X[I])
104  NEXT I
105  GOSUB 500
106  GOSUB 600
107  PRINT "EQUATION 4"
108  PRINT "LOG(VAR 2) =",I9,"    +",S9,"*LOG(VAR 1)"
109  PRINT "ALTERNATE FORM --"
110  PRINT "VARIABLE 2 ="EXP(I9),"*(VAR 1↑",S9,")"
111  PRINT P9,"PERCENT OF THE VARIANCE IN VARIABLE 2 EXPLAINED"
120  GOTO 20
200  REMARK -- SUBROUTINE TO READ DATA
201  READ N
202  PRINT
203  PRINT " ","    DATA "
204  PRINT
205  PRINT "  OBSERVATION","  VARIABLE 1","  VARIABLE 2"
206  PRINT
207  FOR I=1 TO N
208  READ X[I]
209  NEXT I
210  FOR I=1 TO N
211  READ Y[I]
212  PRINT I,X[I],Y[I]
213  NEXT I
214  RETURN
500  REMARK -- SUBROUTINE TO REGRESS N VALUES OF B(I) ON A(I)
510  REMARK -- COMPUTE SUMS
511  LET S1=0
512  LET S2=0
513  LET S3=0
514  LET S4=0
515  LET S5=0
516  FOR I=1 TO N
517  LET S1=S1+A[I]
518  LET S2=S2+B[I]
519  LET S3=S3+(A[I]↑2)
520  LET S4=S4+(B[I]↑2)
521  LET S5=S5+(A[I]*B[I])
522  NEXT I
530  REMARK -- COMPUTE AVERAGES
531  LET A1=S1/N
532  LET A2=S2/N
535  REMARK -- COMPUTE VARIANCES
536  LET V1=(S3-(N*(A1↑2)))/(N-1)
537  LET V2=(S4-(N*(A2↑2)))/(N-1)
540  REMARK -- COMPUTE STANDARD DEVIATIONS
541  LET D1=SQR(V1)
542  LET D2=SQR(V2)
```

Continued

```
550  REMARK -- COMPUTE DIVISOR FOR REGRESSION LINE
551  LET D0=(N*S3)-(S1↑2)
552  REMARK -- COMPUTE INTERCEPT (I9) AND SLOPE (S9)
553  LET I9=((S2*S3)-(S1*S5))/D0
554  LET S9=((N*S5)-(S1*S2))/D0
560  REMARK -- COMPUTE PERCENT OF VARIANCE EXPLAINED (P9)
561  LET P9=((S9↑2)*V1)/V2
570  REMARK  --COMPUTE CORRELATION COEFFICIENT (C9)
571  LET C9=SQR(P9)
572  LET P9=100*P9
580  RETURN
600  REMARK  SUBROUTINE TO FIND PERCENT OF VARIANCE IN VAR 2 EXP
601  LET S8=0
602  LET S7=0
603  FOR I=1 TO N
604  LET E=EXP(I9+(S9*A[I]))
605  LET S8=S8+((Y[I]-E)↑2)
606  LET S7=S7+((Y[I]-A9)↑2)
607  NEXT I
608  LET P9=100*(1-(S8/S7))
609  RETURN
999  REMARK -- TEST DATA FOR BRC
1000  REMARK -- NUMBER OF OBSERVATIONS
1001  DATA 8
1010  REMARK -- DATA
1011  DATA 104,98,93,89.5,84,83,81,78
1012  DATA .466,.55,.716,.768,.743,1.149,.838,1.173
1024  END
```

SAMPLE PROGRAM USED TO CALCULATE RESPONSE TIME BY INTENSITY

HP2000E TIME SHARED BASIC

```
10 DIM C(8),V(8),S(106)
11 READ N
12 FOR I = 1 TO N
13 READ C(I),V(I)
14 NEXT I
15 PRINT" ","RESPONSE TIME BY INTENSITY"
```

Continued

```
16 PRINT
17 PRINT " ","ENVIRONMENT NO. 11"
18 PRINT
19 PRINT"SIGNAL NO.","INTENSITY","REACTION TIME IN SEC."
20 PRINT
21 FOR I = 1 TO N
22 FOR J = 80 TO 105STEP5
23 LET S(J) = J
24 R = EXP(C(I) - (V
ERROR
24 R = EXP( C(I) -V(I)*S(J))
25 PRINT I,J,R
26 NEXT J
27 NEXT I
40 DATA 8
41 DATA 2.609,.0324
42 DATA 3.943,.0557
43 DATA 1.325,.0265
44 DATA 6.467,.0846
45 DATA 1.43,.0308
46 DATA 2.493,.0397
47 DATA 3.003,.0494
48 DATA 5.442,.0724
49 END
RUN

                         RESPONSE TIME BY INTENSITY

                         ENVIRONMENT NO. 11

SIGNAL NO.               INTENSITY           REACTION TIME IN SEC.

 1                        80                  1.01715
 1                        85                  .865023
 1                        90                  .735651
 1                        95                  .625628
 1                        100                 .53206
 1                        105                 .452486
 2                        80                  .598697
 2                        85                  .453165
 2                        90                  .343009
 2                        95                  .259629
 2                        100                 .196518
 2                        105                 .148748
 3                        80                  .451581
 3                        85                  .395541
 3                        90                  .346456
 3                        95                  .303462
 3                        100                 .265803
 3                        105                 .232818
 4                        80                  .740077
 4                        85                  .484809
 4                        90                  .317588
 4                        95                  .208045
```

Continued

```
 3              90              .489681
 3              95              .404947
 3              100             .334874
 3              105             .276927
 4              80             1.20925
 4              85              .872406
 4              90              .629393
 4              95              .454072
 4              100             .327587
 4              105             .236336
 5              80              .475209
 5              85              .42295
 5              90              .376439
 5              95              .335042
 5              100             .298197
 5              105             .265405
 6              80              .533915
 6              85              .490172
 6              90              .411478
 6              95              .345418
 6              100             .289964
 6              105             .243412
 7              80              .545529
 7              85              .470481
 7              90              .405757
 7              95              .349938
 7              100             .301797
 7              105             .260279
 8              80              .806542
 8              85              .602601
 8              90              .450229
 8              95              .336385
 8              100             .251327
 8              105             .187777

DONE

                RESPONSE TIME BY INTENSITY

                ENVIRONMENT NO. 30

SIGNAL NO.      INTENSITY       REACTION TIME IN SEC.

 1              80              .758054
 1              85              .700823
 1              90              .647912
 1              95              .598996
 1              100             .553773
 1              105             .511964
 2              80              .331874
 2              85              .304526
 2              90              .279431
```

Continued

3	105	.226842
4	80	.972389
4	85	.73125
4	90	.54991
4	95	.41354
4	100	.310988
4	105	.233868
5	80	.444858
5	85	.392979
5	90	.347149
5	95	.306665
5	100	.270902
5	105	.239309
6	80	.927744
6	85	.625628
6	90	.421895
6	95	.284507
6	100	.191858
6	105	.12938
7	80	.643393
7	85	.443526
7	90	.305746
7	95	.210768
7	100	.145293
7	105	.100159
8	80	.849591
8	85	.629707
8	90	.466732
8	95	.345936
8	100	.256404
8	105	.190044

RESPONSE TIME BY INTENSITY

ENVIRONMENT NO. 26

SIGNAL NO.	INTENSITY	REACTION TIME IN SEC.
1	80	1.58725
1	85	1.27125
1	90	1.01816
1	95	.815463
1	100	.653117
1	105	.523091
2	80	.722528
2	85	.588017
2	90	.478548
2	95	.389458
2	100	.316954
2	105	.257948
3	80	.716053
3	85	.592147

Continued

```
 4              100            .136286
 4              105            8.92781E-02
 5              80             .355582
 5              85             .30483
 5              90             .261322
 5              95             .224024
 5              100            .19205
 5              105            .164639
 6              80             .505099
 6              85             .414161
 6              90             .339595
 6              95             .278455
 6              100            .228322
 6              105            .187215
 7              80             .387128
 7              85             .302401
 7              90             .236218
 7              95             .18452
 7              100            .144136
 7              105            .11259
 8              80             .704688
 8              85             .490662
 8              90             .341639
 8              95             .237877
 8              100            .16563
 8              105            .115325

DONE


               RESPONSE TIME BY INTENSITY

               ENVIRONMENT NO. 14

SIGNAL NO.     INTENSITY      REACTION TIME IN SEC.

 1              80            1.35121
 1              85            1.08166
 1              90            .865888
 1              95            .693156
 1              100           .554882
 1              105           .444192
 2              80            .924965
 2              85            .668647
 2              90            .483357
 2              95            .349413
 2              100           .252587
 2              105           .182592
 3              80            .781922
 3              85            .610486
 3              90            .476637
 3              95            .372135
 3              100           .290544
```

Continued

```
 2                  95                .256404
 2                  100               .235275
 2                  105               .215887
 3                  80                .306972
 3                  85                .287797
 3                  90                .26982
 3                  95                .252966
 3                  100               .237165
 3                  105               .222351
 4                  80                .33088
 4                  85                .300743
 4                  90                .273351
 4                  95                .248453
 4                  100               .225824
 4                  105               .205255
 5                  80                .300322
 5                  85                .279878
 5                  90                .260826
 5                  95                .243071
 5                  100               .226525
 5                  105               .211105
 6                  80                .311299
 6                  85                .291126
 6                  90                .272259
 6                  95                .254616
 6                  100               .238115
 6                  105               .222684
 7                  80                .298197
 7                  85                .281253
 7                  90                .265272
 7                  95                .250199
 7                  100               .235982
 7                  105               .222573
 8                  80                .30483
 8                  85                .279571
 8                  90                .256404
 8                  95                .235158
 8                  100               .215671
 8                  105               .1978

DONE
                  RESPONSE TIME BY INTENSITY

                  ENVIRONMENT  WHITE NOISE

SIGNAL NO.        INTENSITY         REACTION TIME IN SEC.

 1                  80               1.64872
 1                  85               1.30866
 1                  90               1.03873
 1                  95               .824482
 1                  100              .654424
```

Continued

```
 1                       105                   .519442
 2                       80                    1.46375
 2                       85                    1.01765
 2                       90                    .707513
 2                       95                    .49189
 2                       100                   .341981
 2                       105                   .237758
 3                       80                    .724698
 3                       85                    .599896
 3                       90                    .496585
 3                       95                    .411067
 3                       100                   .340275
 3                       105                   .281675
 4                       80                    1.21046
 4                       85                    .847469
 4                       90                    .593333
 4                       95                    .415405
 4                       100                   .290835
 4                       105                   .20362
 5                       80                    .54991
 5                       85                    .487727
 5                       90                    .432575
 5                       95                    .383659
 5                       100                   .340275
 5                       105                   .301797
 6                       80                    1.24857
 6                       85                    .834018
 6                       90                    .557106
 6                       95                    .372135
 6                       100                   .248578
 6                       105                   .166044
 7                       80                    .731982
 7                       85                    .565243
 7                       90                    .436485
 7                       95                    .337058
 7                       100                   .260279
 7                       105                   .20099
 8                       80                    1.07465
 8                       85                    .767973
 8                       90                    .548811
 8                       95                    .392193
 8                       100                   .28027
 8                       105                   .200288

DONE
```

SAMPLE PROGRAM FOR CALCULATING SUM OF OCTAVE NUMBERS

```
LIST


10   DIM S[10],A[10]
12   READ N,M
14   FOR I=1 TO N
16   READ S[I]
18   NEXT I
20   FOR K=1 TO M
22   FOR I=1 TO N
24   READ A[I]
26   NEXT I
28   READ C,V
30   U=0
32   FOR I=1 TO N
34   B=A[I]/S[I]
36   R=EXP(C-V*S[I])
38   F=R*B
40   U=U+F
42   NEXT I
44   PRINT "   ","SUM =",U
46   NEXT K
100   DATA 7,8
101   DATA 84,99,89,85,80,70,60
102   DATA 56,70,95,90,91,84,67
103   DATA 3.861,.0445
104   DATA 64,67,92,87,91,83,68
105   DATA 5.114,.0649
106   DATA 62,69,102,97,102,87,80
107   DATA 3.714,.0495
108   DATA 69,75,102,97,99,89,76
109   DATA 4.532,.057
110   DATA 64,67,102,96,99,90,77
111   DATA 1.174,.0248
112   DATA 63,75,93,102,90,87,79
113   DATA 6.229,.0788
114   DATA 54,73,85,96,90,83,69
115   DATA 5.511,.0744
116   DATA 64,76,91,97,94,88,73
117   DATA 4.629,.0599
118   END
```

```
               SUM =            11.0172
               SUM =            8.93327
               SUM =            7.35389
               SUM =            9.6277
               SUM =            3.56751
               SUM =            11.3788
               SUM =            6.84367
               SUM =            8.31116
```

VITA

Louis Barclay Trucks

Candidate for the Degree of

Doctor of Philosophy

Thesis: PREDICTING THE EFFECTIVENESS OF AN AUDITORY WARNING SIGNAL

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Birmingham, Alabama, June 14, 1916, the son of Dr. and Mrs. J. Frank Trucks.

Education: Graduated from Woodlawn High School, Birmingham, Alabama, May, 1933; attended University of Alabama in 1934 through 1937; received the Bachelor of Science degree from Auburn University in June, 1939, with a major in Industrial Engineering; received the Master of Science degree from the University of Pittsburgh in 1951, with a major in Industrial Engineering; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in December, 1974.

Professional Experience: Westinghouse Electric Corporation, Staff Industrial Engineer, Foreman, Supervisor of Manufacturing Laboratory, Plant Layout Engineer, General Foreman, and Senior Manufacturing Engineer from 1940 to 1964. On faculty of Auburn University from 1964 to present as Assistant Professor except when on leave for study at Oklahoma State University in 1968 through 1970.

Professional Registrations:
Professional Engineer, Alabama, No. 6347.
Professional Engineer, Pennsylvania, No. 14883.
Certified Safety Professional, No. 3417.