DETECTION OF SIGNALS IN WHITE NOISE

Thesis for the Degree of M. A.

MICHIGAN STATE UNIVERSITY

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1964

DETECTION OF SIGNALS IN WHITE NOISE

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Department of Speech

1964

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CHAPTER I

INTRODUCTION

There is an increasing interest in and importance being attached to the area of hearing research. One of the specific problems that has attracted the attention of researchers pertains to the distortion that occurs in the impaired ear. What is the nature of this distortion, how does it occur, and how might the effects of this distortion be compensated for in hearing aid devices? If the answer to the question pertaining to the nature of distortion were known, the problems of the origination and the correction of the distortion might be more easily answered.

Background

There are many ways in which information regarding the nature of this distortion might be uncovered. One reasonable approach to this problem might be examined. First, select a person who has one sick ear and one healthy ear. Feed some sort of sound stimulus into the sick ear. Feed the same stimulus into the healthy ear. Make some provisions, however, to alter and distort this stimulus entering the healthy ear. Instruct the subject to change the nature of the stimulus entering the healthy ear by means of these alterations and distortions so that it resembles the sound entering the sick ear. If, then, these distortions and alterations were to be analyzed, some knowledge concerning the distortion that takes place to the sound in the sick ear should be revealed. Two questions would have to be answered before this hypothetical study could be undertaken. What sort of sound stimulus should be used, and what sort of alterations and distortions should be introduced in this stimulus? Significant results in the study could very well depend on the solution of these problems.

The hearing mechanism, from the outer ear to the lower centers of hearing in the menencephalon of the brain, is basically composed of two types of energy systems. The first of these is mechanical; the second, electro-chemical. The mechanical part of the mechanism includes the parts of the ear from the outer ear to the inner ear. In the inner ear the stimulus is converted into nerve impulses (electro-chemical energy) for transmission to the lower centers of hearing in the brains. It would seem, therefore, that the distortions characteristic of mechanical and electro-chemical systems.

Distortions in the motion of mechanical systems are introduced by, among other things, stiffness of the components of the system, air resistance of the system, excessive amplitude of vibrations, non-uniform density of the components of the system, and the dissipation of energy during vibration. By means of appropriate force-voltage or force-current analogies, electrical circuits may be devised which produce effects analogous to the vibration of such mechanical systems. Thus such a circuit can be used to study the distortional effects in the mechanical system.

The distortions present in electro-chemical systems are apparently less fully understood. It seems reasonable to assume, however, that analog electrical circuits might be devised to study the effects of this type of system also. Thus one electrical circuit might be devised to study the effects of distortion in both the mechanical and electro-chemical parts of the hearing mechanism.

Statement of the Problem

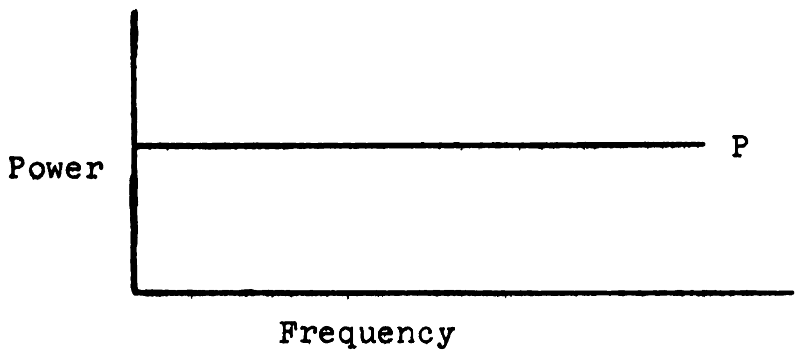
What sort of sound stimulus should be used in such a study? At the present time, most of the hearing testing is being done with pure tone signals. Many of the distortions present in the electrical analog circuit would be, however, characteristic of complex signals. It would seem desirable, then, to use a complex signal as the basis for such a study. White noise is a complex signal which is being used in testing if not quantitatively then qualitatively as masking. The desired alterations and distortions could be introduced into a white noise stimulus.

There is, however, little information available concerning the response of the normal human ear to distortion in white noise. Some appropriate investigations along these lines are needed, and this was the purpose of the present study.

A band of white noise has a power spectrum which is constant over all requencies within the bandwidth of the noise. This is illustrated by means of Figure 1.

Figure 1

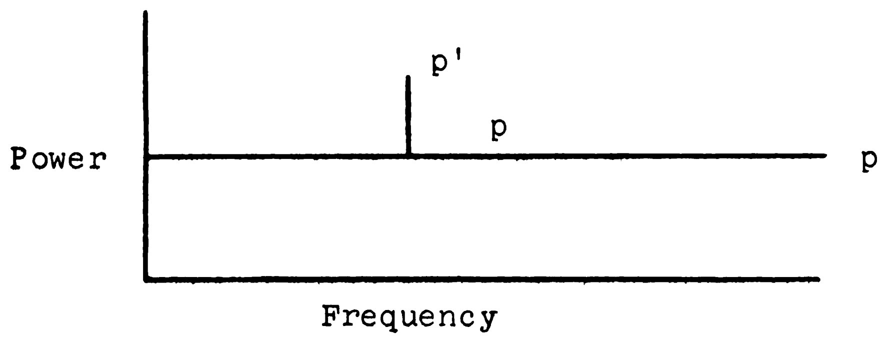
White Noise Power Spectrum



Suppose that at some frequency (or narrow band of frequencies) a "spike" were introduced into the bank of noise. This would appear as illustrated in Figure 2.

Figure 2

Distorted White Noise Power Spectrum



The power increment between the top of this spike and the level of the noise is, as noted on the graph, p. If, then, the capability of the ear to detect such deviations in the noise were to be investigated, some small bit of knowledge concerning the response of the normal human ear to distortion in white noise might be added. This was the purpose of the present study.

Formally stated, the purpose of the present study was to investigate the ability of the normal human ear to detect signals in white noise. Further clarification of the topic will follow.

There are several ways in which a spike might be introduced into white noise. Perhaps one of the easiest would be to superimpose a pure tone signal onto the noise. Denoting the frequency of the signal by f, the spike on the white noise would appear, upon superimposing the sine wave on the noise, at a frequency f. Simply varying the frequency of the sine wave would vary the location of the spike in the white noise.

This procedure of impressing a signal on a band of noise might sound familiar. It is, indeed, the basis for many signal-to-noise studies which have been conducted. Since this is the general procedure which was followed in the present study, what can be said about the uniqueness of the study? Review of many of the previous studies discloses that the present investigation obtained data not available in the other studies.

Most of these previous studies presented the subjects with a band of white noise and then superimposed on the noise the signal. The subject was then instructed to adjust the level of the signal so that it was just distinguishable from the noise. A record of this point was made. Such a precedure was repeated for various signal frequencies and various levels of white noise. This data yielded audiometric curves for the signals in the noise. The present study presented to the subjects signals of various frequencies and at various levels of intensity with respect to the noise. The level presentations were made independent of the control of the subjects. Moreover, these levels were varied randomly when presented to the subjects (several presentations at each level were made). In accord with common practice, the signal intensity which was detected by the subjects 50 percent of the time was defined as the threshold. Lesser signal intensities were detected by the subjects in fewer than 50 percent of the presentations. Signal intensities greater than threshold were detected by the subjects more than 50 percent of the time. The data thus yielded information for an analysis of percentage of detection. Such data, for several frequencies and noise levels, were not found in any of the previous studies. The information seems to be, however, an important addition to the store of knowledge concerning the response of the human ear.

Organization of the Thesis

Chapter Two of the thesis contains a short review of the literature relevant to the present study. Chapter Three contains a discussion of the procedures and equipment employed in the study. Chapter Four presents the results of the study and the statistical analysis of the data. Chapter Five contains a short summary of the study, conclusions, and some possible implications for further research.

CHAPTER II

REVIEW OF THE LITERATURE

Although no specific examples were cited, it was mentioned previously that various studies concerned with signal-noise ratio have been undertaken. This section will attempt, among other things to illustrate generally the type of work that has been done on the subject.

Background

Depending on the relative orientation of the researcher, the investigation of signals in noise has been approached from two viewpoints. The determination of detectable signal-to-noise ratios and the determination of masked audiograms are both concerned with essentially the same thing. The earliest study discovered in the literature approached the subject of signals in noise from the latter viewpoint. Roger Galt, in 1929, determined the noise audiograms for warble tones masked by various environmental noises.[1] Among these noises were a brass

[1]Roger H. Galt, "Methods and Apparatus for Measuring the Noise Audiogram," The Journal of the Acoustical Society of America, I, No. 1 (October, 1929), 147-57.

band, boat whistles, typewriters, and telegraph sounders. The study was reported in the very first issue of The Journal of the Acoustical Society of America. It seems reasonable to assume that earlier studies of signals in noise were conducted. This study was one of the first published investigations dealing with the topic.

One of the important studies concerned with noise masking was reported by Fletcher and Munson in 1937.[1] They plotted masked audiograms for signals from 100 to 10,000 cycles per second. The masking was done with bands of random noise. These bands were: 140 - 160 cps, 1050 - 1250 cps. and 3000 - 3260 cps. On the basis of the final results of the study they made some postulations concerning the mechanical action of the ear in response to signals masked by noise.

The first use of the term "white noise" seems to have been made about the end of 1945 by J. E. Hawkins, Jr., and S. S. Stevens[2] in a study conducted at the Psycho-Acoustic Laboratories of Harvard University. This research was described originally in a restricted OSRD Report #5387 under the date of October 1, 1945. Until this time the masking

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[1]Harvey Fletcher and W. A. Munson, "Relation Between Masking and Loudness," The Journal of the Acoustical Society of America, IX, No. 1 (July, 1937), 1-10.

[2]J. E. Hawkins, Jr. and S. S. Stevens, "The Masking of Pure Tones and of Speech by White Noise," The Journal of Acoustical Society of America, XXII, No. 1 (July, 1950), 6-13.

noise used in the studies was described as random, thermionic noise. Whether some of the studies did, in fact, use white noise before this time may be open to question, but the term was not used before this time. This particular study was concerned with the effects of masking on pure-tone presentations and the resultant threshold shifts. The data were obtained by presenting the signals monaurally to the subjects and allowing them to vary the levels of the signals until they were just distinguishable from the masking noise. Curves were plotted for signals of various frequencies masked by noise of various intensities. The researchers then plotted a series of masked threshold curves. They found that the masking produced by white noise is directly proportional to the level of the noise. That is, when the level of the noise is raised by 10 dB, the masked threshold is also increased by 10 dB.

A related study by George Miller was published in The Journal of Acoustical Society of America.[1] This was one of the first published studies to make use of the term white noise (reference is made, however, to the earlier work by Hawkins and Stevens in this study). Adding further to the knowledge concerning noise and masking, this study

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[1]George A. Miller, "Sensitivity to Changes in the Intensity of White Noise and Its Relation to Masking and Loudness," The Journal of the Acoustical Society of America, XIX, No. 4 (July, 1947), 609-19.

investigated just detectable increments in the intensity of noise, and of signals masked by noise.

A study similiar in some respects to the present one was published by Schafer and Gales in 1949.[1] They plotted the transition curves (recognition probability as a function of level) for an 800 cycle tone. Punched tape switching apparatus was utilized to randomly vary the levels of the signal. The transition curves were also determined and plotted for combinations of four to eight tones masked by the noise.

In 1961 Small and Minifie conducted an investigation similiar in many respects to that of Hawkins and Stevens described earlier.[2] Using frequencies of 250, 500, 1000, 2000, 4000, and 8000 cycles per second, they determined the shift of threshold from masked to unmasked presentation. Noise levels of 60, 90, and 110 dB were used for the masking. Confirming the results of the earlier work of Stevens and Hawkins, Small and Minifie found that there is "nearly a one to one relationship between the masker level

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[1]Tillman H. Schafer and Robert S. Gales, "Auditory Masking of Multiple Tones by Random Noise," The Journal of the Acoustical Society of America, XXI, No. 4 (July, 1949), 392-98.

[2]Arnold M. Small, Jr. and Fred D. Minifie, "Intensive Differential Sensitivity at Masked Thresholds," Journal of Speech and Hearing Research, IV, 164-71.

and amount of masking. For example, if the masker level is increased by 20 dB, so also is the amount af [sic.] masking."[1]

This review of the literature has considered several important investigations concerned with signals in noise. The list of these studies could be expanded. It seems to this writer that further review would provide needless repetition.

Studies Related to Present Experimental Design

Prior to the actual gathering of data the experimental design of the study must be determined. Usually the researcher is quite certain as to the variables which are to be investigated. This doesn't lessen the effect of other variables on the results, however. The researcher may then decide to ignore these other variables. Or he may design the study so that the effects of these variables is constant and, hopefully, cancel out in the final analysis of the data.

There are many factors which affect the threshold determinations of signals in noise. Signal-to-noise ratio, frequency of the signal, duration of signal presentation, transients in switching, mode of presentation (binaural versus monaural) and foreknowledge of the stimulus all affect

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[1] *Ibid.*, p. 168.

the final results. This study was primarily concerned with the signal-to-noise ratio and signal frequency variables. Since the purpose of the study was to obtain the minimum thresholds for signals in noise, factors not of direct interest in the study had to be treated in the design such that their overall effect on the study would be to give these minimum thresholds. It was therefore necessary to refer constantly to the literature for the purpose of determining the manner in which these factors should be treated in the investigation. As a part of the review of the literature, then, this aspect of the study will be considered.

One of the variables mentioned as the duration of the presentation as a factor affecting the threshold determination. Gcldstein and Kramer found that "where reactions for longer tones were explored, greater sensitivity was shown for the longer tones than for 150-200 millisecond tones."[1] There seemed to be, in the words of the authors, a "linear trading relation between time and intensity."[2] As the tones were increased in duration, the sensitivity of the subjects tended to increase. This was true in the region

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[1]Robert Goldstein and Joan C. Kramer, "Factors Affectinc Threshold for Short Tones," Journal of Speech and Hearing Research, III, No. 3 (September 1960), 249-56.

[2]*Ibid.*, p. 255.

of tonal intensity from 20 to 200 milliseconds. As the tones increased in length from 200 milliseconds, the thresholds continued to get lower but at a slower rate. This would indicate an asymptotic behavior of this linear trading function for presentations of greater duration. Since no graphs were included in the results of the study, the exact nature of this asymptotic relation is not known. It might be assumed, however, that no further significant changes in sensitivity would be apparent for tones of duration greater then, say, one second. Regarding the duration of the masking stimulus, Egan has shown that the masked threshold is essentially independent of the duration of the masking stimulus.[1] The results of these two studies would indicate, therefore, that minimum threshold would be obtained for signals of at least one second duration. The masking could be constant with respect to time.

Transients in switching and the rapidity of the switching action were also factors mentioned as having an effect on the final threshold results. Montgomery has shown that for optimum threshold determination conditions, the

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[1]James P. Egan, "Independence of the Masking Audiogram from the Perstimulatory Fatigue of an Auditory Stimulus," The Journal of the Acoustical Society of America, XXVI, No. 4 (July, 1955), 737-40.

transition between tones should be abrupt, instantaneous, and silent.[1] A gradual transition between tones, such as that of a sinuosidal intensity variation, is less easy to detect than an abrupt transition. Wright, also investigating switching transients, presented the subjects with 500-millisecond tones beginning at the time axis and rising to maximum amplitude in 1/4 cycle, 1 1/4 cycle, 2 1/4 cycle, 5 1/4 cycle, and 100 milliseconds.[2] These presentations made use of 500, 1000, 2000, 3000, 4000, and 6000 cycle tones. He found that although switching transients present in pure-tone signals with rapid rise-decay times are quite apparent at supra-threshold levels, the degree to which they affect the measurement of threshold can be relatively slight. These results indicate that switching transients have no appreciable effect upon the threshold determinations for the normal ear. In terms of the objectives of the present study, then, the switching should be abrupt and instantaneous. The switching transients should have no effect on the final results.

Regarding monaural versus binaural presentation of the stimulus, Chappel, Kavanaugh and Zerlin found that the

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[1]H. C. Montgomery, "Influence of Experimental Technique on the Measurement of Differential Intensity Sensititity of of the Ear," The Journal of the Acoustical Society of America, VII, No. 1 (July, 1935), 39-43.

[2]Herbert N. Wright, "Switching Transients and Threshold Determinations," Journal of Speech and Hearing Research, I, No. 1 (March, 1958), 52-60.

average intelligibility score for binaural presentation of the stimulus was about 60 per cent, approximately 20 per cent higher than the average score for the monaural presentation.[1] Although this study concerned intelligibility scores and not thresholds for pure tones, it seems reasonable to assume that the pure-tone threshold would also be lowered by binaural presentation of the stimulus. Thus, in terms of the minimum threshold, binaural presentation of the signal should be make.

Harris found that foreknowledge of stimulus characteristics also affect the final threshold determinations.[2] This factor may operate to shift the threshold determinations, under certain conditions, by 10 dB or more. As he notes in the concluding remarks of the study:

> One may suspect that what one is measuring over a certain signal-to-noise test session may be not the subject's inherent auditory sensitivity at all but the slope of his learning curve; and there may be little relation between the slope of learning versus the asymptotic sensitivity index.[3]

Again, in terms of the minimum threshold, foreknowledge of the stimulus characteristics should be provided

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[1]Richard G. Chappell, James F. Kavanagh, and Stanley Zerlin, "Monaural versus Binaural Discrimination for Normal Listeners," Journal of Speech and Hearing Research, VI, No. 6 (September, 1963), 263-269.

[2]J. Donald Harris, "A Factor Analytic Study of Three Signal Detection Abilities," Journal of Speech and Hearing Research, VII, No. 1 (March, 1964), 71-78.

[3]Ibid.

to the subjects. For this reason, a sample presentation of the signal was provided for each subject prior to the actual gathering of the data.

In summary, previous studies have indicated that, for minimum threshold determinations, the following considerations should be incorporated into the final design of the study: the signal should be of at least one second duration, switching should be abrupt and instantaneous, the signal should be presented binaurally, and the subjects should have foreknowledge of the characteristics of the signals. The effects of masker duration and of switching transients should have no significant effects on the final results of the study. The experimental design was conceived with these considerations in mind.

Classical Psychophysical Methods

The field of psychophysics has grown in importance immensely in the last few years. Psychophysics is basically concerned with the study of the psychological effects of physical stimuli on the human body. One of the more important concepts in the field is that of a threshold. Threshold can be defined as "a boundary separating the stimuli that elicit one response from the stimuli that elicit a different response."[1] Two types of thresholds

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[1]Robert S. Woodworth and Harold Scholsberg, Experimental Psychology (New York: Henry Holt and Company, 1958), p. 193.

may be distinguished. One is often referred to as the stimulus threshold. This threshold separates the stimuli which elicit a response from those which elicit no response. The second type of threshold is known as the difference threshold. Two stimuli which the observer can just distinguish as being different determine this threshold. Due to the importance of thresholds in the study of human responses to various stimuli there have been developed several psychophysical methods for the determination of these thresholds. The classical psychophysical methods are known as The Method of Average Error, The Method of Limits, and The Frequency Method. Each method has its own advantages and disadvantages and its own field of application.

The Method of Limits is the only direct method of locating a threshold. Two categories which elicit different responses from the observer are used in this method. In the case of the stimulus threshold, one of the categories might be the region in which the observer does not detect the stimulus. The other category would then include the region in which the observer does detect the stimulus. The stimulus is then varied between these two categories and the response of the observer recorded. The threshold is taken to be the value of stimulus which locates the observer's response shift from one category to the other. If a large number of such trials are made and the results averaged, this procedure locates quite accurately the threshold point.

The second psychophysical method mentioned was The Method of Average Error. This is normally conducted by instructing the observer to adjust a variable stimulus until it appears equal to a given standard. If this procedure is repeated a number of times, the results can be analyzed mathematically to determine the desired thresholds. The method may be altered somewhat to allow the experimenter to have control over the variable stimulus intensity. The observer then judges at what point the variable stimulus intensity appears equal to the intensity of the standard stimulus.

The third classical psychophysical method and the one employed in the present study is The Frequency Method. In this procedure the variable stimulus is compared with the standard stimulus many times and the relative frequency of the different response categories is counted. This may be done with many intensity levels of the variable stimulus. These data may then be analyzed statistically and the threshold located at the 50 per cent response point between one category and the other. This method is particularly useful in studying the transition zone between stimuli which can nearly always be detected and stimuli which are rarely detected. The threshold may then be taken as the stimulus intensity which elicits a response 50 per cent of the time.

If this transition zone for any sensory modality of the human body is plotted in the form of per cent detection versus intensity of stimulus the resultant curve is an ogive. This is due to the fact that any sensory function variation tends to show as approximately normal distribution of values. The ogive is simply the cumulative form of this normal distribution curve.

Certain modifications of The Frequency Method have been made by various experimenters. Perhaps the best known of these modifications was devised by Muller and Urban and is known as the Muller-Urban weights. Muller and Urban found that sampling errors may occur in the course of obtaining data and that these errors, due to the manner in which the data are analyzed, affect the extreme points of the transition zone more than the central points. For this reason they developed a weighting procedure by which the central points are given more weight than the end points in the analysis of data.

Such researchers as Peterson and Birdsall,[1] Tanner and Swets,[2] and Tanner, Swets and Green[3] have recently

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[1]W. W. Peterson and T. G. Birdsall, The Theory of Signal Detectibility, Electronic Defense Group Technical Report No. 13 (Ann Arbor, Mich.: The University of Michigan, 1953.)

[2]Wilson P. Tanner and J. A. Swets, "A Decision-Making Theory of Visual Detection," Psychological Review, LXI (1954), 401-409.

[3]Wilson P. Tanner, J. A. Swets, and D. M. Green, Some General Properties of the Hearing Mechanism, Electronic Defense Group Technical Report No. 30 (Ann Arbor, Mich.: The University of Michigan, 1956)

expressed dissatisfaction with the classical psychophysical methods. These classical methods still form the basis for most present studies of sensory perception, however.

CHAPTER III

PROCEDURES AND EQUIPMENT

Subjects

Two subjects, both male graduate students in Speech and Hearing Science, were used for the purposes of the study. Both subjects had normal hearing. For the purposes of this study, a subject was considered to have normal hearing if his threshold for 500, 1000, or 2000 cycle per second pure tones was no greater than 10 decibels re USPHS in either ear.

Procedures

A constant level of white noise was presented continuously and binaurally through headphones to the subjects. Noise levels of 70, 80, and 90 dB SPL were used. At each of these levels, 160 two-second presentations of a 500 cycle tone, a 1000 cycle tone, and a 2000 cycle tone were superimposed on the noise. Each such set of 160 presentations of the pure tone consisted of ten presentations at each of 16 intensity levels. Since these intensity levels varied in one-dB steps, a total pure-tone intensity range of 16 dB was encompassed for each set of presentations. The intensity variations were made randomly.

The exact placement of the 16 dB pure-tone intensity range described above was determined immediately before each set of presentations. The highest level of the range was chosen to be a point at which both subjects could clearly hear the tone in the noise. The lowest level was chosen to be a point at which neither subject could detect the signal in the noise. This range varied somewhat for each set of presentations and the exact figures for the ranges used are given in Table 1.

Table 1

PURE-TONE SIGNAL INTENSITY RANGES

Noise Level	Signal Frequency	Signal Intensity Range
70 decibel SPL	500 cps	-22.0 to -37.0 dB SPL
"	1000 cps	-15.5 to -30.5 dB SPL
"	2000 cps	-13.0 to -28.0 dB SPL
80 decibel SPL	500 cps	-12.5 to -27.5 dB SPL
"	1000 cps	-12.0 to -27.0 dB SPL
"	2000 cps	-18.5 to -33.5 dB SPL
90 decibel SPL	500 cps	-11.6 to -26.6 dB SPL
"	1000 cps	-10.6 to -25.6 dB SPL
"	2000 cps	-14.0 to -29.0 dB SPL

A small red signal light indicated the pure-tone presentations. This visual indication was necessary since the lower pure-tone intensity levels were not always detectable by the subjects and the presence of a stimulus interval had to be known if the subjects were to maintain an item count.

The responses of the subjects were recorded on special response sheets. A set of two response sheets was used for each set of 160 presentations (see Appendix B). Each set of two sheets contained 160 pairs of the letters "s" and "n". The letter "s" was used to indicate signal, the letter "n" to indicate noise (no signal).

The subjects were instructed to listen to the noise in the headphones and, simultaneously, to watch the signal light. If, when the light flashed, they were able to detect a signal in the noise they would circle the letter "s" on the response sheet. If the light flashed and they were unable to detect a signal, they would circle the letter "n".

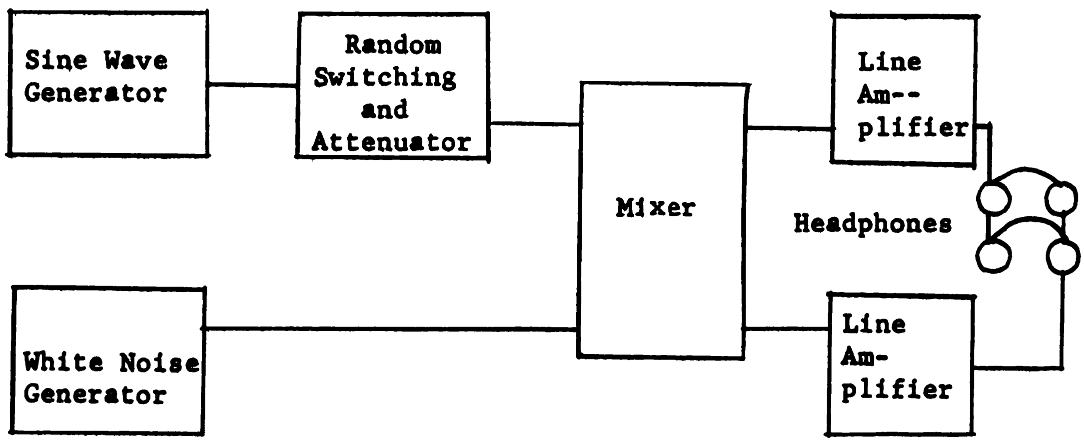
The experimental data were obtained in a converted classroom measuring approximately 20 by 30 feet. The room has plastered walls, a hard floor, and is surrounded on two sides by a blackboard. For this reason the data were obtained on a week-end when the background noises which might have possibly interferred with the study were at a minimum. The controlled white noise level in the experiment exceeded that in the test room while the experiment was being conducted. In order to minimize visual distractions the subjects were seated on chairs facing away from the equipment used in the study. The small signal light was placed in front of the subjects such that it could be clearly seen by them.

Equipment

The block diagram of the equipment used in the study appears in Figure 3.

Figure 3

Block Diagram of Equipment Used in this Study



For a detailed list of the exact equipment used, See Appendix A.

The white noise was fed into one chanell of the electronic mixer unit. The pure-tone signal was fed into the second channel of the unit. This sine wave, as described previously, was varied in intensity through the use of the random switching unit and the 16 channel attenuator unit.

The random switching unit consisted of an assembly containing twenty sets of contacts (or channels), sixteen of which were utilized in this study. The lower part of each set of contacts consisted of an assembly of twenty copper rings mounted on nylon bushing so as to insulate them from each other and from the rest of the switching mechanism. Resting on each of these copper rings was a short brass strip. Each combination of copper ring and brass strip provided a normally-closed switch. The switch might be opened simply by lifting the brass strip from the copper ring. This opening and closing of the contacts was achieved automatically by feeding a programmed card through the unit between the copper rings and the brass strips. The card normally prevented the strips from touching the rings thus holding the switches open. A hole punched in the appropriate position of the card would allow one of the strips to contact the ring below it, thus closing that particular channel. To achieve random switching these holes in the card were punched in a random manner. That is, each of the sixteen channels to be used was assigned a number from one to sixteen. These numbers were then selected from a table of random numbers and the holes were punched in the cards corresponding to the order in which the numbers had been selected. Since ten presentation at each level were desired, each of these numbers was selected ten times in the course of compiling the list of random numbers.

The cards used for the switching were six inches wide and about two feet long. A small one-rpm motor driving two small rubber rollers fed the card through the unit. The diameter of each of these rollers was one and one-quarter inches.

In the course of designing the unit it was found that square holes rather than round holes in the card resulted in more consistent operation of the mechanism. Thus it was necessary to have a square hole punch designed and built for the purpose of the study.

The duration of the signal presentations was controlled by two factors: The size of the holes in the card and the rate at which the card was fed through the unit. Although it was possible to vary somewhat the size of the holes, adjusting the rate of card feed through the unit was preferable in controlling the signal duration. A presentation time of about two seconds was achieved through the use of a 5 to 3 pulley drive reduction on the one-rpm motor.

The attenuator unit consisted of sixteen channels, each of which contained an adjustable potentiometer. Each of these channels was connected to one of the sets of contacts of the switching unit. Each potentiometer was calibrated individually to give the desired amount of attenuation for that particular channel. These procedures for calibration were quite simple. A pure-tone signal of known intensity (as measured by a sound pressure level meter) was fed into the potentiometers. The potentiometers, were then adjusted so that the output of each potentiometer, again as measured by the sound pressure level meter, was the desired amount below the input. Although different pure-tone intensities and frequencies were used in the study, no change in the initial calibration of the potentiometers was necessary.

CHAPTER IV

RESULTS AND ANALYSIS OF DATA

Data Reduction

It was mentioned in Chapter II that for each sensory modality of the human body a transition region can be found. This is the region that ranges from the point at which the stimulus is rarely detected to the point at which the stimulus is nearly always detected. If one obtains the data for such a region and plots it graphically the resultant curve turns out to be an ogive.

If an experimenter is interested in plotting this ogive curve he may obtain his data by some appropriate method and then proceed to plot the curve from these data. Because of random error, the ogive will, of course, not be perfect. Some trial and error curve fitting must be done. This can be done visually but the results of such procedures usually leave much to be desired in the way of accuracy. This is particularly true in the case of complex curves such as the ogive curve. Thus some other method of curve fitting should be employed.

There exist, for straight lines, quite accurate mathematical methods of curve fitting. One of these is the method of least squares. This method yields the line through the points such that the squares of the y-axis deviations of the points from this line are a minimum. The experimenter who has obtained some sort of complex data would thus do well to determine whether the data can be transformed to some coordinate system which would yield a straight line. Linear curve fitting techniques could then be employed.

In the case of the data for the transition region, such a transformation can be made. The original data are in the form of per cent detection plotted against stimulus-intensity. If the per cent-detection data of the ordinate is transformed to normalized standard-score units (z-scores), the resultant graph is linear if the transition function is a normal ogive. The curve fitting can then be done on the reduction of the linear data. The results can then be transformed back into the original per cent-detection versus stimulus-intensity form and the desired ogive plotted.

This short background discussion was presented since it describes the manner in which the data of the present study were analyzed. The raw per cent-detection versus signal-to-noise ratio data were tabulated. Such a set of data was obtained for each subject for each of the nine conditions of frequency and noise level. Since there were two subjects, two sets of data for each set of conditions were actually obtained. The final set of data for each set of parameter conditions was obtained by simply averaging the data of the two subjects.

The per cent-detection data of the ordinate were transformed into z-scores and the resultant signal-to-noise ratio versus z-score units were plotted. Then, by the method of least squares, a straight line was fitted to each set of data. The results were then retransformed back into the original form of per cent-detection versus signal-to-noise ratio and the desired ogive curves were plotted.

The method of least squares yields the slope, m, and the y-intercept, b, of the line of best fit. This line can, of course, be plotted and points read from the line. For the purposes of this study a more accurate approach was used. The lines were not actually plotted but the location of points on the lines was determined mathematically. Such information is easily obtained since the slope and y-intercept of the line of best fit are known.

Some problems were encountered in the analysis of the data. One such problem was concerned with the transformation of per cent-detection points into z-scores. This is easily done except when 100 per cent and 0 per cent detection points must be transformed. Theoretically, 100 per cent-detection corresponds to a z-score of $+\infty$, and 0 cent detection to a z-score of $-\infty$. Obviously such points cannot be used in the mathematical analysis of the data.

A z-score value was arbitrarily assigned to these values. Whenever a 100 per cent detection was encountered in the data, a z-score of 2.50 was assigned to the value. Whenever a 0 per cent-detection point was encountered a z-score value of -2.50 was assigned. The z-score value of 2.50 actually corresponds to a 99.5 per cent detection value. This procedure would correspond very roughly to that advocated by Müller and Urban. They suggested assigning weights to all the z-score values, the weights being the greatest near the center of the curve and the least at the extreme ends. The procedure of assigning a z-score value of 2.50 in place of a value of $+\infty$ has the effect of greatly de-weighting the extreme points for the purpose of the analysis.

Another problem was encountered in some of the data. To illustrate this problem, refer to the hypothetical set of data presented in Table 2.

TABLE 2

PER CENT DETECTION DATA

Per Cent Detection	Signal-to-Noise Ratio
100	-15 decibel SPL
100	-16 decibel SPL
80	-17 decibel SPL
100	-18 decibel SPL
100	-19 decibel SPL
90	-20 decibel SPL
80	-21 decibel SPL

Obviously the data are quite consistent with the exception of the point for -17 dB SPL. Was this point detected only 80 per cent of the time due to the masking effect of the noise or did some other factor account for this failure of the subjects to detect the tone in some of the presentations? For example, did an equipment malfunction account for the low detection precentage at this point (that is, was the signal actually presented less than ten times)? The answers to these questions could significantly affect the final results of the graph. There were two points of intensity less than -17 dB which were detected 100 per cent of the time. Intuitively, one feels that the probability of detecting these points 100 per cent of the time by chance is much lower than the probability of an equipment failure accounting for the drop in detection at -17 dB. In other words, the probability of detecting by chance all presentations at -18 dB is quite small due to their being scattered randomly among 160 presentations. On the other hand, there is a much greater probability, due to the nature of the equipment involved, that a malfunction of equipment accounted for the low detection precentage at -17 dB. Thus one seems justified, on the basis of probability alone, to assign a 100 per cent detection value to the -17 dB point. Closer examination of the data appeared further to justify this procedure. In all cases in which a signal-to-noise ratio was detected less than 100 per cent of the time, and in which a signal of lesser intensity was detected 100 per cent of the time, it was found that the very same presentations were missed by both subjects. This would seem to indicate also equipment malfunction accounting for this effect.

Results

The graphical results of the investigation are presented on the following four pages in Figures 4, 5, 6 and 7.

This is the final data, having been compiled and analyzed as previously described.

Discussion

At 70 dB, the threshold for the 1000 and 2000 cycle tones is somewhat higher than the threshold for the 500 cycle tone. That is, 70 dB of noise more effectively masks 1000 and 2000 cycle tones than it does 500 cycle tones. Keeping the nature of white noise in mind, one might suspect that this would indeed be the case.

White noise has a power spectrum which is constant over all frequencies within its bandwidth. The energy of the noise, however, is concentrated at the higher frequencies. Thus more noise intensity is required to mask tones of lower frequencies. This effect is illustrated quite well by the first set of data. If the 50 per cent detection point is taken as the threshold, the threshold

Figure 4

Signal-to-noise Ratio versus Percent-Detection
for 70 dB SPL Noise Level

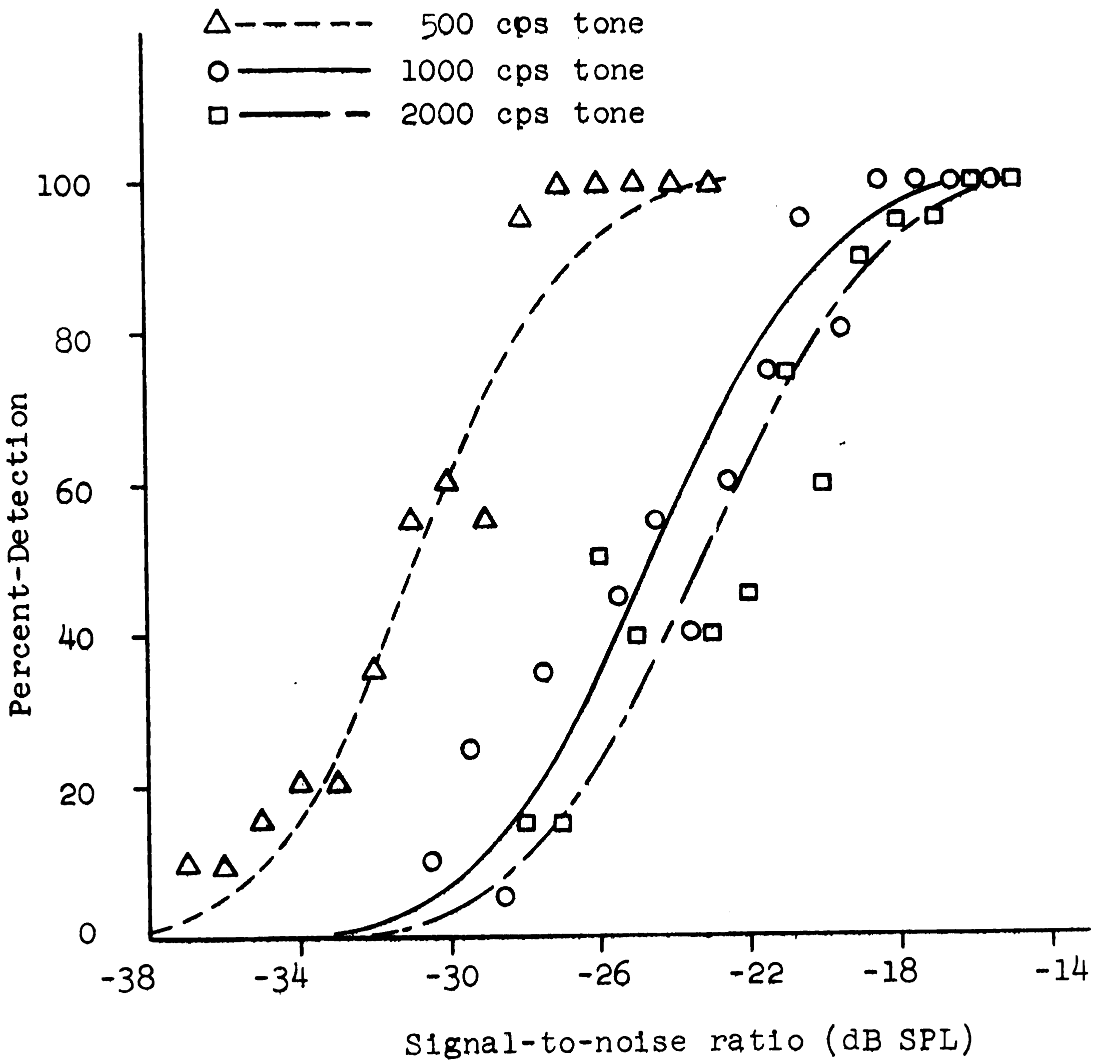


Figure 5

Signal-to-noise Ratio versus Percent-Detection
for 80 dB SPL Noise Level.

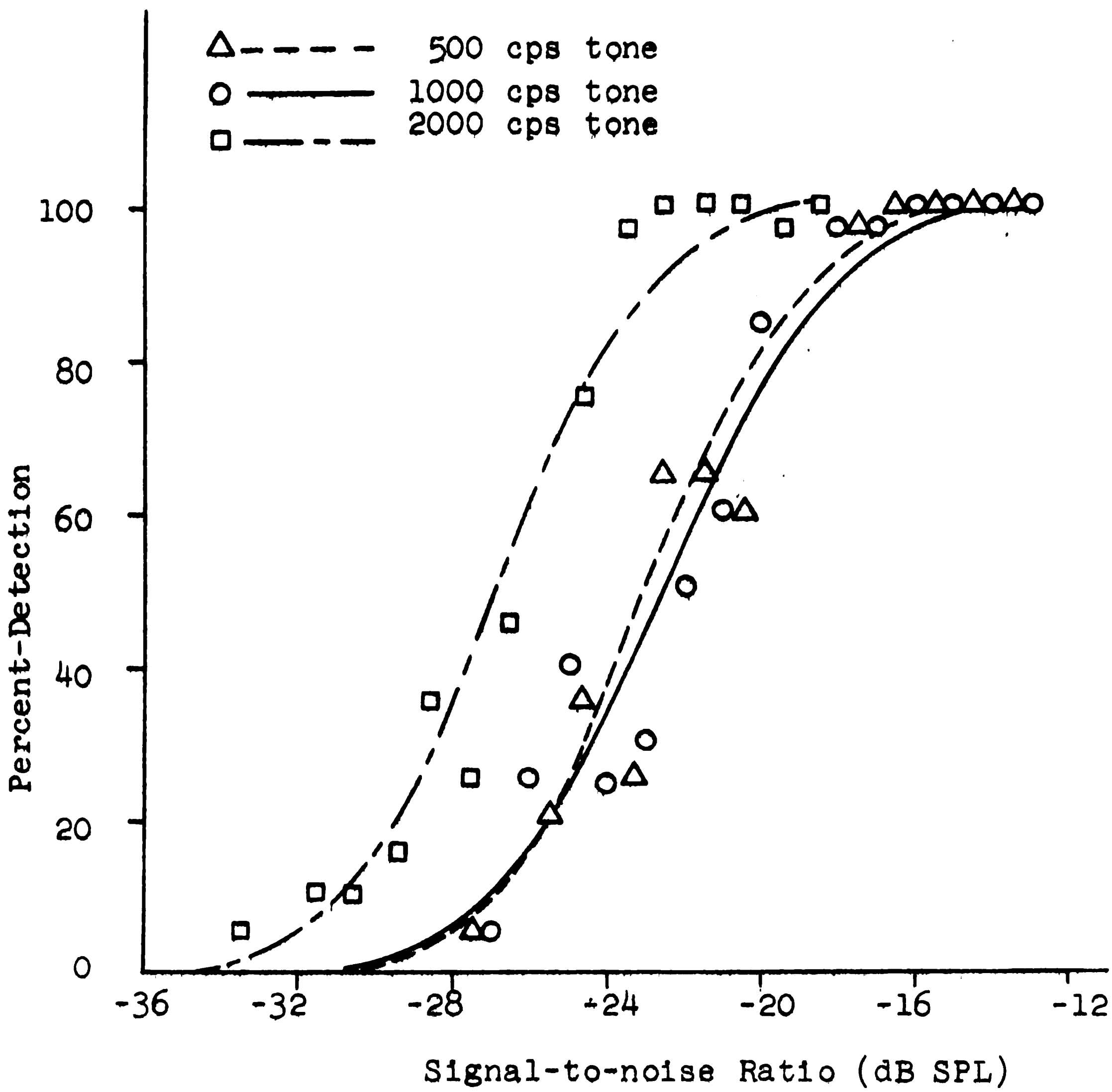


Figure 6

Signal-to-noise Ratio versus Percent-Detection
for 90 dB SPL Noise Level

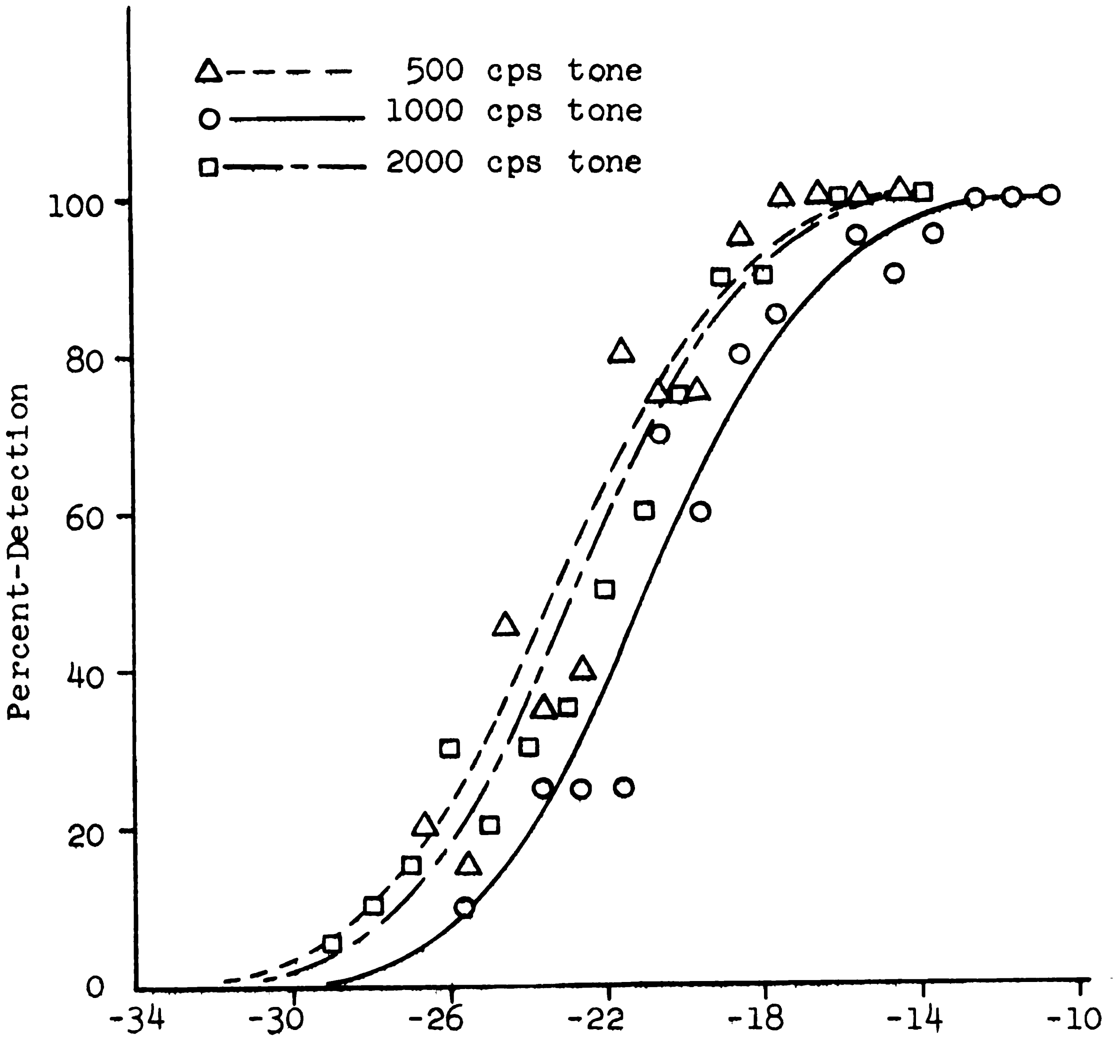
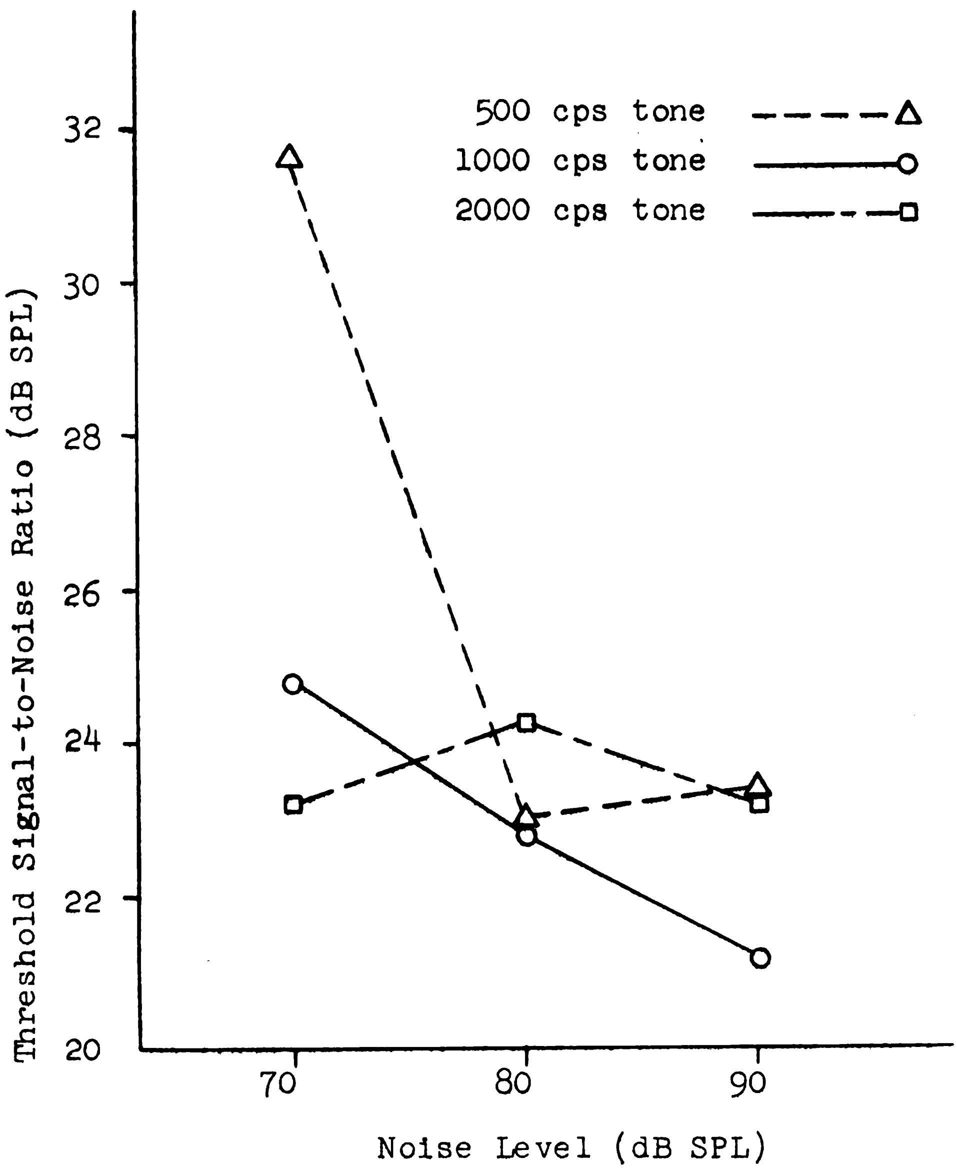


Figure 7

Experimentally Determined Thresholds



for the 1000 and 2000 cycle tones is about 8 - 9 dB higher than the threshold for the 500 cycle tone. Although the threshold for the 1000 cycle tone was about 1 dB lower than the threshold for the 2000 cycle tone, there was, as will be shown later, no significance in the difference. The difference is probably due to random error.

For a noise level of 80 dB the threshold for 2000 cycle tones is again lower than the thresholds for either the 1000 cycle or 500 cycle tones. Again, these differences were not shown to be significant and were probably due to random error in the course of gathering the data. Non-linear response of the headphones, variation in the responses of the subjects, error in the measuring equipment, and so forth could account for the differences.

At a noise level of 90 dB SPL the threshold for the 500 cycle tone is somewhat lower than that for the 1000 cycle tone. The threshold for the 2000 cycle tone is about the same as the threshold for the 500 cycle tone. Again, these differences were not significant and were probably due to random error.

Statistical Analysis

Since some differences did exist in the experimentally determined thresholds under different conditions, it was felt that further analysis of the data was in order. Such analysis could reveal whether the differences were statistically significant or whether they were the result of random error. An analysis of variance therefore was performed on the data in an attempt to answer these questions.

A two-way analysis of variance model was used as the basis for the analysis.[1] The analysis revealed that, at the .05 significance level, differences existed between the different noise levels and between the different frequencies. In addition, a significant interaction was revealed. Since the interaction could very well be responsible for the significance between the frequencies, and between the noise levels, further examination of the data was carried out. The summary table for this analysis is presented as Table 3.

Examination of Figure 7 suggests that the interaction of the 500 cycle tone with the 70 dB SPL noise level could be responsible for the significant results presented in Table 3. On the basis of this assumption, an additional of variance was performed on the data after the 500 cycle-70 dB SPL noise level call had been dropped from the table. The results of this analysis are presented in Table 4.

Since no significant differences are illustrated in this table, it is apparent that the 500 cycle tone at

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[1]Hubert M. Blalock, Social Statistics (New York: McGraw-Hill Book Company, Inc., 1960), p. 254.

TABLE 3

ANAYLSIS OF VARIANCE SUMMARY TABLE

Source of Variation	Sum of Squares	Degree of Freedom	Estimate of Variance	F
Total	181.01	17		
Between				
Subclass	155.16	8		
Noise	28.07	8	14.03	4.88*
Frequency	47.87	2	23.94	8.34*
Interaction	79.22	4	19.80	6.90*
Error	25.85	9	2.87	

* Significant at .05 level of confidence

TABLE 4

ANNALYSIS OF VARIANCE SUMMARY TABLE

Source Variation	Sum of Squares	Degrees of Freedom	Estimate of Variance	F
Total	60.50	15		
Between				
Subclass	38.55	7		
Noise	4.65	2	2.32	.85
Frequency	13.47	2	6.74	2.46
Interaction	20.43	3	6.81	2.49
Error	21.95	8	2.74	

70 dB masking level did, in fact, account for the significance shown in the first analysis of variance.

The results of the procedures outlined above allow one to assert that the differences in the experimentally determined thresholds, except for the 500 cycle tone at 70 dB SPL noise level, were due to random error in the course of gathering the data. The 500 cycle threshold at 70 dB SPL noise level was statistically significant from the other subclasses at the .05 level. Some possible reasons for this difference were mentioned earlier in the chapter.

CHAPTER V

SUMMARY AND IMPLICATIONS FOR FURTHER RESEARCH

Summary and Conclusions

Transition curves for 500 cycle, 1000 cycle, and 2000 cycle tones masked by 70 dB SPL, 80 dB SPL, and 90 dB SPL intensity levels of noise were experimentally determined. From these curves the threshold points at which the subjects detected 50 per cent of the presentations were determined. The threshold for the 500 cycle tone masked by 70 dB SPL of noise was significantly lower than the thresholds for the other sets of conditions.

Previous studies have indicated that the amount of masking is directly proportional to the level of the masker; that is, when the intensity of the masker is increased by 10 dB, so also is the masked threshold. The results of the present study confirm these findings. The average threshold for the subjects at the three noise levels was about 22 - 23 dB below the level of the noise. This means that the threshold for the tones increased in direct proportion to increases in the level of the noise. The overall effect was to keep the threshold for signal-to-noise ratios at constant value.

Further conclusions regarding the response of the hearing mechanism to the type of sound stimulus used in this study cannot be made at this time. More information will be needed for such conclusions to be drawn.

The response of the subject as to whether he hears a certain presentation or does not hear a presentation is determined on the basis of pass-fail criteria. That is, the subject sets standards for identification of the signal. If the signal meets or surpasses these standards the subject reports that he heard the signal. If the signal does not meet these standards the subject reports that he has not heard the signal. This pass-fail criterion is not defined in terms of absolute physical measurements but rather in terms of the response of the auditory system. It has been hypothesized that the response of the auditory system is not constant but varies from moment to moment. This accounts for the fact that signals of certain intensities may be detected only part of the time. It is basically this pass-fail criterion which determines the threshold obtained for the subjects. The actual location of this point and thus the threshold obtained may vary under different conditions. For instance, the instructions which are given to the subjects may affect this point.

In the case of the present study, the subjects were familiar with the study and therefore were aware of the procedures to be used. They were aware, for example, that the signal was being presented each time that the signal light flashed, even though some of these presentations were not audible. It might be advisable, in further studies of this sort, to advise the subjects that a signal would not necessarily be presented each time that the signal light flashed. This would provide some actual uncertainty as to whether the signal did exist or did not exist for some of the presentations.

One might suspect that the subject's knowledge of a signal presentation each time that the light flashed might lower the pass-fail criterion. That is, he might identify signal presentations which wouldn't have been identified had he not known that a signal accompanied each flash of the signal light. In the present study it is highly probable that the opposite effect was true. The subjects were aware that they were supposed to detect some of the signals and not detect some of the signals. Thus it seems reasonable to assume that the criterion was not lowered but actually raised. This would assure that some of the signal presentations would be undetected. A repeat of this study using different instructions for the subjects might well result in lowered, or at least different thresholds.

Implications for Further Research

Several recommendations for further study along the present lines could be made. The scope of the present investigation could be widened to include a greater number of noise levels and signal frequencies. It might be desirable to use noise levels from 20 dB SPL upwards to those of the present study. Also, additional frequencies could be added. Although they are out of the speech range, frequencies to 15,000 or 20,000 cycles per second might be investigated.

It might be interesting to note whether other types of masking by noise would give results comparable to those of the present study. Specific narrow bands of white noise might be used as the masking stimulus. Research has indicated that the band of white noise extending from one octave below to one octave above the frequency of the signal being masked is responsible for the majority of the masking. Plotting the transition curves using these limited bands of white noise might result in some interesting data.

The curves for transition regions might be plotted using different types of signal stimulus. The stimulus might be some sort of tone, or it might be speech sounds. The transition curves for different speech sounds might be plotted and the results compared. Two main pieces of information could be obtained from this sort of investigation. First, the threshold in terms of signal-to-noise ratio could be determined. Second, from the slope of the transition curves, information regarding the ability of the ear to detect small intensity changes in the different speech sounds could be obtained.

This study was planned, as previously explained, to be the first step in a series of investigations leading ultimately to more complete knowledge about the types of distortions occuring in the hearing mechanism. Such studies could provide much valuable information concerning steps that might be taken in compensating for these hearing losses. The present study was initiated in terms of an investigation concerned with the ability of the ear to detect amplitude distortions in white noise. Signal-to-noise ratio may, however, be interpreted in this way. Certainly the signal is presenting amplitude distortion in the noise. The next step in this series of studies might be to measure the effects of other types of distortions on the ear. Harmonic distortion, intermodulation distortion, and phase distortion are only a few examples. White noise could be used as the stimulus. Such studies might contribute a wealth of information concerning the operation of the normal and impaired ear.

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APPENDICES

APPENDIX A

Equipment used in the study:

Hewlett-Packard Low Frequency Oscillator, Model 202 C

Grason-Stadler Noise Generator, Model 455 B

Ampex Four Channel Mixer-Preamplifier, Catalog Number 96910-01.

Bruel and Kjaer Electronic Voltmeter, Type 620.

Ampex Model 620 Line Amplifier (2 used)

Telephonics Headphones, Model TDH - 39.

APPENDIX B

Response Form

1. S N	24. S N	47. S N	70. S N
2. S N	25. S N	48. S N	71. S N
3. S N	26. S N	49. S N	72. S N
4. S N	27. S N	50. S N	73. S N
5. S N	28. S N	51. S N	74. S N
6. S N	29. S N	52. S N	75. S N
7. S N	30. S N	53. S N	76. S N
8. S N	30. S N	54. S N	77. S N
9. S N	31. S N	55. S N	78. S N
10. S N	32. S N	56. S N	79. S N
11. S N	33. S N	57. S N	80. S N
12. S N	34. S N	58. S N	81. S N
13. S N	35. S N	59. S N	82. S N
14. S N	36. S N	60. S N	83. S N
15. S N	37. S N	61. S N	84. S N
16. S N	38. S N	62. S N	85. S N
17. S N	39. S N	63. S N	86. S N
18. S N	40. S N	64. S N	87. S N
19. S N	41. S N	65. S N	88. S N
20. S N	42. S N	66. S N	89. S N
21. S N	43. S N	67. S N	90. S N
22. S N	44. S N	68. S N	91. S N
23. S N	45. S N	69. S N	92. S N

93. S N	110. S N	127. S N	144. S N
94. S N	111. S N	128. S N	145. S N
95. S N	112. S N	129. S N	146. S N
96. S N	113. S N	130. S N	147. S N
97. S N	114. S N	131. S N	148. S N
98. S N	115. S N	132. S N	148. S N
99. S N	116. S N	133. S N	149. S N
100. S N	117. S N	134. S N	150. S N
101. S N	118. S N	135. S N	151. S N
102. S N	119. S N	136. S N	152. S N
103. S N	120. S N	137. S N	153. S N
104. S N	121. S N	138. S N	154. S N
105. S N	122. S N	139. S N	154. S N
106. S N	123. S N	140. S N	155. S N
107. S N	124. S N	141. S N	156. S N
108. S N	125. S N	142. S N	157. S N
109. S N	126. S N	153. S N	158. S N