FREQUENCY AND COMPLEXITY OF HARMONIC SOUNDS AS FUNCTIONS OF AN OPTIMUM WARNING SYSTEM

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ABSTRACT

FREQUENCY AND COMPLEXITY OF HARMONIC SOUNDS AS FUNCTIONS OF AN OPTIMUM WARNING SYSTEM

by Bruce Donald Olsen

The purpose of this study was to determine whether any significant differences exist in subjects rating of the alerting potential between harmonic complex tones made up of two, three, four, and five pure tones half an octave apart; and if any significant differences exist in subjects rating of the alerting potential between harmonic tones with frequencies ranging from 700 cps to 4000 cps.

The subjects participating in this study were twenty-four students at Michigan State University who were tested and found to have normal hearing thresholds. The subjects were asked to rate eighty-eight different sounds in relation to nine characteristics. Each characteristic was rated along a five point continuum allowing the subject to determine the strength of a sound in relation to each characteristic. These sounds were played on a tape recorder and were heard through a pair of earphones.

The findings of this study indicate that there is a significant difference in subject ratings of alerting potential between complex harmonic sounds. The more complex the sound the better it was rated by the subjects as an

alerting signal. The range between 1800 cps and 2200 cps for the lowest frequency of complex harmonic sounds was also shown by subjects rating of alerting potential to be an optimum range for alerting signals.

It would appear then, that from the results of subjects rating of alerting potential, the complexity and frequency of harmonic sounds play a significant role in determining if they are suitable for an optimum warning system.

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By

Bruce Donald Olsen

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

A study was completed at Michigan State University, September, 1963, for the Office of Civil Defense, Contract No. OCD-OS-62-182 by Oyer and Hardick. The title of the project was "Response of Population to Optimum Warning Signal." The project isolated characteristics that were believed to be useful as a warning system by subjects in the experiment.

> Because of time limitations and the broad focus of the research objectives outlined in the contract, it was not feasible to attempt to explore in depth some areas that required further study. Therefore it is recommended that the audio warning signal selection process be continued within the ranges of frequency, intensity and time specified in the present investigation.[1]

One of the suggestions for further investigation was to determine the differential effects of signal complexity and relationships of components comprising the spectrum on judgments of alerting potential of audio signals.[2] It was

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[1] Herbert J. Oyer and Edward J. Hardick, "Response of Population to Optimum Warning Signal," Office of Civil Defense, Contract No. OCD-OS-62-182, September, 1963, p. 7.

[2] *Ibid.*

from this suggestion that the present study evolved. This study involves determining frequency and complexity of tones with harmonic relationships that would be most successful as optimum warning signals.

Areas that should be explored in greater depth are those that involve determination of more refined estimates of signal characteristics based on the ranges determined by the present study.[1] The frequency range studied therefore was limited to the area suggested by research results of the study by Oyer and Hardick. The optimal warning signal should be within the range of 700 cps to 4000 cps.[2]

Since the research findings indicate that isolated pure tones do not have as great an alerting potential as complex signals,[3] all sounds in this study were complex sounds being made up of two or more pure tones that were harmonically related. The intensity of the harmonic sounds used was held constant with an output of 70 dB (re: .0002 dyne/cm^2) through earphones. Two variables were therefore isolated for study, difference of frequency and difference of complexity of harmonic complex sounds.

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[1]Ibid., p. 3.

[2]Ibid., p. 4.

[3]Ibid.

Hypotheses

In order to determine results from this study, the following null hypotheses have been proposed.

1. There are no statistically significant differences between the means of subjects rating of the alerting potential of complex harmonic sounds of two, three, four, and five components, as measured on a nine point scale along a five point continuum.

2. There are no statistically significant differences between the means of subjects rating of the alerting potential of different frequencies of harmonic sounds, as measured on a nine point scale along a five point continuum.

Importance of Study

Little attention has been focused on human responses as criteria for determining optimal audio alerting signal characteristics.[1] This area has grown in importance as greater emphasis is placed on civil defense.

> The impetus was the advent of World War II when it was necessary to provide warning in areas far removed from the zone of combat. In addition, it was necessary to provide warning to large numbers of people, many of whom lived in noisy metropolitan areas.[2]
>
> It is rather obvious that efficient alarms sounded in time for people to take self-protective measures

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[1] *Ibid.*, p. 7.

[2] *Ibid.*, p. 12.

> are important for the maintenance of high morale, and should decrease the possibility of panic among the public.[1]

It is for these reasons that studies in this area are important.

State of Problem and Purpose of Study

This study attempted to determine whether any significant differences exist in subjects rating of the alerting potential due to changes of the lowest frequency component of complex sounds.

In order to investigate possible differences in these areas, subjects attending Michigan State University, between the ages of twenty-two and thirty-four, and found by testing to have normal hearing, participated by judging eighty-eight sounds. The sounds were confined to frequencies of between 700 cps and 4000 cps. The sounds were each heard twice (eighty-eight sounds in total) and were judged on a nine point scale along a five point continuum.

Definition of Terms

Complex Tones: Two or more tones between 700 cps and 4000 cps combined so that they are harmonically related in half octave steps.

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[1]Federal Civil Defense Administration. Final Report: The Effectiveness of Sonic Outdoor Warning Devices. November, 1953, p. 17.

Optimum Warning Signal: In order to have a warning system it must first be an alerting signal. An alerting signal should have "grabbing power," it should be an "attention getter," should have "distracting ability."[1] Operationally defined, it is used to attract attention.

> Warning is defined as alerting people to the threat of extraordinary danger and the related effects of disaster. An alerting signal can provide warning to the population only when the signal is associated with the threat of danger and the related effects of disaster through a conditioning process.[2]

Scaling: Scaling is defined as the ordering of stimuli along one or more continua on the basis of magnitude of human response.[3] Stevens states the assignment of numerals (numbers) to aspects of objects or events creates a scale.[4]

> Decibel (dB): Although the absolute amount of sound intensity can be measured, it is more common to express it in terms of the ratio between the intensity of the sound being measured and a standard reference intensity, which for audiologic convenience compares closely with the threshold of the human ear. The most common reference point from which sound intensities are computed is a power of ten to the minus sixteen watt per square centimeter, or a pressure of .0002 dyne/cm2 (two tenthousanths dyne per square dentimeter).

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[1]Oyer and Hardick, op. cit., p. 23.

[2]Ibid., p. 12.

[3]Ibid., p. 10.

[4]S. S. Stevens (ed.), Handbook of Experimental Psychology (New York: John Wiley and Sons, Inc., 1951), p. 23.

The ratio between this reference point and any given intensity is expressed in terms of a logarithmic unit called the decibel.[1]

Harmonics: When the frequencies of the partials are integral multiples of the lowest or fundamental frequency they are called harmonics.[2]

Equal Loudness: Inspection of the loudness curve shows that there is only a slight difference in loudness between 700 cps and 4000 cps when intensity is held constant at 70 dB. For this study, equal loudness was defined as a constant intensity level of 70 dB.[3]

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[1]Haves A. Newby, Audiology (New York: Appleton-Century-Crofts, Inc., 1958), p. 12.

[2]Giles W. Gray and Claude M. Wise, The Bases of Speech (New York: Harper and Brothers, 1959), p. 114.

[3]Harvey Fletcher, Speech and Hearing in Communication (New York: D. Van Nostrand Company, Inc., 1961), p. 188.

CHAPTER II

REVIEW OF THE LITERATURE

Development of Studies in the Area

> There is very little published research concerning the evaluation of auditory stimuli within the context of alerting or warning. Much of the reported research has been concerned with engineering problems related to signal generation and propagation. Little attention has been focused on human responses as criteria for determining optimal audio warning signal characteristics.[1]

Some of the reports reviewed in this chapter are taken from a secondary source since they were not available to this writer.

In 1942 Volkmann and Graham reported a designed to determine the audibility sound level requirements of alarm signals in the quest for an adequate signal that would give basic outdoor coverage and supplementary indoor coverage for air raid warnings.

> As the center frequency was changed, noticeable changes with frequency occurred due to masking characteristics of the noise. The most effective center frequency for noise penetration was around 2000 cps. Since in the case of local coverage no noticeable loss occurrs for the transmissions of high frequencies in the air, a signal frequency of approximately 2000 cps was found to be desireable.[2]

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[1]Oyer and Hardick, op. cit., p. 7.

[2]J. E. Volkmann and M. L. Graham, "A Survey on Air Raid Alarm Signals," Journal of the Acoustic Society of America, 14 (1942), p. 1.

Houston and Walker conducted tests to determine the probability of hearing the various signals in a background of simulated aircraft noise. A variety of noise spectra were used. A pure tone of 2500 cps, presented intermittently through earphones was found to be the most effective warning signal.[1]

A study sponsored by the Federal Civil Defense Administration stated that a multitone signal showed promise of being effective, especially a signal with a two-tone inharmonic relationship.[2] This report, according to Oyer and Hardick, did not represent experimentation designed to yield data reflecting differential human response to auditory signal characteristics as pertaining to alerting.

In a study conducted by Solomon, he reported that:

> Twenty passive sonar recordings were ranked by fifty subjects in terms of the aurally perceived (psychological) characteristics on seven different dimensions. Correlations were run between octave band sound pressure level measurements of the sounds and their rank orders on seven psychological dimensions. Meaningful relationships were found between ranks on certain psychological dimensions and energy concentration within certain octave bands.
>
> Also, an analysis was made of the manner in which the twenty sounds clustered within the space defined by seven psychological dimensions. Analyses of

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[1]R. C. Houston and R. Y. Walker, "The Evaluation of Auditory Warning Signals for Aircraft," Air Force Technical Report No. 5762 (June, 1949) as quoted in Oyer and Hardick, op. cit., p. 13.

[2]Federal Civid Defense Administration. Final Report: op. cit., p. 19.

these sound clusters revealed that the rhythmic beat pattern of stimulus is a principal attribute upon which sonar men base their judgments of similarity.[1]

Erlick and Hunt reported that a desirable warning signal should: (1) be easily detectable; (2) hold attention; (3) be quickly and accurately identifiable; and (4) be infinitely retainable as a function of time with regard to meaning. They indicated that pure tones particularly of frequencies above 1000 cps have a tendency to interfere with operator effectiveness. They implied that research in this area should center on the evaluation of sounds already used for "attention getting" purposes. These sounds, they stated, employ the fundamental techniques used to gain perceptual attention.[2]

Studies in Alerting Potential

An area of importance to optimum warning is the alerting of the population. Studies in this area will be discussed in relation to this study to serve as a broad foundation from which this study evolved.

Kryter reported that the annoyance of noise appeared to vary in relation to (1) unexpectedness; (2) interference with auditory behavior; (3) inappropriatness; (4) intermittency; (5) reverberation; (6) loudness; (7) frequency pattern.[3] His earlier results indicated

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[1]L. N. Solomon, "Search for Physical Correlates to Psychological Dimensions of Sounds," Journal of Acoustical Society of America, 31, no. 4 (1959), p. 492.

[2]D. E. Erlick and D. P. Hunt, Evaluation of Audio Warning Displays of Weapons Systems. Wright Air Development Division, Technical Report 60-814, March, 1961, as quoted by Oyer and Hardick, op. cit., pp. 14-15.

[3]K. D. Kryter, "The Effects of Noise on Behavior: Feelings of Annoyance," Journal of Speech and Hearing Disorders, Monograph Supplement, 1950, pp. 17-18.

that annoyance was discriminable from loudness, and that higher frequency bands were more annoying than the lower frequency bands of equal loudness.[1]

> Sataloff states that annoyance was related to loudness, pitch, and modulation of pitch and/or loudness.
> Loudness--The most important single factor in determining annoyance-judgments is the intensity of the sound.
> Pitch--In general, sounds having their energy concentrated among the higher audible frequencies are more annoying than low-frequency noises.
> Modulation of Loudness and Pitch--A third important factor is the modulation which the sound undergoes. Apparently the changes in loudness are more effective than changes in pitch but the individual differences on this point are too conspicuous to permit a safe generalization.[2]

Oyer and Hardick reported that when all acoustic characteristics other than frequency are held constant. . . the optimum warning signal should be within the range of 700 cps and 4000 cps.[3]

Criterion of Observer

A final area which requires attention is that of the observe reaction. Since he is the judge of the sounds being tested, information should be discussed pertinent to variables that must be taken into account by the experimenter in relation to him.

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[1]*Ibid*.

[2]J. Sataloff, *Industrial Deafness* (New York: McGraw-Hill Book Company, Inc., p. 47.

[3]Oyer and Hardick, *op. cit*., p. 4.

In a study for the Armed Services Technical Information Agency, it was reported that:

> In order to evaluate the performance of an observer, it is necessary to consider the decision function which this observer is attempting to maximize. In the particular case where the observer is attempting to maximize the expected value of his decision concerning the presence or absence of a signal it was seen that the observer must utilize three types of information. First, he must utilize the information which occurs in the observation interval. He must consider the values and costs associated with his decisions as well as the probability of a signal occurring in the observation interval. It is not possible to interpret meaningfully data reflecting on an observer's ability to utilize information presented in an observation interval without considering these additional variables. That is to say, the responses of an observer in a psychophysical experiment must be regarded as responses of the total organism and not simply as outputs of the sensory system under study.[1]

In a more recent study, Egan and Clarke emphasize that the decision of an observer may depend on (a) the information content of the stimulus (b) the information available to the observer before the presentation of the stimulus, (c) the properties of the sensory analyzer and (d) motivation variables as they relate to the consequences of each decision.[2]

> Tanner states that psychoacoustician may be interested in studying the auditory equipment of observers in listening to acoustic signals. He may find that analyses he wishes to perform can best be carried out if he uses signals and noises which are atypical to those of everyday environments. This may permit greater agreement between the

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[1] W. P. Tanner, T. G. Birdsall, and F. R. Clarke, "The Concept of the Ideal Observer in Psychophysics," AD239022 Contract No. AF 19 (604)-2277, (April, 1960), p. 39.

[2] J. P. Egan and F. R. Clarke, "Psychophysics and Signal Detection," AD-291450. Washington, D. C.: Ofice Technical Service, Department of Communication (1963) as quoted in <u>dsh abstracts</u> (Vol. III no. 3, July, 1963), p. 205.

> physical conditions of the experiment and the assumptions made to permit conputations. The fact that the physical conditions are atypical with regard to everyday environments does not necessarily degrade the quality or the usefulness of the answers to the questions he is asking.[1]

It may be seen through this review of the literature that there has not been a great deal of work done in the field of an optimum warning signal. This writer substantiates Oyer and Hardick in their statement concerning literature in this vital area. Samples of sounds have been small and in most studies results have been generalized from the laboratory to outside situations. The literature review pointed up the need for a study focused on evaluation of many auditory signals as related to alerting, with relevant judgments made of their effectiveness by groups of subjects representing the population.[2]

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[1]W. P. Tanner, Jr. "The Theory of Signal Detectability as an Interpretive Tool for Psychophysical Data," AD239022 Contract No. AF 19(604)-2277, (May, 1960), p. 8.

[2]Oyer and Hardick, <u>op. cit</u>., p. 17.

CHAPTER III

SUBJECTS, EQUIPMENT, AND TESTING PROCEDURES

Subjects

The twenty-four subjects (14 male and 10 female) who participated in this study were all students at Michigan State University. They ranged from undergraduates to PhD candidates and were between the ages of twenty-two and thirty-four. All subjects were screened before they participated in the experiment and were found to have binaural hearing within normal limits. Normal hearing subjects were defined as having binaural thresholds of 15 dB or better at 500 cps, 1000 cps, 2000 cps, and 4000 cps.[1]

Equipment

Forty-four complex tones (lowest frequency and at least one harmonically related tone half an octave above the lowest tone and not over 4000 cps) were recorded twice on a tape in random order. The equipment at the Michigan State University Speech and Hearing Science Laboratory was utilized both for recording of the sounds

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[1] H. Davis and R. Silverman, Hearing and Deafness (New York: Holt, Rinehart, and Winston, Inc. 1960), p. 245.

and for carrying out the experiment. Twelve chairs, each equipped with a set of earphones, were used for both sessions of the experiment.

The arrangement of equipment for recording is pictured in Figure 1. The equipment used included three audio oscillators (Hewlett-Packard Model 2026, Hewlett-Packard Model 200A, and B and W Model 200); two tape recorders (Ampex Model 601-2, and Ampex Model 601); a mixer (Ampex Model 35); two reels of tape (3m number 111); level recorder (Bruel and Kjaer Model 2305); a spectrometer (Bruel and Kjaer Model 2112); voltmeter (Bruel and Kjaer Model 2409); 6cc coupler (artificial ear, Bruel and Kjaer Model 2203). The electronics technician employed by the Michigan State University Speech Department aided with equipment procedures and supervised the use of equipment during the experiment.

Procedure

In order to record the complex sounds needed for this experiment three audio oscillators, each set at a different half octave interval in relation to the lowest frequency were employed. If only two frequencies were needed for the complex sound, only two audio oscillators were used. If four or five frequencies made up the complex sound all three audio oscillators were used. The lowest frequency and the next two half octave frequencies were fed

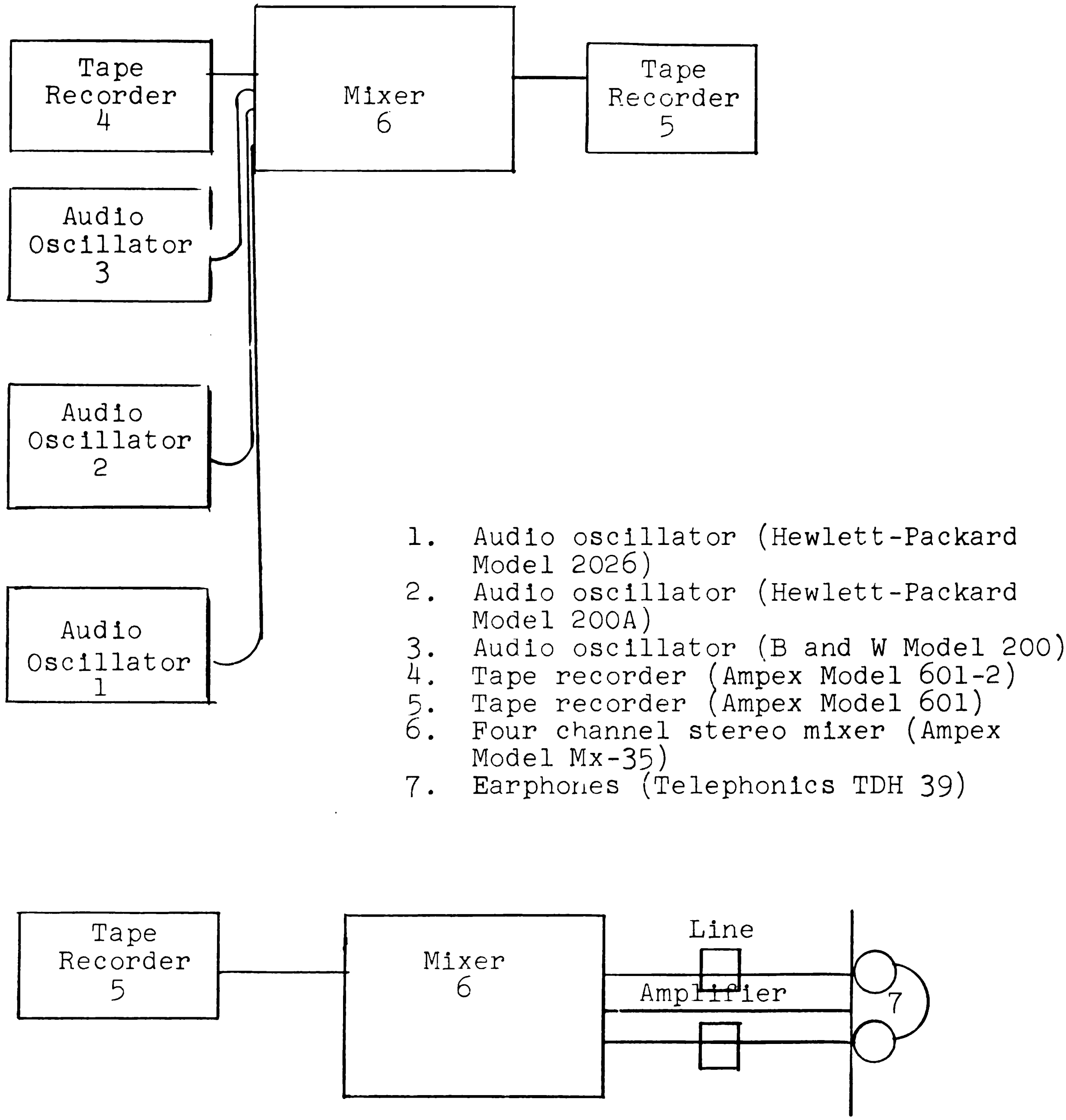

Figure 1.--Block diagram of instrumentation utilized for recording audio signals on magnetic tape.

into the mixer and recorded on one of the tape recorders. The complex sound was about ten seconds in length to allow some flexibility in playback. This tape recorder was played with the first three frequencies recorded on the tape as the final frequency or two frequencies were put into the mixer from two audio oscillators. This combination yielded the four or five frequency sound which was required. The complex sound was then recorded on the second tape recorder for five seconds. Ten seconds of silence between each sound was allowed in order that the subjects have time to make their judgments. The timing for the five second sound and the ten second interval was measured by a stop watch. A booklet of eighty-eight response sheets was given to each subject. Each page represented the ratings across nine scales along a five point continuum for a specific sound. Pencils were also provided.

The complex sounds were recorded in the random order in which they were presented to the subjects. In order to keep the subjects from losing their place, since they were to listen to eighty-eight sounds, each sound was cued by number just before it was heard.

In order to obtain an output of approximately equal intensity from the twelve sets of earphones of 70 dB (re: .0002 dyne/cm^2) at all of the testing frequencies, and adjustment in the input of the intensities of frequencies into the mixer was necessary in order to fit the frequency curve of the earphones. To do this, eight earphones (four pairs) were randomly selected from the twelve pairs used in the experiment. Each receiver was evaluated using an artificial ear, voltmeter, spectrometer, and level recorder. The intensity was plotted from the 6cc coupler on a graph level recorder for the frequencies 500 cps, 1000 cps, 2000 cps, 3000 cps, and 4000 cps. These figures were averaged for each frequency and plotted on a graph on semilogarithmic graph paper. Other intensities were then interpolated from the curve of best fit.

The intensity of each frequency to be measured was analyzed using 90 dB of white noise. The results of four randomly selected pairs of earphones are shown in Table 1.

Table 1

INTENSITY CURVE OF FOUR RANDOMLY SELECTED PAIRS OF EARPHONES AT 500 CPS, 1000 CPS, 2000 CPS 3000 CPS AND 4000 CPS

Earphone Set		500	1000	2000	3000	4000
Pair 1	phone 1	88 dB	93 dB	93	95	99
	Phone 2	87	90	93	99	99
Pair 2	phone 1	88	92	94	100	99
	phone 2	88	94	93	96	98
Pair 3	phone 1	87	90	95	99	96
	phone 2	86	91	94	99	96
Pair 4	phone 1	85	89	86	88	102
	phone 2	87	90	89	95	100
Total		698	729	737	771	789
Average		87	91	92	96	99

Reference Point 90 dB SPL.

The graph in Figure 2 illustrates the curve of best fit.

To state this curve in terms of actual changes of intensity of the above frequencies, the reference point on the curve of best fit was set arbitrarily at 1000 cps and all other frequencies were corrected in terms of intensity to this reference point.

During the experiment the sounds were presented through earphones to the subjects for a period of five seconds per sound with ten seconds between sounds. Each sound was heard twice during the experiment, for a total of eighty-eight sounds. The subjects were asked to rate the eighty-eight sounds in terms of nine characteristics along a five point continuum. Each sound was numbered and analyzed by the scale shown in Table 2. The results were interpreted for an alerting signal in terms of rating of pitch and complexity of tones.

The subjects were given a copy of the directions so that they could follow them as they were read orally by the experimenter before the experiment began. The experiment lasted forty minutes including one five minute break after sound 44, half way through the test.

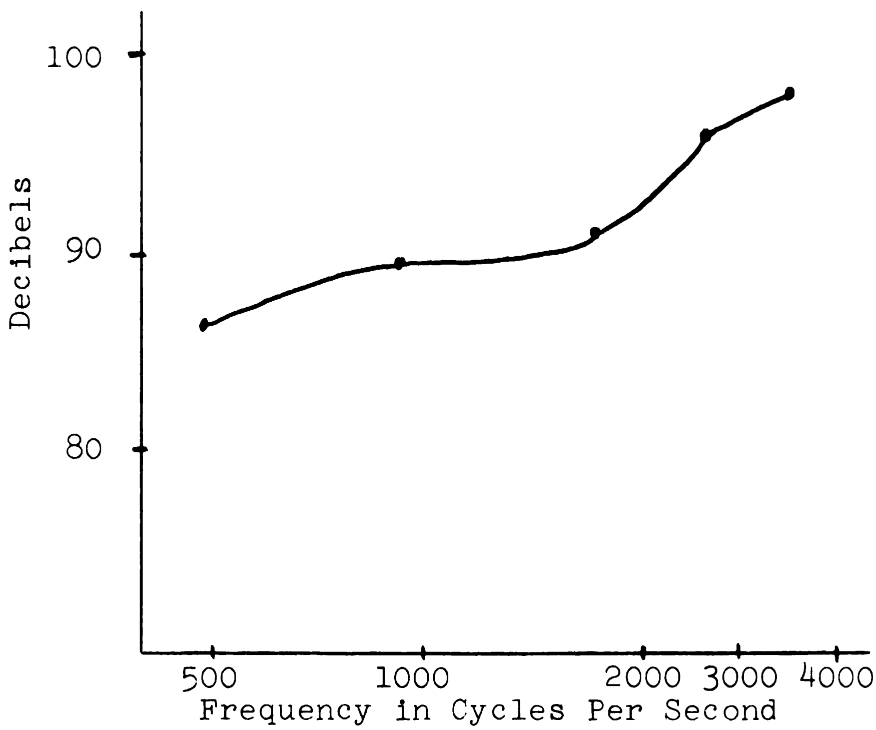

Figure 2.--Curve of best fit for four pairs of ear-phones. The horizontal line represents intensity expressed in decibels. The vertical line represents frequency expressed in cycles per second.

Table 2.--Format of response sheet utilized to determine relevant dimensions for rating alerting characteristics of audio signals.[31]

Does this sound have UNPLEASANT___:___:___:___:___: PLEASANT characteristics

Does this sound have ALARMING___:___:___:___:___: SOOTHING characteristics

Does this sound have INSISTENT___:___:___:___:___: IGNORABLE characteristics

Does this sound have ALERTING___:___:___:___:___: NONALERTING characteristics

Does this sound have WARNING___:___:___:___:___: NONWARNING characteristics

Does this sound have ANNOYING___:___:___:___:___: NONANNOYING characteristics

Does this sound have STARTLING___:___:___:___:___: NONSTARTLING characteristics

Does this sound have URGENT___:___:___:___:___: CASUAL characteristics

Does this sound have BIZARRE___:___:___:___:___: ORDINARY characteristics

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[31]Oyer and Hardick, op. cit., p. 24.

CHAPTER IV

RESULTS AND ANALYSIS

Introduction

As indicated in Chapter I, a significant difference in subjects rating of the alerting potential of the lowest frequency and tone complexity would seem to indicate two characteristics that are important in determining an optimum warning system. This study was concerned with determining whether or not a difference exists in terms of change in frequency and change in complexity. The following statistical procedures were therefore employed to determine the significance of the differences and the reliability of the subject ratings of those who participated in this experiment. Both of the null hypotheses listed in Chapter I were tested to determine whether or not they should be rejected.

Analyses

In order to analyze the results of this experiment each of the five spaces along the continuum was assigned a number. These were numbered from left to right. This would mean that those sounds which achieved low scores by subject judgment would be considered to have characteristics which would lend them to be acceptable for a warning system.

Those sounds which were rated high by subject judgment were rejected as sounds for an alerting signal.

Since each sound was heard by the subjects twice, a reliability estimate could be obtained by averaging the score over the nine characteristics for each sound the first time it was heard by the twenty-four subjects and comparing it with the average score the second time each subject heard it. Because this study was basically dealing with the characteristics of an alerting signal, it was decided to check the reliability of only the ten sounds that had the lowest scores (most acceptable for an alerting signal) and only the ten highest scores (least acceptable for an alerting signal) as representative of the overall reliability.

To determine the reliability the Pearson Product-Moment correlation was employed. It measured, in this case, strength of relationship of the nine characteristics of a sound heard two different times during the experiment. This correlation measures the amount of spread about the linear least-squares equation. The explanation and the formula was taken directly from Blalock's book, Social Statistics.[1]

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[1]Hubert M. Blalock, Social Statistics (New York: McGraw-Hill Book Company, Inc., 1960), p. 286.

Reliability had a wide range in this study. It ranged from -.0005 to .83 with an average reliability of .53. One reason for the low reliability may have been that only ten seconds were allowed between sounds to judge the sound on nine scales. A second reason may have been that there were no practice sounds given to the subjects. As a result the subjects may not have been able to analyze the first sounds because they lacked internal criteria in comparing the sound to another sound. It is felt, however, that within the range of reliability certain conclusions may be reached.

The first hypothesis subjected to a statistical analysis was: no statistically significant differences exist between the means of subjects rating of the alerting potential of harmonic tones of two, three, four, and five components, as measured on a nine point scale along a five point continuum. To do this a one way analysis of variance was utilized as disucssed in Blalock's book, Social Statistics.[1] From this analysis, Table 3 evolved.

Required at the .01 level of significance for 3 and 92 degrees of freedom (df) is 4.04. Since 86.65 is larger than 4.04, the null hypothesis is rejected.

This analysis is graphically represented in Figure 3.

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[1] Ibid., p. 250.

TABLE 3

COMPUTATIONS FOR ANALYSIS OF VARIANCE OF TONE COMPLEXITY

	Sums of Squares	Degrees of Freedom	Estimate of Variance	F*
Total	59.78	N-1=95		
Between	44.18	k-1= 3	14.73	86.65
Within	15.60	N-k=92	.17	

*4.04 F is significant.

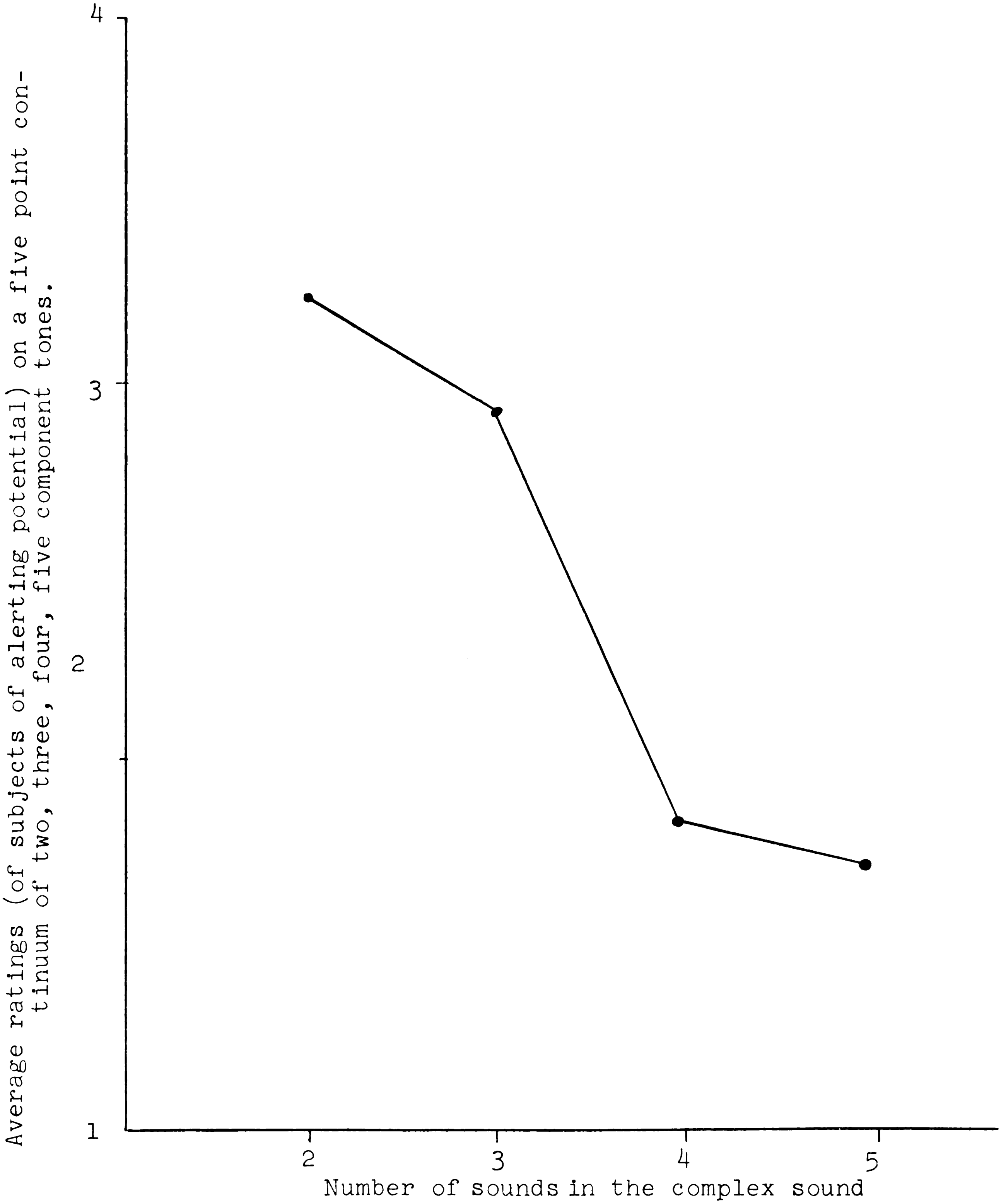

Figure 3.--The average of (subjects rating of alerting potential) two, three, four, and five component sounds across twenty-four subjects.

Although an analysis of variance shows there is a statistically significant difference, it does not indicate where the difference or differences are. Therefore, a *t*-test was utilized to note where the significant differences occurred in terms of sound complexity. The formula for the *t*-test was taken directly from Lindquist's book, *Design and Analysis of Experiments in Psychology and Education*.[1]

In order to use this formula discussed by Lindquist, an average of subjects rating of the alerting potential of two component sounds across all twenty-four subjects was made. The same procedure was followed for all three component sounds, all four component sounds and all five component sounds. The value for *t* was found in the *t*-table for 92 degrees of freedom at the .01 level of significance for a two-tailed test. This value (d) was then compared with the differences between the averages of the columns. If the difference was greater than the d value it was concluded that there was a significant difference. Table 4 shows a comparison between complex tones. Two, three, and four component sounds are listed horizontally and are compared with three, four, and five component sounds listed across the top. Significant differences are shown in all cases except for between the complex

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[1]E. F. Lindquist, *Design and Analysis of Experiments in Psychology and Education* (Boston: Houghton Mifflin Co., 1956), p. 93.

TABLE 4

COMPARISONS OF MEANS OF SOUND COMPLEXITIES
MEASURED BY SUBJECT JUDGMENT

Number of Components	Number of Components		
	3	4	5
2	.36	1.42	1.60
3		1.06	1.24
			.18

d = .31

sounds of four and five component sounds. Graphically the downward trend can still be noted, but it has leveled off to a great extent.

The second hypothesis tested was: there are no statistically significant differences between the means of subjects rating of the alerting potential of different frequencies of harmonic sounds as measured on a nine point scale along a five point continuum. The same design for one way analysis of variance was utilized.[1] The resulting data are summarized in Table 5, and graphically represented in Figure 4.

TABLE 5

COMPUTATION FOR ANALYSIS OF VARIANCE OF LOWEST FREQUENCY COMPONENT

	Sums of Squares	Degrees of Freedom	Estimate of Variance	F*
Total	187.08	N-1 = 455		
Between	30.71	k-1 = 18	1.71	4.78
Within	156.37	N-k = 437	.358	

*1.99 is significant.

Required at the .01 level of significance for 18 and 455 degrees of freedom (df) is 1.99. Since the F value of 4.78 is greater than 1.99, the null hypothesis is rejected.

[1]Blalock, op. cit., p. 250.

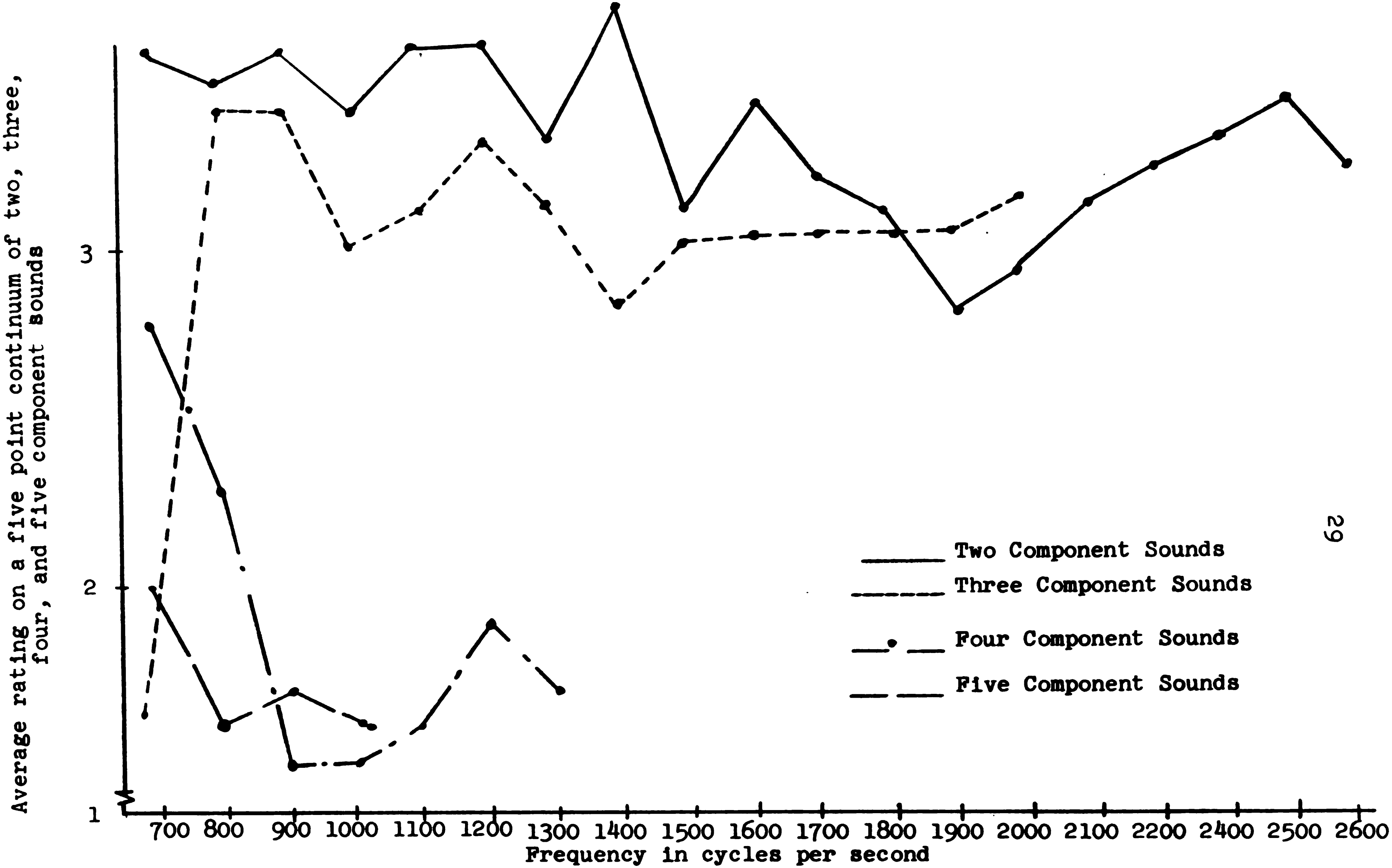

Figure 4.--Two, three, four, five component sounds (of subjects rating of the alerting poten- averaged across twenty-four subjects, on a five point continuum.

Since the one way analysis of variance did not show where the difference or differences occur, the *t*-test was again utilized. Table 6 indicates the total results. Some significant differences occur throughout the table but seem to follow no logical pattern except between the frequencies of 1800 cps and 2200 cps, where they seem significantly different with other frequencies, but not among themselves.

Discussion of Results

The statistical analyses performed indicate that the first hypothesis could be rejected. The *t*-scores computed to test the mean differences for the four different complexities, showed that the greater the complexity of the sound, the better it seemed to be for an alerting signal. Although there was no significant difference between complex sounds made up of four or five components, a noticeable trend can be noted for the more complex sounds to be judged by the subjects as having greater alerting potential.

The statistical analysis for the second hypothesis indicates that it too may be rejected. A particular range of frequencies was shown by the *t*-test of subjects rating of alerting potential to be significantly more alerting than those above or below the range. The significant range was found to be 1800 cps to 2200 cps. It would appear on

Table 6.--Differences between all pairs of means computed for two component sounds.

Frequency of Lowest Component in Cycles per Second	Frequency of Lowest Component in Cycles per Second[a]																	
	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2400	2500	2600
700	.08	.24	.24	.00	.02	.30	.07	.44	.18	.39	.47	.82	.20	.54	.44	.25	.17	.40
800		.12	.16	.08	.10	.22	.15	.36	.09	.31	.39	.74	.72	.46	.36	.17	.09	.32
900			.28	.04	.02	.34	.03	.48	.21	.43	.51	.81	.79	.58	.48	.29	.21	.44
1000				.24	.26	.06	.31	.20	.17	.15	.23	.58	.56	.20	.20	.01	.07	.16
1100					.02	.30	.07	.44	.18	.39	.47	.82	.80	.54	.44	.25	.17	.40
1200						.32	.05	.46	.19	.41	.49	.84	.82	.56	.46	.27	.19	.41
1300							.37	.14	.13	.09	.17	.52	.50	.24	.14	.05	.13	.10
1400								.51	.24	.46	.54	.89	.87	.61	.51	.32	.24	.47
1500									.27	.05	.03	.28	.36	.10	.00	.19	.27	.04
1600										.22	.30	.65	.63	.37	.27	.08	.00	.23
1700											.08	.43	.41	.15	.05	.14	.22	.01
1800												.35	.33	.07	.03	.22	.30	.07
1900													.02	.28	.38	.51	.65	.42
2000														.26	.36	.45	.63	.40
2100															.10	.29	.37	.14
2200																.19	.27	.04
2400																	.08	.15
2500																		.23
2600																		

[a]Any d value exceeding .45 is significant at the .01 level.

the basis of these results that alerting signals as judged by subjects rating of alerting potential should have their lowest frequency within this band.

Discussion

The findings based on the two hypotheses seem to conflict somewhat. The findings of the first hypothesis demonstrates that the greater the complexity of A sound, as judged by subjects rating on the alerting potential, the better the sound is for use as an alerting signal. The complex sounds, particularly those of four and five components, however, have their lowest frequency well below the level of between 1800 cps and 2200 cps. The question arises then, as to what accounts for the fact that four and five component sounds were judged to be better as alerting signals than two and three component sounds with lowest frequencies within the optimum range band? Although it was not possible within the framework of this design to determine the variable or variables involved in answering this question two possible reasons will be discussed.

The first reason why the most complex sounds might have been rated better for alerting signals is that a four or five component tone may override the fact that 1800 cps to 2200 cps was considered the optimum range. All complex sounds that had as their lowest frequency 1800 cps to 2200 cps were either made up of two or three components because of the frequency limit of 4000 cps. It may be discovered that if complexity was held constant, the range of 1800 to 2200 cps may have continued to show up as the optimum frequency range.

The second reason why four or five component sounds may have been judged to be better for an alerting signal is that as the complex sounds were made up of more than three components, the optimum range of the lowest frequencies is shifted downward. This would account for subjects judging four and five component sounds as best for an alerting system since all four and five component sounds had low frequency tones as their starting point. Those sounds made up of four and five components had 700 cps, 800 cps, 900 cps, 1000 cps, 1100 cps, 1200 cps, and 1300 cps as their lowest component. Further study is indicated in this area.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Because the area of optimum warning is so vast, it must be studied in terms of specific isolated characteristics in order that these characteristics may be studied in detail. A survey of the literature shows that work has been done in the areas of signal detection and optimum frequencies developed to attract attention in spite of noise. Very little research, however, in the area of optimum warning signals has been published.

In this study, two specific characteristics were studied in isolation, complexity of tones, and frequency of tones in subjects rating of the alerting potential as functions of an optimum warning system. If it were possible to show that a significant difference existed in either or both of the characteristics it would be possible to state more specifically two areas that could be controlled appropriately for an optimum warning system.

Twenty-four subjects judged forty-four different sounds which contained the two variables of this study, frequency of the sounds and the complexity of the sounds. The subjects were asked to judge these sounds on a nine point scale along a five point continuum. Each sound was heard twoice (total of eighty-eight sounds) in a random order for five seconds with a ten second interval to allow the subjects to rate the sounds. The data were then subjected to analysis. A one way analysis of variance was used for each variable to determine if the results of this study were significant. A series of *t*-tests were run to determine where the significant difference between means of subjects rating of the alerting potential of sounds occurred.

Two reasons discussed for the low reliability in this study were: not enough time to rate the nine scales accurately and some practice sounds might have helped the subjects establish a reference point for rating before the actual test began.

Conclusions

The results of this study indicated that significant differences exist in subjects rating of the alerting potential between complexities of sounds for alerting signals. It demonstrated, within the limits of this study, that the more complex the tone, the more useful it appeared to be as an alerting signal. It also demonstrated that a frequency range for the lowest component of between 1800 cps and 2200 cps in subjects rating of the alerting potential seemed to be an optimum alerting range of frequencies.

Areas for Further Study

This study suggests areas of further research. Such characteristics as longer length of time between sounds, actually hearing the sounds while deciding on their characteristics, and varying intensity are all vital studies which could add considerable knowledge to this field.

Perhaps the most interesting points for further study are the somewhat contradictory results of this study since the frequency range that seemed significant as the lowest component frequency was well above the lowest component frequency of the complex sounds which were judged as the optimum sounds for an alerting signal. Such a study would compare sounds of equal complexities within the frequency range found in this study with the lowest component of sounds above and below this range to note if any significant differences appeared.

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APPENDICES

APPENDIX A

DIRECTIONS TO SUBJECTS

You are going to hear some sounds. You will be asked to rate each sound on its own separate sheet, according to the scale found on the sheet. Each sound is numbered at the top of the page and is introduced by a voice stating the number of the sound. For example, before sound one a voice will state "sound one." There are a total of eighty-eight sounds to be rated. Each sound will be five seconds long followed by ten seconds of silence. During the silent period you will be asked to rate each sound on the accompanying scales.

As you listen to a specific sound you should come to some decision as to the degree of the characteristics listed the sound has for you. Make your judgments of degree on the following basis:

1. If you feel the sound is extremely related to the characteristics listed, place your check at an extreme end. If you feel, for example, that a sound is very unpleasant place a mark at the box nearest the word unpleasant.
2. If you feel the sound is moderately related to one or the other end of the scale, but not extremely related, you should place your check just to the side of the middle space.

3. If you consider the sound neutral on the scale, then you should place a check in the middle space.

Place a check in the middle of the space, not on the boundaries.

Be sure you check every scale for every sound-do not omit any.

APPENDIX B

LIST OF INDIVIDUAL TONES COMPRISING THE FORTY-FOUR COMPLEX SOUNDS

Sound Number	Sound Components in cycles per second
1	700, 1050
2	800, 1200
3	900, 1300
4	1000, 1500
5	1100, 1650
6	1200, 1800
7	1300, 1950
8	1400, 2100
9	1500, 2250
10	1600, 2400
11	1700, 2550
12	1800, 2700
13	1900, 2850
14	2000, 3000
15	2100, 3150
16	2200, 3300
17	2400, 3600
18	2500, 3750
19	2600, 3900
20	700, 1050, 1400
21	800, 1200, 1600
22	900, 1350, 1800
23	1000, 1500, 2000
24	1100, 1650, 2200
25	1200, 1800, 2400
26	1300, 1950, 2600
27	1400, 2100, 2800
28	1500, 2250, 3000
29	1600, 2400, 3200
30	1700, 2550, 3400
31	1800, 2700, 3600
32	1900, 2850, 3800
33	2000, 3000, 4000
34	700, 1050, 1400, 2100
35	800, 1200, 1600, 2400
36	900, 1350, 1800, 2700

LIST OF INDIVIDUAL TONES COMPRISING THE FORTY-
FOUR COMPLEX SOUNDS--Continued

Sound Number	Sound Components in cycles per second				
37	1000,	1500,	2000,	3000	
38	1100,	1650,	2200,	3300	
39	1200,	1800,	2400,	3600	
40	1300,	1950,	2600,	3900	
41	700,	1050,	1400,	2100,	2800
42	800,	1200,	1600,	2400,	3600
43	900,	1350,	1800,	2700,	3600
44	1000,	1500,	2000,	3000,	4000

APPENDIX C

Raw Data, average over eighteen scales for each sound by subject.

Subjects	Sound Number 1	2	3	4	5	6	7	8	9	10	11	12
1	4.22	4.00	3.94	3.83	3.33	3.83	4.10	4.11	3.77	3.88	3.60	3.26
2	3.44	3.11	3.16	2.55	3.32	2.16	3.10	3.40	2.94	2.00	3.44	3.66
3	3.10	2.94	3.22	3.72	3.00	3.66	3.38	3.44	2.88	2.94	2.99	2.94
4	3.94	4.44	4.49	4.41	3.77	3.55	2.33	3.84	2.99	3.22	2.49	3.10
5	2.44	3.11	2.11	2.83	2.44	2.60	2.71	2.11	2.10	1.94	2.44	2.05
6	4.00	2.77	4.88	3.32	4.16	3.99	3.49	4.66	3.14	3.44	3.77	3.33
7	3.10	3.77	3.55	4.10	4.33	4.11	3.33	3.69	3.29	4.22	2.54	2.88
8	4.38	4.94	4.66	3.94	4.33	4.38	4.21	4.00	3.55	3.71	2.88	3.10
9	3.77	3.44	3.83	3.22	4.11	3.33	3.22	3.10	2.55	3.38	3.33	2.10
10	3.16	2.46	3.68	3.00	5.00	4.44	2.88	3.72	4.00	3.38	3.50	2.94
11	4.38	3.94	4.22	3.94	3.94	4.33	3.27	4.60	3.16	4.05	3.11	2.94
12	3.38	3.33	3.55	3.33	3.55	3.60	3.60	3.71	3.38	3.60	3.77	3.60
13	4.27	3.83	4.60	3.77	4.32	4.05	4.38	4.82	3.10	4.05	3.05	2.33
14	3.16	3.60	3.22	3.27	3.66	3.66	3.16	3.10	3.10	3.27	2.94	3.49
15	2.56	3.32	2.50	2.94	2.94	2.50	3.00	3.05	2.50	3.55	3.21	3.05
16	3.05	2.94	2.77	2.88	3.00	3.22	2.94	2.88	2.72	3.0	2.88	2.84
17	3.88	4.95	4.06	2.94	4.27	3.38	3.71	4.27	4.10	4.27	3.71	3.61
18	3.00	2.94	3.00	3.00	2.94	3.00	2.94	3.00	2.94	3.00	2.94	3.00
19	3.27	3.55	3.88	3.60	4.38	4.11	3.05	4.10	3.49	4.38	3.44	3.66
20	4.71	4.32	4.22	4.50	4.05	4.60	3.88	4.60	3.83	4.38	4.77	3.55
21	3.50	3.50	3.27	3.00	3.00	3.60	3.50	3.00	2.94	3.00	3.00	2.77
22	3.05	2.71	3.11	2.44	2.88	2.77	1.94	2.77	2.33	2.88	2.40	1.99
23	4.66	4.38	4.50	4.47	4.00	5.00	4.10	4.33	4.16	4.16	4.55	4.55
24	3.05	3.16	3.00	3.61	3.38	3.11	3.44	4.05	3.05	3.05	2.88	3.44

Raw Data, average over eighteen scales for each sound by subject--<u>Continued</u>.

Subjects	Sound Number											
	13	14	15	16	17	18	19	20	21	22	23	24
1	2.77	2.77	2.82	2.99	3.49	3.43	2.66	1.16	3.94	3.10	3.55	1.66
2	3.27	3.77	3.77	3.77	3.77	3.55	3.49	2.00	2.44	2.61	2.22	2.00
3	3.05	2.72	2.77	3.05	3.27	3.44	2.98	2.33	2.88	3.21	2.66	2.66
4	2.33	2.60	3.22	2.88	2.36	4.05	3.49	1.77	3.77	3.55	2.44	1.99
5	1.83	2.38	1.88	1.99	2.33	2.11	1.99	1.27	2.33	2.55	2.33	2.44
6	3.10	2.66	2.66	2.66	3.33	2.99	2.93	1.33	4.38	4.00	3.94	3.66
7	2.88	2.22	3.99	2.99	3.66	3.77	3.93	1.94	2.44	4.21	2.88	4.77
8	3.33	2.77	3.49	3.44	3.93	3.21	3.32	1.00	4.38	4.38	3.77	4.00
9	2.44	2.71	3.44	2.66	3.49	3.55	2.99	2.55	3.33	3.33	.255	2.33
10	3.44	4.16	3.66	3.50	3.88	4.00	3.72	1.05	3.50	2.88	2.10	4.00
11	2.16	2.72	2.55	3.83	3.10	3.83	2.77	1.66	4.00	4.00	3.33	3.55
12	2.55	3.33	3.49	3.82	3.49	3.60	3.60	2.77	3.55	3.55	3.05	3.33
13	2.21	2.44	2.49	3.32	2.66	3.60	2.71	2.44	4.38	4.33	2.33	4.33
14	2.49	2.77	2.88	3.33	3.27	2.88	1.86	2.54	3.44	2.99	2.60	3.00
15	2.55	3.00	2.94	2.00	2.88	2.50	3.50	2.11	3.00	2.22	2.22	3.00
16	2.49	3.00	2.88	2.93	2.88	2.77	3.05	2.22	2.77	2.99	3.05	2.88
17	2.82	3.27	2.99	4.33	4.55	4.82	4.21	1.00	2.83	3.00	2.16	3.22
18	2.88	2.88	2.94	3.00	2.94	2.93	3.00	2.44	3.00	3.00	3.00	2.88
19	2.88	2.84	3.29	3.10	3.99	4.10	3.88	1.44	3.10	4.27	3.66	3.55
20	3.94	3.49	4.05	4.05	3.77	4.38	4.16	2.10	4.44	4.27	2.83	2.88
21	2.94	2.50	3.00	3.00	3.27	2.00	2.77	1.55	3.71	3.44	3.88	3.00
22	2.43	1.33	2.44	2.22	2.66	2.94	2.66	1.27	2.88	2.72	2.58	2.77
23	3.55	3.88	2.99	4.00	3.61	4.50	3.94	1.55	3.94	3.58	2.83	3.66
24	3.05	2.77	3.04	3.33	2.71	3.33	3.50	2.05	3.05	2.72	3.87	3.33

Raw Data, average over eighteen scales for each sound by subject--Continued.

Subjects	Sound Number											
	25	26	27	28	29	30	31	32	33	34	35	36
1	2.55	3.66	2.55	2.77	2.71	2.88	2.55	3.71	3.27	3.05	2.66	1.22
2	2.00	2.00	2.05	2.05	3.50	2.83	3.32	3.00	2.83	2.00	1.61	1.50
3	2.94	2.49	2.16	2.61	2.66	2.77	2.55	2.55	2.71	2.66	1.88	1.88
4	2.21	2.77	2.77	2.88	2.71	2.55	2.66	2.77	3.05	2.70	2.11	1.27
5	1.94	1.77	2.10	1.94	2.49	1.77	1.99	1.77	1.79	2.55	1.66	1.00
6	3.50	3.16	2.88	2.88	2.83	3.27	2.60	3.33	2.16	2.49	3.05	2.00
7	3.99	4.21	4.33	3.77	2.88	3.11	3.44	3.66	3.88	3.60	1.77	1.22
8	2.94	3.00	3.11	2.44	2.86	2.94	3.40	2.77	2.88	2.99	2.38	1.00
9	2.71	3.00	2.60	3.26	2.88	3.10	3.10	3.11	2.33	2.21	2.66	1.94
10	2.50	2.88	2.0	3.10	3.44	3.70	3.33	3.10	3.27	2.38	1.50	1.00
11	3.44	3.10	3.22	3.05	3.44	2.83	2.49	2.88	3.44	3.10	2.77	2.15
12	3.60	3.55	3.44	4.10	3.21	3.60	3.55	3.60	3.60	3.33	3.33	2.44
13	3.77	3.10	2.32	3.32	2.22	2.55	1.49	2.38	2.94	2.16	3.44	1.16
14	3.44	3.38	2.66	2.27	2.83	2.94	2.55	2.88	2.60	2.38	2.88	1.33
15	2.22	2.50	2.52	2.61	2.94	2.16	3.00	2.00	3.50	3.27	1.77	1.44
16	2.50	3.11	2.27	2.66	3.00	3.00	3.00	3.00	3.05	2.33	2.66	2.00
17	3.44	3.33	3.16	3.72	3.83	4.16	3.21	3.38	3.72	3.72	1.66	1.00
18	3.00	3.00	2.94	3.00	3.00	3.00	3.00	3.00	3.00	2.66	2.66	2.44
19	3.66	3.33	3.88	3.60	3.60	2.55	3.49	3.05	3.99	2.70	2.66	1.77
20	3.60	4.15	3.99	3.55	3.38	4.33	4.00	4.22	3.66	3.50	1.92	1.33
21	3.33	3.66	2.55	2.77	2.50	2.50	3.00	3.27	2.50	2.16	1.50	1.50
22	1.66	2.33	2.77	2.55	1.77	2.33	2.05	2.33	2.55	2.88	1.83	1.16
23	3.94	3.50	3.00	4.27	2.88	3.11	3.72	3.40	3.66	2.60	2.44	1.00
24	3.22	2.71	2.71	2.72	3.55	2.82	3.16	2.60	2.71	2.94	2.72	1.99

Raw Data, average over eighteen scales for each sound by subject--Continued.

Subjects	Sound Number							
	37	38	39	40	41	42	43	44
1	1.27	1 11	1.66	1.71	1.38	1.05	1.44	1.00
2	1.50	2.00	2.00	1.50	1.44	2.00	1.50	1.94
3	1.33	1.93	1.72	1.33	1.83	1.00	1.66	2.05
4	1.11	1.22	1.27	1.11	1.11	1.38	1.27	1.11
5	1.11	1.00	1.22	1.00	1.27	1.11	1.49	1.05
6	1.55	1.00	1.77	2.00	2.32	1.27	2.00	1.50
7	1.77	1.22	1.99	1.00	2.10	1.11	1.55	1.44
8	1.00	1.00	1.44	1.00	2.32	1.00	1.00	1.00
9	2.11	2.05	2.27	2.22	2.49	1.83	3.10	1.99
10	1.00	2.00	1.40	1.38	2.00	1.50	1.50	1.00
11	1.49	1.88	1.71	1.49	2.59	2.10	2.11	2.21
12	2.33	2.55	2.88	2.60	2.55	2.44	3.10	2.33
13	1.72	1.55	2.22	2.21	1.94	1.94	1.38	1.33
14	2.05	1.88	1.71	2.27	1.44	2.05	1.94	1.72
15	1.88	2.05	2.16	1.50	1.50	1.00	1.00	2.05
16	2.05	2.22	2.00	2.66	2.33	2.11	2.05	2.22
17	1.00	1.00	2.72	1.61	1.77	1.50	1.22	1.05
18	2.44	2.44	3.33	2.44	2.71	3.55	2.44	2.72
19	1.60	1.50	2.16	1.49	2.27	1.27	1.44	1.77
20	1.49	1.38	1.83	1.38	1.83	1.05	1.55	1.38
21	1.00	1.00	1.77	1.11	1.50	1.00	2.00	1.50
22	1.22	1.11	1.22	1.11	1.83	1.11	1.22	1.22
23	1.00	1.00	1.55	1.77	1.77	1.00	1.50	1.50
24	1.71	2.22	2.49	2.22	2.27	1.94	2.38	2.15