AN INVESTIGATION OF INTELLIGIBILITY OF SPEECH AS A FUNCTION OF BANDWIDTH AND INTENSITY

Thesis for the Degree of M. A.

MICHIGAN STATE UNIVERSITY

Lowell J. Sahlstrom

1964

~~NOV 25 1974~~ 1526

ABSTRACT

AN INVESTIGATION OF INTELLIGIBILITY OF SPEECH AS A FUNCTION OF BANDWIDTH AND INTENSITY

by Lowell J. Sahlstrom

This study investigated the effects of band-pass filtering and intensity variation upon the intelligibility of speech. Two bandwidths were employed: the first was 480 cps wide from 1320 cps to 1800 cps; the second bandwidth was 960 cps wide from 1080 cps to 2040 cps. Both bandwidths were centered at 1560 cps.

Twenty-four normal hearing adults served as subjects in this study. The subjects were divided into two groups of twelve, each of which listened to the test material under one of the bandwidth conditions. Both groups of subjects listened to the stimulus at average intensity levels of 35 dB, 50 dB, and 70 dB sound pressure level. Each group listened to a practice list at 90 dB SPL before hearing the experimental stimuli.

The test material utilized in this investigation were lists of one-syllable words. These lists were recorded on magnetic tape from the commercial discs of the CID W-22 word lists (lists 1E, 2E, 3E, and 4E). Listener's responses were recorded on prepared answer sheets.

A two way analysis of variance was performed to test for significant differences between the variables (intensity and width of bandpass) involved in this study. The results of the analysis indicated that there was no significant difference in intelligibility scores between a 480 cps bandwidth condition and a 960 cps bandwidth condition, both of which were centered at 1560 cps. The data obtained showed that there was a significant difference in intelligibility scores due to increase in intensity level. It was also found that there was no significant interaction between bandwidth and intensity level.

On the basis of this study, the following conclusions were made:

1. Doubling the size of a 480 cps bandwidth centered around 1560 cps, does not significantly improve intelligibility.

2. An increase in average intensity level was found to produce an increase in percent correct recognition of one syllable words.

3. Bandpass filtering does impair speech intelligibility so that correct responses do not reach one-hundred percent correct, even at high intensity levels.

Some questions arising from this study were posed as possible areas for further research relative to speech intelligibility.

AN INVESTIGATION OF INTELLIGIBILITY OF SPEECH AS A FUNCTION OF BANDWIDTH AND INTENSITY

By

Lowell J. Sahlstrom

A THESIS

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

MASTER OF ARTS

Department of Speech

1964

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Intelligibility of speech has been the subject of research for many years. The first major use of intelligibility tests followed the development of such tests by the Bell Telephone Laboratories[1] (Fletcher and Steinberg) during the first quarter of this century. Articulation or intelligibility curves are now widely employed as measurements of communication efficiency.

In general the dependent variable has been the percentage of correct recognition. The independent variable may have taken the form of overall gain of the communication channel. Other parameters which have been involved in such tests include frequency band width and location, signal to noise ratio, communication channel distortion, dialectical differences between speakers and listeners, hearing acuity, and type of speech material utilized in the presentation.[2]

---

[1]Lee E. Travis, _et al_. _Handbook of Speech Pathology_ (New York: Appleton Century Crofts, Inc., 1957), p. 141.

[2]H. Fletcher, and J. E. Steinberg, "Articulation Testing Methods," _Bell Systems Technical Journal_, 8 (1929), 850-854.

There are several aspects to perception of speech and one of the important ones is the process that allows a listener to correctly recognize and to record the speech sounds which are spoken to him. This is the recognition aspect of speech perception. One method of measuring this aspect of perception is to have a speaker read a certain number of words or sounds to a listener who writes the word or sounds that he thinks he hears.[3]

The research that has been done in the area of intelligibility has examined this phenomenon under many different conditons and situations. In a study done by Peterson and Subrahmanyan,[4] intelligibility was investigated under conditions of a narrow band speech transmission system which scanned the time-frequency plane in a sinusoidal manner across a range of 6800 cps.

Another study done by French and Steinberg[5] investigated intelligibility using low pass and high pass filters which filtered out portions of the frequency spectrum above and/or below a given point on the frequency scale.

---

[3]Harvey Fletcher, Speech and Hearing in Communication (New York: D. Van Nostrand Co., Inc., 1953), p. 278.

[4]G. Peterson and D. Subrahmanyan, "Evaluation of Time-Frequency Scanning for Narrowband Speech Transmission," Journal of the Acoustic Society of America, 31 (1959), 113.

[5]N. R. French and J. Steinberg, "Factors Governing Intelligibility of Speech Sounds," Journal of the Acoustic Society of America, 19 (1949), 90.

Kryter[6] reported a study on methods for arriving at an Articulation Index for use in estimating the intelligibility potential of electronic instrumentation without having to use elaborate intelligibility tests. Other research performed by Huizing, Kruisinga, and Taseloar[7] examined speech reception under conditions of groupings of band pass filters, giving a wide range of frequency response.

In a study done by Egan and Weiner,[8] groups of band pass filters were used with two types of masking noise and a test presentation of nonsense syllables to evaluate intelligibility.

A study reported by Hirsh, Reynolds, and Joseph,[9] investigated the intelligibility of different speech materials.

This research then, has investigated the intelligibility of speech under many environmental listening conditions such as noise, limited frequency, various kinds

---

[6]Karl Kryter, "Methods for the Calculation and Use of the Articulation Index," Journal of the Acoustic Society of America, 34 (1962), 1689.

[7]H. S. Huizing, R. J. Kruisinga, and M. Taseloar, "Triplett Audiometry: An Analysis of Band Discrimination in Speech Reception," Acta Oto-laryngology, 51 (1960), 256.

[8]J. P. Egan and G. Weiner, "On the Intelligibility of Bands of Speech in Noise," Journal of the Acoustic Society of America, 18 (1946), 435.

[9]I. J. Hirsh, E. G. Reynolds, and M. Joseph, "Intelligibility of Different Speech Materials," Journal of the Acoustic Society of America, 26 (1954), 530.

of distortion of sound, and different speech materials. These studies have used high pass filters, low pass filters, and band pass filters in groupings.

In different ways with different materials and equipment, intelligibility has been examined quite thoroughly. However, none of this research was oriented towards examining intelligibility with a single band pass filter in quiet conditions. Furthermore, this does not appear to have been done with monosyllabic phonetically balanced words, the type of speech material generally used in audiometric testing today.

The research that has been done relative to intelligibility has often contributed much toward the goals discussed in this introduction. In the present study, one more aspect of this problem has been investigated in the hope that still more information might be gained in this area.

Statement of Problem and Purpose of Study

The purpose of this study was to investigate the relationship between intelligibility and: (1) width of bandpass, and (2) intensity. This investigation utilized two conditions of filtering with a band-pass filter: a bandwidth of 480 cps; and a bandwidth of 960 cps. Both bands were centered at 1560 cps.

This study analyzed and compared the results obtained from normal hearing subjects as they responded to the CID Auditory Test W-22 (lists 1E, 2E, 3E, and 4E.) under each condition of filtering and at three different levels of intensity within each bandpass condition.

In order to analyze the difference in intelligibility found between the two bandwidths, the discrimination scores of the subjects responding to the test material under the condition of narrow band pass filtering were compared with the discrimination score of the group of subjects who responded to the test material under the wider band pass condition. Secondly, the discrimination scores for each intensity were compared with that of the other two intensity levels for each bandwidth in order to determine differences in intelligibility due to changes in stimulus intensity. Thirdly, the scores were analyzed for any interaction between width of bandpass and level of intensity.

Hypotheses

The following null hypotheses were tested to investigate the differences in intelligibility due to: (1) width of bandpass; (2) variations in intensity, and; (3) interaction of these factors:

1. There is no significant difference in intelligibility scores derived from listening to a band of frequencies 480 cps wide and a band of

frequencies 960 cps wide with both bands centered at 1560 cps.

2. There is no significant difference in intelligibility scores obtained with filtered speech due to increase in intensity level.
3. There is no significant interaction effect between width of band-pass and intensity levels.

Importance of Study

An extensive amount of research has been done in the area of intelligibility. Much of this research has been directed toward a determination of the effects of noise on intelligibility. Other studies have attempted to determine how much of the speech range of frequencies can be filtered out of the presentation of various types of speech materials and still maintain a sufficient degree of intelligibility for normal communication. Research of this type has implications for hard-of-hearing persons, for communication under conditions of excessive noise, and for communication under limited frequency conditions due to other causes.

The present study proposed to investigate intelligibility within a narrow frequency range of speech, namely that range from 1080 cps to 2040 cps. It was believed that the results of this study would contribute to the available information regarding the phenomenon of intelligibility under limited frequency conditions, without the presence of any masking or other type of noise. Secondly, these results would yield further information regarding the influence of intensity variations upon intelligibility of one syllable words.

Definition of Terms

Decibel.--A relative unit of measurement of sound intensity expressed in a logarithmic ratio of intensity differences.

Normal Hearing Adults.--Fourteen graduate and ten undergraduate students, all demonstrating pure tone air conduction thresholds at 10 dB (re: audiometric zero) or better for the frequencies 500, 1000, and 2000 cps in both ears, when tested in a sound treated room with a portable pure tone audiometer.

Intelligibility.--The accuracy with which speech is received by the listener, after having been passed through a communication channel.

Speech Discrimination or Articulation Test.--A test which allows for evaluation of an individual's ability to discriminate between acoustically similar words or words that contain acoustically similar sounds. It is used to determine a person's discrimination loss for speech, and is usually designated as a percentage of the total list which the person records correctly.

Phonetically Balanced.--Test items in which all, or nearly all, of the language phonemes are represented. The frequency of occurence of these fundamental sounds is in proportion to their distribution in normal speech.[10]

CID Auditory Test W-22.--A discrimination test consisting of four lists of 50 phonetically balanced, one-syllable words adapted by the Central Institute for the Deaf[11] from the Phonetically Balanced Word Lists (PB-50) of the Psycho-Acoustic Laboratory, Harvard University.[12] Each list has been scrambled to make six different word orders.

Band-pass Filter.--A filter is an electrical circuit which transmits with only a small loss, certain frequencies or bands of frequencies, and provides attenuation for other frequencies. A band-pass filter transmits frequencies in the interval between a low and a high cutoff frequency.[13] The band-pass filter used in the present study is a one-tenth octave filter with a rejection rate of 30 dB per octave.

---

[10] James P. Egan, "Articulation Testing Methods," Laryngoscope, 58 (1948), 957.

[11] Ira J. Hirsh, et al., "Development of Materials for Speech Audiometry," Journal of Speech and Hearing Disorders, 17 (1952), 328-329.

[12] Egan, op. cit., p. 961.

[13] Travis, op. cit., p. 133.

Bandwidth.--A frequency band expressing in cycles per second, the range of frequencies between the low and high cutoff points of a band-pass filter. The present study used two bandwidths; 1320-1800 cps, and 1080-2040 cps; both of which had a center frequency of 1560 cps.

Intensity.--The pressure level of the test material presentation measured in decibels relative to .0002 dynes per square centimeter.

Organization of the Thesis

Chapter I has included an introduction to the problem of intelligibility and an outline of the purpose of this study. It has set forth the hypotheses to be tested, the importance of the study, a definition of terms used, and an outline of the thesis.

Chapter II presents a review of the literature pertinent to the present study of intelligibility.

Chapter III describes the subjects, equipment, materials, and procedures utilized in this study.

Chapter IV consists of an analysis and discussion of the results of the study.

Chapter V contains the summary and conclusions of the study, and implications for further research.

CHAPTER II

Review of the Literature

A great deal of research has been done in the area of intelligibility. Much of this research has been done with phonetically balanced words in defining what has been termed the articulation function. This work has been done with normal ears as well as with ears having different types of impairments. Articulation curves have been constructed, showing how the scores obtained on articulation tests by normal hearing people and by people with impaired hearing, are affected by the intensity at which the word lists are presented. Several different studies have been directed at a determination of the effects of noise on intelligibility. Other research has attempted to determine how much of the speech range can be filtered out of the presentation and still maintain a sufficient degree of intelligibility for adequate communication.

It remained for telephone engineers interested in the adequacy of their equipment to develop procedures for the quantitative investigation of speech perception. The concern was with intelligibility rather than perception, in terms of what the equipment can do rather than what the listeners can do. The results were used to evaluate equipment rather than listeners or speakers.[14] Since perception is a psychological aspect of speech, the telephone personnel were primarily interested in intelligibility as it related to the performance of their equipment.

There are several different aspects of speech perception but the foremost is the process of discrimination which enables one to recognize correctly and to record the speech sounds which are spoken. This can be called the recognition aspect of speech perception.[15] The method of measuring this aspect of perception is to have a speaker read aloud a certain number of speech sounds to a listener who writes what he thinks he hears. A quantitative measure of the intelligibility of speech may be obtained by counting the number of discrete speech units correctly recorded by the listener in an articulation test. Lists of syllables, words, or sentences are read aloud and the percentage of items correctly recorded is called the articulation score.[16]

The procedure for administering the articulation tests is to have the listeners record their responses on

---

[14] S. S. Stevens, (ed), Handbook of Experimental Psychology (New York: John Wiley and Sons, Inc., 1951), p. 1040.

[15] Fletcher, op. cit., p. 278.

[16] James P. Egan, op. cit., p. 955.

a paper with numbered blank spaces. In this way, there can be little doubt as to whether or not the subject or listener, has heard the words correctly, and a permanent record of his responses is available for analysis of his discrimination errors.[17] This procedure leaves some chance for inaccuracy due to unclear or poor writing on the part of the listeners, which produces responses that may be unreadable.

Articulation tests have proved useful for comparing communication equipment, for evaluating the effects of noise on communication, for determining the basic audibility of different words, for hearing examinations, and for rating and training communication personnel. The experimental variables are the quality and intensity of the announcer's or speaker's voice, his pronounciation and enunciation of words, his accent and proper or improper use of the equipment. Also involved is the phonetic composition and difficulty of items in the test material. The communication channel is a factor to be considered in terms of the noise present in the system, the intensity of the signal presented, and the overall fidelity of the equipment. Finally, the listener is another variable in terms of his hearing acuity, his ability to discriminate

---

[17] Hayes Newby, Audiology (New York: Appleton Century Crofts, 1964), p. 116.

speech sounds and his ability to ignore any masking noise. Thus this three part system of speaker, channel, and listener contains an extensive list of variables which are involved in the use of articulation tests in evaluating any aspect of intelligibility. And yet these must be considered because of the effects each may have on the results of an articulation test.[18]

In some of the work done on the relation of intensity to intelligibility, it has been found that the individual's threshold for speech (the speech level necessary in order to identify half the test items correctly) depends upon the type of speech material in the test. Kryter reported that a level of 31 dB sound pressure level was necessary for fifty per cent recognition of monosyllables in a free-field.[19] Davis reported a level of 33 dB SPL for monsyllables with earphones.[20] In the same study, Davis found spondees to be reported correctly half the time at a level of 22 dB SPL with earphones.[21] Shaw, Newman, and Hirsh reported spondees at a threshold level

---

[18]Egan, op. cit., p. 1043.

[19]K. D. Kryter, "Effects of Ear Protective Devices on the Intelligibility of Speech in Noise," Journal of the Acoustic Society of America, 18 (1946), 416.

[20]Hallowell Davis (ed.), Hearing and Deafness (New York: Murray Hill, 1947), p. 150.

[21]Ibid.

of 17 dB SPL monaurally and 14 dB SPL when tested binaurally.[22] French and Steinberg found nonsense syllables to be recorded correctly fifty per cent of the time at approximately 30 dB.[23] Hawkins and Stevens examined thresholds for connected discourse and found a level of 24 dB SPL when presented by earphones.[24]

The naive listener who takes an articulation test for the first time, will yield initial thresholds which are several decibels poorer than his later thresholds will be, particularly if time is not taken to familiarize him with the test words prior to the initial test. On the other hand, any person having appreciable prior experience with the speech material to be used in the test will obtain thresholds which appear better by several decibels than they would, had they not had that experience with the material.[25] This would seem to indicate that in any investigation of intelligibility, it would be advisable

---

[22]W. A. Shaw, E. B. Newman, and I. J. Hirsh, "The Difference between Monaural and Binaural Thresholds," Journal of Experimental Psychology, 37 (1947), 240.

[23]French and Steinberg, op. cit., p. 117.

[24]J. E. Hawkins, Jr. and S. S. Stevens, "The Masking of Pure Tones and of Speech by White Noise," Journal of the Acoustic Society of America, 22 (1950), 12.

[25]J. Jerger, R. Carhart, T. Tillman, and J. Peterson, "Some Relations Between Normal Hearing for Pure Tones and Speech," Journal of Speech and Hearing Research, 2 (1959), 139.

to provide a practice session in which the subjects are allowed to become familiar with the required tasks. In this way the effects of test familiarity are controlled.

Lists of phonetically balanced words are often used for articulation tests. Two of the more commonly known such tests are the Phonetically Balanced Word Lists of the Psycho-Acoustic Laboratory, Harvard University developed by Egan,[26] and the Central Institute for the Deaf W-22 lists which were developed from the PAL-50 lists by Hirsh.[27] Both of these tests are composed of monosyllabic words.

It has been found that as intensity is increased above the individual's threshold for speech, scores achieved on phonetically balanced word tests increase rapidly until the intensity at which the words are presented reaches a level of about 40 dB greater than the individual's threshold for speech. At this point the curve tends to flatten out and there is a negligible increase in discrimination score beyond this level.

Hirsh and others report a study designed to investigate whether the different lists of the CID W-22 test were of equal difficulty. They provided a practice run in which the subjects first listened to one list at a

---

[26]Egan, op. cit., pp. 955-991.

[27]Hirsh, op. cit., pp. 321-337.

level of 100 decibels. This gave the listeners an indoctrination period in which the words were presented at a sufficiently high level for them to become adapted to the type of task assigned. This study found that there were no consistent differences between scores that were obtained from listeners responding to the different lists of the W-22 test.[28]

In another study of the differences in difficulty of the W-22 word lists, Elpern[29] accumulated 1490 monaural discrimination scores from Veterans Administration Audiology Clinics in six major cities. He collected such scores on each of the four fifty word lists which make up the W-22 test. Each of these lists are recorded in six different word orders designated A, B, C, D, E, and F. Elpern found that there were differences between these lists. These differences existed in both average level of difficulty and in average range of difficulty, among the four word lists. However, these differences are found to be so small that they would not interfere with normal clinical usage. In certain research applications the differences may be great enough to warrant more careful attention, according to Elpern. He found that the only lists which do not differ in any respect

---

[28]Ira J. Hirsh, et al., op. cit., p. 333.

[29]Barry S. Elpern, "Differences in Difficulty Among the CID W-22 Auditory Test," Laryngoscope, 70 (1957), 1564.

from one another are lists 2 and 3; and lists 3 and 4. He concludes that these pairs may be employed in research situations without danger of unequal difficulty of word lists being an uncontrolled variable in the design. Another alternative would be to use but one of the lists, and to use different groups of subjects for each treatment.

In considering the equal difficulty of articulation test, one must look at all variables. If such lists are to be used in a study which entails conditions of distortion of any kind, there may be a change in the relative difficulty of a given list due to the phonetic elements which are lost as a result of the filtering producing the distortion. Thus another variable is introduced which should be investigated. One study was done on this subject by Hardick and Deal.[30] In this investigation, speech discrimination under conditions of filtering was studied. Listeners were asked to respond to the W-22 word lists which were presented to them. The speech signal was distorted by the use of a low-pass filter. The results of this study indicated that the four lists of the W-22 test were of equal difficulty under the adverse listening conditons that resulted from frequency distortion of the speech signal.

---

[30]Edward Hardick and Leo Deal, "The Effects of Frequency Distortion on Speech Discrimination" (unpublished study, Speech Department, Michigan State University, 1962).

Continuous discourse is representative of speech encountered in everyday life. There are those who feel that this would be the best means of testing intelligibility, especially in a clinical situation. Scoring of such a test presents a much greater problem than word lists, however. Giolas and Epstein[31] compared intelligibility scores obtained on the W-22 word lists, the PB-50 lists and continuous discourse. It was found that the monosyllabic words of the W-22 lists yielded higher scores than the PB-50 lists. Frequency distortion was produced by the use of low-pass filters. Six different filtering conditions were presented with the speech sample being subjected to all six filtering conditions as well as to full-range reproduction. Listeners responded to the stimulus presentation by writing their answers on numbered sheets of paper. The results of this study indicate that frequency distortion has an effect on the W-22 lists which is much the same as the effect on continuous discourse. With both types of speech material, errors increased as distortion increased.

In a study of the effect of word familiarity on intelligibility, Owens[32] presented several lists of

---

[31]Thomas G. Giolas and Aubrey Epstein, "Comparative Intelligibility of Word Lists and Continuous Discourse," Journal of Speech and Hearing Research, 6 (1963), 354.

[32]Elmer Owens, "Intelligibility of Words Varying in Familiarity," Journal of Speech and Hearing Research, 4 (1961), 124.

monosyllable words to groups of listeners. Each list was presented under conditions of frequency distortion caused by the use of filters. It was found that those words which are more familiar are significantly more intelligible. In relating these findings to the PB-50 and W-22 word lists, it was learned that the W-22 words then are apparently more familiar, easier to understand, resulting in a higher intelligibility score. This is possibly the reason that the W-22 lists score closer to continuous discourse than other word lists.

Black did a study on the relative intelligibility of words, in which he investigated the relationships between aspects of the syllabic pattern, word familiarity, and the phonetic characteristics of words.[33] These factors were examined both in a quiet environment and under conditions of noise. It was found that more familiar words are more accurately identified by listeners in either quiet or noise conditions. Words containing two syllables are more intelligible than those of one syllable. Those words that have the accent on the second syllable are more intelligible than words having an accent on the first syllable. Finally, it was found that the more sounds contained in a word, the more intelligible the word becomes.

---

[33]John W. Black, "Accompaniments of Word Familiarity," Journal of Speech and Hearing Disorders, 17 (1952), 416.

Licklider and Miller[34] investigated the possible effect that interruption of the speech signal would have upon intelligibility. They varied the rate of the interruption and the regularity of the interruption. The high rate of interruption of the signal did not significantly impair intelligibility. When using a low rate of interruption of the signal, there was impairment or reduction of intelligibility. When the interruption is sufficiently slow that it may remove entire syllables from the presentation, it is quite likely that articulation scores will fall as a result. Intelligibility was found to be approximately proportional to the amount of time the signal was present when using the slow rate of interruption. In varying the regularity of the interruption, it was found that such interruptions produced little change in intelligibility, whether the interruptions were regular or irregular.

Siegenthaler and Hardick[35] produced articulation curves for normal hearing adults as obtained with several common word lists. Various phonetically balanced word lists were used as the test material. Children were used

---

[34]J. C. R. Licklider and G. A. Miller, "The Intelligibility of Interrupted Speech," Journal of the Acoustic Society of America, 20 (1948), 593.

[35]Bruce Sigenthaler and Edward Hardick, "Intelligibility Scores Using Various Phonetically Balanced Word Lists," Pennsylvania Speech Annual, (1959), 8.

in the study in a comparison of the same lists with two phonetically balanced word lists designed for use with children. It was found that there was little difference in difficulty between the W-22 and the PB-50 word lists, which is of special interest to the present study. The study indicates that for normal-hearing children and adults, differences in articulation curves are relatively small when listening to these phonetically balanced word lists in a free-field situation.

Hirsh, Reynolds and Joseph[36] studied the relative intelligibility of different speech materials. The obtained articulation scores for nonsense syllables, monosyllables, disyllables and polysyllables. The speech signal was passed through various filtering conditions before being presented to the listeners. The articulation scores were also studied as a function of the filtering condition using low and high pass filters. The results of this study indicated that eliminating all frequencies above 1600 cycles per second did not impair the intelligibility of speech seriously. Elimination of all frequencies below 1600 cps also produced very little reduction in intelligibility. Examination of the data pertinent to the number of syllables in a word indicated

---

[36] I. J. Hirsh, E. G. Reynolds, and M. Joseph, "Intelligibility of Different Speech Materials," Journal of the Acoustic Society of America, 26 (July, 1954), 537.

that intelligibility is a direct function of the number of syllables in the word. Monosyllables are more intelligible than nonsense syllables; disyllables are more easily understood than monosyllables; and polysyllables are more intelligible than disyllables and so on up to continuous discourse.

Pollack[37] investigated the effects of filtering on intelligibility by having two speakers read lists of monosyllables under various conditions of filtering, employing both high pass and low pass filters. Intensity was also varied. All stimuli were presented in a background of white noise. At low intensities, he found that the low frequencies are more important to intelligibility than they are at high intensities. That is, the low frequencies are important when the speech signal is weak, but not so important with a strong signal. During one part of the study, two speakers read lists of monosyllable words (PAL and PB-50 word lists) at a level of 68 decibels re: .0002 dynes per square centimeter. It was found that frequencies above 2375 cps contributed little to the overall intelligibility of speech at this intensity level. Under the same condition of intensity, frequencies below 425 cps also had little effect on

---

[37] Irwin Pollock, "Effects of High Pass and Low Pass Filtering on the Intelligibility of Speech in Noise," Journal of the Acoustic Society of America, 20 (1948), 265.

intelligibility. In general, it was found that intelligibility increased as the bandwidth and the intensity level of the speech signal were increased.

Harris, Harris, and Myers[38] were interested in the importance of the 3000 cps area of the frequency spectrum for the understanding of speech. They used speech which was unfiltered, but distorted the speech signal through a speed-up in words-per-minute. This signal was presented to persons whose audiograms were similar to that which would be obtained with low pass filtering at a cutoff frequency of 3000 cps. Sentence intelligibility tests were used as the test material. It was found that a normal or near normal pure tone audiogram in the region of 3000 cps is essential for high sentence intelligibility when the signal is distorted through a speed-up in words-per-minute. These results indicated that about fifteen per cent of the cues for sentence intelligibility are dependent upon the frequencies around the 3000 cps region. With a slower speed of the speech signal, at or near normal speeds in terms of words per minute, these lost cues can be compensated for by the redundancy of cues in normal speech. When the speech is speeded up as in this study, the listener is unable to pick up enough of these clues to maintain intelligibility.

---

[38] J. D. Harris, L. Harris, and C. K. Myers, "The Importance of Hearing at 3KC for Understanding Speeded Speech," Laryngoscope, 70 (1957), 144.

French and Steinberg[39] report an extensive study of the factors that influence the intelligibility of speech. They used filtering of various kinds upon a speech signal emitted by both male and female voices. The results indicated that articulation scores increased as gain was increased. Here again, it was found that the low frequencies contribute little to intelligibility, despite the fact that they carry most of the speech power. When all frequencies above 1900 cps were eliminated; and when all frequencies below 1900 cps were eliminated, approximately the same articulation scores were achieved. The authors described a measure called the "Articulation Index" which can be computed from the intensities of speech received by the ear as a function of frequency.[40] This provides an easier method for determining the efficiency of a communication system. That is, one can tell from a stated value of the Articulation Index, the degree of intelligibility one can receive from a given system without the necessity of completing articulation tests with the apparatus using trained subjects.

---

[39] N. R. French and J. Steinberg, "Factors Governing Intelligibility of Speech Sounds," Journal of the Acoustic Society of America, 19 (1949), 117.

[40] Ibid., p. 109.

A study reported by Licklider[41] investigated the effects of amplitude distortion upon intelligibility. The primary type of amplitude distortion used was peak clipping. In this process the points of greatest amplitude are clipped off so that the speech signal loses some of its phonetic elements. Doing this in quiet situations it was found that peak clipping, even with the speech signal reduced to one-tenth of its original amplitude, did not cause much decrease in intelligibility. Listeners reported ninety-six per cent of the words correctly under these conditions. The same procedure carried out under conditions of noise produced almost complete loss of intelligibility. Two different types of noise conditions were used by changing the location of the peak clipping apparatus within the system. In the first, the clipper was inserted so that both the noise and the speech were clipped. In the second, the clipper was inserted in the system so that only the speech signal was clipped and the noise retained its original amplitude.

The intelligibility of bands of speech in noise was studied by Egan and Weiner.[42] They utilized four

---

[41] J. C. R. Licklider, "Effects of Amplitude Distortion upon the Intelligibility of Speech," Journal of the Acoustic Society of America, 18 (1946), 430.

[42] J. P. Egan and F. M. Weiner, "On the Intelligibility of Bands of Speech in Noise," Journal of the Acoustic Society of America, 18 (1946), 439.

groups of filters with varying bandwidths within the group of filters but with each filter in a given group having a common center frequency. Each of the four groups had a different center frequency and band width. A masking noise was presented with the speech signal at all times. Two types of masking noise were used; one in which the noise was filtered along with the speech signal; and a second in which the noise was not filtered. Nonsense syllables were used as the test material and scored as per cent correct. The results of this investigation were plotted in terms of equal-articulation curves, yielding a family of such curves. This provided a system by which one can determine from this graph, the amount of increase in intensity needed to counteract or to compensate for a given decrease in the bandwidth of a speech signal presentation. Of special interest here is that it was found that for constant levels of received speech, the articulation score obtained with wide bands of speech is always higher than the articulation score obtained with narrower bands of speech.[43] This would seem to indicate that the wider the bandwidth, the better the articulation score which will be obtained.

---

[42]J. P. Egan and F. M. Weiner, "On the Intelligibility of Bands of Speech in Noise," Journal of the Acoustic Society of America, 18 (1946), 439.

[43]Ibid., p. 440.

Kryter used band pass filters in combinations of one, two, or three filters, and using various center frequencies to study the effects of speech bandwidth compression.[44] This investigation also utilized unfiltered conditions. The study used both phonetically balanced words and sentence intelligibility tests. It was found that one bandpass filter with wide band limits will give intelligibility scores which are nearly double that achieved with several bandpass filters at narrow settings of bandwidth but with the bands adjacent to each other. The results of the study indicated that the region around 1600-1700 cps appeared to contribute the most to speech intelligibility when speech was filtered with a single pass band system.[45] Kryter states that:

> Presumably then it is still an open question as to how much and what protions of the speech spectrum can be eliminated before intelligibility is reduced below an acceptable level.[46]

In this study, Kryter examined the effects of speech bandwidth compression under conditions of noise. However, the question pertinent to the present study relates to the same factors in quiet conditions.

---

[44]K. D. Kryter, "Speech Bandwidth Compression Through Spectrum Selection," Journal of the Acoustical Society of America, 32 (1960), 547.

[45]Ibid., p. 549.

[46]Ibid., p. 547.

Another study accomplished by Kryter led to the determination of twenty frequency bands of speech which produced equal contribution to the intelligibility of speech.[47] One purpose of this study was to develop an improved method of calculating the Articulation Index developed by French and Steinberg.

Harris and Brown[48] subjected a speech signal of a sentence intelligibility test to several types of distortion while filtering with a variable bandpass filter. They studied the interaction of distortion and filtering upon the intelligibility of the speech signal. The types of distortion employed in this study were; shouting, interruption of the signal, and reverberation. One type of distortion, that of reverberation, caused a reduction in intelligibility of eighty per cent. With the other types of distortion and with speech filtered so that at the widest bandwidth used in this study, that of 1500 cps, the intelligibility of key words in a sentence intelligibility test remained high. This band was centered around 1600 cps. Despite the introduction of distortion, an articulation score of ninety-five per cent

---

[47] K. D. Kryter, "Methods for the Calculation and Use of the Articulation Index," Journal of the Acoustical Society of America, 34 (1962), 1691.

[48] J. D. Harris and L. W. Brown, "Interactions Among Bandwidth, Center Frequency, and Type of Distortion in Speech Intelligibility," Journal of the Acoustic Society of America, 34 (1962), 1999.

was obtained. At the narrowest bandwidth used, (500 cps) the optimum center frequency for all distorted speech shifted upward to 1900 cps or above. With the lowest center frequency utilized in this study, 800 cps, intelligibility remained just as good as at the next higher center frequency of 1200 cps when both bands were at a width of 500 cps.

Summary

This survey of the literature relevant to speech intelligibility has illustrated the extensive amount of research that has been performed in this area. As a result of these studies, much is now known about the effects of such factors as; distortion, filtering, bandwidth compression, different speech materials, increased speech signal speed, and noise upon the intelligibility of speech. This survey also reveals, however, that intelligibility of monosyllable words has not been examined under a single bandpass filtering condition in a quiet environment, and as a function of intensity. The present study is an attempt to fill this gap in the research on speech intelligibility and to add to the fund of knowledge in this area.

CHAPTER III

SUBJECTS, EQUIPMENT, MATERIALS, AND PROCEDURES

Subjects

The subjects participating in this study were twenty-four male and female students majoring in speech attending Michigan State University. There were fourteen graduate and ten undergraduate students. Each subject demonstrated a hearing level of 10 dB re: normal threshold or better in both ears, at the frequencies of 500, 1000, and 2000 cycles per second. The hearing level was determined by testing each subject with a portable pure tone audiometer (Beltone, Model 10-C) in a sound treated room. No individual was used as a subject in this study who had extensive experience with the CID W-22 word lists.

Equipment

Pure-tone portable audiometer (Beltone, Model 10-C)

Tape recorder (Ampex, Model 601)

Phonograph (Thorens)

Filter (Allison, Model 25)

Electronic Mixer (Ampex, Model MX-35)

Binaural earphones (Telephonics, Model TDH-39)

Electronic Voltmeter (Bruel & Kjaer, Type 2409)

Materials

CID Auditory Test W-22 (Lists 1E, 2E, 3E, and 4E)
Magnetic recording tape (Audio Master acetate)
Forms for recording responses by subjects (see Appendix B)

Procedure

Preliminary procedures.--The commercially available disc recordings of the CID Auditory Test W-22 were used. These recordings were transcribed onto magnetic tape. The discs were played on a phonograph (Thorens). The output signal was fed directly to the input circuit of a tape deck (Ampex, Model 601). The calibration tone on the recordings was set to zero level on the phonograph output VU meter. The same calibration tone was transcribed onto the tape recording at a level of -10 on the tape deck VU meter. The phonograph output was adjusted to a level of 85 dB re: audiometric zero. The four CID W-22 word lists, 1E, 2E, 3E, and 4E were then transcribed onto the magnetic tape with a fifteen second pause between each list.

A voltmeter was used to determine the output levels of the stimulus material, using the dbm scale of the meter. Output of the amplifier was converted from the dbm scale as sound pressure level by the use of the following formula: SPL = 130 + A - M - 20*; where M = meter range, dbm scale;

A = meter reading; and * = a correction factor for transducer loss previously derived through the use of white noise.

The calibration tone of the tapes of the CID lists was set at specified levels prior to the actual presentation. Using the above formula, output of the amplifier was adjusted to the four desired levels for each bandwidth condition and the output controls of the amplifier were marked at these points. In this way output levels could be easily changed to the necessary new levels during the presentation. Such settings were determined for average levels of 35 dB, 50 dB, 70 dB, and 90 dB, re: .0002 dynes per square centimeter. The electronic apparatus used in the presentation of this study was set up in the manner illustrated in Figure 1.

Presentation.--The presentation of the test material was carried out in the Speech and Hearing Science Laboratory of Michigan State University. The walls and ceiling are plastered; the floor is tiled. The room is equipped with twelve desk-type chairs, each of which is provided with binaural earphones connected to the output of the amplifier. On week-days the ambient noise present due to classes and activity in other parts of the building is relatively high. To eliminate much of this noise, this study was conducted on a Saturday morning when there was little activity in other parts of the building and surrounding area.

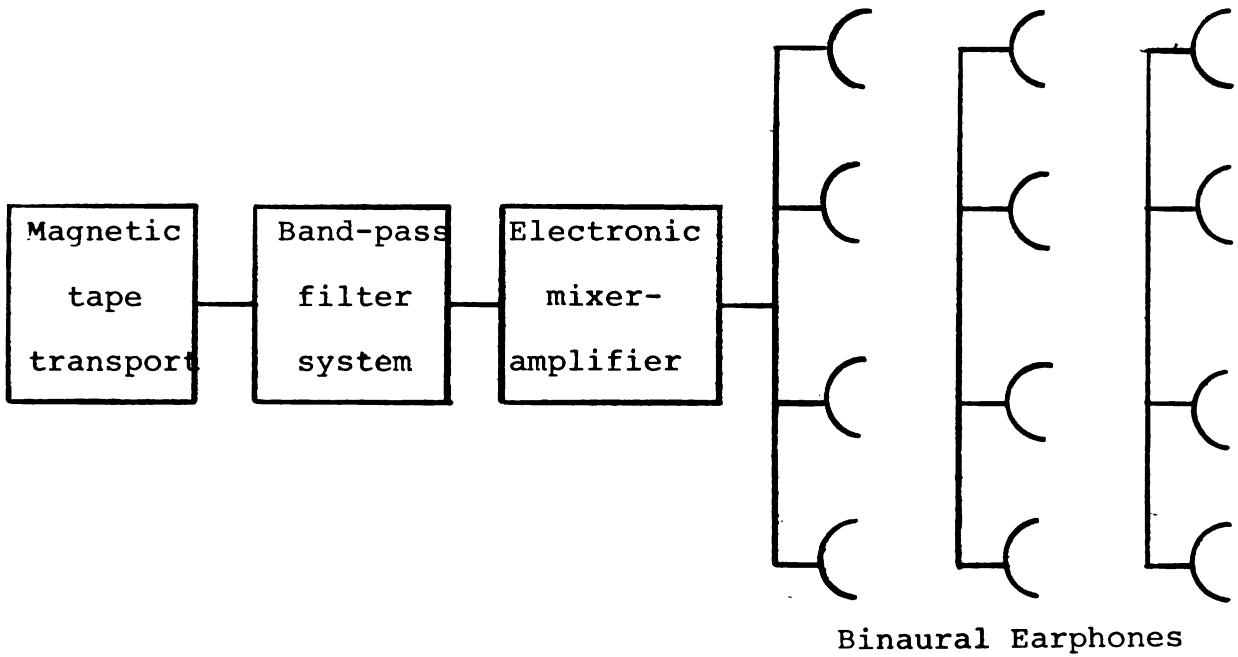

Fig. 1.--Schematic Diagram of Stimulus Presentation Apparatus

The twenty-four subjects were randomly divided into two groups of twelve persons each. Each group received a separate treatment or condition of the study. As each group entered the room, they were seated in the desks provided for them. Answer sheets were provided for each subject. Each answer sheet consisted of two sets of fifty numbered blank spaces. Two answer sheets were given to each subject (see Appendix B). The subjects were then given instructions appropriate to the task they were being asked to perform (see Appendix C).

Testing, group I.--The band-pass filter was adjusted to pass a band of 480 cps from 1320 to 1800 cps with a center frequency of 1560 cps. Since the output levels had been previously calculated, it was necessary only to set the master output control of the mixer to the setting desired. The first intensity level for Group I was 90 dB. The filter setting was accomplished by setting both the low and high cutoff controls at 1200 cps. The low cutoff multiplier was set at 1.1 and the high cutoff multiplier at 1.5.

The subjects were told to place the earphones on their ears and prepare to respond as instructed. The tape transport was turned on and allowed to run through the entire first list of words. The operator listened to the words through a monitor headphone as a check on the operation of equipment and as a guide to progress of the list. The first was considered a practice list. During the fifteen second pause between lists on the tape, the output setting on the master control of the mixer was re-adjusted to the 70 dB setting. The subjects had time to turn to the next list of numbered blank spaces. The tape was allowed to play through the second list. During the pause between lists the master control was adjusted to the 50 dB setting. Again, the tape was allowed to continue through the third list of fifty words. Once again the output control was adjusted during the pause between lists, to the 35 dB setting. At the end of this list, the tape recording was re-wound to the beginning of the first list and the equipment power supply was switched off. Subjects responses were collected and the subjects dismissed.

Testing, Group II.--In testing the second bandwidth condition, again both the low cutoff and high cutoff controls of the filter were set at 1200 cps. The low cutoff multiplier was set at .9 and the high cutoff multiplier was set at 1.7. This yielded a band pass of 960 cps from 1080 to 2040 cps, with a center frequency of 1560 cps. The master output control of the mixer was again set at the 90 dB setting.

The subjects were seated, given the instructions and answer blanks, and told to place the earphones and prepare to respond as instructed. The tape transport was turned on as before. The presentation of material and output settings were adjusted during pauses between lists in the same manner as described for Group I. The first list presented at 90 dB again served as a practice list only. At the end of the fourth list, the equipment was switched off and the listeners answer sheets collected and the subjects dismissed.

Summary.--Group I listened to four lists of W-22 words under a 480 cps bandpass filtering condition. Group II listened to the same four lists of W-22 words under a 960 cps bandpass filtering condition. Both bandwidths were centered at 1560 cps. Both groups listened to list 1E at 90 dB, which was used as a practice list. List 2E was presented to both groups at 70 dB, list 3E at 50 dB, and list 4E at 35 dB, all intensity levels with reference to .0002 dynes per square centimeter.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

One of the problems investigated in this study was whether there was any significant difference in intelligibility scores obtained from subjects listening to two narrow but different bandwidths of speech. A second question sought to determine whether there was any significant increase in intelligibility due to increase in stimulus intensity. Thirdly, the question was asked regarding the presence of any significant interaction between bandwidth and intensity.

The quantification of responses was done for each of the two filtering conditions at each of the three intensity levels. The per cent correct intelligibiltiy scores for filtered speech are illustrated in Table 1.

Analysis

A two-way analysis of variance was done to determine whether there was any significant difference between bandwidths, between intensity levels, and whether there was any significant interaction between bandwidth and

TABLE 1

INTELLIGIBILITY SCORES (PER CENT CORRECT)
FOR FILTERED SPEECH

Subject	35 dB*	50 dB*	70 dB*	90 dB*
Within the 1320 to 1800 cps Bandwidth Condition				
1	26	74	86	90
2	18	74	76	88
3	20	60	74	78
4	16	76	72	76
5	18	60	70	74
6	26	60	72	68
7	16	58	72	60
8	18	68	74	58
9	20	56	66	50
10	18	62	68	48
11	4	56	60	26
12	2	52	80	6
X	16.83	63.0	72.5	60.16**
Within the 1080 to 2040 cps Bandwidth Condition				
1	24	70	82	88
2	16	58	84	78
3	28	72	80	78
4	18	60	82	72
5	18	56	62	68
6	10	66	74	64
7	10	52	66	62
8	14	46	68	60
9	24	44	66	54
10	20	56	74	50
11	12	44	56	46
12	16	52	78	36
X	17.5	56.3	72.6	63.0**

* Intensity levels re: .0002 dynes per square centimeter.
** Denotes practice lists.

intensity level. A two-factor Type I mixed design as described by Lindquist[49] was utilized for this analysis.

In the statistical analysis summarized in Table 2, the B effect represents the differences in intelligibility scores obtained between bandwidths. The A effect represents the differences in intelligibility scores obtained between intensity levels. The AB effect represents the interaction between bandwidth and intensity levels.

The analysis in Table 2 indicates that there is no significant difference in intelligibility scores at the five per cent level of confidence between bandwidths used in this study. Presenting one bandwidth 480 cps wide and a second bandwidth 960 cps wide results in no significant difference in intelligibility scores. Therefore, the first hypothesis that there is no significant difference in intelligibility scores between a 480 cps bandwidth condition and a 960 cps bandwidth condition, both of which have a center frequency of 1560 cps, cannot be rejected.

The second hypothesis states that there is no significant difference in intelligibility scores due to increase in intensity level. The analysis in Table 2 shows that there is significant difference in intelligibility scores between intensity levels at the five

---

[49]E. F. Lindquist, Design and Analysis of Experiments in Psychology and Education (Boston: Houghton Mifflin Co., 1953), p. 267.

TABLE 2

ANALYSIS OF TYPE I DESIGN

Source	df	Sums of Squares	Mean Squares	F
Between Subjects	23	2617.278		
B (Bandwidth)	1	68.055	68.055	.587*
Error (b)	22	2549.223	115.873	
Within Subjects	48	42016.00		
A (Intensity)	2	40352.776	20176.388	607.320**
AB (Interaction)	2	201.446	100.723	3.03.=
Error (w)	44	1461.778	33.222	
Total	71	44633.278		

* An F of 4.30 is required for significance at the 5 per cent level of confidence, with df = 1, 22.

** An F of 3.214 is required for significance at the 5 per cent level of confidence, with df = 2, 44.

= An F of 3.214 is required for significance at the 5 per cent level of confidence, with df = 2, 44.

per cent level of confidence. Increasing the intensity level of the speech signal from 35 dB SPL to 50 dB SPL to 70 dB SPL under both bandwidth conditions results in an increase in intelligibility scores. Under the 480 cps bandwidth condition this change in intelligibility scores increased from about 16 per cent correct at 35 dB to 63 per cent correct at 70 dB. Under the 960 cps bandwidth condition there was an increase from 17.5 per cent correct at 35 dB to 56.3 per cent at 50 dB, to 72.6 per cent correct at 70 dB. Since there is significant difference in intelligibility scores as a function of intensity, the second hypothesis can be rejected.

The analysis of the AB effect in Table 2 (interaction between bandwidth and intensity level) reveals no significant interaction between bandwidth and intensity levels. Therefore, the third hypothesis which states that there is no significant interaction effect between width of bandpass and intensity levels, cannot be rejected.

Discussion

The analysis of the data obtained in this study indicated that the first hypothesis regarding differences in intelligibility scores obtained from two bandwidth condition, could not be rejected. The two bandwidths used in this study were one of 480 cps and another of 960 cps. The first included the range from 1320 to 1800 cps. The second enclosed the range of frequencies from 1080 to to 2040 cps. Both bandwidths had a center frequency of 1560 cps. The first bandwidth is only one-half as wide as the second bandwidth.

The analysis indicated, however, that there was no significant difference in intelligibility scores obtained under the two conditions. This would indicate that under the conditions of this study, intelligibility of speech was not impaired any more seriously by the narrowest bandwidth condition than it was by the widest bandwidth condition. Apparently enough information is transmitted through a 480 cps bandwidth centered around 1560 cps so that listeners are able to discriminate speech fully as well as they can when the bandwidth is twice as wide.

This finding is not in agreement with a study reported by Egan and Weiner[50] and reviewed in Chapter II of this thesis. They reported that intelligibility scores obtained from wide bandwidth conditions are always higher than those obtained from narrower bandwidths. This does not specify, however, how much wider that bandwidth must be in order to reach a significant increase in intelligibility scores.

One possible explanation for this inconsistency is that both bandwidths that were used in the present

---

[50]Egan and Weiner, op. cit., p. 439.

study were centered at 1560 cps. Kryter[51] and Harris and Brown[52] have reported in separate studies that the region around 1600 cps is the most important area for speech. It appears from the present study that enough phonetic clues are carried in this frequency region so that more than double the width of a 480 cps band of frequencies is required to produce a significant increase in intelligibility scores from one bandwidth condition to another.

Filtering such as that used in this study, produces frequency distortion of the speech signal. Such distortion is known to cause a decrease in intelligibility scores. In the report of Giolas and Epstein[53] reviewed in Chapter II, it was concluded that errors in intelligibility tests increase as distortion is increased by filtering. Any increase in distortion caused by filtering will produce a decrease in intelligibility scores. Such a decrease in intelligibility scores did not occur in the present study. One would expect that the 480 cps bandwidth would have more errors and thus a lower intelligibility score than the 960 cps bandwidth condition, according to the Giolas and Epstein study. Under the conditions of the present study, increase in distortion did not cause an increase in errors of intelligibility.

---

[51] Kryter, op. cit., p. 547.

[52] Harris and Brown, op. cit., p. 1999.

[53] Giolas and Epstein, loc. cit.

The widest bandwidth used in this study was twice as wide as the narrow bandwidth. There was no significant difference in intelligibility scores between the two bandwidths. This raises the question of how much wider the widest bandwidth of frequencies must be in order to produce a significant difference in intelligibility scores.

At the center frequency of 1560 cps, doubling the width of a 480 cps frequency band does not produce a significant difference in intelligibility scores. One is led to ponder what the results of a similar study would be if the center frequency of two like bandwidths were shifted either upward or downward on the frequency spectrum. For example, would there still be no significant difference in intelligibility scores for a bandwidth twice as wide as a second bandwidth if the center frequency for both bands were at 2500 cps, or at 1000 cps? Secondly, would the ratio of one bandwidth to another in terms of the needed increase in bandwidth to produce significant difference in intelligibility, be the same as it is for a center frequency of 1560 cps? Or would we find that this ratio would change at other points on the frequency spectrum?

The second hypothesis which dealt with differences in intelligibility of speech due to changes in intensity levels was rejected at the five per cent level of confidence. Three intensity levels were used in this study; 35 dB, 50 dB, and 70 dB sound pressure level.

Normal hearing adults will usually achieve a fifty per cent recognition score at about 22 dB sound pressure level, with monosyllable words in unfiltered conditions.[54] Under the filtering conditions used in the present study, intelligibility scores reached just over fifty per cent at the fifty decibel intensity level, twenty-eight decibels greater than that obtained under unfiltered conditions. At the lowest level of 35 dB, 13 dB above expected unfiltered speech reception threshold for the W-22, intelligibility scores obtained in this study did not reach twenty per cent correct.

Under unfiltered conditions, normal hearing adults can be expected to achieve a one hundred per cent correct intelligibility score at approximately speech reception threshold plus forty dB or at about sixty-two dB sound pressure level. In the present study, however, at the highest intensity level used (70 dB) intelligibility scores only reached a level of about seventy-two per cent correct, or twenty-eight per cent below what would be expected under unfiltered conditions for normal subjects.

The data in Figure 2 shows a large increase in intelligibility scores from 35 dB to 50 dB sound pressure level, but a much smaller increase from 50 dB to 70 dB sound pressure level. There is an increase in intelligibility scores due to increase in intensity. This is in

---

[54] Hirsh, et al., op. cit., p. 334.

agreement with a study reported by French and Steinberg[55] and reviewed in Chapter II, in which it was stated that an increase in intensity produces an increase in per cent correct recognition on articulation tests.

Improvement in intelligibility scores as a result of intensity increase appears to be a diminishing function as higher levels of intensity are reached, as illustrated by the smaller difference in scores between 50 dB and 70 dB as compared to the difference in scores between 35 dB and 50 dB. There is a rapid increase seen in per cent correct recognition as intensity increases at lower levels of intensity, but then there appears to be a tendency for the articulation curve to level or assume a maximum score at the higher intensity level without reaching one hundred per cent correct recognition. If a curve of best fit were drawn to produce such an articulation curve in Figure 2, it would appear to be of a similar shape to those found by Siegenthaler and Hardick[56] in a study of intelligibility scores for normal hearing adults and children under unfiltered conditions. The difference found between such a curve based on the present study and compared to the Siegenthaler and Hardick study would be one of placement of the curve rather than shape. That is, under the filtered

---

[55] French and Steinberg, <u>op. cit.</u>, p. 117.

[56] Siegenthaler and Hardick, <u>loc, cit</u>.

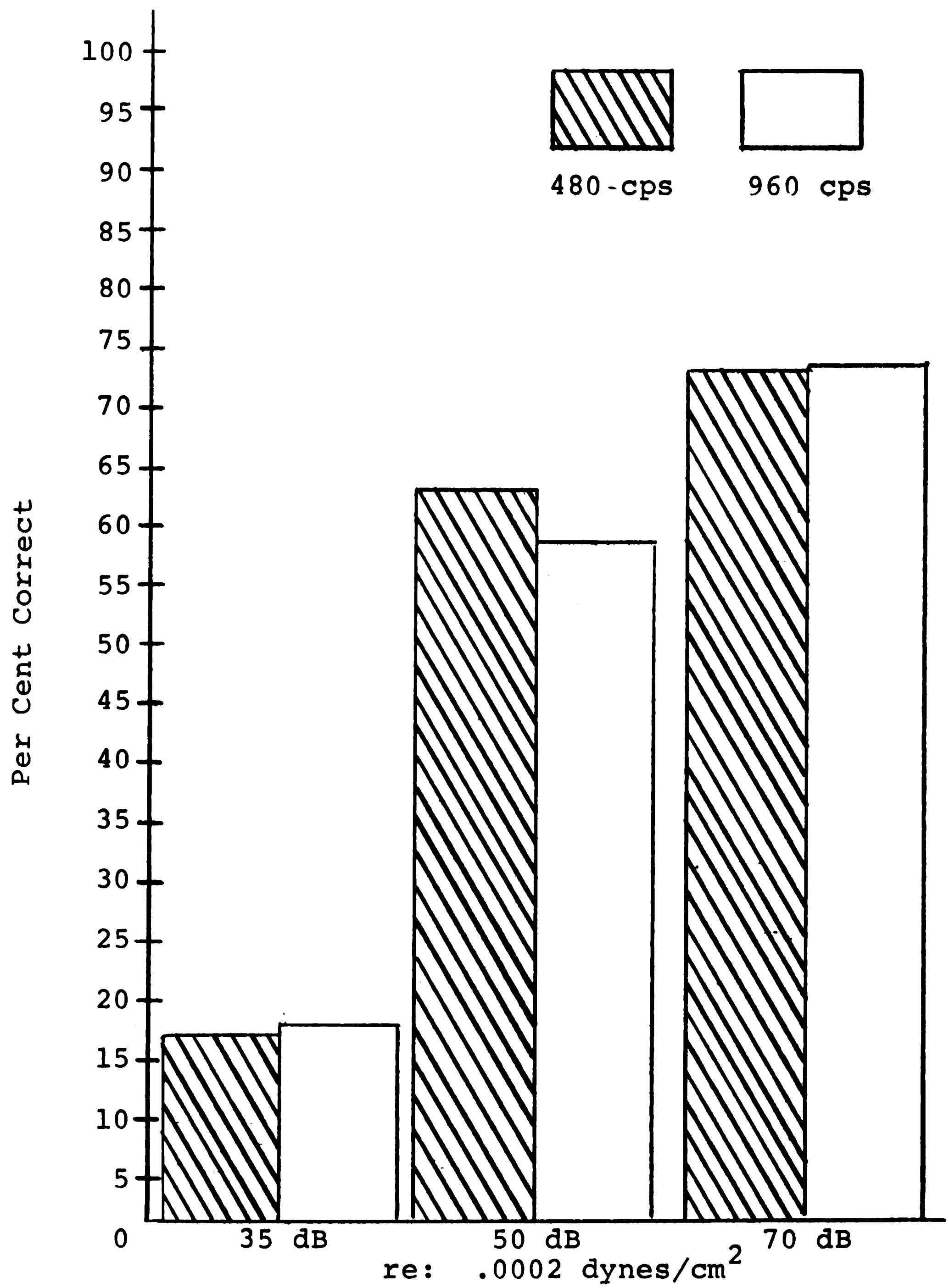

Fig. 2.--Mean Per Cent Scores Under Conditions of Filtering

conditions, the curve would be shifted to the higher intensity levels, and depressed into the lower intelligibility scores, but retain much the same shape.

Rejection of the second hypothesis indicates that there are significant differences in intelligibility scores obtained at one or more different intensity levels. Figure 2 illustrates the mean per cent correct scores for each bandwidth group at the three intensity levels used in the present study. One can see from this chart that there is a definite increase in intelligibility scores as intensity is increased. However, the scores obtained are lower than scores obtained from a similar articulation test under unfiltered conditions and do not reach a level of one hundred per cent correct recognition, regardless of the amount of increase in intensity.

Analysis of the data obtained in this study resulted in a failure to reject the hypothesis of no significant interaction between bandwidth and intensity levels. There are no outstanding scores obtained in this study that would indicate that any particular bandwidth reacts with a certain intensity level to produce unusual results.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Intelligibility of speech has been studied under many different conditions. This research has used test material made up of phonetically balanced word lists, nonsense syllables, continuous discourse, spondees, and other types of speech material. Some studies have been done employing normal hearing subjects and other studies have utilized subjects having various types of hearing impairments. Still other studies have attempted to simulate various types of hearing loss through the use of low-pass, high-pass, and band-pass filters. Filters have also been used to introduce frequency distortion into the speech signal so as to examine the effects of such distortion on intelligibility of speech. Filter systems have been used singly or in combinations to investigate the effects of a limited frequency spectrum upon intelligibility. Many studies have reported the effects of noise on intelligibility of speech, both in distortion-free investigations and under conditions of various kinds of distortion.

The present study investigated the effects of band-pass filtering upon the intelligibility of a common monosyllable word list. It was asked whether there would be a significant difference in intelligibility of speech between two bands of frequencies which are of different widths. A second aspect of this investigation was concerned with the effects of variation in intensity levels upon intelligibility. It was asked if there would be an increase in the intelligibility of speech with an increase in intensity level of the stimulus presentation. Finally, this study searched for any effects of interaction between bandwidths and intensity levels.

Twenty-four normal hearing subjects served as listeners in this study. These subjects were selected from the graduate and undergraduate student population of the Speech Department of Michigan State University. No persons were used who had extensive acquaintance or experience with the CID Auditory Test W-22. All subjects demonstrated a hearing acuity level of 10 dB (re: normal threshold) or better in both ears as measured by a portable pure tone audiometer in a sound treated room.

The subjects were randomly divided into two groups of twelve each. One group listened to the W-22 word lists under a 480 cps bandwidth condition centered at 1560 cps. The second group of subjects listened to the same lists under a 960 cps bandwidth condition at the same center frequency. Both groups of subjects recorded responses to a practice list at 90 dB SPL before beginning the actual experiment. Each group then listened to the lists at three intensity levels (35 dB, 50 dB, 70 dB, re: .0002 dynes per square centimeter). All listeners recorded their responses to the test material on prepared answer sheets.

Responses obtained from the two groups of subjects were analyzed using a two-way mixed Type I design analysis of variance. The result of this analysis indicated that there was no significant difference in intelligibility scores between a 480 cps bandwidth condition and a 960 cps bandwidth condition, both of which are centered at 1560 cps. The data showed that there was a significant difference in intelligibility scores as a result of intensity changes. There was found to be no significant interaction between bandwidth and intensity, under the conditions of this study.

Conclusions

From the findings of this study, it may be concluded that:

1. Limiting the frequency spectrum through the use of filtering produces a decrease in intelligibility of common monosyllable words.

2. Increasing the width of a band of frequencies from 480 cps to 960 cps while maintaining the same center frequency of 1560 cps, does not significantly improve intelligibility scores.

3. Under the conditions of this study, increasing the intensity level of the stimulus presentation produces an increase in the number of correct recognitions of the CID Auditory Test W-22 word lists.

4. There was found to be no interaction between the bandwidths and intensity levels utilized in this study.

Implications for Future Research

Analysis and discussion of the results of the present study have led to the formulation of several questions which have grown out of the data obtained in this experiment.

It has been found that doubling the width of a 480 cps band of frequencies centered at 1560 cps did not produce a significant difference in intelligibility scores. This finding leads one to question how much wider must the wide band be in order to obtain significantly different intelligibility scores between the two bandwidths.

Since there was no difference in intelligibility scores between these two bandwidths at a center frequency of 1560 cps, one wonders whether this would still be true at other center frequencies, such as at a center frequency of 1000 cps. Assuming that the factor of difference in bandwidth is not the same for other center frequencies, another question is raised, namely, how much difference is required for significant results at these other levels?

These questions indicate merely a small portion of the lack of knowledge regarding some areas of speech intelligibility. Despite the abundance of research on the intelligibility of speech, there is need of much more information.

BIBLIOGRAPHY

Books

Davis, Hallowell. Hearing and Deafness. New York: Holt Rinehart and Winsotn, Inc., 1963.

Fletcher, Harvey. Speech and Hearing in Communication. New York: D. Van Nostrand Co. Inc., 1953.

Gray, Giles W., and Wise, Claude M. The Bases of Speech. New York: Harper and Brothers, 1959.

Hirsh, Ira J. The Measurement of Hearing. New York: McGraw-Hill Book Co. Inc., 1952.

Lindquist, E. F. Design and Analysis of Experiments in Psychology and Education. Boston: Houghton Mifflin Co., 1953.

Newby, Hayes. Audiology. 2nd ed. revised. New York: Appleton Century Crofts, 1964.

Stevens, S. S. (ed.). Handbook of Experimental Psychology. New York: John Wiley & Sons, Inc., 1951.

Travis, Lee Edward, et al. Handbook of Speech Pathology. New York: Appleton Century Crofts, Inc., 1957.

Periodicals

Black, John W. "Accompaniments of Word Familiarity," Journal of Speech and Hearing Disorders, 17 (1952), 409-418.

Egan, James P. "Articulation Testing Methods," Laryngoscope, 58 (1949), 955-991.

Egan, James P. and Weiner, F. M. "On the Intelligibility of Bands of Speech in Noise," Journal of the Acoustic Society of America, 18 (1946), 435-441.

Elpern, Barry S. "Differences in Difficulty Among the CID W-22 Auditory Tests," Laryngoscope, 70 (1957), 1560-1565.

Fletcher, H. and Steinberg, J. C. "Articulation Testing Methods," Bell Systems Technical Journal, 8 (1929), 850-854.

French, N. R. and Steinberg, J. C. "Factors Governing the Intelligibility of Speech Sounds," Journal of the Acoustical Society of America, 19 (1949), 90-119.

Galt, Rogers G. "The Importance of Different Frequency Regions for Speech Intelligibility," Journal of the Acoustical Society of America, 20 (1948), 592.

Giolas, Thomas G. and Epstein, Aubrey. "Comparative Intelligibility of Word Lists and Continuous Discourse," Journal of Speech and Hearing Research, 6 (1963), 349-355.

Harris, J. Donald and Brown, Lawrence W. "Interactions Among Bandwidth, Center Frequency, and Type of Distortion in Speech Intelligibility," Journal of the Acoustical Society of America, 34 (1962), 1999.

Harris, J. Donald, Harris, H. L., and Myers, C. K. "The Importance of Hearing at 3KC for Understanding Speeded Speech," Laryngoscope, 70 (1957), 131-146.

Hawkins, J. E. and Stevens, S. S. "The Masking of Pure Tones of Speech by White Noise," Journal of the Acoustical Society of America, 22 (1950), 6-13.

Hirsh, Ira J., et al. "Development of Materials for Speech Audiometry," Journal of Speech and Hearing Disorders, 17 (1952), 321-337.

Hirsh, Ira J., Reynolds, E. G., and Joseph M. "Intelligibility of Different Speech Materials," Journal of the Acoustical Society of America, 26 (1954), 530-538.

Hudgins, C. V., et al. "The Development of Recorded Auditory Tests for Measuring Hearing Loss for Speech," Laryngoscope, 57 (1947), 57-89.

Huizing, H. S., Kruisinga, R. J., and Taseloar, M. "Triplett Audiometry: An Analysis of Band Discrimination in Speech Reception," Acta Oto-Laryngology, 51 (1960), 252-256.

Jerger, James, _et al._ "Some Relations Between Normal Hearing for Pure Tones and Speech," _Journal of Speech and Hearing Research_, 2 (1959), 126-140.

Kryter, Karl D. "Effects of Ear Protective Devices on the Intelligibility of Speech in Noise," _Journal of the Acoustical Society of America_, 18 (1946), 413-417.

Kryter, Karl D. "Methods for the Calculation and Use of the Articulation Index," _Journal of the Acoustical Society of America_, 34 (1962), 1689-1692.

Kryter, Karl D. "Speech Bandwidth Compression Through Spectrum Selection," _Journal of the Acoustical Society of America_, 32 (1960), 547-556.

Licklider, J. C. R. "Effects of Amplitude Distortion upon the Intelligibility of Speech," _Journal of the Acoustical Society of America_, 18 (1946), 429-434.

Licklider, J. C. R. and Miller, G. A. "The Intelligibility of Interrupted Speech," _Journal of the Acoustical Society of America_, 20 (1948), 593.

Owens, Elmer. "Intelligibility of Words Varying in Familiarity," _Journal of Speech and Hearing Research_, 4 (1961), 113-129.

Peterson, G. and Subrahmanyan, D. "Evaluation of Time-Frequency Scanning for Narrowband Speech Transmission," _Journal of the Acoustic Society of America_, 31 (1959), 110-114.

Pollack, Irwin. "Effects of High Pass and Low Pass Filtering on the Intelligibility of Speech in Noise," _Journal of the Acoustical Society of America_, 20 (1948), 259-266.

Shaw, W. A., Newman, E. R., and Hirsh, I. J. "The Difference Between Monaural and Binaural Thresholds," _Journal of Experimental Psychology_, 37 (1947), 229-242.

Sigenthaler, Bruce B. and Hardick, Edward. "Intelligibility Scores Using Various Phnetically Balanced Word Lists," _Pennsylvania Speech Annual_, (1959).

Tiffany, William and Bennett, Delmond. "Intelligibility of Slow-Played Speech," Journal of Speech and Hearing Research, 4 (1961), 248-258.

Unpublished Material

Hardick, Edward and Deal, Leo. "The Effects of Frequency Distortion on Speech Discrimination," Unpublished paper, Department of Speech, Michigan State University, 1962.

APPENDIX A

C.I.D. AUDITORY TEST W-22

List 1E	List 2E	List 3E	List 4E
1. them	1. that	1. add (ad)	1. ought (aught)
2. give	2. ill	2. we	2. wood (would)
3. it	3. knee	3. ears	3. through (thru)
4. ace	4. pew	4. start	4. ear
5. deaf	5. star	5. is	5. men
6. law	6. and	6. on	6. darn
7. yard	7. tree	7. jar	7. can
8. earn (urn)	8. odd	8. oil	8. shoe
9. see (sea)	9. dumb	9. smooth	9. tin
10. an	10. ham	10. end	10. so (sew)
11. dad	11. smart	11. use (yews)	11. my
12. what	12. with	12. book	12. am
13. toe	13. off	13. aim	13. few
14. jam	14. thin	14. wool	14. all (awl)
15. none (nun)	15. gave	15. do	15. clothes
16. ache	16. now	16. this	16. save
17. or (oar)	17. send	17. have	17. near
18. high	18. move	18. pie	18. yet
19. carve	19. ice	19. may	19. toy
20. there (their)	20. eat	20. lie (lye)	20. eyes (ayes)
21. day	21. rooms	21. raw	21. bread (bred)
22. not (knot)	22. cars	22. hand	22. pale (pail)
23. she	23. air (heir)	23. though	23. leave
24. bells	24. new (knew)	24. cute	24. yes
25. wire	25. jaw	25. year	25. they

26. owl	26. will	26. three	26. be (bee)
27. up	27. die (dye)	27. bill	27. dolls
28. twins	28. one (won)	28. chair	28. jump
29. poor	29. then	29. say	29. of
30. him	30. own	30. glove	30. than
31. thing	31. bin (been)	31. nest	31. why
32. ran	32. key	32. farm	32. arm
33. chew	33. oak	33. he	33. hang
34. as	34. young	34. owes	34. nuts
35. true	35. live (verb)	35. done (dun)	35. aid
36. stove	36. hit	36. ten	36. net
37. felt	37. by (buy)	37. are	37. who
38. low	38. chest	38. when	38. chin
39. bathe	39. show	39. tie	39. where
40. skin	40. cap	40. camp	40. stiff
41. us	41. ail (ale)	41. shove	41. go
42. hunt	42. tare (tear)	42. knit	42. hit
43. knees	43. hurt	43. no (know)	43. cook
44. mew	44. way (weigh)	44. king	44. art
45. you (ewe)	45. else	45. if	45. will
46. east	46. does	46. out	46. tea (tee)
47. me	47. yore (your)	47. dull	47. in (inn)
48. wet	48. too (two, to)	48. tan	48. our (hour)
49. could	49. flat	49. ate (eight)	49. dust
50. isle (aisle)	50. ease	50. west	50. at

APPENDIX B

Subjects Answer Sheet

1. ______	26. ______	1. ______	26. ______
2. ______	27. ______	2. ______	27. ______
3. ______	28. ______	3. ______	28. ______
4. ______	29. ______	4. ______	29. ______
5. ______	30. ______	5. ______	30. ______
6. ______	31. ______	6. ______	31. ______
7. ______	32. ______	7. ______	32. ______
8. ______	33. ______	8. ______	33. ______
9. ______	34. ______	9. ______	34. ______
10. ______	35. ______	10. ______	35. ______
11. ______	36. ______	11. ______	36. ______
12. ______	37. ______	12. ______	37. ______
13. ______	38. ______	13. ______	38. ______
14. ______	39. ______	14. ______	39. ______
15. ______	40. ______	15. ______	40. ______
16. ______	41. ______	16. ______	41. ______
17. ______	42. ______	17. ______	42. ______
18. ______	43. ______	18. ______	43. ______
19. ______	44. ______	19. ______	44. ______
20. ______	45. ______	20. ______	45. ______
21. ______	46. ______	21. ______	46. ______
22. ______	47. ______	22. ______	47. ______
23. ______	48. ______	23. ______	48. ______
24. ______	49. ______	24. ______	49. ______
25. ______	50. ______	25. ______	50. ______

APPENDIX C

You are going to hear four lists of one-syllable words. Some lists will be very loud and some lists will be very quiet. Each list contains fifty words which correspond with the fifty numbered blank spaces on the answer sheet in front of you. You are to write the word you hear, or think you hear, in the appropriate numbered space. If you miss a word or cannot make out what the word is, leave the space blank and go on to the next one. Listen carefully and write down as many words as you can.

At the end of each list will be a short pause during which you should locate the next list of blanks on your answer sheet. You will notice that the lists on your answer sheet are numbered from one to four. Be sure to use them in that order.

Please work as quietly as possible in order to reduce the amount of noise in the room.

Thank you for your assistance.