



A STUDY OF ENERGY VARIATIONS OF
TWELVE VOWEL SOUNDS USING THREE
METHODS OF PICKUP WITHIN
THREE BANDWIDTHS

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ABSTRACT

A STUDY OF ENERGY VARIATIONS OF TWELVE VOWEL SOUNDS USING THREE METHODS OF PICKUP WITHIN THREE BANDWIDTHS

by Glenna Collins

The purpose of this study is to explore the energy variations at each of three bandwidths for twelve vowels of the English language simultaneously recorded at the lips and forehead of six different speakers using three types of pickup devices.

The subjects for this study were six air cadets at the Naval Air Station, Pensacola, Florida. They were asked to intone the twelve vowel sounds [*i, I, e, ε, æ, a, ʌ, o, u, ʊ, ʌ, and ʒ*] which were then simultaneously recorded from pickup points at the forehead by a bone oscillator and condenser microphone, and by a condenser microphone at the lips.

The findings of this study indicate a greater mean vowel amplitude for air conduction. They also indicate a significant difference in the mean amount of energy between vowels for bandwidths I, II, and III (100-199 cps, 200-499 cps, 500-999 cps), between pickup methods for bandwidths I, II, and III, and a significant interaction between vowels and points of pickup for bandwidths I and III at the 5 percent level of confidence. The significant difference between any two vowel sounds may be due to some interaction taking place

between the two vowels in question and the points of pickup or may be a function of the pickup points. The findings also indicate the relationship between any two points of pickup and the amount of energy for any given vowel.

The conclusions which were drawn from this study suggest that air conduction is a better method of pickup than bone or tissue conduction as far as vowel amplitude is concerned. The front vowels tend to be alike in mean energy in all of the bandwidths. Also, most of the significant relationships between any two points of pickup and the amount of energy for any given vowel are found in bandwidth I.

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By

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Past studies indicate that intelligible speech can be recorded from various locations on the speaker's body other than the lips. Several studies have been done either directly or indirectly on tissue transmitted speech, and some have appeared to have merit as far as intelligibility of speech and listener preference are concerned.

The problem under investigation in this study is to compare the energy variations at each of three bandwidths for twelve vowels of the English language simultaneously recorded at the lips and forehead of six different speakers using three types of pickup devices. Knowledge in this area should provide additional insight as to the possibility of using body transmitted speech in place of speech picked up at the lips of the speaker.

Statement of Problem and Purpose of Study

The problem from which this study arose is that of determining the intelligibility of tissue transmitted speech with different types of pickup equipment. The purpose of this study is to analyze the results obtained from exploring systematically the energy variations of twelve vowel sounds picked

up at the forehead and the lips using a condensor microphone and bone oscillator at the forehead and a control microphone for the mouth emitted signal pickup.

From this analysis it is hoped that answers to the following questions can in part be obtained:

1. Does the mean amount of energy differ from vowel to vowel within each of the three bandwidths?
2. Does the mean amount of energy differ as a function of pickup methods within each of the three bandwidths?
3. Is there an interaction between vowels and points of pickup within each of the three bandwidths?
4. What is the relationship between any two points of pickup and the amount of energy for each vowel?

Hypotheses

These questions can be formulated into the following null hypotheses:

1. There is no significant difference in the mean amount of energy between vowels within each of the three bandwidths.
2. There is no significant difference in the mean amount of energy between pickup methods within each of the three bandwidths.
3. There is no significant interaction between vowels and points of pickup within each of the three bandwidths.

4. There is no significant correlation between the amount of energy for any given vowel and any two points of pickup.

Importance of Study

Several studies relating directly or indirectly to tissue transmitted speech have been reported. Numerous anatomical sites have appeared to have merit as far as intelligibility of speech and listener preference are concerned.

This study was designed to explore systematically the variations in energy signals of speech picked up at the lips and the forehead. It will provide additional information concerning the energy of vowels for different bandwidths and give insight as to the possibility of using the forehead as a point of pickup of speech.

This type of information could be of value to those working on special projects concerned with transmission of speech signals.

Definition of Terms

Bandwidth

A frequency band expressing in cycles per second the range of frequencies from 100-9,999 cps within which six divisions were made in the original study as follows: 100-199 cps; 200-499 cps; 500-999 cps; 1000-1999 cps; 2000-4999 cps; 5000-9999 cps.

Decibel

A relative unit of power using .0002 dyne per cm² as a reference level which increases as a logarithm of the ratio of the greater intensity to the lesser intensity.¹

Bone Conduction Pickup

A method of picking up sound waves that are conducted via bone using a bone oscillator on the frontal bone of the speaker's skull, one inch above the nasalis.

Tissue Conduction Pickup

A method of picking up sound waves that are conducted via tissue using a condensor microphone (Altec 21 D) at the forehead of the speaker.

Air Conduction Pickup

A method of picking up sound waves that are conducted via air from the lips using a microphone (Altec 21 D) positioned approximately eighteen inches in front of the speaker's mouth.

¹Giles W. Gray and Claude M. Wise, The Bases of Speech (New York: Harper & Brothers, 1959), pp. 106-107.

CHAPTER II

REVIEW OF THE LITERATURE

During the past thirty-six years some interest has been manifested by several investigators in the recording of vocal and speech signals from various locations on the body of the speaker. Some investigators have designed experiments in order to measure the intelligibility of the tissue transmitted signals, whereas others have merely mentioned their observations of such signals while in the process of exploring something else.

As far back as 1926, Robert West reported a study of the nature of vowel sounds utilizing a stethoscope at various anatomical locations to listen to sounds as they were produced.²

In 1927 an article in the Quarterly Journal of Speech Education written by Clarence Simon and Franklin Keller described in detail how seven areas of the body were examined and how the vibrations were photographically recorded as the subject intoned the vowel [O].

Voice and chest waves were recorded simultaneously by means of phonoscopes. Contact with the body was made with a carbon microphone, with the diaphragm removed. The protruding

²Robert West, "The Nature of Vocal Sounds," Quarterly Journal of Speech Education, 12 (1926), pp. 224-293.

pin picked up vibrations within a restricted area of three inches around the point of contact. In all subjects, vibrations picked up from the right wing of the cartilage followed most closely the cord tone.³

In 1932 an investigation of chest resonance, as reported by Claude Wise, showed that the conductile efficiency of human tissue varied and decreased in the following sequence: (1) body tissue, (2) tendinous tissue, (3) tense muscle tissue, (4) relaxed muscle tissue, and (5) soft nonmuscular tissue.⁴

In the early thirties, the Signal Corps Acoustical Laboratory, Fort Monmouth, New Jersey, was interested in developing a microphone that could be used in noisy environments and could be worn in such a manner to leave both hands free. The late George Graham, a section chief at that time suggested that a sound powered receiver unit might be employed as a receiver and as a microphone driven by the sound transmitted via the Eustachian tube. Information concerning this research project was obtained by Oyer in communications with those associated with the research.⁵

³Clarence Simon and Franklin Keller, "An Approach to the Problem of Chest Resonance," Quarterly Journal of Speech Education, 13 (1927), pp. 432-439.

⁴Claude M. Wise, "Chest Resonance," Quarterly Journal of Speech, 18 (1932), pp. 446-452.

⁵Herbert J. Oyer, "Relative Intelligibility of Speech Recorded Simultaneously at the Ear and Mouth," The Journal of the Acoustical Society of America, 27 (November, 1955), pp. 1208-1209.

Harry W. Parmer (in early thirties), Chief, Advanced Systems Engineering Group, recalled (in 1955) that a bone conduction receiver was modified to provide a small diaphragm for driving the receiver unit. When properly placed in close contact with the skin, the diaphragm was fairly effective in excluding external noise. Highest output was obtained when the unit was employed as a throat microphone, but the best speech quality was derived when the unit was located on the cheek close to the top of the ear or directly in front of the lower part of the ear. The possibility of utilizing cheek units, however, was abandoned due to mounting difficulties.⁶

Albert E. Woodruff (in the early thirties, a member of the Research Department, Automatic Electric Company) recalled that the Company was requested by the Signal Corps to design an especially sensitive receiver for use as an ear microphone. His observations led him to believe that an ear microphone was not successful if it were pressed tightly against the ear. This led him to believe that successful use of the ear microphone was largely dependent upon air-bourne speech signals. The use of effective ear cushions and other means of decreasing air-bourne signals seemed to confirm this notion, thus leading to the conclusion that no more speech energy could be picked up from the ear canal than from the skull elements surrounding it.⁷

⁶Ibid.

⁷Ibid.

In 1949 James Mullendore reported on a study of the relative amplitudes of sound vibration at various body locations during sustained productions of vowel sounds. This study showed the composite rank of intensity at ten microphone positions to be: (1) thyroid cartilage, (2) mandible, (3) nose, (4) top of head, (5) clavicle, (6) vertebra, (7) sternum (superior end), (8) sternum (inferior end), (9) mastoid, (10) fifth rib.⁸

In 1951 von Békésy and Rosenblith reported in the Handbook of Experimental Psychology that vibrations of the surface of the skin that are recorded by means of a pickup at various body locations while the subject sings a vowel that has a displacement amplitude in the vicinity of the ear is only one-twentieth of the amplitude recorded near the vocal cords. The attenuation between the oral cavity and the ear canal was reported to be forty to fifty decibels.⁹

Hirsh and Benson in 1952 stated in a WADC Technical Report that the ear canal does provide a source of sound pressure which can be utilized for delivery of speech from talker to listener in a communications system. Sounds from this source appear to have quality as good as sounds picked up at the lips of the talker.¹⁰

⁸James M. Mullendore, "Relative Amplitudes of Sound Vibrations at Various Body Locations," Speech Monographs, 16 (1949) pp. 163-177.

⁹S. S. Stevens (ed.), Handbook of Experimental Psychology (New York: John Wiley & Sons Inc., 1951), pp. 111.

¹⁰I. J. Hirsh and R. W. Benson, "Wright Air Development Center, WADC Technical Report No. 52, 175," (May, 1952), pp. 20-21.

In 1955 Oyer carried out a study to determine the relative intelligibility of simultaneously recorded speech signals picked up at the lips and left ears of speakers. This study, as recorded by Oyer, showed that as listening conditions became more difficult the signal picked up at the ear canal was more intelligible than simultaneous recordings at the lips.¹¹

The need for improved microphones and receivers in aviation was pointed out in the 1956 study reported by Moser and Dreher. They stated that both transmission and reception of signals would be improved by lightening the weight and simplifying the radio equipment. Hygiene and sanitation would be improved by equipment inexpensive enough to allow personal ownership of components. The ear and bone units used as microphones in this experiment proved to be equal in performance to those presently used.¹²

In the course of ear-signal investigation (from 1955-1957) at Ohio State University Psycholinguistics Laboratory a report of relative intensities of sounds at various anatomical locations of the head and neck during phonation of the vowels was made by Moser and Oyer. Results showed the signals that were most intense were picked up immediately

¹¹Oyer, op. cit.

¹²Henry M. Moser and John J. Dreher, "Operational Tests of Miniature Microphones and Receiver" (Technical Report No. 36", AFCRC TN 56-57, (Oct., 1956), pp. 1-3.

below the superior thyroid notch of the laryngeal prominence and least intense signals were picked up from the squama of the temporal bone one inch above the external auditory meatus. The forehead signal was weak but quite clear.¹³

In 1958 Oyer, Moser, and Wolfe did a further analysis of the 1955 Oyer study. It was the purpose of this study to analyze differences in listener's responses to speech signals picked up in the ear and in front of the lips. It was found that more confusion occurred for ear-recorded than for lip-recorded speech signals. As the listening conditions became more adverse, the listeners tended to omit more of the words recorded at the lips but continued to make attempts to respond to those recorded at the ear. Words containing the[ʌ] sound were significantly more intelligible when the stimulus was recorded at the lips whereas the opposite was true for[i, ɛ, e, and I] vowels. There was no apparent relationship between consonant structure and intelligibility of the test words. It appears from this study that a trained listening panel takes more cues from the vowel and diphthong components than from the consonants.¹⁴

A preliminary study reported by Snidecor, Rehman, and Washburn in 1959 investigated the relative power of the vowels

¹³Henry M. Moser and Herbert J. Oyer, "Relative Intensities of Sounds at Various Anatomical Locations of the Head and Neck during Phonation of the Vowels," The Journal of the Acoustical Society of America, 30 (April, 1958), pp. 175-177.

¹⁴Herbert J. Oyer, Henry M. Moser, and Susan M. Wolfe, "Relationship of Phonetic Structure to the Intelligibility of

[i, ɛ, ʌ, ʊ] and the relative quality preference for a standard sample of continuous speech. The locations of forehead, mastoid process, larynx, mandibular angle, ear canal, and nose give promise of being suitable pickup positions during military duties requiring that no lip or free-field microphone be used.¹⁵

Words Simultaneously Recorded at Ear and Lips," Journal of Speech and Hearing Research, 3 (March, 1960) pp. 44-50.

¹⁵John C. Snidecor, Irving Rehman, and David D. Washburn, "Speech Pickup by Contact Microphone at Head and Neck Positions," Journal of Speech and Hearing Research, 2 (Sept., 1959).

CHAPTER III

SUBJECTS, EQUIPMENT, MATERIALS, AND PROCEDURES

Introduction

The material in this chapter is divided into two parts. In Part I is presented an explanation of the experimental arrangements pertaining to the simultaneous recording of the vowel sounds.¹⁶ In Part II is presented an explanation of the experimental arrangements involved in the physical analyses of the acoustic properties of the vowel sounds.

Part I

I. Subjects

The subjects participating in the original study were air cadets at the Naval Air Station, Pensacola, Florida. There were six in all.

II. Equipment

The equipment employed in the original study were as follows:

1. Tape Recorder
2. Two Condenser Microphones (Altec 21B)

¹⁶Information derived from personal interviews with H. J. Oyer. July, 1962; January, 1963.

3. Bone Oscillator (Dyna-Jet)

4. Helmet (Naval Flight Type)

III. Material

The material utilized in this study consisted of twelve vowels. They were as follows: [*i*, *I*, *e*, *ε*, *æ*, *a*, *ɔ*, *o*, *u*, *ʌ*, *ɜ*'].
u, *ʌ*, *ɜ*'].

IV. Procedure

The procedures employed in the original study were as follows:

Recording

Each of the six subjects was requested to sit in a chair that had attached to it a head stabilizer. A helmet that contained one condenser microphone and a bone oscillator was then placed on the head of the subject. A condenser microphone was placed eighteen inches from the lips of the speaker and was mounted on a microphone stand. The subject was asked to intone the twelve vowel sounds listed above. With this arrangement it was possible to effect a simultaneous recording of vowel sounds picked up at the forehead by the bone oscillator and the condenser microphone at the same time the vowel sounds were being picked up at the lips.

Figure 1 presents a schematic representation of the arrangement of recording equipment.

Part II

The recorded vowel sounds were then fed to an analyzer for analysis of acoustic components. The type of equipment

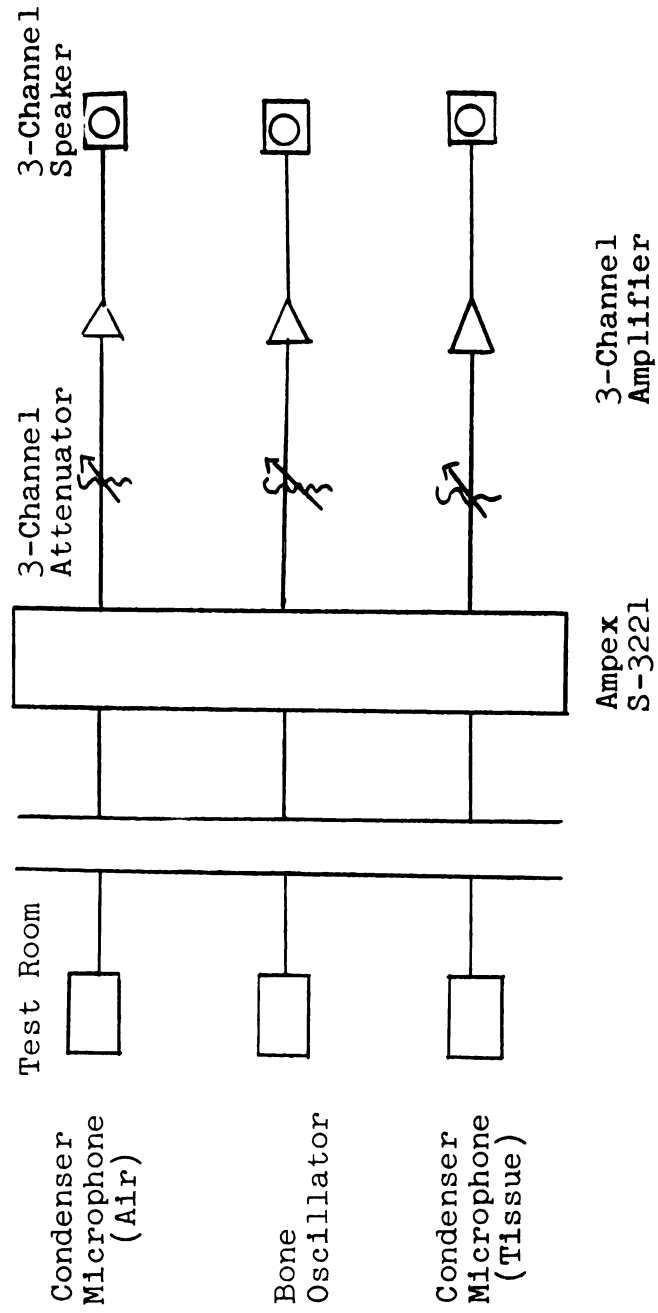


Figure 1.--Schematic representation of equipment arrangement utilized in simultaneous recording of vowel sounds. Level was set on Speaker 1 so that each channel produced Zero VU. Levels were adjusted slightly for each speaker.

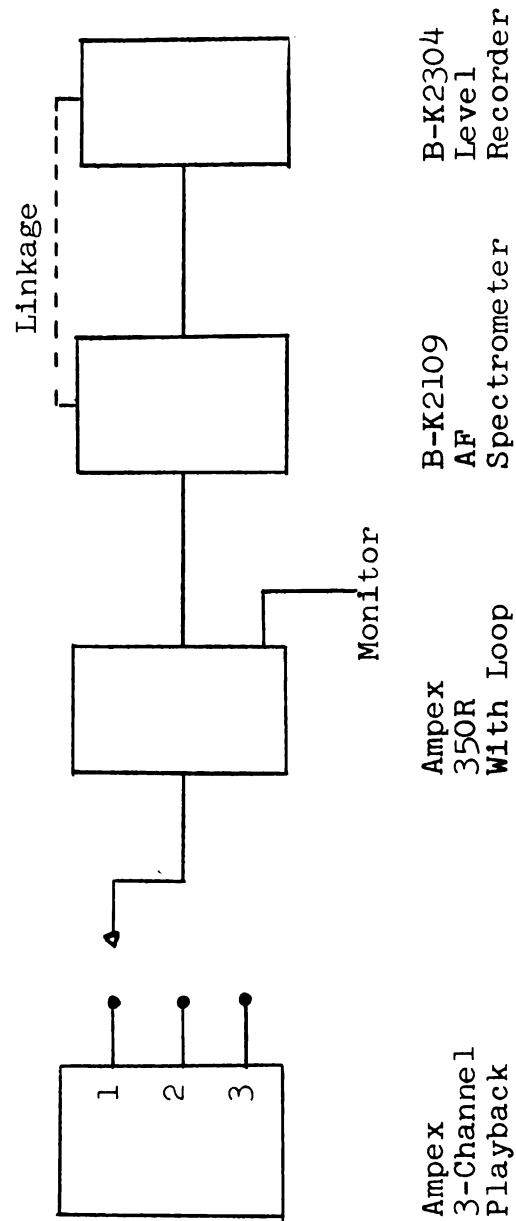


Figure 2.--Schematic representation of equipment employed in the one-third octave band analysis of the vowel. Tape Loop Level set at -5VU for [i]. Level Recorder set at 40 for [i] in linear channel.

employed permitted a one third octave band analysis. Figure 2 presents a schematic representation of the equipment employed.

The paper tapes from the level recorder were then analyzed. These tapes were divided vertically into six bandwidths expressed in cycles per second from 100-9,999 and horizontally into decibels. A tape was made as each speaker intoned a vowel sound covering the three methods of pickup. Consequently there were thirty-six tapes for each of the six speakers or two hundred-sixteen paper tapes to be analyzed in all.

The mean energy was tabulated for each bandwidth by finding the average of the three highest peaks of the tracings within each bandwidth. These raw scores were then charted by speakers for each method of pickup over all twelve vowels. Since it was evident at this point that there were mostly zero scores for the last three bandwidths, only three bandwidths were included in this study with 100-199 cycles per second being referred to as bandwidth I, 200-499 cycles per second being referred to as bandwidth II, and 500-999 cycles per second being referred to as bandwidth III.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The data necessary to begin this study were obtained by analyzing the paper tapes taken from the level recorder. The mean amplitude in decibels was found for each bandwidth and these data were charted according to vowels, speakers, and points of pickup. A separate analysis of variance was done for each of the three bandwidths utilized in this study in order to determine whether or not a significant difference was evident between vowels and between points of pickup and whether or not there was a significant interaction between vowels and points of pickup at the 5 percent level of significance.

A test of individual comparisons was applied to all possible pairs of means to determine which means were significantly different in each of the three bandwidths over all three methods of pickup.

Correlation coefficients were worked out between each possible pair of pickup points for each of the twelve vowel sounds to establish the relationship between the points of pickup and the amount of energy for any given vowel.

Bandwidth

Upon inspection of the raw scores it was evident that very little acoustical energy was contained in the last three of the six bandwidths. Because the mean amplitudes for these last three bandwidths were close to zero, they were omitted for not contributing anything to the analysis. For this reason, only three bandwidths were utilized in this study. These bandwidths expressed in cycles per second were 100-199, 200-499, and 500-999 and shall be referred to as bandwidths I, II, and III respectively.

Raw Scores

Raw scores were obtained for each of the bandwidths by computing the mean amplitude or energy in decibels using the three highest peaks within each of the bandwidths. The raw scores for each of the three bandwidths used were placed according to vowels and points of pickup, with each of the twelve vowels having six values, one for each speaker for each of the three points of pickup. These raw scores are presented in Appendix I.

Results

From Table I it is evident that the mean vowel amplitude is greater for air conduction than for bone or tissue conduction in all three bandwidths. One might expect air conduction to have the highest mean vowel amplitude since air is known to be a good conductor of sound waves. Then one would

TABLE I

MEAN AMPLITUDE (db re: 0.0002 dyne/cm²) OF TWELVE
VOWELS IN EACH OF THREE BANDWIDTHS FOR THREE
PICKUP POINTS WITHIN EACH BANDWIDTH

													Mean Vowel Ampli- tude	
<i>i I e ɛ æ a ʌ o ʊ u ʌ ʒ</i>														
I	AC	33.2	32.6	31.1	29.3	29.3	29.2	28.8	31.2	32.8	34.0	31.1	31.1	31.14
	BC	21.4	17.7	18.2	14.2	12.8	13.8	14.7	18.0	20.3	21.1	15.5	17.5	17.10
	TC	28.8	23.9	24.5	20.1	19.0	19.4	21.3	25.6	26.8	29.1	22.1	25.0	23.80
II	AC	32.2	37.2	36.8	32.2	30.2	29.2	31.3	38.1	39.5	37.2	32.2	37.2	34.45
	BC	32.6	32.6	33.7	26.6	23.4	24.2	25.3	32.9	34.3	34.5	27.0	31.8	29.91
	TC	30.5	29.9	30.4	23.0	20.8	21.5	22.0	29.3	32.3	32.4	22.6	29.7	27.03
III	AC	11.0	23.7	22.5	33.1	36.0	40.4	41.3	33.3	29.6	23.2	38.8	30.5	30.28
	BC	10.8	19.6	19.0	26.1	27.5	31.3	33.2	27.9	24.2	19.4	29.2	24.0	24.35
	TC	4.6	6.1	5.4	7.9	8.2	11.0	13.3	12.5	9.4	7.4	10.8	9.2	8.82

AC = air conduction

BC = bone conduction

TC = tissue conduction

probably expect bone conduction to have the next highest mean vowel amplitude and tissue conduction to have the lowest since bone or any solid substance with a high density is a better conductor of sound waves than tissue of unequal density and resiliency. However, from Table I it can be seen that bandwidth I did not follow this pattern in this study. Further research is needed in this area to obtain any definite conclusions.

A separate analysis of variance was done for each of the three bandwidths. The differences in column means, (vowels) and the differences in row means, (points of pickup) were investigated utilizing an analysis of variance design described by Dixon and Massey as appropriate with two variables of classification and repeated measurements.¹⁷

The analysis in Table II reveals that there is significant difference in the mean amount of energy between vowels at the 5 percent level of confidence. There is also a significant difference in the mean amount of energy between pickup methods at the 5 percent level of confidence and a highly significant interaction between the vowels and points of pickup.

Therefore, in view of this information, the first hypothesis which states that there is no significant difference in the mean amount of energy between vowels for bandwidth I would be rejected. The second hypothesis which states that there is no significant difference in the mean amount of energy between

¹⁷Wilfrid J. Dixon and Frank J. Massey Jr., Introduction to Statistical Analysis (New York: McGraw-Hill Book Company Inc., 1957), pp. 163-168.

TABLE II

ANALYSIS OF VARIANCE OF THE MEAN AMOUNTS OF
ENERGY IN BANDWIDTH I OF THE TWELVE VOWELS
UNDER THREE METHODS OF PICKUP

Source	Sum of Squares	df	Mean Square	F
Row Means or Pickup Points	7,035.24	2	3,517.62	2,883.3*
Column Means or Vowels	1,412.37	11	128.40	105.2**
Interaction	4,253.74	22	193.35	158.5 ^x
Subtotal	12,701.35	35		
Within Groups	220.45	180	1.22	
Total	12,921.80	215		

*With df of 2 and 180 and F of 3.00 is required for significance at the 5 percent level of confidence.

**With df of 11 and 180 an F of 1.79 is required for significance at the 5 percent level of confidence.

^xWith df of 22 and 180 an F of 1.54 is required for significance at the 5 percent level of confidence.

pickup methods for bandwidth I would also be rejected, and the third hypothesis which states that there is no significant interaction between the vowels and pickup points for bandwidth I would be rejected.

The analysis shown in Table III reveals that at the 5 percent level of confidence there is a significant difference in the mean amount of energy between vowels. There is also a significant difference in the mean amount of energy between pickup methods. However, the data shows a non-significant interaction between the vowels and points of pickup.

The presentation of data for bandwidth II reveals that the first and second hypotheses which state that there is no significant difference in mean amount of energy between vowels and between pickup methods would be rejected. Results indicate a failure to reject the third hypothesis because there is no significant interaction between the vowels and points of pickup for bandwidth II.

Table IV reveals that there is a significant difference in the mean amount of energy between vowels and between points of pickup at the 5 percent level of confidence. There is also a significant interaction between the vowels and points of pickup at the 5 percent level of confidence for bandwidth III.

In view of this information, the first, second, and third hypotheses would be rejected for bandwidth III.

The F-Test in this analysis is regarded as an overall test of significance determining whether the amount of energy for any one or more of the twelve vowels is significantly different from the amount of energy for any of the other twelve

TABLE III

ANALYSIS OF VARIANCE OF THE MEAN AMOUNTS OF
ENERGY IN BANDWIDTH II OF THE TWELVE VOWELS
UNDER THREE METHODS OF PICKUP

Source	Sum of Squares	df	Mean Square	F
Row Means or Pickup Points	2,020.22	2	1,010.11	76.9*
Column Means or Vowels	3,189.20	11	289.9	22.1**
Interaction	207.17	22	9.4	.72 ^x
Subtotal	5,416.59	35		
Within Groups	2,363.89	180	13.13	
Total	7,780.48	215		

*An F of 3.00 is required for significance at the 5 percent level of confidence with df of 2 and 180.

**An F of 1.79 is required for significance at the 5 percent level of confidence with df of 11 and 180.

^xAn F of 1.54 is required for significance at the 5 percent level of confidence with df of 22 and 180.

TABLE IV

ANALYSIS OF VARIANCE OF THE MEAN AMOUNTS OF
ENERGY IN BANDWIDTH III OF THE TWELVE
VOWELS UNDER THREE METHODS OF PICKUP

Source	Sum of Squares	df	Mean Square	F
Row Means or Pickup Points	17,140.25	2	8,570.12	310.06*
Column Means or Vowels	11,011.04	11	1,001.00	36.21**
Interaction	2,074.39	22	94.29	3.42 ^x
Subtotal	30,255.68	35		
Within Groups	4,975.25	180	27.64	
Total	35,200.93	215		

*An F of 3.00 is required for significance at the 5 percent level of confidence with df of 2 and 180.

**An F of 1.79 is required for significance at the 5 percent level of confidence with df of 11 and 180.

^xAn F of 1.54 is required for significance at the 5 percent level of confidence with df of 22 and 180.

vowels. It does not necessarily follow that the mean amount of energy for each of the twelve vowels differs from all other vowels. Therefore, a test of individual comparisons was applied to all possible pairs of means to determine which means were significantly different in each of the three bandwidths over all three methods of pickup.

The critical difference was computed corresponding to the 5 percent level. The mean amount of energy for each vowel was compared with each other vowel in bandwidths I, II, and III over all three methods of pickup with the results presented in Tables V, VI, and VII respectively.¹⁸

¹⁸ E. F. Lindquist, Design and Analysis of Experiments in Psychology and Education (Boston: Houghton Mifflin Company, 1953), pp. 90-96.

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TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH I
AIR CONDUCTION

[illegible]

TABLE V--Continued

TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH I
BONE CONDUCTION

[illegible]

TABLE V--Continued

TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH I
TISSUE CONDUCTION

[illegible]

TABLE VI

TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH II
AIR CONDUCTION

	I	e	ɛ	æ	ɑ	ɔ	o	ʊ	u	ʌ	ɜ
i	4.9*	4.5*	.1	2.1	3.1	.1	5.8*	7.2*	4.9*	.1	4.9*
I		.4	5.0*	7.0*	8.0*	5.9*	.9	2.3	0	5.0*	0
e			4.6*	6.6*	7.6*	5.5*	1.3	2.7	.4	4.6*	.4
ɛ				2.0	3.0	.9	4.1*	7.3*	5.0*	0	5.0*
æ					1.0	1.1	7.9*	9.3*	7.0*	2.0	7.0*
ɑ						2.1	8.9*	10.3*	8.0*	3.0	8.0*
ɔ							6.8*	8.2*	5.9*	.9	5.9*
o								1.4	.9	5.9*	.9
ʊ									2.3	7.3*	2.3
u										5.0*	0
ʌ											5.0*
ɜ											
i											
I											
e											
ɛ											
æ											
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ɜ											

With a critical difference of 4.12 at the 5 percent level of confidence, the values for the pairs of vowels marked with an asterisk show a significant difference.

TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH II
BONE CONDUCTION

[illegible]

TABLE VI--Continued

TABLE VII--Continued

TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH III
BONE CONDUCTION

[illegible]

TABLE OF DIFFERENCES FOR PAIRS OF VOWELS IN BANDWIDTH III
TISSUE CONDUCTION

TC

When comparing all of the front vowels [*i*, *I*, *e*, *ɛ*, *æ*] with each other over all three bandwidths, approximately one-third tend to be alike in mean energy. That is, there is not enough difference between this one-third to be significant according to the critical difference determined for each bandwidth. Approximately one-fourth of the back vowels [*ʊ*, *u*, *o*, *ɔ*], and one-sixth of the central vowels [*ʌ*, *ɜ*[^]] tend to be alike in mean energy over all three bandwidths. When looking at the bandwidths separately, bandwidth II contains the greatest number of vowel pairs that tend to be alike in mean energy or that are not significantly different in mean energy. Bandwidth III has the second highest number with bandwidth I having the fewest. In all three bandwidths, the front vowel pairs are the most numerous in tending to be alike in mean energy to the extent that they are not significantly different with the back vowel pairs being second highest in number.

When comparing all of the pairs of front vowels with each other, it can be seen that ten pairs of front vowels are alike in mean energy in bandwidth I, seventeen pairs in bandwidth II, and one pair in bandwidth III. In bandwidth I there are four pairs of central vowels alike in mean energy. The front vowels are the only pairs of vowels with the exception of the central vowels in bandwidth I that show a likeness in mean energy. None of these pairs of vowels is the same from bandwidth to bandwidth.

More research is needed in this area to determine the significance of more pairs of front vowels falling within bandwidth II, and to determine the significance of more pairs of front vowels being alike than the back vowels, or central vowels.

To find the answer to the fourth question concerning the relationship between any two points of pickup and the amount of energy for any given vowel, correlation coefficients between each possible pair of pickup points for each of the twelve vowels were obtained using the Pearson Product-Moment correlation coefficient.

The results of this treatment are presented in Table VIII.

An attempt was made to classify the significant coefficients according to front, back and central vowels. It can be seen that seven of the fifteen significant coefficients fall among the front vowels, six among the back vowels, and two among the central vowels. It should also be noted that eleven of the significant coefficients fall in bandwidth I among all combinations.

The vowels [ɛ, ɔ, ʊ] show a significant relationship between AC-BC and AC-TC in bandwidth I with values approaching significance between BC-TC.

An explanation of these findings cannot be made without further research in this area.

TABLE VIII

PRESENTATION OF CORRELATION COEFFICIENTS BETWEEN ALL
COMBINATIONS OF TWO POINTS OF PICKUP FOR ALL TWELVE
VOWELS IN THE THREE BANDWIDTHS

		i	I	e	ɛ	æ	a	ʌ	o	ʊ	u	ʌ	ʒ
AC-BC	I	.73	.95*	.57	.97*	.37	.03	.57	.95*	.65*	.81*	.80*	.67
	II	-.36	-.21	.21	.22	.40	.23	.42	.09	.30	.30	.62	-.002
	III	.82*	.73	.74	.32	.41	.36	.41	.71	.48	.01	-.29	.30
AC-TC	I	.77	.48	.90*	.83*	.57	-.58	.14	.84*	.91*	.14	.75	.67
	II	.87*	.65	.48	-.14	.06	.61	.49	.40	-.06	.87*	.63	.82*
	III	.35	.13	.75	.59	.38	.32	.49	.59	.24	.24	-.12	.68
BC-TC	I	.81*	.37	.46	.78	-.001	-.08	.06	.68	.64	.71	.66	.76
	II	-.07	.34	.55	.35	.24	.78	.37	.39	.38	.31	.34	.40
	III	.47	.30	.67	.48	.53	.25	.36	.54	.42	.09	.05	.64

*In a sample of this size with $df=4$, a coefficient must be equal to or greater than $\pm .81$ to be significant at the 5 percent level of confidence.

Therefore, the fourth hypothesis which states that there is no significant correlation between the amount of energy for any given vowel and any two points of pickup would be accepted, in general.

Discussion

The purpose of this study was to determine the significance of energy variations of twelve vowel sounds using three methods of pickup within three different bandwidths.

One can see from Table I that the mean vowel amplitude is greater for air conduction than for bone or tissue conduction in all three bandwidths. Bandwidths II and III follow the expected pattern of having bone conduction second highest and tissue conduction third since bone is thought to be a better conductor of sound waves than tissue of unequal density. However, bandwidth I does not follow this pattern. Further study is needed in this area to establish the reasons behind these findings.

The results of data analysis indicated a significant difference in the mean amount of energy between vowels and between pickup methods at the 5 percent level of confidence for all three bandwidths. There was a significant interaction between vowels and points of pickup at the 5 percent level of confidence for bandwidths I and III but not for bandwidth II.

Since it was desirable to know which vowel sounds were different from which other vowel sounds, the critical difference was computed for each bandwidth and the resulting information was presented in Tables V, VI, and VII.

Using these tables it can be noted that in comparing the two vowel sounds [e] and [o], the significant differences in bandwidths I and II are a function of the pickup points. This can be explained by the fact that there was no significant difference between these two vowels when they were picked up by the same method. However, there was a significant difference between bone and tissue pickup in bandwidth II. In bandwidth III there was a significant difference between these two vowels when each of them was picked up by the same method but there was no significant difference between the two when one was picked up by air conduction and the other by bone conduction. This information indicates that there must be some interaction taking place between these two vowel sounds and the points of pickup.

When comparing the two vowel sounds [ɤ] and [u], it can be seen that there is some interaction taking place in all three bandwidths. In bandwidths I and II there was a significant difference between the two vowel sounds when they were picked up by the same method but there was no significant difference between them when one was picked up by air conduction and the other by tissue conduction. In bandwidth III there was a significant difference in all

combinations of the two vowel sounds except when they were both picked up through tissue conduction.

In looking at the two vowel sounds[Λ]and[U]it is seen that some interaction is evident in bandwidths I and III but the significant differences in bandwidth II are a ' function of pickup points.

In comparing all of the pairs of front vowels with each other, it is noted that most of the like pairs fall in bandwidth I with the second highest number in bandwidth II. However, none of these pairs of vowels is the same from bandwidth to bandwidth.

In terms of significance, the front vowels include the greatest number of pairs that tend to be alike in mean energy, that is they are not significantly different from each other, with the back vowels second in line followed by the central vowels.

In addition to the above information, it was desirable to attempt to find the relationship, if any, between any two points of pickup and the amount of energy for any given vowel. From the correlation coefficients between the three points of pickup and each of the twelve vowel sounds, the significant coefficients were found to be located mostly in bandwidth I. The vowel sounds[ϵ , o , u]show a significant relationship between AC-BC and AC-TC in bandwidth I with values approaching significance between BC-TC.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

During the past thirty-six years investigators have designed experiments to measure the intelligibility of tissue transmitted signals and to record vocal signals from various locations on the body of speakers.

From past studies it is known that intelligible speech can be picked up at various locations on a speaker's body other than the lips.

The purpose of this study was to compare the energy variation at each of three bandwidths over twelve vowels of the English language simultaneously recorded at the lips and forehead of six different speakers using three types of pickup devices. This information provides some insight into the possibility of utilizing the forehead as a point of pickup.

The three bandwidths involved in this study were expressed in cycles per second and divided into groupings of 100-199, 200-499, and 500-999 and were referred to as bandwidths I, II, and III respectively. The twelve vowel sounds that were used were [i, I, e, E, æ, a, ʌ, o, v, u, ʌ, and ʒ].

A separate analysis of variance was done on relative intensity measures derived for each of the three bandwidths. The analysis for bandwidth I showed a significant difference in the mean amount of energy between vowels, between pickup methods, and a significant interaction between vowels and points of pickup at the 5 percent level of confidence.

Since the F-Test revealed whether the amount of energy for any one or more of the twelve vowel sounds was significantly different from the amount of energy for any of the other vowels, a test of individual comparisons was desirable to determine which pairs of vowels were significantly different in each of the three bandwidths over all three methods of pickup. Critical difference scores were computed for each bandwidth with the results given in Tables V, VI, and VII.

By using Tables V, VI, and VII and two vowel sounds can be compared. It can be established whether the significant differences are a function of the pickup points or whether there is some interaction taking place between the two vowel sounds in question and the points of pickup.

Correlation coefficients between the three points of pickup and each of the twelve vowel sounds were obtained using the Pearson Product-Moment correlation to determine the relationship between any two points of pickup and the amount of energy for any given vowel. The results of this treatment are given in Table VIII.

Conclusions

Upon inspection of the results obtained from data analysis the following conclusions can be made:

1. The mean vowel amplitude is greater for air conduction than for bone or tissue conduction in all three bandwidths.
2. The mean amount of energy differs from vowel to vowel within each of the three bandwidths.
3. The mean amount of energy differs as a function of pick-up methods within each of the three bandwidths.
4. There is an interaction between vowels and points of pick-up within bandwidths I and III but not within bandwidth II.
5. The front vowels tend to be more alike in mean energy over all bandwidths than the back or central vowels.
6. Bandwidth II contains the greatest number of vowel pairs that are not significantly different in mean energy.
7. The front vowel pairs are the only pairs of vowels that show an exact likeness in mean energy in bandwidths II and III. Bandwidth I also has four pairs of central vowels showing an exact likeness in mean energy.
8. Eleven of the fifteen significant coefficients fall in bandwidth I among all combinations.
9. The vowels $[E, o, \upsilon]$ show a significant relationship between AC-BC and AC-TC in bandwidth I with values approaching significance between BC-TC.
10. In comparing two vowel sounds, some show interaction taking place between them and the points of pickup as

in [æ] and [u], and some show that the significant differences are a function of pickup points such as in [ʌ] and [u].

Implications for Future Research

This study suggests several areas for continued research. Since air conduction did show a greater mean vowel amplitude in all of the three bandwidths, further study could be done to test this trend. Would this trend be evident if another study were done using different speakers or using speech signals instead of vocal signals? Would bandwidth I still show tissue conduction pickup as having a higher mean vowel amplitude than bone conduction pickup? Would the trend of fewer alike vowel pairs falling in bandwidth I be continued? Would the front vowels have more alike pairs than the back or central vowels?

This study showed eleven of the fifteen significant coefficients falling in bandwidth I among all the combinations. Would other points of pickup show similar results?

Since the condenser microphone that was used on the forehead for tissue conduction pickup was of the same type that was used in front of the lips for air conduction pickup, the fact that this type microphone would produce better results with air conduction pickup is evident. If this study were done again using equipment especially made for tissue pickup, would tissue pickup still produce a higher mean vowel amplitude than bone conduction pickup as was true for bandwidth I in this study?

APPENDIX I

PRESENTATION OF RAW SCORES FOR SPEAKER I
OVER TWELVE VOWELS IN SIX BANDWIDTHS
FOR AIR, BONE, AND TISSUE
CONDUCTION PICKUP

[illegible]

APPENDIX I--Continued

PRESENTATION OF RAW SCORES FOR SPEAKER II
OVER TWELVE VOWELS IN SIX BANDWIDTHS
FOR AIR, BONE, AND TISSUE CONDUCTION
PICKUP

[illegible]

APPENDIX I--Continued

PRESENTATION OF RAW SCORES FOR SPEAKER III
OVER TWELVE VOWELS IN SIX BANDWIDTHS
FOR AIR, BONE, AND TISSUE CONDUCTION
PICKUP

[illegible]

APPENDIX I--Continued

PRESENTATION OF RAW SCORES FOR SPEAKER IV
OVER TWELVE VOWELS IN SIX BANDWIDTHS
FOR AIR, BONE, AND TISSUE CONDUCTION
PICKUP

[illegible]

APPENDIX I--Continued

PRESENTATION OF RAW SCORES FOR SPEAKER VI
OVER TWELVE VOWELS IN SIX BANDWIDTHS
FOR AIR, BONE, AND TISSUE CONDUCTION
PICKUP

[illegible]

BIBLIOGRAPHY

Books

- Dixon, Wilfrid J., and Massey Frank J. Jr. Introduction to Statistical Analysis. New York: McGraw-Hill Book Company Inc., 1957.
- Gray, Giles W., and Wise, Claude M. The Bases of Speech. New York: Harper and Brothers, 1959.
- Lindquist, E. F. Design and Analysis of Experiments in Psychology and Education. Boston: Houghton Mifflin Company, 1953.
- Stevens, S. S. (ed). Handbook of Experimental Psychology. New York: John Wiley and Sons Inc., 1951.

Articles and Periodicals

- Moser, Henry M., and Oyer, Herbert J. "Relative Intensities of Sounds at Various Anatomical Locations of the Head and Neck during Phonation of the Vowels," The Journal of the Acoustical Society of America, 30 (April, 1958).
- Mullendore, James M. "Relative Amplitudes of Sound Vibrations at Various Body Locations," Speech Monographs, 16 (1949).
- Oyer, Herbert J. "Relative Intelligibility of Speech Recorded Simultaneously at the Ear and Mouth," The Journal of the Acoustical Society of America, 27 (November, 1955).
- Oyer, Herbert J., Moser, Henry M., and Wolfe, Susan M. "Relationship of Phonetic Structure to the Intelligibility of Words Simultaneously Recorded at Ear and Lips," Journal of Speech and Hearing Research, 3 (March, 1960).
- Simon, Clarence, and Keller, Franklin. "An approach to the Problem of Chest Resonance," Quarterly Journal of Speech Education, 13 (1927).

Snidecor, John C., Rehman, Irving, and Washburn, David D. "Speech Pickup by Contact Microphone at Head and Neck Positions," Journal of Speech and Hearing Research, 2 (September, 1959).

West, Robert. "The Nature of Vocal Sounds," Quarterly Journal of Speech Education, 12 (1926).

Wise, Claude M. "Chest Resonance," Quarterly Journal of Speech, 18 (1932).

Reports

Hirsh, I. J., and Benson, R. W. "Wright Air Development Center, WADC Technical Report No. 52, 175," (May 1952).

Moser, Henry M., and Dreher, John J. "Operational Tests of Miniature Microphones and Receivers," (Technical Report No. 36), AFCRC TN 56-57, (October, 1956).

Other Sources

Oyer, Herbert J., Personal interviews, Michigan State University. July, 1962; January, 1963.

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