THE FORMANT BEHAVIOR OF VOWELS IN SELECTED TENOR VOICES

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ABSTRACT

THE FORMANT BEHAVIOR OF VOWELS
IN SELECTED TENOR VOICES

By

Paul William Schultz

The Problem

The problem of the study was to discover whether there are similar patterns of formant behavior in the spectra of sung vowels judged to be excellent in quality in tenor voices. The study attempted to discover the formants present in a given vowel and any similarity in patterns present, and to compare the results with those of previous research.

The study included the vowels [a], [e], [i], [o], and [u] on the pitches e-165 Hz, b-246 Hz, and $g^{\#}$-415 Hz. The voices studied were high school, university, and mature tenor voices selected by qualified choral directors and applied voice teachers at various high schools, universities, and cities in Michigan.

The Procedure

Thirty singers (10 high school tenors, 10 university tenors, and 10 mature tenors) sang each vowel on each of the three pitches. Recording techniques were the same for each singer. The recording of each subject took place in a voice studio. The sample used for spectrographic analysis was selected by 20 adjudicators, all having much vocal teaching experience.

Samples of voices to be analyzed were prepared in random order on separate tapes for each of the three pitches and for each of the age groups--a total of nine tapes. The adjudication took place on three consecutive days for each adjudicator.

Only those vowel samples receiving a simple majority of excellent ratings, with no fair or poor ratings, were used for spectrographic analysis. The number of samples selected as excellent within a given age level varied according to vowel sound and pitch.

Selected samples were prepared into tape loops and converted into spectrographs at the Audiology and Speech Sciences Laboratory at Michigan State University. The spectrographs were analyzed and reproduced graphically, indicating the frequencies, intensities, and locations of the fundamental and first two formants for each subject selected.

Conclusions

Adjudicator evaluations were found to be highly consistent. Using Hoyt's reliability method, results showed coefficients ranging from .9698 to .9819 for all vowels analyzed.

Formants occurred on partial frequencies for all subjects. This was true, even though formants occasionally occurred on different partials for a given vowel or pitch.

The first formant was consistent in location for all subjects on all vowels and pitches. Not one variation occurred in the study.

The second formant was not as consistent in location, especially on the lower pitches. The location of the second formant differed for two subjects singing the vowel [a] at e-165 Hz. The second formant occurred on four different frequencies for the vowel [e] at e-165 Hz. The location of the second formant differed for two subjects singing the vowel [i], three subjects singing the vowel [o], and one subject singing the vowel [u] at e-165 Hz. For pitch b-246 Hz, the location of the second formant differed for one subject singing the vowel [a], two subjects singing the vowel [o], and two subjects singing the vowel [u]. There was total consistency in location of the second formant for the vowels [e] and [i] at b-246 Hz. For pitch $g^{\#}$-415 Hz, the location of the second formant differed for two subjects singing the vowel [a] and one subject singing the vowel [i]. All subjects were consistent in the location of the second formant for the vowels [e], [o], and [u] at $g^{\#}$-415 Hz. Only 17, out of 120 vowels analyzed, differed in formant location.

There was little indication that the age of the singer created basic differences in formant behavior. Formant intensities were relatively similar for all subjects. There was a noticeable variation in the intensities of the fundamentals, especially between high school and mature subjects.

A prominent region of energy above the second formant was present in most spectrograms. Although this energy region has been referred to as the third formant in previous research, it was not consistent among subjects and failed to be as prominent as either the first or second formants.

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TABLE OF CONTENTS

Chapter | Page

Chapter | Page

LIST OF TABLES

LIST OF FIGURES

Figure		Page

Figure | Page

Figure | Page

Figure		Page

Figure		Page

Figure | Page

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Purpose of the Study

It is the purpose of this study to discover formant patterns present in high school, university, and mature tenor voices that may lead to consistent judgments regarding quality in all voices.

Statement of the Problem

The problem of this study is as follows: Are there similar patterns of formant behavior in the spectra of sung vowels judged to be excellent in quality in tenor voices? In answering this question, this research will attempt to discover the formants present in a given vowel, any similarity in patterns present, and compare the results with those of previous research. Previous research relating to this study will be presented in Chapter II.

Methodology

The Sample

The voices studied were high school, unversity, and mature tenor voices selected by qualified teachers of applied voice at various high schools, universities, and cities throughout Michigan. The sample used for spectrographic analysis was determined from the total sample by twenty adjudicators selected from the Michigan School Vocal Association's list of solo adjudicators.

Design and Methods

Each tenor in the sample sang the vowels [a], [e], [i], [o], and [u] on three different pitches (e-165 Hz, b-246 Hz, and $g^{\#}$-415 Hz) representing lower, middle, and upper ranges of the tenor voice. Thus, each tenor was rated on fifteen different utterances. Each adjudicator rated the quality of each sound based on a scale of 1--Excellent, 2--Good, 3--Fair, and 4--Poor. This design is a modified version of previously designed procedures used by Jones[1] and Wash.[2]

To implement the above design, the following conditions were necessary:

1. Five vowels were included in the study in order to determine the effects of different formant patterns on auditor preference.

2. Three pitches were used to insure covering the entire range of the tenor voice.

3. The singers were chosen on the basis of a strong recommendation from a highly respected voice teacher or music educator.

4. The singers were grouped on tape at each maturity level (high school, university, and mature voices) to insure uniform comparisons.

5. The singers were recorded at the same volume level, on the same equipment, and the same distance from the microphone to

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[1]J. Loren Jones, "A Cinefluorographic and Spectrographic Analysis of the Effect of Velum Positions on Sung Vowels" (D.M.Ed. dissertation, School of Music, Indiana University, 1971).

[2]Nathaniel Hubert Wash, "The Formant Behavior of the Vowels [a], [i], and [u] in Baritone Voices in Relation to Different Voice Ranges" (Ph.D. dissertation, Michigan State University, 1971).

insure against differences in timbre which might result from uneven signal strengths.

6. The adjudicators chosen for the study were engaged in studying, performing, or teaching voice or choral music at the high school, university, or professional level. In addition, they were designated as solo adjudicators on the Michigan School Vocal Association's adjudication list.

7. The material was presented to the adjudicators in a totally random manner so that each singer, pitch, and vowel could be evaluated individually.

8. Adjudicator reliability was determined by appropriate statistical computation.

In order to determine the environment in which the singers would be recorded and how the tapes would be presented to the adjudicators, the following experiment was undertaken before the study began:

1. Two mature tenor voices were selected to sing two different pitches (b-246 Hz and g-396 Hz) on the vowel [a].

2. Two different recording environments (a sound-treated room and a studio-type room) were selected for recording the singers.

3. The same recording equipment and same testing procedures were implemented in each environment.

4. Ten qualified adjudicators were selected to listen to the recordings and determine which environment produced the most natural sounding result.

5. The presentation of tapes to the adjudicators was designed so that the observations could be tested for reliability, individual differences, and determining the method of presenting tapes to adjudicators in the final research.

Analysis of Data

Each sung vowel chosen by a simple majority of the adjudicators as excellent in quality was used for spectrographic analysis. In addition, Hoyt's reliability coefficient was calculated to determine reliability among adjudicators.

Limitations of the Study

High school, university, and mature tenor voices were used as subjects in this study. The high school singers were limited to those between the ages of 16 and 18 having fully completed their voice change, and were members of either the Michigan School Vocal Association's Honors Choir or the Youth for Understanding Chorale, two of the most highly selective high school choral organizations in the state of Michigan. The university singers were limited to those between the ages of 19 and 24, and the mature tenor voices from 25 to 50.

Five vowels were used in this study. Previous studies have used two or three vowels, but have usually recommended that future research include at least five vowels.

The three pitches chosen for this research represent the lower, middle, and upper ranges of the tenor voice. These pitches caused some technical difficulty with some singers (i.e., some high school singers had difficulty with either the lower pitch or the higher pitch, and, in some cases with both extremes) depending upon the experience or the vocal and physical maturity of the individual.

Three 20-minute tapes were prepared for each of the three classifications of singers. To avoid a possible fatigue factor in the evaluation of the tapes by some adjudicators, the adjudicators were asked to evaluate the tapes on three separate days, with short breaks between each tape.

Only those vowel sounds rated excellent by a simple majority of the adjudicators were used for spectrographic analysis. Because of the purpose and magnitude of this study, those not selected as excellent were not considered for comparison. Consideration was given only to the sung vowels and not to the singer producing those vowels. Consequently, it was possible that only one or two of the vowels sung by an individual were used in the final spectrographic analysis, and not necessarily all of the vowels sung by that individual.

Background of the Problem

The requirements of singing necessarily make it different from speech. Listeners normally understand speech, but this cannot be said of a listener's ability to recognize the same words when sung. The differences between the act of speech and the act of singing are created because of such variables as range, duration of pitch, tempo, and mood. This is supported by Fletcher after conducting and experiment comparing melodic curves of the same sentence when spoken and sung.

> In the case of the sung sentence the pitch changes are around definite intervals on the musical scale while for the spoken sentence the pitch varies irregularly, depending upon

> the emphasis given. The pitch of the fricative and stop consonants is ignored in the musical score, and since these consonants form no part of the music, they are generally slid over, making it difficult for a listener to understand the meaning of the words. Some teachers of music object to this statement of the situation, but I think most people will agree that a singer's principal aim is to produce beautiful vowel quality and to manipulate the melodic stream so as to produce emotional effects. To do this, it is necessary in singing to lengthen the vowels and to shorten and give less emphasis to the stop and fricative consonants. It is for this reason that it is more difficult to understand song than speech.[3]

Vennard[4] observes that pronunciation in singing demands that the sound be enough like normal speech to create an illusion of naturalness. This means that while vowels should be kept as pure and musical as possible, they must be modified were necessary in favor of more familiar or recognizable pronunciation. Pronunciation of vowels and concepts of tone production are often the explanation of a person's ability to speak clearly and sing unrecognizably.

From the research examined in this study and discussed in more detail in Chapter II, claims have been made concerning the characteristic frequencies of the basic vowel formants most evident in, or important to, good singing. The results are not always in agreement as evidence in the following summary which Vennard entitles "The Acoustical Dilemma":

> If Helmholtz made any mistake, it was in assuming that the voice functions entirely like a musical instrument. He applied to vowels the same principles which explain the tone color of instruments. Those who dispute this assumption are

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[3]Harvey Fletcher, Speech and Hearing in Communication (New York: Van Nostrand Company, Inc., 1953), pp. 54-56.

[4]William Vennard, Singing, the Mechanism and the Technic (5th ed. rev.; Ann Arbor: Edwards Brothers, Inc., 1964), pp. 166-167.

> primarily phoneticists. Scripture, for example, based his studies largely upon the spoken word. He analyzed graphs of the recitations of Joseph Jefferson, and found few vowels of the kind that a singer produces. Instead of diphthongs he found triphthongs, continually merging into consonants, no sound prolonged for enough time to establish musicality. Small wonder he found more inharmonic partials than harmonics . . . .
>
> Possibly the confusion could be resolved by saying that in singing, where we want the voice to be a musical instrument, we shape the resonators to be in tune with the fundamental, and so our vowel formants are harmonic, whereas in speech, this need not be the case. As a matter of fact Paget analyzed the vowel [o] as sung throughout a chromatic scale and found that "of the fourteen upper resonances heard, ten were actual harmonics of the larynx, i.e., their frequency of vibration was a numerical multiple of that of the larynx note. In two of the remaining cases, the relation, though not harmonic, was musically a simple one, namely an interval of two octaves and a fourth; in the last remaining cases there was apparently no simple relation between the larynx note and the upper resonance heard" (pp. 48-52) . . . . Of course, to make the voice musical, we must also free the valve to provide more and better partials in the glottal tone. Scripture did not recognize this possibility, and phoneticians generally do not concern themselves with it, though of course speech therapists do.[5]

There is a critical need for more information resulting from carefully controlled observation and reporting of the several physiological and acoustical phenomena in relation to excellence in performance. Because of the broad scope of controversy in this area, this study will be but one step toward building the necessary amount of information needed to begin resolving such controversy.

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[5]Ibid., p. 166, citing Hermann L. F. Helmholtz, Sensations of Tone (4th ed.; New York: Dover Publications, 1954), pp. 39-41; Edward Wheeler Scripture, "Analysis and Interpretation of Vowel Tracks," Journal of the Acoustical Society of America, V (1933), 148-152; and Sir Richard A. Paget, Human Speech (New York: Harcourt, Brace, and World, 1930), pp. 48-52.

Definition of Terms

Decibel represents a relative quantity. It is a logarithm of a ratio of two values of power, and equal changes in decibels represent equal ratios. The decibel is most often used in acoustics for expressing the sound-pressure level and the sound level: abbreviated dB.

Formant is a region of pitch in which all partials are strengthened. For every vowel there are at least two formants of fixed pitch. The relative strength of a formant is an important factor in determining the quality of a sound. The abbreviation F is followed by a numeral denoting the chronological order of those formants observed within the spectrum of a given sound (i.e., F^1, F^2, F^3).

Hertz is synonymous with cycles per second and abbreviated Hz.

International Phonetic Alphabet is abbreviated I.P.A. and designed to represent phonetic sounds and avoid makeshift spellings. The following are the five basic vowel symbols used in the present study:

[a] as in calm

[e] as in pay

[i] as in beet

[o] as in tone

[u] as in boot

Partial refers to any of the simple components of a complex tone, the frequencies of the upper components being exact multiples of the fundamental. The abbreviation P is followed by a numeral denoting the ascending position of the partial, beginning with P^1 as the fundamental.

Spectrograph is the graphic display of the frequency composition of a sound.

VU is the abbreviation for volume unit.

VU Meter is the meter on a tape recorder indicating signal strength.

CHAPTER II

REVIEW OF RELATED LITERATURE

The research to be reviewed in this chapter will be concerned with both spoken and sung vowels. The linguistic studies are valuable in providing information relevant to the early opinions on formant behavior, many of which apply to sung vowels. Conclusions from the linguistic studies reviewed may not relate directly to the sung vowel, but the overall content of these studies reveals that speech and singing are greatly related.

Formant Theories

Such classifications as absolute formant theory, relative formant theory, and fixed formant theory are the results of linguistic studies. In these studies, attempts have been made to define the number of formants for each vowel and which formants are most important for vowel quality and vowel perception. Since vocal quality, in relation to formant behavior, has been a controversial subject, this portion of Chapter II will present some varying opinions regarding the three formant theories mentioned previously.

The Absolute Formant Theory

This theory suggests that for a listener to recognize a vowel phoneme, he must depend upon the absolute values of the formant frequencies of that vowel. It is also suggested that these values remain unchanged regardless of the sex of the performer or the acoustical environment in which the vowel is produced.[6]

Before the word formant became associated with vocal or vowel quality, the principle of harmonic reinforcement was under investigation. In the nineteenth century Helmholtz studied the vowels [a], [o], and [u] for one position of the oral cavity, and included the vowels [e] and [i] for another position. By placing a series of vibrating tuning forks before the mouth after it was shaped for the phonation of a given vowel, Helmholtz determined the harmonics most strongly reinforced. Helmholtz discovered one partial reinforced for the vowels [a], [o], and [u], and two for the vowels [e] and [i].[7]

Helholtz discovered similar formant frequencies for men, women, and children in the above experiment. He reports:

> The pitch of strongest resonance of the oral cavity depends solely upon the vowel for pronouncing which the mouth has been arranged, and alters considerably for even slight alterations in the vowel quality, such, for example, as occur in the different dialects of the same language. On the other hand, the proper tones of the cavity of the mouth are nearly independent of age and sex. I have in general found the same resonances in men, women, and children. The want of space in the oral cavity of women and children can be easily replaced by a great closure of its opening, which will make the resonance as deep as in the larger oral cavities of men.[8]

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[6]William E. Castle, The Effect of Selective Narrow-Band Filtering on the Perception of Certain English Vowels (The Hague: Mouton and Company, 1964), p. 17.

[7]Helmholtz, op. cit., pp. 104-107.

[8]Ibid., pp. 50-51.

Aikin[9] performed experiments similar to those of Helmholtz and found that for a given vowel, women resonated a pitch approximately a minor third higher than a man, and children higher than women. This was due to the size of the resonators producing a comparable resonant note. Aikin offers a humble apology in differing with the findings of Helmholtz:

> I regret to be obliged to mention that the great physiologist Helmholtz believed the pitch of this resonant note to be the same "in men, women, and children." I can only attribute this error to the use of artificial aids to hearing, and not trusting to the sensitiveness of the ear alone. I have invariably met with not only the differences between the sexes above described, but also the subtler differences between individuals of the same sex proportionate to the actual measurements of the cavities in their necks and mouths.[10]

Before Aikin's experiment it was already apparent that proponents of this theory were not sound in their logic. Erickson made the following observations concerning vocal quality or timbre:

> Peculiarities of timbre may then be due quite as much to the presence or absence of partials with certain pitches as to the relative intensities among the partials. This will account for differences in timbre between musical and non-musical voices; between the voices of children and those of adults; between the voices of men and those of women; although all may produce the same vowel sounds at the same pitch.[11]

Based on the previous observations, the absolute formant theory is not sound when applied to the singing voice or, for that

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[9] William A. Aikin, The Voice (New York: Longmans, Green and Company, 1951), pp. 48-51.

[10] Ibid., pp. 50-51.

[11] Carl I. Erickson, "The Basic Factors in the Human Voice," Psychological Monographs, XXXVI (February, 1927), 90-91.

matter, to the spoken voice, especially when observing performers of different sex or maturity levels.

The Relative Formant Theory

This theory, also referred to as the harmonic theory, suggests that vocal quality results from a fundamental frequency and the relationship of the upper partials to the fundamental. The frequencies of the partials are all exact multiples of the fundamental. Several studies support this theory.

Holmes[12] concluded that vocal quality is dependent upon two main factors: (1) the relationship between the fundamental and the harmonic frequencies of a musical sound; and (2) the proper functioning of the vocal mechanism depending upon anatomical, physiological, and psychological factors. Holmes felt that, in addition to the above factors, correct vowel placement on a pitch suitable for a given voice is essential for good vocal quality. Holmes' second point may seem too obvious to be included in this study but, in reality, the present investigation is dealing with that point in great depth. Without the proper functioning of the vocal mechanism and correct vowel placement, consistent measurement of formant behavior would not be possible.

Borchers studied the relationship between intensity and harmonic structure by having four well-known professional male singers

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[12] F. Lincoln P. Holmes, "An Experimental Study of Individual Vocal Quality," Quarterly Journal of Speech, XVI (October, 1930), 351.

(two basses and two tenors) sing the vowel [a] at three intensity levels. The results were as follows:

> 1. There is without exception a greater percentage of energy in the fundamental of tones sung with less intensity but at the same approximate pitch. Inversely, there is less energy in the fundamental of tones sung at greater intensity levels but at the same approximate pitch.
> 2. There is an increasing amount of energy in the fundamental from low to high tones which are sung pianissimo.
> 3. The second partial shows characteristic changes in energy with changes in intensity level which are very similar to the changes in the fundamental.
> 4. The centroid of the total dispersion of energy changes to markedly higher frequencies in tones sung at greater intensity levels but at the same pitch.[13]

Borchers' conclusions bear out the relative formant theory. However, these conclusions may not be the only important features in vowel recognition.

Castle[14] tested the hypothesis that the acoustic information necessary for the recognition of context vowels is different from that for isolated vowels. This hypothesis suggests that formant bandwidths and the fundamental frequency may be as important to vowel recognition as the elements of the relative formant theory.

Castle's results indicated:

> The sufficient acoustic information for the recognition of context vowels differs from that for isolated vowels. It appears that identification of context vowels may be less dependent on steady state formant information and more dependent on temporal variations and comparison vowel information than is identification of isolated vowels. In addition, there is indication that there may be a perceptual heirarchy [sic] among the formants of a given vowel, that

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[13] Orville J. Borchers, "The Relation Between Intensity and Harmonic Structure in Voice," Psychological Record, III (April, 1939), 64.

[14] Castle, op. cit., pp. 157-160.

ratio hypotheses of vowel perception are not completely valid, and that the most important frequencies for the identification of the vowels of continuous speech may be between 1500 and 2500 cps.[15]

The Fixed Formant Theory

This theory, also known as the formant theory, is defined by Bartholomew:

> The formant theory states that the characteristic tone quality of an instrument is due to the relative strengthening of whatever partial lies within a fixed or relatively fixed region of the musical scale. This region is called a formant of the tone.[16]

Concerning these fixed regions, Gray and Wise,[17] summarizing several research studies, state that formants are characteristic frequency regions which determine the different speech sounds. The summary also reveals approximate formant frequencies for two vowels not used in the present investigation, and that the formants of men are lower than those of women and children.

Delattre,[18] in an article comparing vowel color and voice quality, made observations concerning fundamental and formant behavior. He stated that formant frequency and, occasionally, formant intensity are the necessary factors for vowel identification. Regarding voice quality Delattre stated:

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[15] Ibid., p. 160.

[16] Wilmer T. Bartholomew, Acoustics of Music (New York: Prentice-Hall, Inc., 1942), p. 17.

[17] Giles Wilkeson Gray and Claude Merton Wise, The Bases of Speech (3d ed.; New York: Harper and Brothers, 1959), pp. 117-131.

[18] Pierre Delattre, "Vowel Color and Voice Quality: An Acoustic Articulatory Comparison," National Association of Teachers of Singing Bulletin (October, 1958), 4-7.

> The work of correlating voice formants with types and classes of voices has not yet been done successfully. It is generally agreed, however, that voice quality in singing is mainly characterized by the two or three vowel formants whose frequencies are just above the vowel formants.[19]

Delattre identified those frequencies for a male between 2400 and 4000 Hz. He further stated that high frequency overtones are necessary for rich vocal quality in the singing voice.

The studies dealing with the fixed formant theory also refer to the number of formants necessary for vowel distinction. Potter, Kopp, and Kopp[20] found the third and fourth formants were either very weak or, in many cases, blended together. Delattre[21] found that the first three formants are necessary for vowel identification of front-unrounded vowels, but the third formant is very close to the second. The first two formants, only, were necessary for identification of other vowels. Winckel stated that each vowel is formed from two formants or more, but those beyond the second formant are insignificant. He continues:

> The characterization of sound essentially through two formants is of great significance, even though it is not organically adjusted to the hearing process; this is because we do not distinguish single resonance areas of the spectrum, as does the keyboard of the bulging basilar membrane in the inner ear, but rather hear an integrated blending. However, there is no other characterization of tone color known.[22]

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[19] Ibid., p. 5.

[20] Ralph K. Potter, George A. Kopp, and Harriet Green Kopp, Visible Speech (New York: Dover Publications, Inc., 1966), pp. 54-56, 66, 69.

[21] Delattre, op. cit., p. 5.

[22] Fritz Winckel, Music, Sound and Sensation (New York: Dover Publications, Inc., 1967), p. 20.

Comparison of the Relative and Fixed Formant Theories

Bartholomew illustrated the two theories on a chart showing the fundamental and strengthened partials of three separate pitches. He summarized the differences between the theories as follows:

> Thus, according to the harmonic theory, if the instrument plays a different pitch, the vibration form will be similar, since, although the particular harmonic series will be shifted, its members will still retain the same intensity relation to each other. But according to the formant theory, whatever partial lies within or close to the formant range will be strengthened. If the pitch of the fundamental changes, so that some other partial comes into the formant range, this other partial will be strengthened. Thus, although the formant range is fixed, the vibration form will change as the fundamental changes.[23]

Vennard[24] referred to the harmonic theory as the Relative Pitch Theory and to the formant theory as the Fixed Pitch or Formant Theory. He suggests that the formant behavior of various instruments bears out both theories. The relative pitch theory explains why strong formants can be found in certain regions of most instruments. Vennard suggests this explains only 80 or 90 percent of the formant behavior of instruments. Using the flute to illustrate this suggestion, Vennard explains:

> The second partial is always strongest, and this bears out the Relative Pitch Theory; but you will also notice that in the C_4 spectrum the first partial is weaker than the third, while as the pitch of the tone rises, the first partial grows in strength and the third diminishes. This can only be explained by the Formant Theory; that is, there could be discovered in the flute a formant whose pitch was fixed somewhere between the first and third partials, so that as the first moved up toward it, that partial was augmented, and as the third moved away from it, that partial was diminished.[25]

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[23]Bartholomew, op. cit., p. 17.

[24]Vennard, op. cit., pp. 125-127.

[25]Ibid., p. 125.

A great amount of research regarding formant behavior has been done in the area of vocal acoustics, but such research is not readily applied to instrumental acoustics. It is evident that formant behavior in instruments depends not only on the range of the formant, but also on the intensity within that range, relative to the fundamental, to determine timbre.

Vennard also stated that formants may be detrimental to the vocal tone and that bronchotracheal formants created vocal problems, i.e., voice sputtering when changing registers. Vennard concluded:

> The supraglottal formants, however, are essential, and the story of vocal timbre reverses that of instrumental timbre. Here eighty or ninety per cent of the proportioning of the harmonics is controlled by formant, and the rest is relative to the fundamental.[26]

Directly Related Research

The remainder of this chapter will deal with four studies which relate directly to the present investigation. These studies combine to serve both as motivation for the present research, and to formulate most of the methods and research design used by this investigator.

Appelman is one of the leading authorities on the singing voice and formant behavior. He discussed the creation of vowel formants as follows:

> As the sound passes through the resonating cavities of the throat and mouth, the profile of the spectrum changes, since each cavity resonates to some of the tones in the spectrum more readily than to others and each adds its own

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[26] *Ibid.*

characteristics to such tones. This reinforcement gives the partials greater energy at the point of cavity resonance. These points of greater energy are called formants.

In passing through the resonating system of the throat and mouth, the partials in the harmonic sequence do not change from their original location in the tonal spectrum; rather, some are strengthened and reinforced by cavity resonance, while others are weakened or damped out.

The values of the natural frequencies of the resonating cavities within the vocal tract are determined by their shape; as a result, as the shape of the tract is altered the amplitudes of the partials within the spectrum will be greater at different frequencies. Thus every configuration of the total vocal tract has its own set of characteristic formant frequencies which gives to the laryngeal sound a particular vowel quality.

The resonance frequency of any cavity is not necessarily equal to the frequency of any partial of the spectrum. The frequencies of the formants need not be the same as those of the partials, but they may coincide. The formant frequencies are determined by the configuration of the total vocal tract as a series of resonators while the partials within the spectrum are determined by the vocal folds. The vocal tract and the vocal folds can change independently of each other.

When the cavities of the throat and mouth remain fixed, a laryngeal sound of lower pitch may be passed through the system, and the vowel characteristic will remain the same because the energy within each formant has not varied. Only the fundamental will be lower since it is determined by the frequency of the vibration of the vocal folds.[27]

Appelman's discussion of the vowels is also very pertinent to the present investigation. He states:

One must have a series of acoustically stable sung vowels that will serve as a standard scale or measure by which the singer may compare all other sung vowels when they are produced at any pitch level or any intensity and timbre. Such acoustically stable vowels have been designed by the author and are as follows:

1. The Basic Vowel--A standardized recorded vowel sound to be used as a point of phonemic reference for all singers.
2. The Quality Alternate Vowel--A modification of the basic vowel sung.

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[27] D. Ralph Appelman, The Science of Vocal Pedagogy (Bloomington: Indiana University Press, 1967), pp. 126-127.

3. The Pure Vowel--An identifiable area, surrounding both the basic vowel and its quality alternate, which enables a singer to select the phoneme of his choice for any given pitch or intensity.[28]

Appelman stated that the pure vowel "is sung within the stable vowel pitch range."[29] For tenors, Appelman defined the stable vowel pitch range as c-131 Hz to b-247 Hz. He further stated that when a pitch is sung above this range, vowel modification is necessary to maintain quality and vowel recognition. In other words, the vowel must be modified by changing the basic vowel coloring.

Two of the three pitches used in the present investigation fall within Appelman's stable vowel pitch range (e-165 Hz and b-246 Hz). The discrepancy in frequency on the pitch b is common depending upon the equipment or acoustical reference material used. All subjects in the present investigation were made aware of the fact that the vowels sung on the pitch g#-415 Hz must be modified.

The research by Jones[30] dealt with quality judgment of sung vowels relative to different positions of the velum. Cinefluorography was used to observe the proper positioning of the velum during the course of the study. Seven baritone and bass singers were used as subjects, each singing three vowel phonemes, [i], [a], and [u], on two pitches, using three positions of the velum. The two pitches were e-330 Hz and c-128 Hz, although a discrepancy of 2 Hz occurs throughout the study on the latter pitch depending upon the reference in the text or corresponding charts; the text stating c-128 Hz and the

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[28] Ibid., p. 223.

[29] Ibid., p. 228.

[30] Jones, op. cit.

charts c-130 Hz. The samples were recorded and presented to selected auditors for their judgments of vowel recognition, nasal quality, and preference.

Results show that the auditors deviated very little in their opinion concerning vowel recognition and they strongly preferred non-nasal tones. Vowels produced with a completely open nasal port with the velum sagging down and away from the pharyngeal wall were most preferred by the auditors. Of these, the samples with a preferred rating of 90 percent or better were examined for formant behavior. Conclusions regarding formant behavior were as follows:

> The evidence presented in the discussion and in the graphs of the acoustical properties shows that, first, the fundamental pitch is consistently strengthened when a phoneme is sung with some degree of naso-pharyngeal space, and, second, that there is a general tendency for partials in the lower frequencies of the spectrum to increase in strength. If the added strength in the fundamental and in the lower frequencies of the spectrum are attributed to the addition of nasal space into the oral and pharyngeal coupled cavity system, then the increase in strength may be said to be the result of nasal resonance. If this is true, then nasal resonance and nasal quality are the same, for both are associated with the increase in amplitude of the fundamental and other partials in the lower frequencies of the sound spectrum, as well as those specific alterations pointed out in the above discussion and charts for the several vowel phonemes and pitches. Further, since the effect of naso-pharyngeal opening causes a vowel phoneme to be less preferred by auditors, it can be said that nasal resonance is an undesirable quality characteristic and should be avoided. The sounds which are preferred by auditors are those produced without nasal quality or without nasal resonance.[31]

[31] Ibid., pp. 235-236.

Sullivan's[32] research compared the relationships between subjective evaluations of auditors and the acoustical properties of a given phoneme. Specifically, the study dealt with judgment of tone quality, vowel quality, vibrato rate, and the intensity of tone.

Eighteen male singers representing a wide range of vocal quality, ranging from excellent to poor, were chosen for the study. The vowels studied were [a], [i], and [u] on two pitches: $a^{\#}$-234 Hz and f-347 Hz. The given frequencies, corresponding to selected pitches, are Sullivan's and may vary with frequencies reported by various acousticians. All samples were recorded and presented to a jury of expert voice teachers. The jury was given two tones to compare for each phoneme and pitch. The mean score of the judges' preferences was used to rank the tone of each singer.

Each tone was analyzed spectrographically and the resulting formants were measured in terms of location, intensity, and width. The results were as follows:

> The intensity of each partial on both sections was measured by taking the average of the four points. Measurement was in millimeters, each millimeter representing a change of approximately 5 db [dB] in amplitude.
>
> Each measurement was then described in terms of the ratio of the intensity of the partial to the fundamental, thus providing a measure that could be compared throughout all the tones.
>
> Formants were measured for locations, intensity, and width. In many cases the location of the first two formants was so close together they overlapped. Here it was difficult to determine by measurement alone the location of the formant peak. The phonetic transcriptions were consulted. The

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[32]Ernest G. Sullivan, "An Experimental Study of the Relationships between Physical Characteristics and Subjective Evaluation of Male Voice Quality in Singing" (Ph.D. dissertation, School of Music, Indiana University, 1956).

formants were estimated using the sonagram patterns in conjunction with the known formants of the vowels as transcribed by the phoneticians.

The width of a formant was considered to be the total frequency range covered by the formant. It was measured on the section. In the case of overlapping formants, the width was measured between the lowest points on either side of the peak. Where two or even three formants overlapped, the entire band width was also measured.[33]

Sullivan's conclusions relating to the present study are as follows:

1. The proximity of the strongest formant above formant 2 [F^2] to a given optimum location is an index of quality as judged by voice teachers. The optimum location seems to vary according to the vowel and the pitch at which the tone is sung.[34]

2. The intensity of Fs [Fs designated as the strongest formant above F^2] provides the most significant index of jury tonal preference. The influence of this intensity may be expressed in the following ways:

   a. As the intensity of Fs (measured absolutely) is increased, the tone is ranked higher in quality.

   b. The ratio of the intensity of Fs to the intensity of Fl has a high positive correlation with jury tonal preference. Fs should be between one and two times as strong as Fl.

   c. There is some evidence of correlation between the ratio of the intensity of Fs to the intensity of the fundamental and rank order of jury preference. As Fs is stronger in relation to the fundamental, the tone is considered to be better. The evidence is not as conclusive here as in the preceding correlation.[35]

3. As formant 1 [F^1] becomes weaker, the tone is judged better in quality.[36]

4. There was no evidence from this study to justify the assumption that the width of Fl or Fs influences jury evaluation of the tone. This, of course, does not preclude the possibility of formant width affecting vocal quality.[37]

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[33] _Ibid._, pp. 46-47.

[34] _Ibid._, p. 164.

[35] _Ibid._, pp. 164-165.

[36] _Ibid._, p. 165.

[37] _Ibid._, p. 166.

5. For tones with the vowel [i] it may be concluded that as the width of F2 becomes narrower, the tone is judged as improved. The [i] vowel was the only one studied which provided a measurable second formant throughout all tones.[38]

Sullivan's final conclusion is extremely interesting since it relates his findings to a description of good male vocal tone. He concludes:

Good male vocal tone may be described as one which can be sung at high intensity, its spectrum showing the following characteristics: a weak first formant; a narrow second formant with twice the energy of the first; a group of strong partials between 2,500 cps and 3,000 cps (Fs), the location of this group dependent upon the vowel being sung, and its intensity equal to or stronger than that of the first formant.[39]

The study by Wash[40] provides a design and information leading directly to the present investigation. The purpose of Wash's study was to determine the formant behavior of sung vowels selected as excellent by a panel of judges. Five baritone voices, judged to be of professional quality, sang the vowels [a], [i], and [u] on the pitches e-165 Hz, c-256 Hz, and e-330 Hz. The recording of the singers took place in an acoustically treated room. A panel of 22 judges was chosen to evaluate the quality of the tones and identify the vowels. The three most highly preferred tones from each sample were analyzed spectrographically. Spectrograms were analyzed in terms of frequencies, intensities, bandwidths, and locations of the fundamental and first three formants.

Wash's research resulted in the following conclusions:

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[38] Ibid.

[39] Ibid., p. 167.

[40] Wash, op. cit.

1. Auditor judgment was relaible [sic] and had a high factor of agreement in evaluating the quality of sung vowels.[41]

2. The relationships between the fundamental and F1 varied according to vowel and pitch as follows:

a. For the vowel [a] the relative intensity of F1 increased as the pitch rose. F1 had a frequency of 660 Hz. when the fundamental was 165 Hz. or 330 Hz. When the fundamental was 256 Hz., the frequency of F1 was 512 Hz.

b. For the vowel [i] F1 was absorbed by the fundamental as the pitch rose. When the fundamental was 165 Hz., F1 was 330 Hz. When the fundamental was 256 Hz. or 330 Hz., F1 was on the same frequency as the fundamental.

c. For the vowel [u] F1 was absorbed by the fundamental as the pitch rose. When the fundamental was 165 Hz., F1 was 330 Hz. When the fundamental was 256 Hz., it had absorbed much of the energy of F1, but F1 was still evident as a separate energy peak at 512 Hz. When the fundamental was 330 Hz., it had absorbed most of the energy of F1.[42]

3. The relationships between the fundamental and F2 varied according to vowel and pitch as follows:

a. For the vowel [a] the intensity of F2 remained constant at the lower pitches whereas the intensity of the fundamental was low. These characteristics were reversed at the highest pitch. When the fundamental was 165 Hz., F2 had a frequency of 990 Hz. When the fundamental was 256 Hz., F2 had a frequency of 1024 Hz. When the fundamental was 330 Hz., F2 had a frequency of 990 Hz.

b. For the vowel [i] (recognized as [I] by a consensus of auditors) the intensity of F2 remained constant at the lower pitch, whereas the intensity of the fundamental was low. On higher pitches the fundamental increased as it absorbed F1 energy. When the fundamental was 165 Hz., F2 had a frequency of 1650 Hz. When the fundamental was 256 Hz., F2 had a frequency of 1792 Hz. When the fundamental was 330 Hz., F2 had a frequency of 1650 Hz.

c. For the vowel [u] the intensity of F2 tended to decrease slightly in the middle range and to increase slightly at the highest pitch. There was an increase in the fundamental as the pitch rose and absorbed F1. When the fundamental was 165 Hz., the frequency of F2

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[41] _Ibid._, p. 64.

[42] _Ibid._

was 990 Hz. When the fundamental was 256 Hz., the frequency of F2 was 768 Hz. When the fundamental was 330 Hz., the frequency of F2 was 990 Hz.[43]

4. The relationships between F1 and F2 were as follows:
a. For the vowel [a] the intensity of F1 increases and that of F2 decreased as the pitch rose.
b. For the vowel [i] the intensity of F1 was absorbed by the fundamental and that of F2 remained constant as the pitch rose.
c. For the vowel [u] the intensity of F1 was gradually absorbed by the fundamental and that of F2 remained constant as the pitch rose.[44]

5. F2 was broad when F1 was narrow. The reverse of this was observed also.[45]

Wash had several conclusions regarding F3. Since the present investigation will not deal with the third formant those findings are not pertinent. Wash's final conclusion was that formants always occurred on partial frequencies.

Summary of Related Research

Research relating to the formant theories reveals that the absolute formant theory is not applicable to all voices. However, both the relative formant theory and the fixed formant theory can easily be applied to vocal acoustics. Most of the related research indicates the first two formants are essential for vowel recognition, and formants beyond the second formant are insignificant and difficult to measure accurately.

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[43] *Ibid.*, p. 65.

[44] *Ibid.*, pp. 65-66.

[45] *Ibid.*, p. 66.

It is interesting to compare the findings of Appelman,[46] Jones,[47] Sullivan,[48] and Wash.[49] Wash discovered that formants showed greatest intensity on partial frequencies. Appelman, quoted earlier in this chapter, stated that formant frequencies need not be the same as those of partials, but they may coincide. Furthermore, the fixed formant locations given by Appelman do not agree with those found by Wash. Sullivan found the formants to be in the same general area as those of Wash, but not directly related to the partials. However, Sullivan and Wash were in agreement on the variations in location and strength of F3. The lack of agreement may be due, in part, to recording environments, pitches, and differences in performer ability. The research of Jones agreed with that of Wash, in that formants showed greatest intensity on partial frequencies.

Recommendations for future research from the four studies mentioned above suggest that all vowels be analyzed at all singable pitch levels, and in all voice ranges and classifications. It is also suggested that the most desirable formants for singers be determined and a reliable formula be developed for accurately measuring the intensity and width of formants. One of the most interesting recommendations comes from Wash regarding the recording environment. He states:

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[46]Appelman, op. cit.

[47]Jones, op. cit.

[48]Sullivan, op. cit.

[49]Wash, op. cit.

Although subjects were selected as excellent by competent voice teachers, the evaluations of tones made by auditors in this study were not as high as expected. A possible explanation for ratings may be the clinical conditions under which tones were recorded and presented. It is recommended that future experiments should record tones in a room with acoustic properties more normal to the average listening environment.[50]

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[50]*Ibid.*, p. 69.

CHAPTER III

DESIGN AND PROCEDURES

Before the research design for the present survey was completed, the recording environment, the adjudicator's environment, and the method of presentation to the adjudicators had to be established. Two mature tenor voices were used for this experiment. Each voice was recorded on the same sound equipment in two different environments: (1) a sound-treated room in the Department of Audiology and Speech Sciences at Michigan State University and (2) a voice studio. The tenors participating in the experiment were asked to sing two pitches: b flat-234 Hz and g-396 Hz. The results were arranged by flip of the coin as to order by environment for each pitch sung by each performer, and then placed on tape for the adjudicators. A group of ten adjudicators (five university professors, three graduate assistants in voice, and two high school voice teachers) were asked to respond to the tape in terms of the most natural sound, as determined by each adjudicator, between the two performances of each pitch. The adjudicators followed the format of the Voice Experiment found in Appendix A. In addition to choosing the most natural sound, the adjudicators were asked (1) to determine the degree of difference between the two sounds in terms of great, moderate, or very little, and (2) to say whether they preferred to listen to the tape through earphones or from speakers. The results are shown in Table 1.

TABLE 1.--Results of the voice experiment to determine recording environment and adjudicator environment.

Subject	Samples	Tone	Recording Environment	Adjudicators: Percent Selecting Tone	Adjudicators: Percent Equal	Adjudicators: Average Difference
1	1*	A	Treated	0	0	0
		B	Studio	100		1.9
2	2	A	Treated	20	70	1.5
		B	Studio	10		1.0
1	3	A	Treated	70	0	2.4
		B	Studio	30		2.7
2	4	A	Studio	70	10	2.1
		B	Treated	20		2.5
1	5**	A	Studio	10	50	2.0
		B	Treated	40		1.3
2	6	A	Treated	50	40	1.2
		B	Studio	10		3.0
1	7	A	Studio	70	10	2.4
		B	Treated	20		3.0
2	8	A	Studio	100	0	2.3
		B	Treated	0		0

*Samples 1 through 4 monitored through earphones.

**Samples 5 through 8 monitored through speakers in a studio without earphones.

Samples 1 though 4 were monitored by the adjudicators through earphones while samples 5 through 8 were monitored through speakers in a studio. The figures for average difference were computed on the basis of great--3, moderate--2, and very little--1. All adjudicators indicated a preference to monitor the tape using earphones. The samples were presented in the same order when heard through speakers, but the recording environment was still arranged by flip of the coin.

For samples heard through earphones, 27.5 percent of the adjudicators preferred tones produced in a sound-treated room, with 52.5 percent choosing the studio environment and 20 percent finding no difference in the two tones heard. The average difference was 2.3 for those choosing the sound-treated room and 2.1 for those choosing the studio environment.

For samples heard through speakers in a studio, 27.5 percent preferred tones produced in a sound-treated room, 47.5 percent preferred tones produced in a studio, and 25 percent found no difference in the two tones heard. The average difference for those choosing the sound-treated room was only 1.6 while for those choosing the studio environment it was 2.4.

Although the same tones were presented in samples 5 through 8, but in slightly different order than in samples 1 through 4, the adjudicators' preferences obtained by the speaker method were not consistent with those heard through earphones. Though the adjudicators selected the opposite tone from their previous choice approximately 40 percent of the time in samples 5 through 8, the tones produced in the studio were still preferred to those produced in the sound-treated room by a margin of nearly two to one. Degrees of difference were generally higher for the studio environment than for the sound-treated room.

In addition to the statistics shown in Table 1, a spectrographic analysis was run on the samples in the voice experiment for both environments. Figures 1 and 2 show spectrographic comparisons for subject 1 between the sound-treated room and the studio environment for the pitch b flat-234 Hz. Figures 3 and 4 show the same comparison for subject 2. Figures 5 and 6 show spectrographic comparisons for subject 1 between the sound-treated room and the studio environment for the pitch g-396 Hz. Figures 7 and 8 show the same comparisons for subject 2.

Figures 1 through 4 show that the formants occurred on the third and fifth partials for both subjects on the lower pitch, with only the first five and the twelfth partials registering intensity. The formant bandwidths were almost identifical for both subjects in either environment. Figures 5 through 8 show that the formants occurred on the second and third partials for both subjects on the higher pitch. Only the first four and the seventh partials registered intensity. The fourth partial showed a very low intensity peak of approximately 8 dB for both subjects.

In general, there is seemingly little difference in the intensity levels for either F^1 or F^2 for both subjects in either environment. Figures 1 and 3 show a lower intensity level of the fundamental for both subjects when singing in the sound-treated room than that of the studio environment (Figures 2 and 4). However, Figures 5 through 8

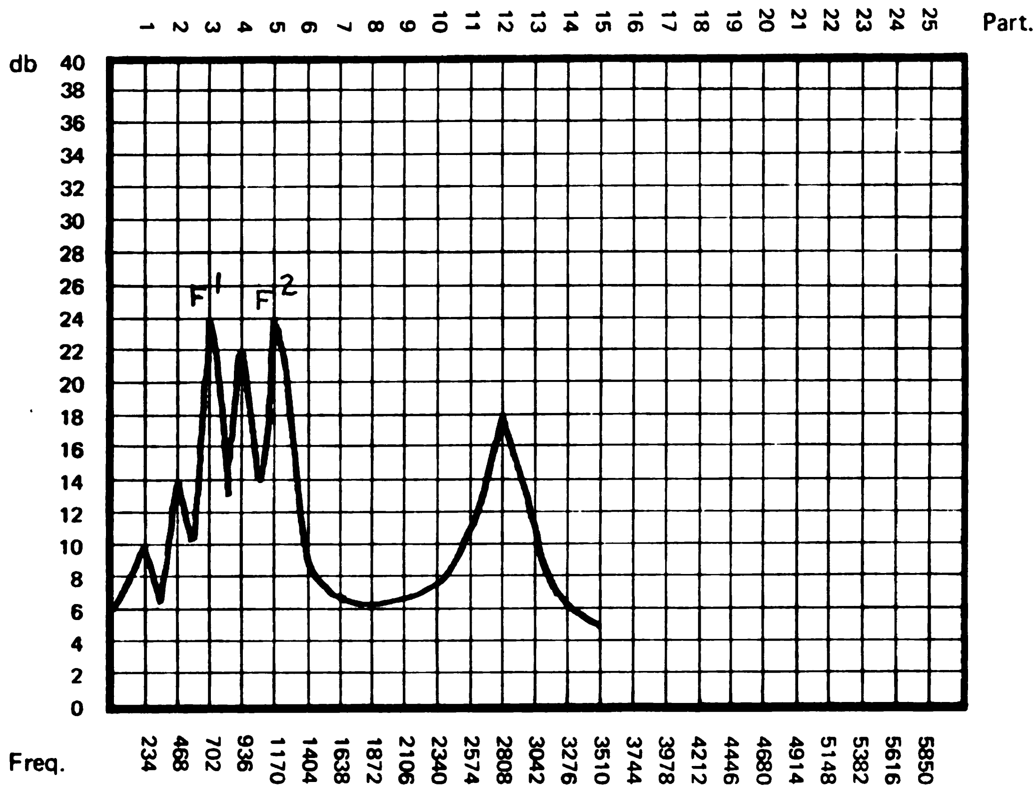

Figure 1.--Spectrograph of subject 1 singing b flat-234 Hz in a sound-treated room environment.

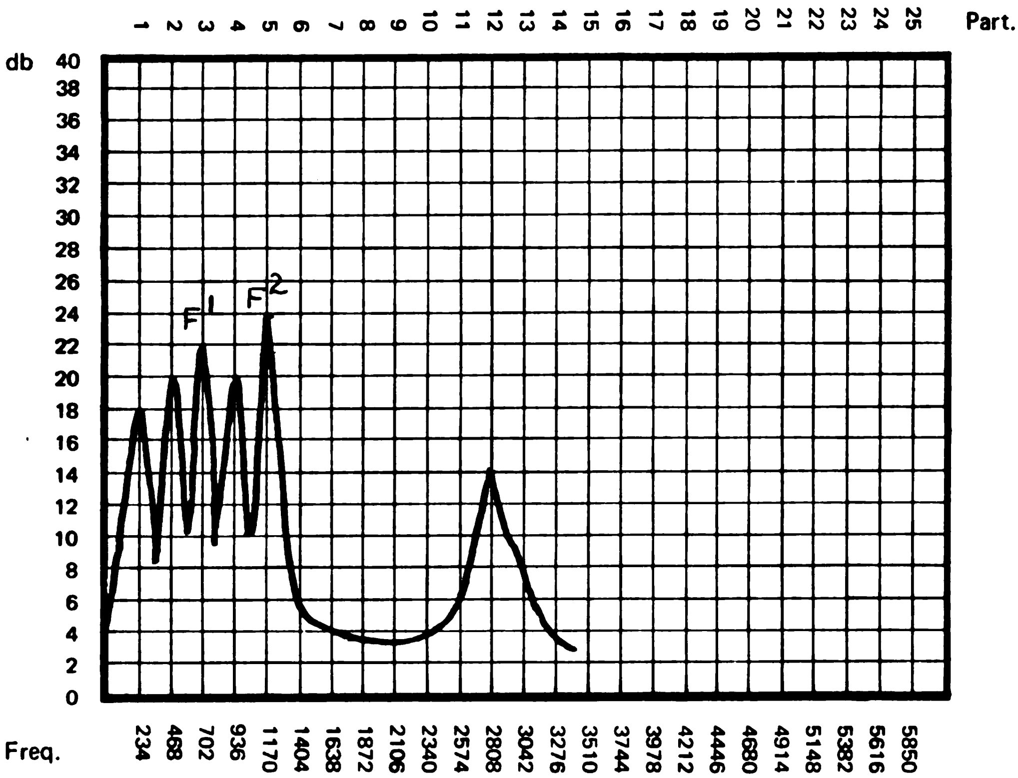

Figure 2.--Spectrograph of subject 1 singing b flat-234 Hz in a studio environment.

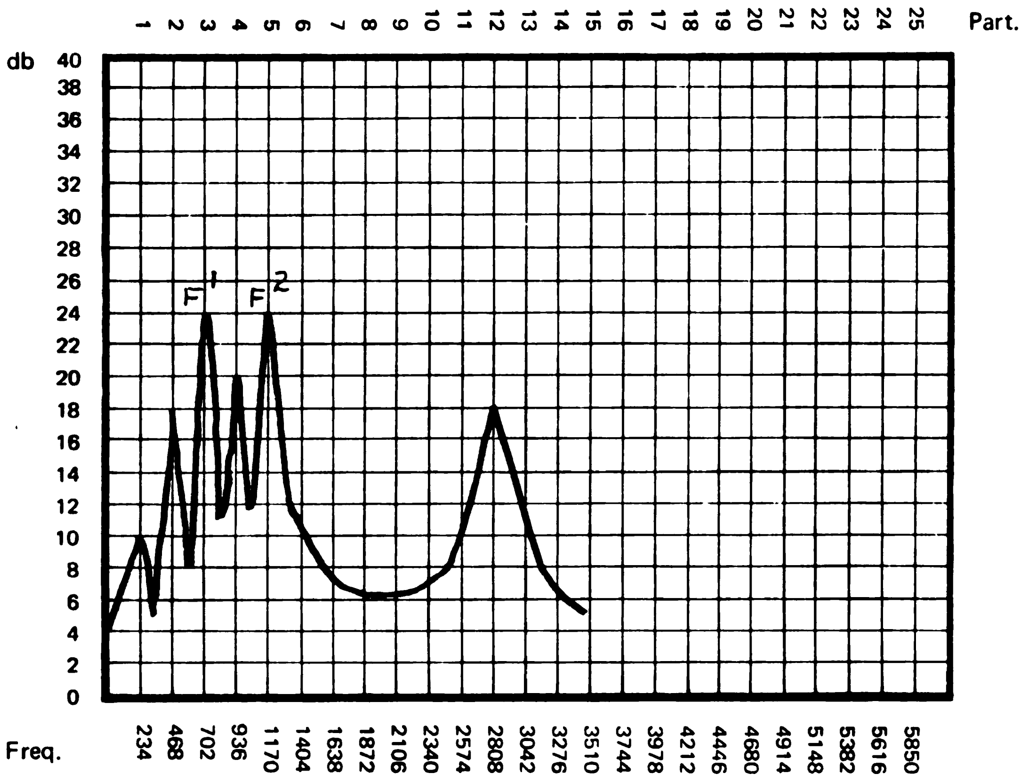

Figure 3.--Spectrograph of subject 2 singing b flat-234 Hz in a sound-treated room environment.

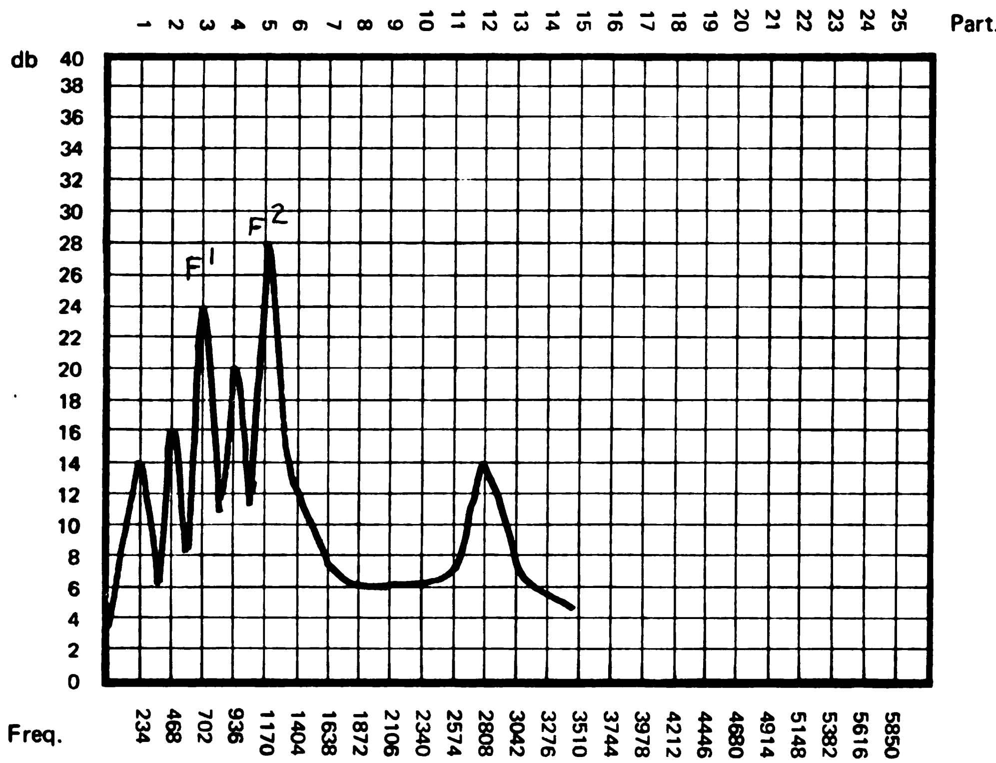

Figure 4.--Spectrograph of subject 2 singing b flat-234 Hz in a studio environment.

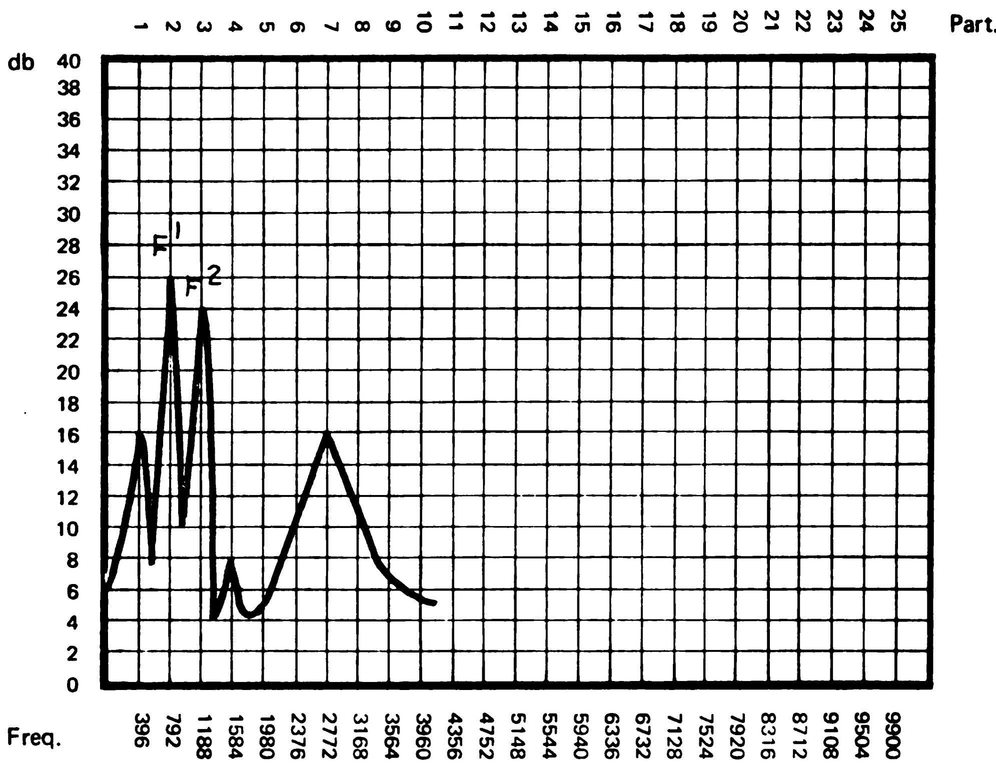

Figure 5.--Spectrograph of subject 1 singing g-396 Hz in a sound-treated room environment.

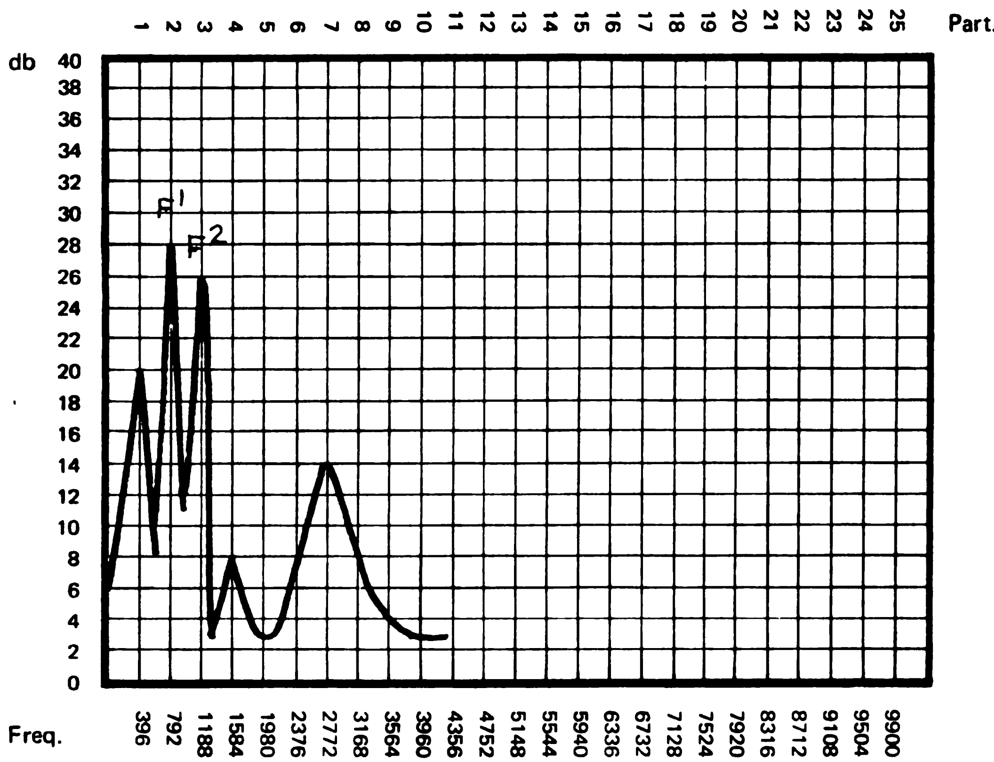

Figure 6.--Spectrograph of subject 1 singing g-396 Hz in a studio environment.

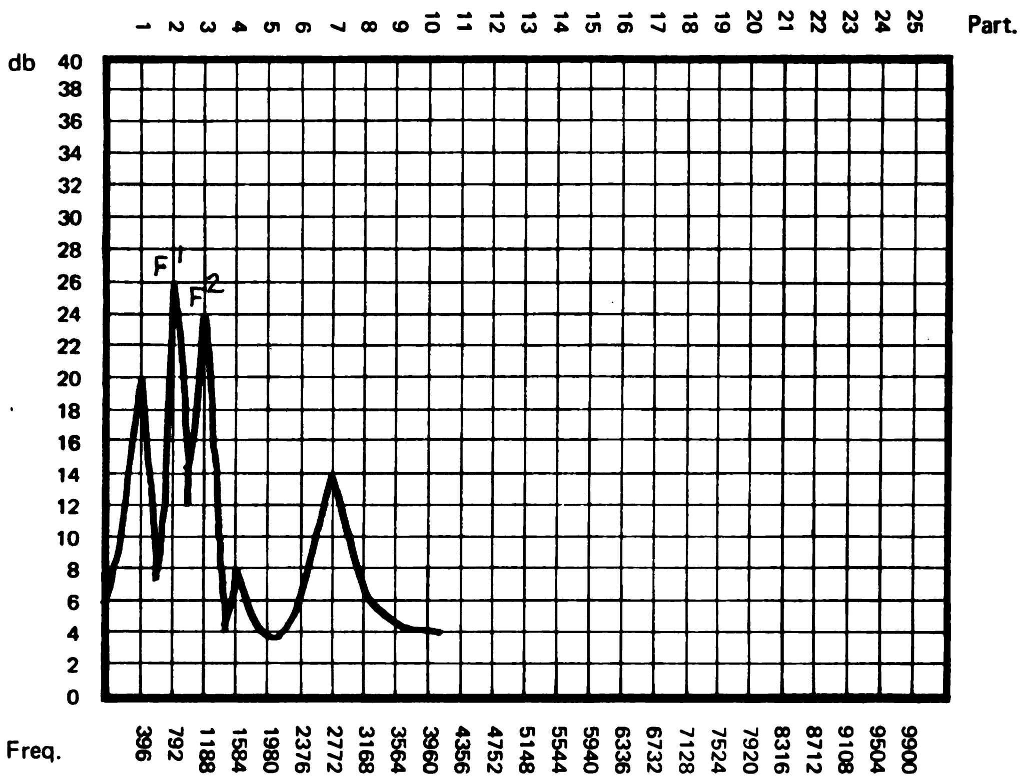

Figure 7.--Spectrograph of subject 2 singing g-396 Hz in a sound-treated room environment.

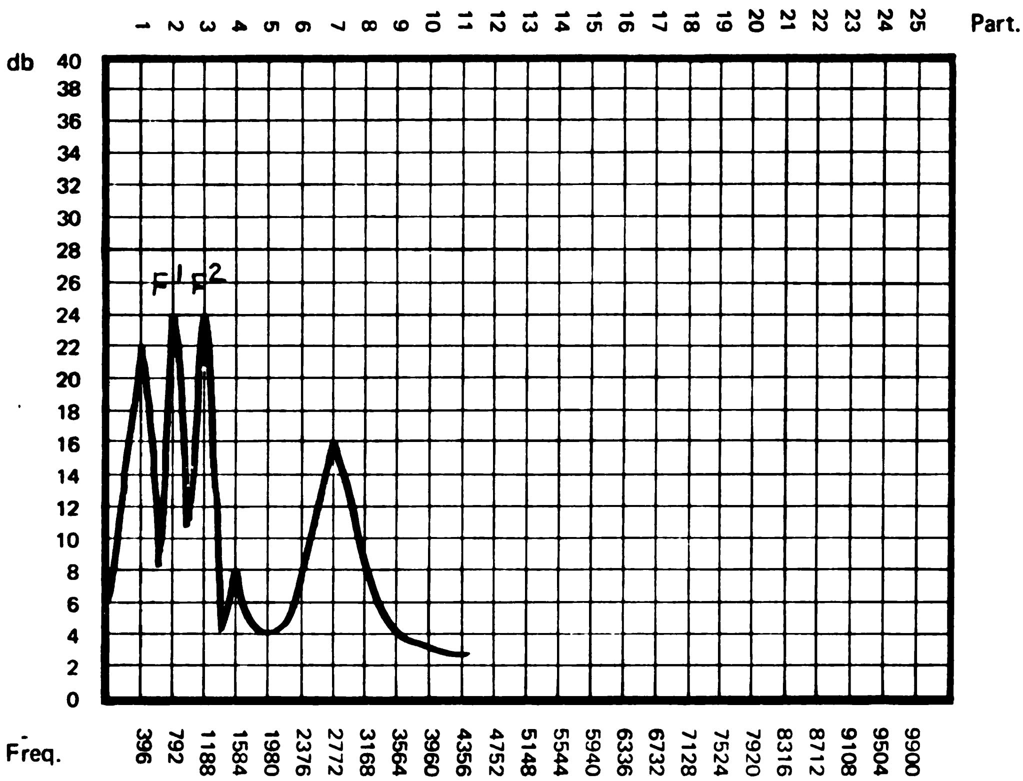

Figure 8.--Spectrograph of subject 2 singing g-396 Hz in a studio environment.

reveal this is not the case for the higher pitch, as the intensity of the fundamental is nearly identical in either environment.

The study of these spectra reveals there is little difference between the two acoustical environments in terms of the formant patterns, bandwidths, and over-all formant behavior. Since the studio environment was preferred over the sound-treated room by a margin of nearly two to one, the adjudication results of this voice experiment will serve as a basis and justification for using samples from a studio environment in this investigation. In addition, the adjudicators in this investigation will use earphones when evaluating samples since the adjudicators in the voice experiment expressed their preference to do so. All equipment used in recording and adjudicating the voice experiment was deemed to be reliable after a calibration check was made by the technician in the Audiology and Speech Sciences Department at Michigan State University.

Selection of Subjects

Tenor voices to be compared in this study were chosen from three levels: (1) high school voices (ages 16 to 18); (2) university voices (ages 19 to 24); and (3) mature tenor voices (ages 25 to 50). Subjects for these three groups were selected upon recommendation by voice teachers and choral directors chosen from various high schools and universities throughout Michigan. A copy of the initial communication sent to these teachers is found in Appendix B. A total of 35 teachers was contacted and responses were received from 21. A total of 10 subjects at each level was chosen to participate in the study. The selection was based entirely on the order in which affirmative responses were received from the teachers, and the willingness and availability of those recommended to participate. Participating subjects were assigned numbers 1 through 10 for identification at each level.

Equipment for Recording

The recorder used for recording subjects was a Sony Stereo Tapecorder TC-666D. This is a four-track, stereophonic or monophonic machine with a frequency response of 20 to 22,000 Hz. The tape speed was 7-1/2 inches per second with all subjects recorded monophonically. The microphone used was a Sony model F-98 Cardioid Dynamic semi-directional, high impedance. Scotch recording tape number 201 was used and each subject was recorded in a studio similar to the one used in the voice experiment.

Recording of the Singers

After each singer was informed regarding the purpose of the study, he was allowed ample warm-up time and practice runs in order to assure readiness for recording. During this practice time each singer was checked for his ability to produce all pitches with accurate intonation and his ability to produce the five vowel sounds without modification. Volume levels were set for recording each singer during this warm-up period. To further insure uniformity of recording, the microphone was placed at mouth level and a line was marked on the floor for the singer's toes so that his mouth was approximately 15 inches from the microphone. The VU meters indicating the recording signal strength were calibrated prior to the recording. The signal strength of each voice taped was controlled manually by volume controls so the VU meter remained between a minus two or three at approximately 62 dB. Singers were instructed as to the proper pitch, vowel, and duration of each pitch before each vowel recorded. Attacks and releases were controlled by hand signal with each pitch lasting six seconds. The recorder was stopped after the singing of each vowel. This procedure was repeated until each subject had sung the five vowels used in this study on the three pitches e-165 Hz, b-246 Hz, and $g^{\#}$-415 Hz.

The pitches chosen for the singers represent the lower, middle, and upper voice ranges of the tenor voice. All subjects had to be able to produce all pitches on all vowels accurately or they were eliminated from the study and replaced by another singer. Singers were especially checked on the pitch $g^{\#}$-415 Hz to insure they were not using falsetto voice. All pitches were chosen upon recommendation of Dr. J. Loren Jones of the voice faculty at Michigan State University.

Information as to name, age, and address of each singer was recorded prior to his singing. Prior to singing, each singer identified himself by assigned number on the tape.

Preparation of the Adjudicator's Tape

The taped samples were prepared in numerical order, beginning with the first singer. A separate tape was made for each of the three pitches and for each of the age groups; a total of nine tapes. Samples representing the five vowel sounds at each of the three pitches were recorded. The order of the samples was selected, by vowel, according to random number tables. Each sample was recorded twice with a pause of three seconds between. Aural instructions on the tape kept the adjudicator informed as to the sample, pitch, and vowel performed.

Instructions prior to adjudication were given verbally and then repeated on tape. The instructions can be found in Appendix C. In addition, the investigator was present to answer any questions not covered by instructions before proceeding.

The separate tapes for each pitch and for each of the age groups of tenors participating lasted approximately 15 minutes in length per tape. The nine tapes totaled approximately 135 minutes of listening for each adjudicator.

Selection of Adjudicators

The adjudicators were voice teachers and choral directors, 16 of whom taught at universities and four of whom taught at secondary schools in Michigan. All of them were solo adjudicators on the Michigan School Vocal Association's list of adjudicators. In order to qualify for this list, they must be actively involved in teaching voice and must attend one state sponsored adjudication clinic biennially. A total of 20 adjudicators was used in the present investigation.

Presentation of Tapes to Adjudicators

Because of a possible fatigue factor, each adjudicator listened to only three tapes at one time. This totaled approximately one hour including time for instructions and changing tapes. In an attempt to insure greater reliability among adjudicators, each adjudicator started with a tape different from that of the previous adjudicator. Tapes were presented sequentially beginning with the first adjudicator. This sequence was repeated with the tenth and eighteenth adjudicators.

After the playing of each sample, the adjudicator indicated the quality of the vowel heard based on a rating scale of 1 to 4: (1) excellent, (2) good, (3) fair, and (4) poor. The adjudicator's quality judgment for each vowel was placed on a score sheet and then transferred to a master chart for statistical analysis (see Appendix D). A Hoyt's Reliability Calculation was used to determine reliability among adjudicators.

The equipment used to present the tapes to the adjudicators was a Sony 540 Tape Recorder, having a frequency response of 30 to 20,000 Hz, and Superex model PRO-B earphones, having a frequency response of 18 to 22,000 Hz. All tapes were presented at the same level of intensity to all adjudicators; thus, the playback environment was identical for all adjudicators.

Samples Selected for Spectrographic Analysis

Since this study deals with judgments of excellent quality, only those vowel samples receiving a simple majority of excellent ratings were used (i.e., 11 or more). In addition, the sample was eliminated from the final analysis if any single adjudicator rated the vowel as fair or poor. The number of samples selected as excellent within a given level varied according to vowel sound, age level of the performer, and pitch. For example, a singer may have produced what was judged to be an excellent [a] vowel but did not receive an excellent rating for the four remaining vowels. Some high school tenors had problems producing excellent vowels at either the higher or lower pitches, but were rated excellent in the middle voice range.

Preparation of Tapes for Spectrographic Analysis

After the tapes had been presented to the adjudicators, results were compiled to determine the samples selected for analysis. The appropriate section of tape from the original recording for each vowel rated as excellent was removed and marked for identification. Each selected sample was then cut, eliminating the attack and release of each vowel, leaving a tape 31 inches in length. After sufficient practice to become proficient in splicing recording tape, loops were made and placed on a pegboard in readiness for transportation to the Department of Audiology and Speech Sciences for analysis.

Spectrography

The following design, procedures, and technical information was first utilized and described by Jones.[51] Wash's research continued the same design and was helpful in providing additional information.[52]

The loops were converted into spectrographs at the Audiology and Speech Sciences laboratory at Michigan State University. With the assistance of the technician, proper connections and adjustments were made between the Ampex Model AG 440 tape recorder, the Bruel and Kjaer 2107 frequency analyzer, and the Bruel and Kjaer 2305 Level Recorder. When these are combined, the print-out of the spectrum is automatically

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[51] Jones, op. cit., pp. 48-49, 55-57.

[52] Wash, op. cit., pp. 21-23, 26-27.

produced on frequency-calibrated paper. A reading of 10 dB was used on the VU meter to insure uniformity of signal strength.

The analyzer has a linear frequency response of 2 to 40,000 Hz. The scanning of the spectrum is done in six stages: 20 to 63 Hz, 63 to 200 Hz, 200 to 630 Hz, 630 to 2000 Hz, 2000 to 6300 Hz, and 6300 to 20,000 Hz. The different ranges may be either included or excluded by a manually operated switch. The accuracy of the band pass characteristics, depending on the attenuation desired, is plus or minus 0.5 dB. Signal shaping is possible through three weighted networks, or the signal may be analyzed linearly from 20 to 40,000 Hz, or 2 to 40,000 Hz.

The level recorder has a frequency range of 2 to 200,000 Hz and is accurate to within 1 dB. It will accept input signals up to 100 volts and will respond to signals as low as 5 mV. The calibrated paper for the print-out is connected automatically to the different frequency ranges of the analyzing systems to which it is coupled. The writing speed of the stylus and the speed of the paper are selectable. The resulting spectrograph is a highly accurate reproduction of the location of frequencies within the tone being analyzed and a highly accurate indication of the relative strengths. Having this information, a comparison of formant patterns in vowels judged to be excellent in quality may be made.

The following settings were used on the Bruel and Kjaer 2107 frequency analyzer and the 2305 Level Recorder:

Analyzer

Meter range	100 dB, s 1
Input potentiometer	5
Signal input	direct
Weighting network	linear
Frequency range	20 to 20,000 Hz
Meter switch	fast RMS
Range multiplier	0 dB
Frequency analysis octave selector .	40 dB
Function selector	automatic

Level Recorder

Paper speed	3 mm. per sec.
Continuous record	on
Voltage selector	115
Potentiometer	50 dB range
Input potentiometer	4
Input attenuator	10
Lower limiting frequency	20 Hz
Writing speed	40 mm. per sec.

After the tape loop was in proper position, the gain control was adjusted to 20 dB, chart paper was set at 0, and the process started. After the spectrograph was completed, the subject information was transferred to the spectrogram. Each individual loop was processed in the same manner.

After all loops were completed, a detailed analysis of the formant patterns for all vowels, pitches, and age groups were made and developed. In addition, a Hoyt's Reliability Calculation was made at the Computer Center at Michigan State University for each vowel at each of the three pitches to check adjudicator reliability. The results and conclusions regarding these analyses will be presented in the following chapters.

CHAPTER IV

PRESENTATION OF DATA

Statistics from the master score charts (Appendix D) show the evaluations of all subjects by the adjudicators. Only those vowel samples receiving a simple majority of excellent ratings were used for spectrographic analysis. A datum was eliminated from the spectrographic analysis if any adjudicator rated the vowel as fair or poor. Subjects at each maturity level (high school, unversity, and mature voices) were given numerical identification from 1 to 10. Tables 2, 3, and 4 identify those subjects (by numerical identification) selected for spectrographic analysis for each pitch and vowel.

The number of samples selected as excellent within a given level varied according to vowel, maturity level of the performer, and pitch. A sample of 120 tones was chosen for spectrographic analysis. There were 45 samples chosen at e-165 Hz, 41 at b-246 Hz, and 34 at g#-415 Hz. A sample of 51 mature tones was chosen as compared to 33 university and 36 high school tones.

Adjudicator Reliability

To determine adjudicator reliability, a Hoyt's Reliability Coefficient was calculated by the Control Data 6500 Computer at the Michigan State University Computer Center. A separate program, using all data, was run for each vowel at each of the three pitches,

TABLE 2.--Subjects selected for spectrographic analysis on pitch e-165 Hertz.

Vowels	High School Subjects	University Subjects	Mature Subjects
[a]	3	1	1
	4	4	3
	10	9	4
			7
			10
[e]	3	1	1
	4	4	3
	10		4
			10
[i]	3	1	1
	4	3	3
	10	4	4
			10
[o]	3	1	3
	4	4	4
	10		10
[u]	3	1	3
	10	3	4
			10

TABLE 3.--Subjects selected for spectrographic analysis on pitch b-246 Hertz.

Vowels	High School Subjects	University Subjects	Mature Subjects
[a]	5	3	3
	10	9	4
			10
[e]	4	3	3
	9	9	9
	10		10
[i]	9	3	3
	10	9	4
			9
			10
[o]	4	3	3
	10	4	4
		9	9
			10
[u]	5	4	3
	9	9	4
	10		9
			10

TABLE 4.--Subjects selected for spectrographic analysis on pitch $g^{\#}$-415 Hertz.

Vowels	High School Subjects	University Subjects	Mature Subjects
[a]	9 10	3 9	4 9 10
[e]	3 10	3 9	3 4 9
[i]	9 10	1 3	3 4 9
[o]	9 10	3 9	3 9 10
[u]	9 10	3 9	4 10

producing a total of fifteen programs. The resulting print-out produced a reliability score (r) and the standard error of measurement (SE) for each of the fifteen sets of data. The results are found in Table 5.

Table 5 shows extremely high reliability coefficients for all vowels at all pitches, ranging from .9698 for the vowel [u] at $g^{\#}$-415 Hz to .9819 for the vowel [a] at $g^{\#}$-415 Hz. The standard errors of measurement are also very consistent, ranging from 2.2916 for the vowel [u] at b-246 Hz, to 2.7804 for the vowel [u] at $g^{\#}$-415 Hz. These data show adjudicators for this study to have been highly consistent in their judgment of vowel sounds and voice quality. The adjudicators used in this research apparently had similar concepts of tone quality for tenor voices at all maturity levels.

TABLE 5.--Scores for reliability and standard error of measurement for each vowel at each of the three pitches.

Pitch and Vowel	r	SE
e-165 Hz		
[a]	.9797	2.3494
[e]	.9761	2.6243
[i]	.9783	2.4515
[o]	.9791	2.2935
[u]	.9744	2.4948
b-246 Hz		
[a]	.9745	2.4095
[b]	.9767	2.3561
[i]	.9788	2.3052
[o]	.9723	2.5147
[u]	.9785	2.2916
g#-415 Hz		
[a]	.9819	2.3520
[e]	.9791	2.4537
[i]	.9778	2.4933
[o]	.9784	2.4980
[u]	.9698	2.7804

Spectographic Analysis

The remainder of this chapter deals with the evaluation of the 120 tones selected for spectrographic analysis. Each tone will be evaluated in terms of (1) intensity of the fundamental, (2) location and intensity of F^1, (3) location and intensity of F^2, and (4) location and intensity of prominent energy regions above F^2, often referred to as F^3. A comparison will also be made within each maturity level and between the three groups used in this investigation.

Figures 9 through 128 are graphs presenting the information found within each spectrograph. Each figure accurately illustrates the locations and intensities of various energy peaks. However, these figures do not show information such as vibrato rate, formant bandwidth, or other scale reproductions of various acoustical data shown on the original spectrograph. The figures do provide the data required for the purpose of this investigation. Each figure is identified as to performer, maturity level, pitch, and vowel.

Vowel [a] at Pitch e-165 Hz

Figures 9 through 11 are spectrographs showing the formant behavior of high school subjects singing the vowel [a] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 28 to 32 dB. The variation in fundamental intensity for these subjects, and those to follow, are the result of differences in each voice and not the methods used in recording each singer. Much care was taken, as mentioned in previous chapters, to insure that each subject was recorded at the same intensity on the VU meter of the tape recorder.

2. F^1 occurs on the fourth partial (660 Hz) for all three subjects. Decibel readings are 38, 36, and 40, respectively, for high school subjects 3, 4, and 10.

3. F^2 occurs on the sixth partial (990 Hz) for high school subjects 4 and 10. Decibel readings are 34 and 32, respectively.

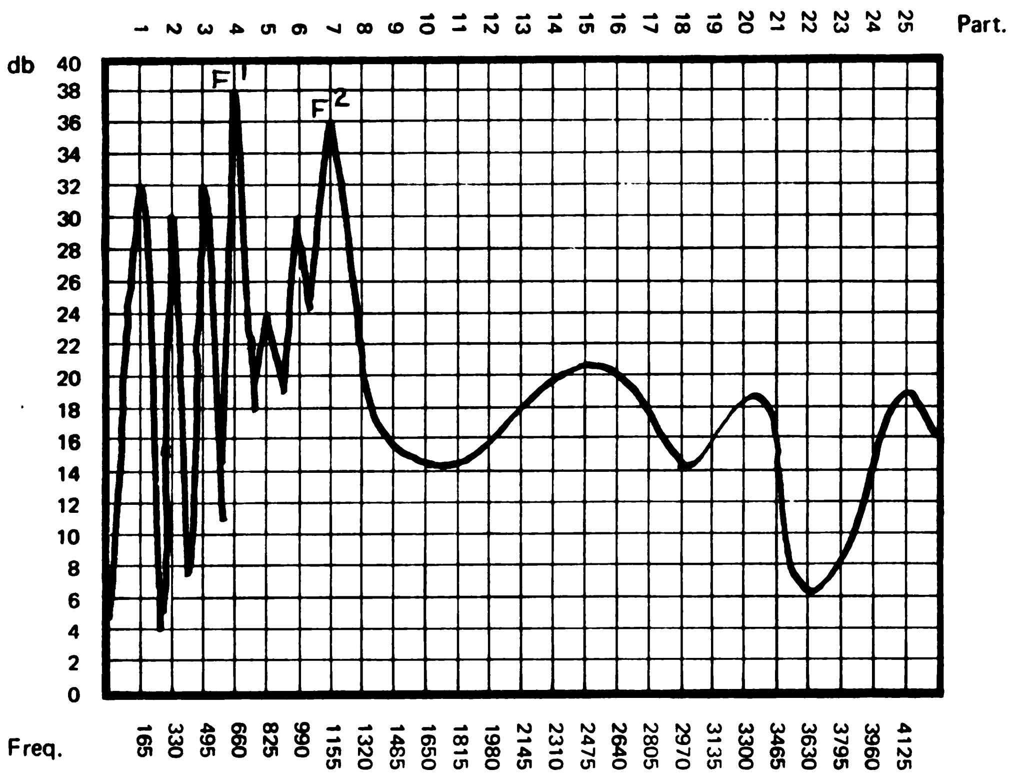

Figure 9.--Spectrograph of high school subject 3 singing the vowel [a] at e-165 Hz.

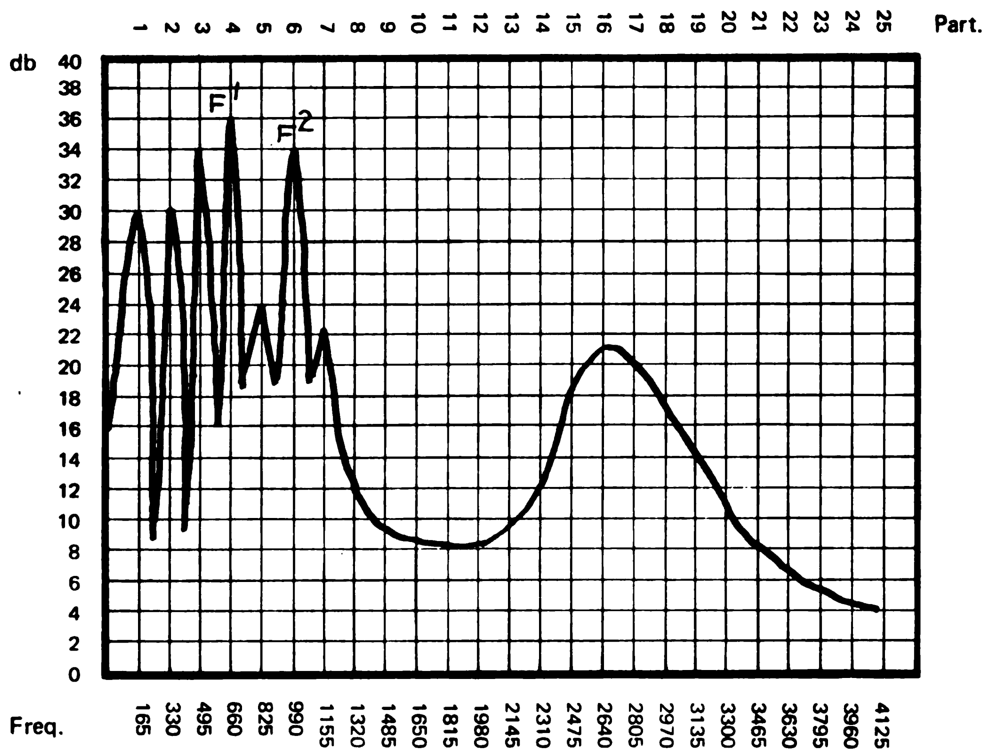

Figure 10.--Spectrograph of high school subject 4 singing the vowel [a] at e-165 Hz.

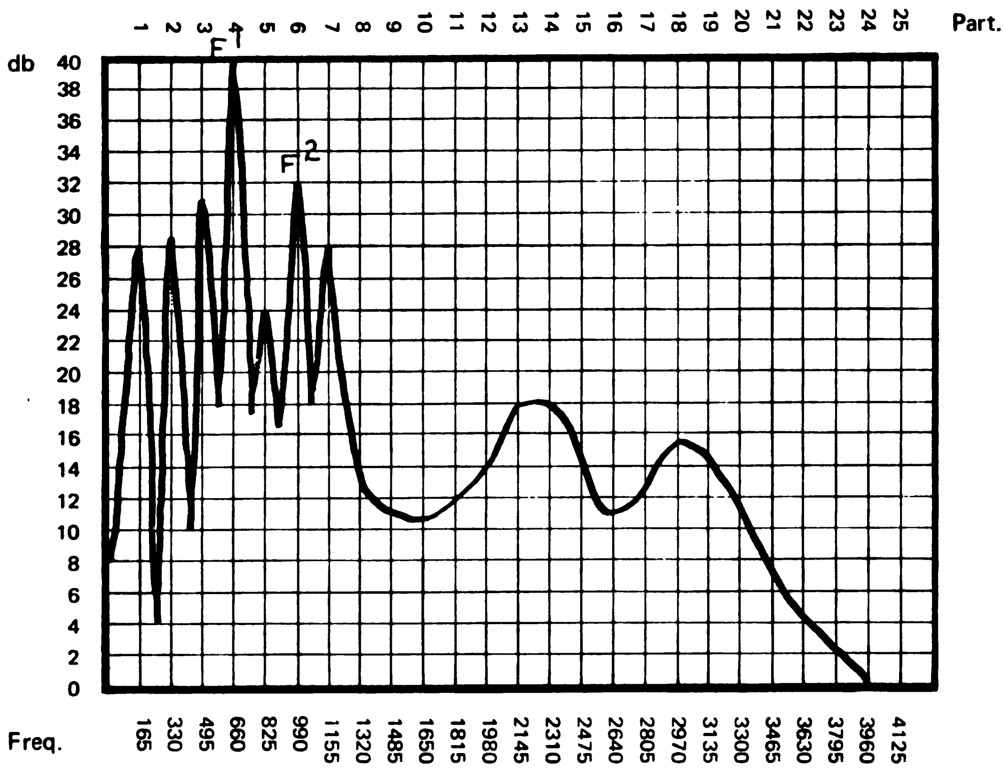

Figure 11.--Spectrograph of high school subject 10 singing the vowel [a] at e-165 Hz.

F^2 occurs on the seventh partial (1155 Hz) for high school subject 3, with a decibel reading of 36.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region ranges from the eleventh partial (1815 Hz) to the nineteenth partial (2970 Hz) at 14 to 20 dB for high school subject 3. The range for high school subject 4 is from the thirteenth partial (2145 Hz) to the twentieth partial (3300 Hz) at 10 to 21 dB. For high school subject 10 the energy region ranges from the tenth partial (1650 Hz) to the sixteenth partial (2640 Hz) at 10 to 18 dB. While previous studies may have designated this energy region F^3, the present investigation deals only with the first two formants. Conclusions and recommendations regarding this energy region will be discussed in Chapter V.

Figures 12 through 14 are spectrographs showing the formant behavior of university subjects singing the vowel [a] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 29 to 32 dB.

2. F^1 occurs on the fourth partial (660 Hz) for all three subjects. Decibel readings are 40, 38, and 34.5, respectively, for university subjects 1, 4, and 9.

3. F^2 occurs on the sixth partial (990 Hz) for all three subjects. Decibel readings are 34 for all three subjects.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region ranges from the sixteenth partial (2640 Hz) to the twenty-fourth partial (3690 Hz) at 8 to 16 dB for university subject 1. The range for university subject 4 is

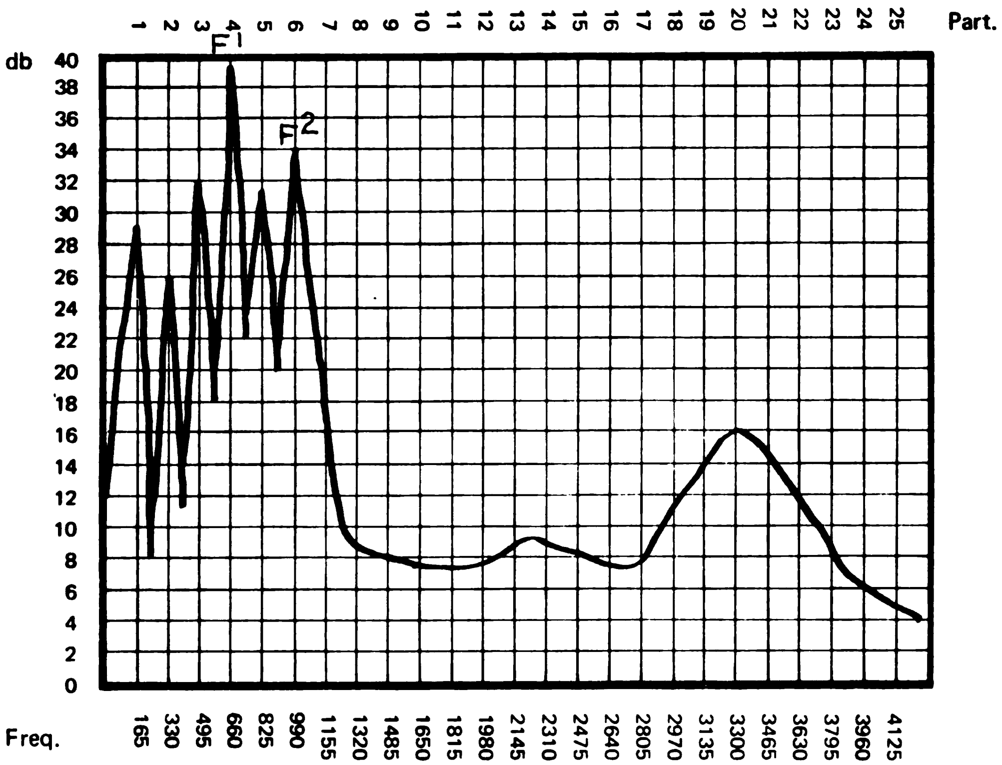

Figure 12.--Spectrograph of university subject 1 singing the vowel [a] at e-165 Hz.

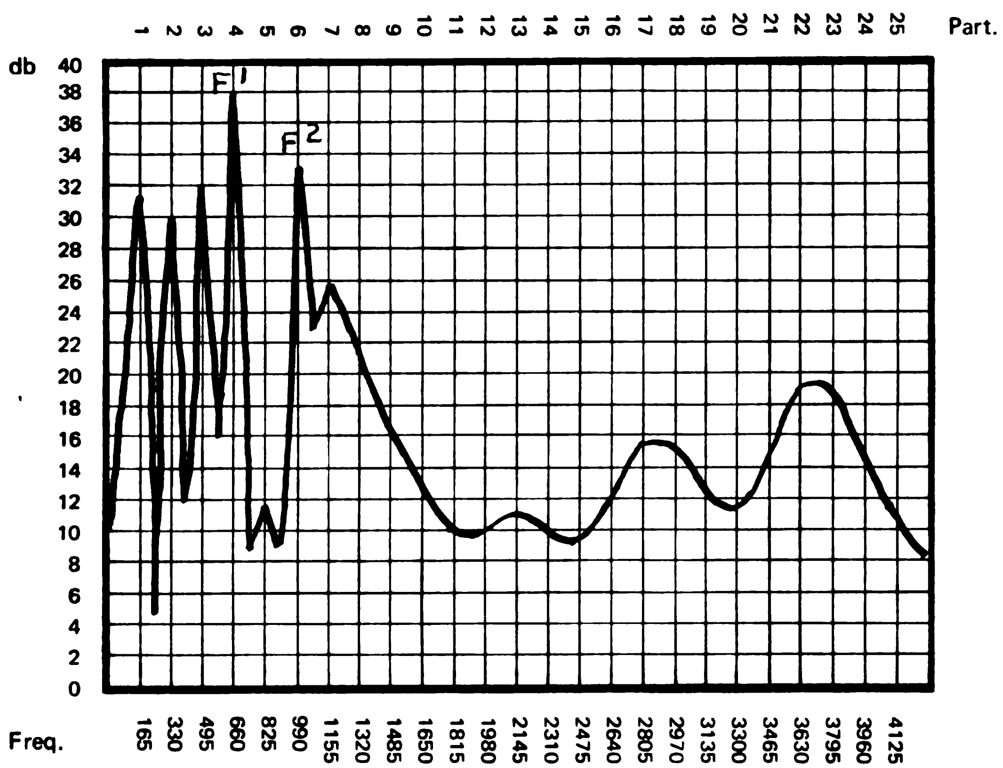

Figure 13.--Spectrograph of university subject 4 singing the vowel [a] at e-165 Hz.

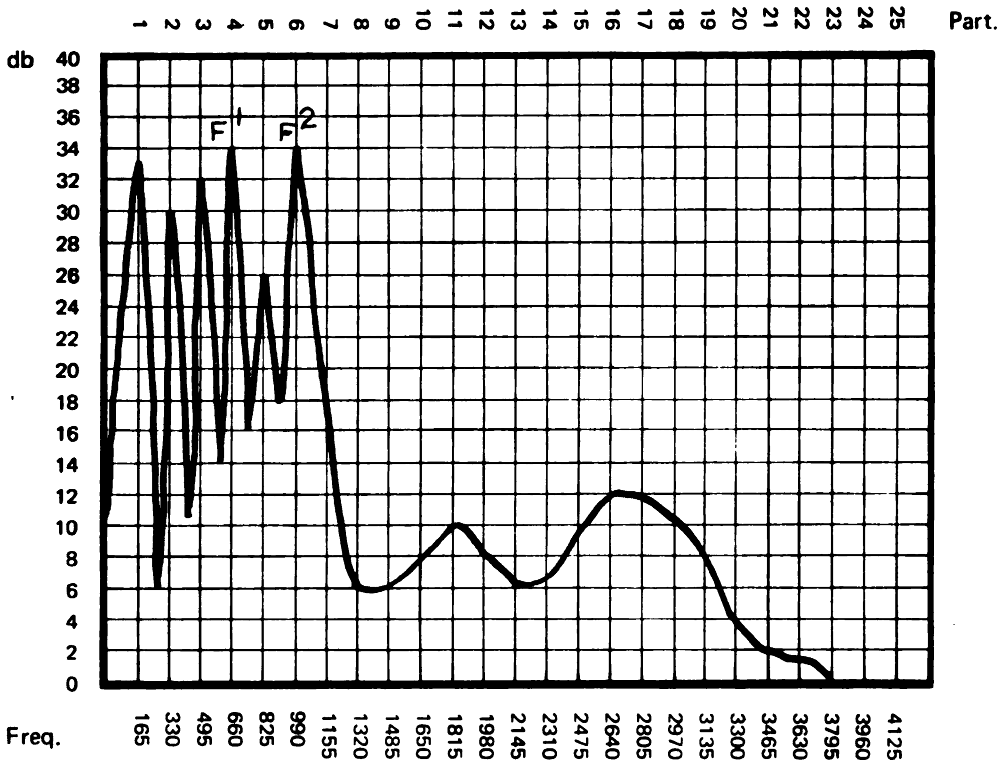

Figure 14.--Spectrograph of university subject 9 singing the vowel [a] at e-165 Hz.

from the fifteenth partial (2475 Hz) to the twenty-fifth partial (4125 Hz) at 10 to 19 dB. The energy region ranges from the tenth partial (1650 Hz) to the eighteenth partial (2970 Hz) at 6 to 10 dB for university subject 9.

Figures 15 through 19 are spectrographs showing the formant behavior of mature subjects singing the vowel [a] at e-165 Hz and include the following information:

1. The intensities of the fundamental range from 28 to 33 dB for all subjects except mature subject 10, who registers a fundamental intensity of 22 dB. This lower intensity cannot be accounted for as the adjudicators did not evaluate subject 10 significantly better or worse than the other four subjects.

2. F^1 occurs on the fourth partial (660 Hz) for all five subjects. Decibel readings are 38, 39, 36, 38, and 36, respectively, for mature subjects 1, 3, 4, 7, and 10.

3. F^2 occurs on the sixth partial (990 Hz) for all subjects except mature subject 3. Decibel readings on the sixth partial are 32, 32, 36, and 32, respectively, for mature subjects 1, 4, 7, and 10. The decibel reading for mature subject 3, occurring on the seventh partial (1155 Hz), is 40.

4. A prominent energy region above F^2 is present in all spectrograms except that of mature subject 7. This energy region ranges from the twelfth partial (1980 Hz) to the twenty-second partial (3630 Hz) at 14 to 18 dB for mature subject 1. The range for mature subject 3 is similar to that of mature subject 1, but at 8 to 17 dB. The range for mature subject 4 is a very intense peak from the

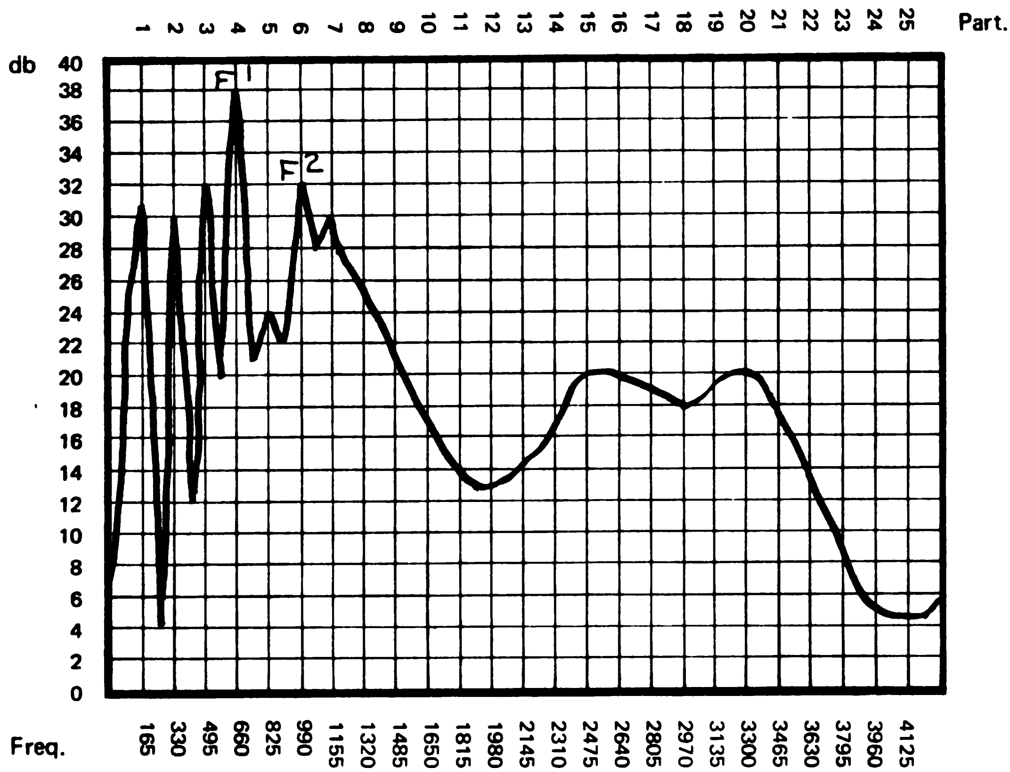

Figure 15.--Spectrograph of mature subject 1 singing the vowel [a] at e-165 Hz.

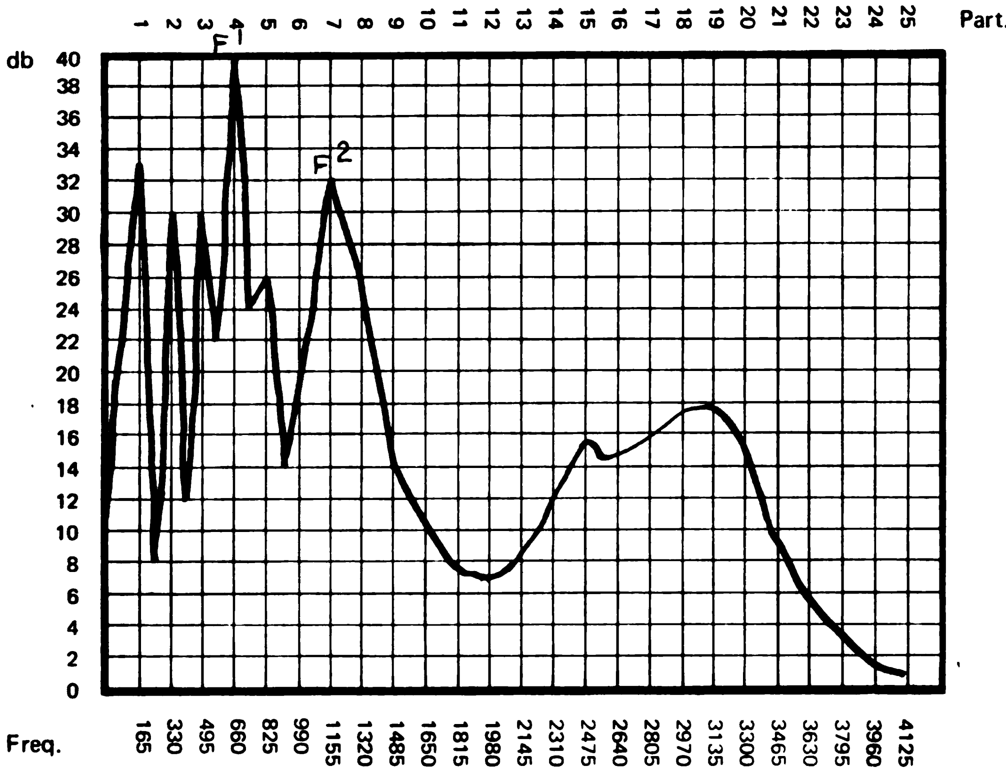

Figure 16. Spectrograph of mature subject 3 singing the vowel [a] at e-165 Hz.

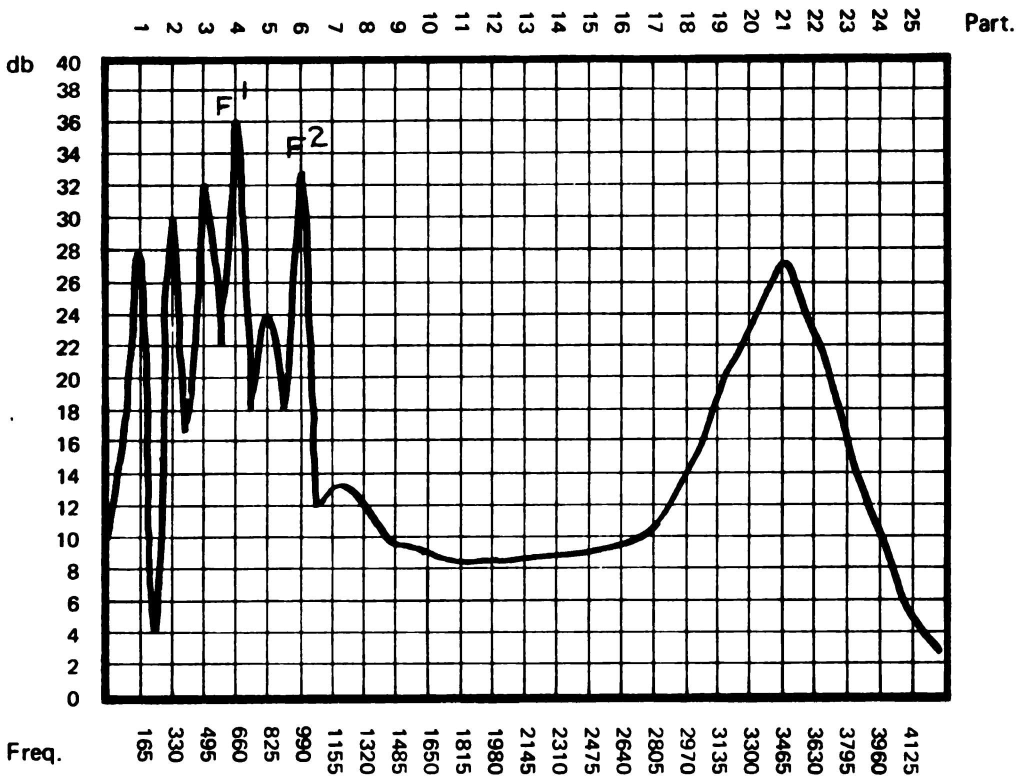

Figure 17.--Spectrograph of mature subject 4 singing the vowel [a] at e-165 Hz.

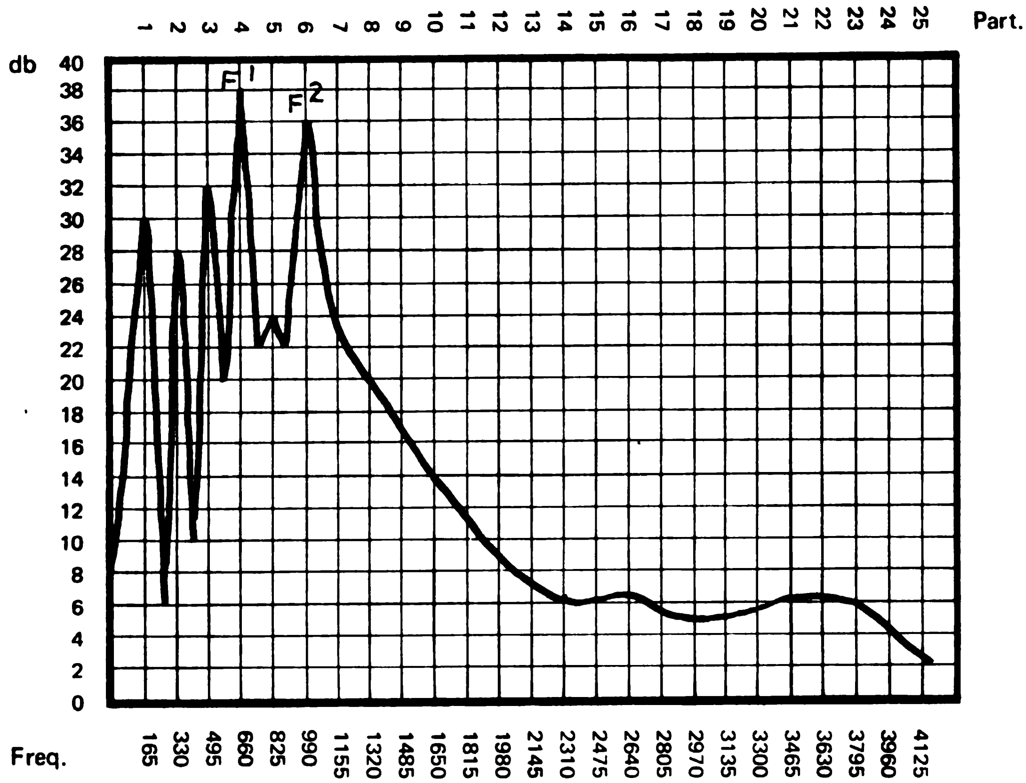

Figure 18.--Spectrograph of mature subject 7 singing the vowel [a] at e-165 Hz.

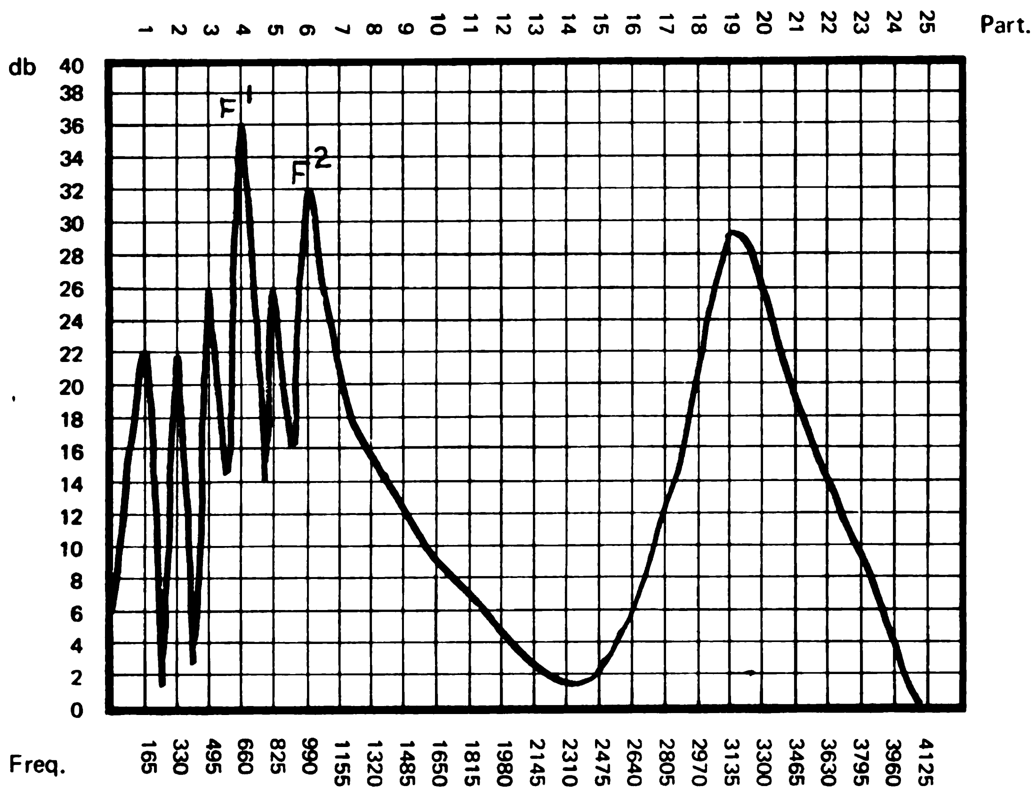

Figure 19.--Spectrograph of mature subject 10 singing the vowel [a] at e-165 Hz.

sixteenth partial (2640 Hz) to the twenty-fourth partial (3960 Hz), the highest intensity peaking on the twenty-first partial (3465 Hz) at 27 dB. The range for mature subject 10, also with an intense peak, is from the sixteenth partial (2640 Hz) to the twenty-third partial (3795 Hz), the highest intensity peaking on the nineteenth partial (3135 Hz) at 29 dB.

A Comparison of All Subjects Singing the Vowel [a] at e-165 Hz

1. With the exception of mature subject 10, the intensities of the fundamental range from 28 to 33 dB for all subjects.

2. F^1 occurs on the fourth partial (660 Hz) for all subjects with decibel readings ranging from 34.5 to 40.

3. F^2 occurs on the seventh partial (1155 Hz) for high school subject 3 and mature subject 3 with decibel readings of 36 and 40, respectively. F^2 occurs on the sixth partial (990 Hz) for all other subjects with decibel readings ranging from 32 to 36.

4. A prominent energy region above F^2 is present in all spectrograms except that of mature subject 7. The length and intensity of this energy region varies among subjects, occurring between the thirteenth (1980 Hz) and twenty-first (3465 Hz) partials at 10 to 20 dB.

Vowel [e] at Pitch e-165 Hz

Figures 20 through 22 are spectrographs showing the formant behavior of high school subjects singing the vowel [e] at e-165 Hz, and include the following information:

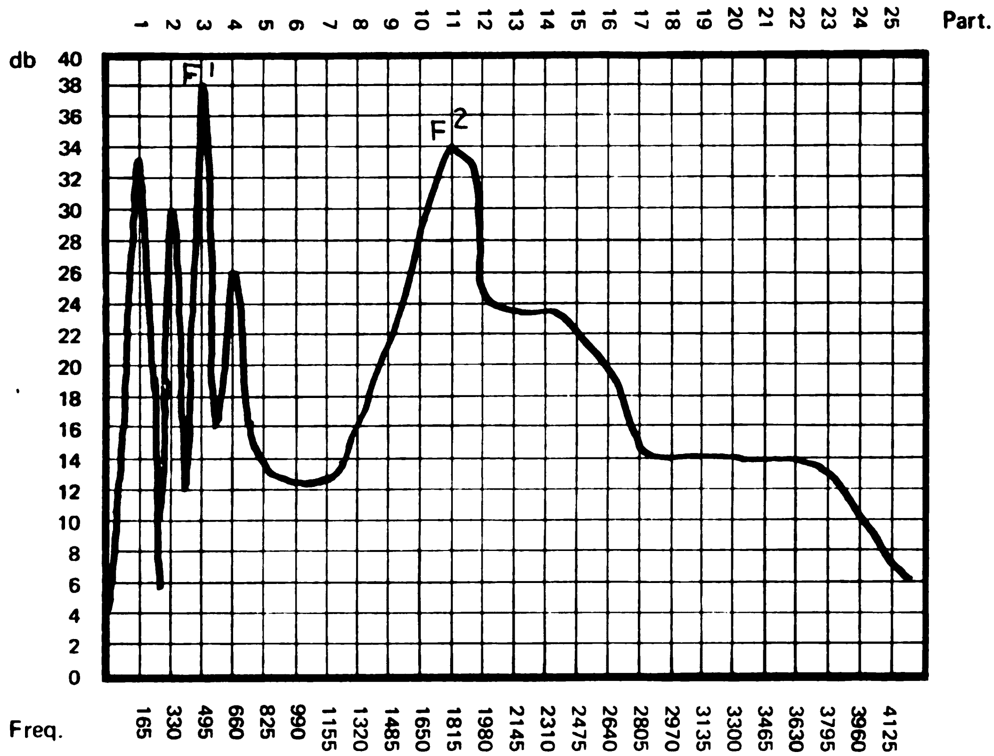

Figure 20.--Spectrograph of high school subject 3 singing the vowel [e] at e-165 Hz.

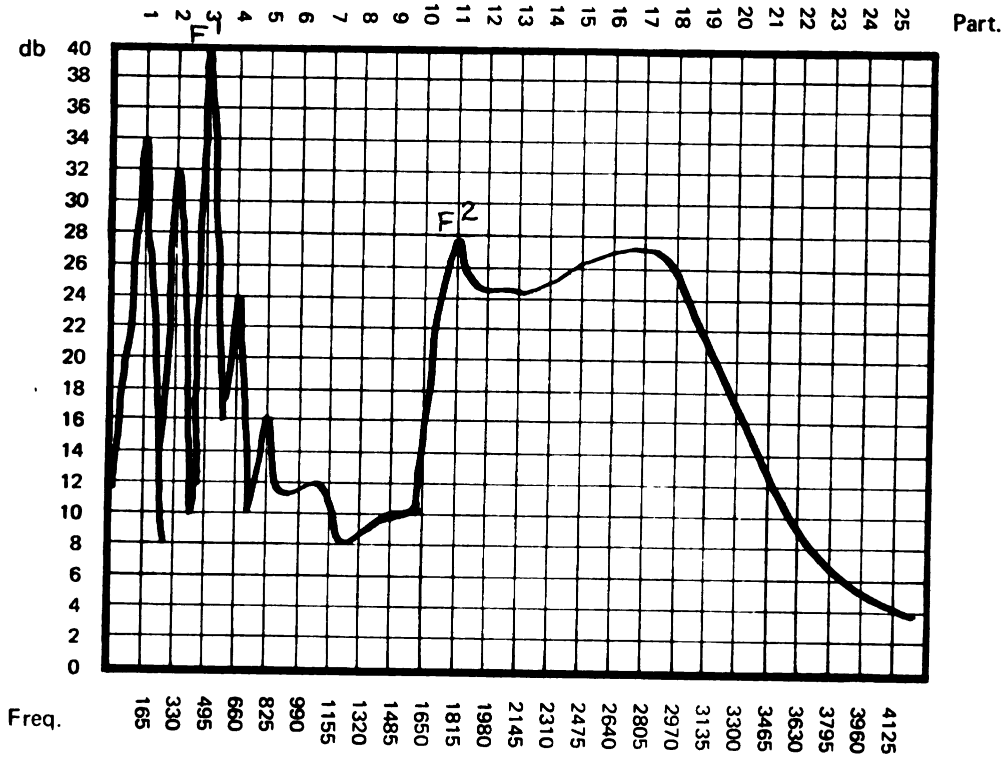

Figure 21.--Spectrograph of high school subject 4 singing the vowel [e] at e-165 Hz.

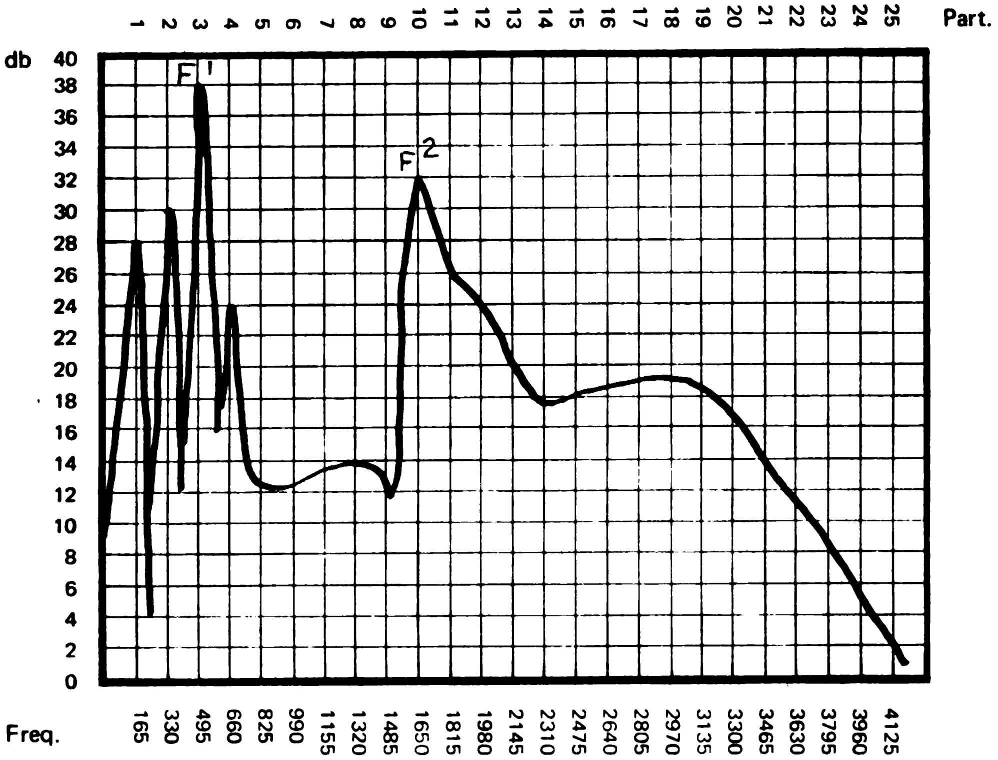

Figure 22.--Spectrograph of high school subject 10 singing the vowel [e] at e-165 Hz.

1. The intensities of the fundamental range from 28 to 34 dB.

2. F^1 occurs on the third partial (495 Hz) for all three subjects. Decibel readings are 38, 40, and 38, respectively, for high school subjects 3, 4, and 10.

3. F^2 occurs on the tenth partial (1650 Hz) for high school subject 10, with a decibel reading of 34. F^2 occurs on the eleventh partial (1815 Hz) for high school subjects 3 and 4 with decibel readings at 34 and 28, respectively.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region begins at approximately the fourteenth partial (2310 Hz) at 18 to 24 dB with a gradual decrease in intensity to 0 dB at the twenty-fifth partial (4125 Hz).

Figures 23 and 24 are spectrographs showing the formant behavior of university subjects singing the vowel [e] at e-165 Hz, and include the following information:

1. The intensities of the fundamental are 31 and 33 dB.

2. F^1 occurs on the third partial (495 Hz) with decibel readings at 36 for both subjects.

3. F^2 occurs on the tenth partial (1650 Hz) for both subjects, with decibel readings at 34 for university subject 1 and 33 for university subject 4.

4. A prominent energy region above F^2 is present in both spectrograms. This energy region ranges from the twelfth partial (1980 Hz) to the twenty-fifth partial (4125 Hz) with energy peaks occurring at 24.5 dB and 30 dB at approximately the fifteenth partial (2475 Hz) and the twenty-first partial (3465 Hz), respectively, with

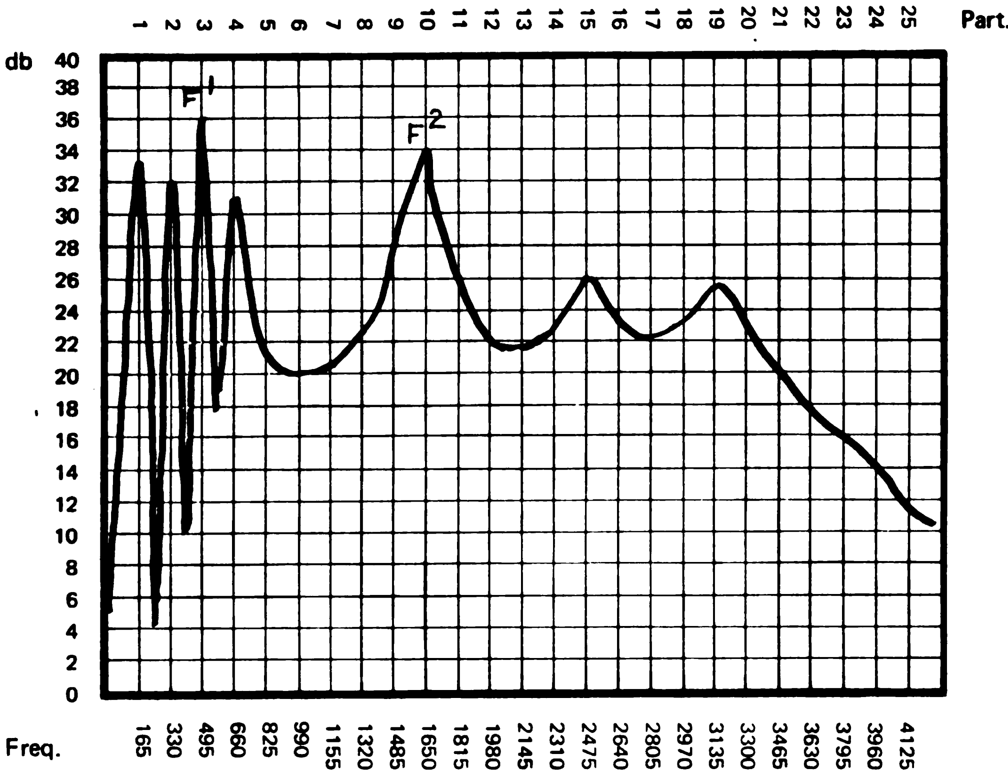

Figure 23.--Spectrograph of university subject 1 singing the vowel [e] at e-165 Hz.

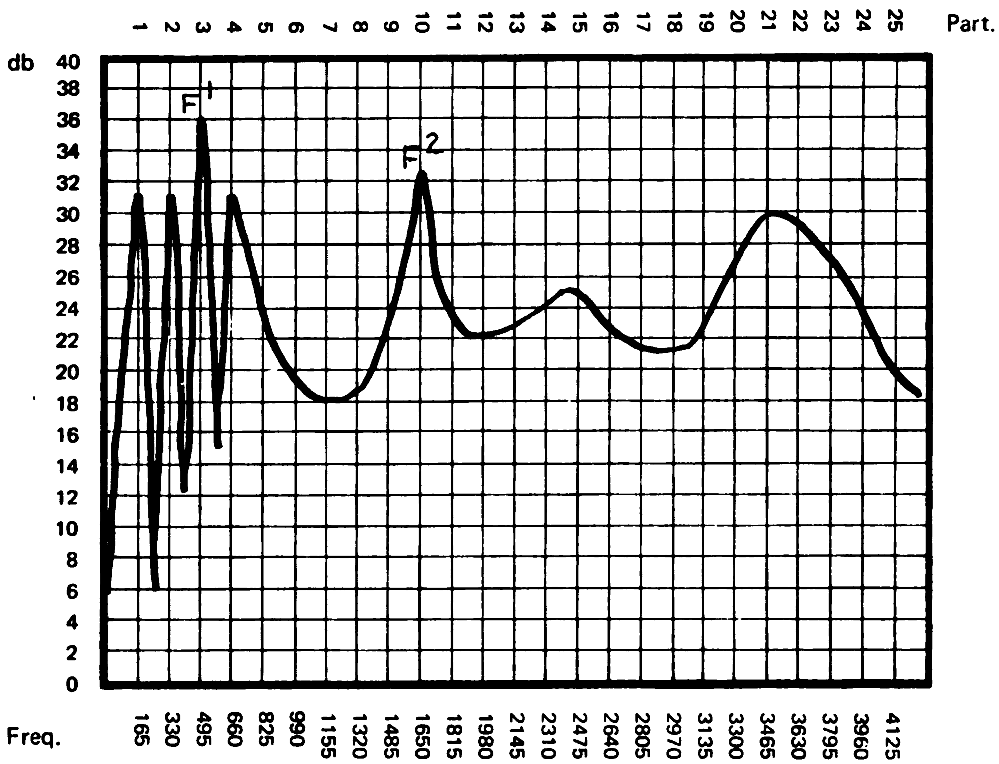

Figure 24.--Spectrograph of university subject 4 singing the vowel [e] at e-165 Hz.

a gradual decrease in intensity of between 10 and 15 dB through the twenty-fifth partial (4125 Hz).

Figures 25 through 28 are spectrographs showing the formant behavior of mature subjects singing the vowel [e] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 30 to 32 dB for all subjects except mature subject 10. Subject 10 shows a fundamental intensity of 22 dB, identical to his fundamental intensity for the vowel [a] at the same pitch.

2. F^1 occurs on the third partial (495 Hz) for all four subjects. Decibel readings are 36, 38, 38, and 40, respectively, for mature subjects 1, 3, 4, and 10.

3. F^2 occurs on the eighth partial (1320 Hz) for mature subject 4, with a decibel reading of 32. F^2 occurs on the ninth partial (1485 Hz) for mature subjects 3 and 10, with decibel readings of 32 and 24, respectively. F^2 occurs on the eleventh partial (1815 Hz) for mature subject 1, with a decibel reading of 34.

4. A prominent energy region above F^2 is present in all four spectrograms. This energy region ranges from approximately the fourteenth partial (2310 Hz) to the twenty-second partial (3630 Hz) at 26 to 29 dB with a sharp drop to 0 dB at the twenty-fifth partial (4125 Hz).

A Comparison of All Subjects Singing the Vowel [e] at e-165 Hz

1. With the exception of mature subject 10, the fundamental intensities range from 28 to 34 dB for all subjects.

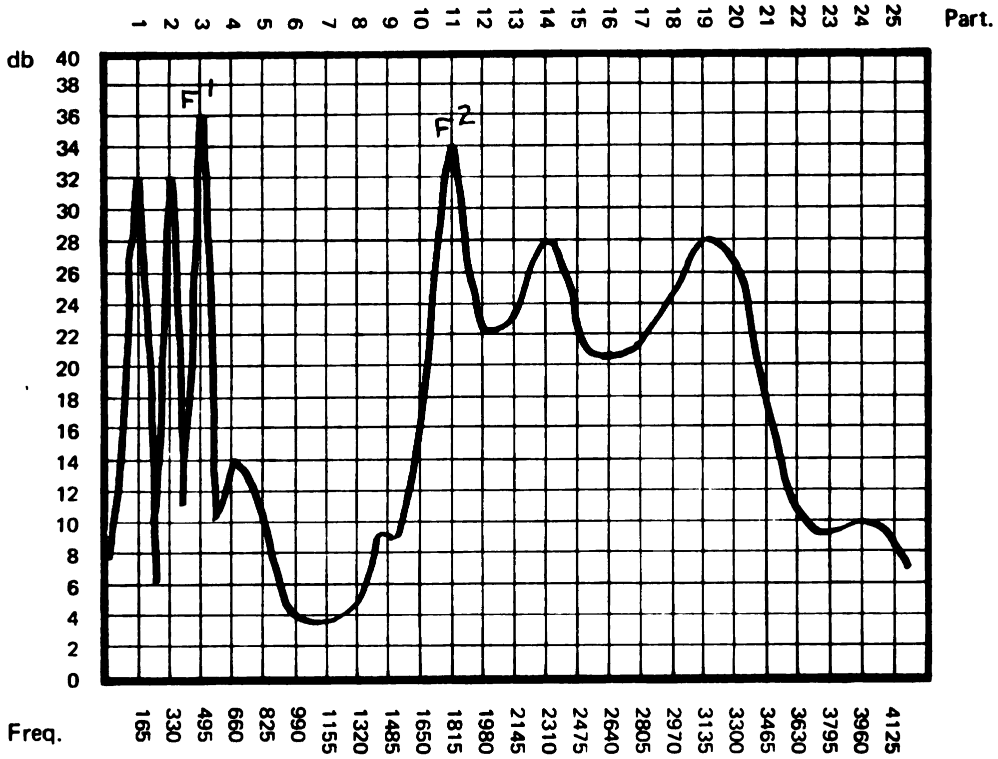

Figure 25.--Spectrograph of mature subject 1 singing the vowel [e] at e-165 Hz.

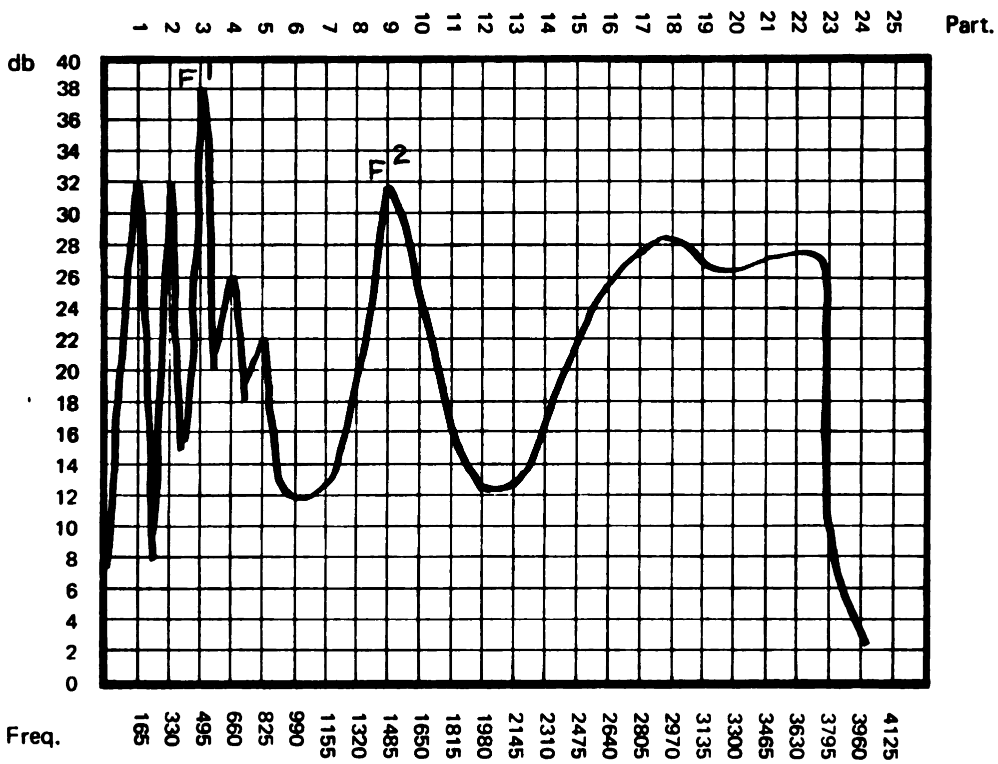

Figure 26.--Spectrograph of mature subject 3 singing the vowel [e] at e-165 Hz.

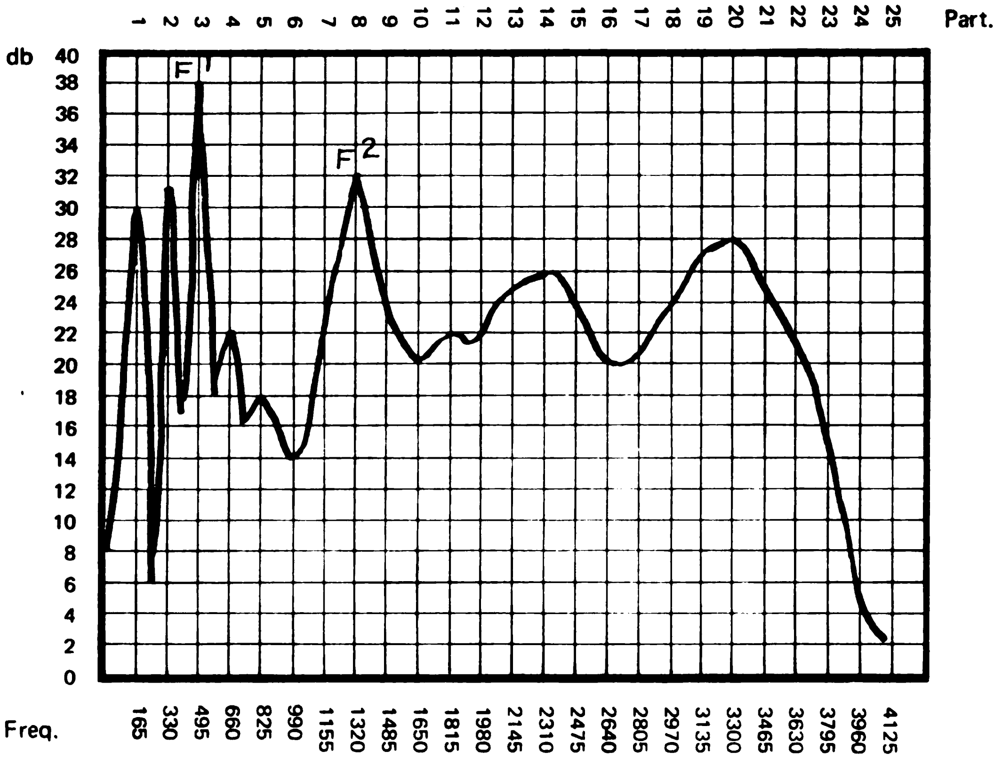

Figure 27.--Spectrograph of mature subject 4 singing the vowel [e] at e-165 Hz.

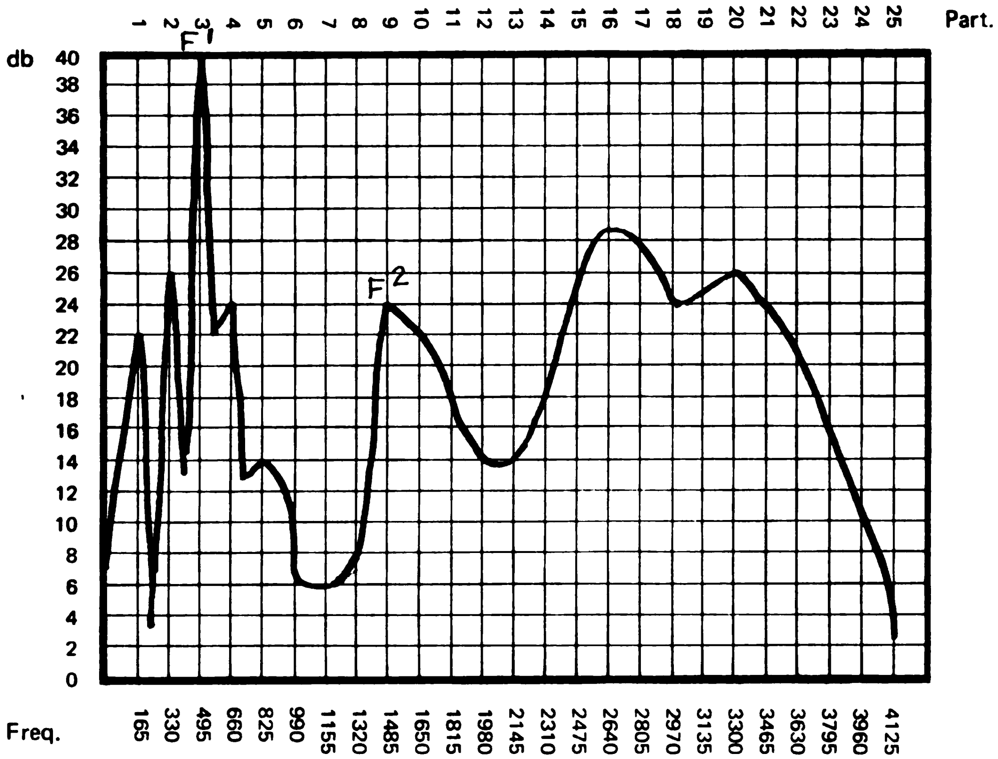

Figure 28.--Spectrograph of mature subject 10 singing the vowel [e] at e-165 Hz.

2. F^1 occurs on the third partial (495 Hz) for all subjects with decibel readings ranging from 36 to 40.

3. F^2 occurs on the eighth partial (1320 Hz) for mature subject 4, on the ninth partial (1485 Hz) for mature subjects 3 and 10, on the tenth partial (1650 Hz) for high school subject 10 and both university subjects, and on the eleventh partial (1815 Hz) for high school subjects 3 and 4, and mature subject 1. With the exception of high school subject 4 and mature subject 10, decibel readings for F^2 range from 32 to 40.

4. A prominent energy region above F^2 is present in all spectrograms. The pattern is very similar for all subjects, ranging from approximately the fourteenth partial (2310 Hz) to the twenty-second partial (3630 Hz) at 26 to 29 dB. Most spectrograms show a sharp decrease in energy to 0 dB at the twenty-fifth partial (4125 Hz) with no prominent energy peaks in the energy region.

Vowel [i] at Pitch e-165 Hz

Figures 29 through 31 are spectrographs showing the formant behavior of high school subjects singing the vowel [i] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 30 to 38 dB.

2. F^1 occurs on the second partial (330 Hz) for all three subjects. Decibel readings are 38, 38, and 40, respectively, for high school subjects 3, 4, and 10.

3. F^2 occurs on the eleventh partial (1815 Hz) for high school subject 10, with a decibel reading of 32. F^2 occurs on the

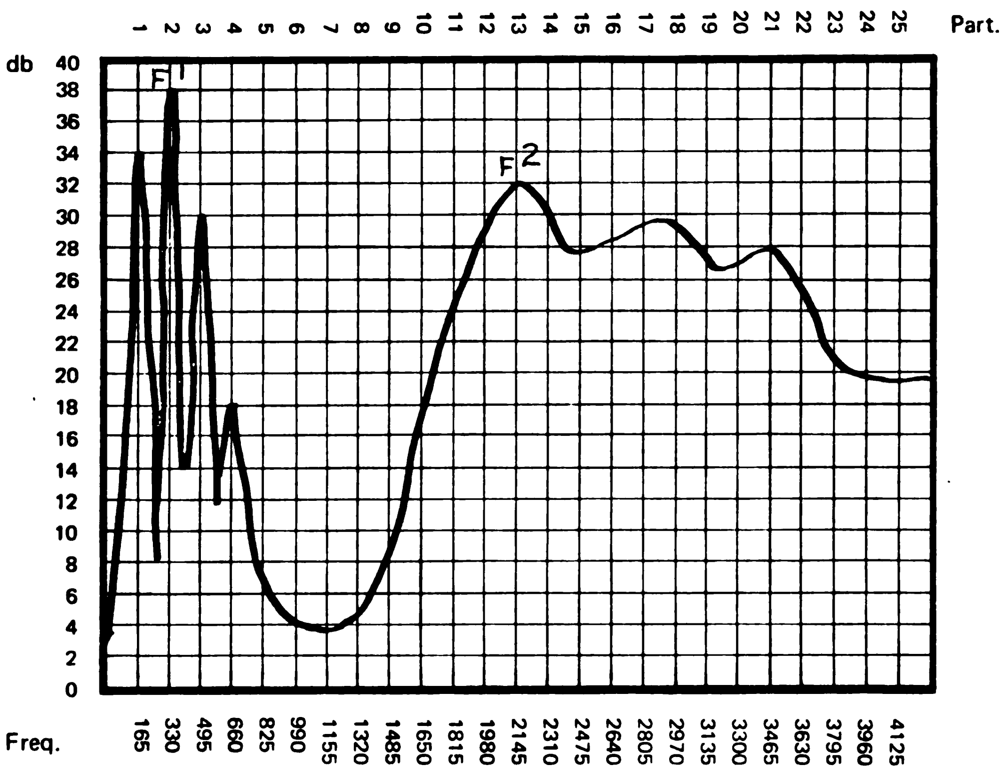

Figure 29.--Spectrograph of high school subject 3 singing the vowel [i] at e-165 Hz.

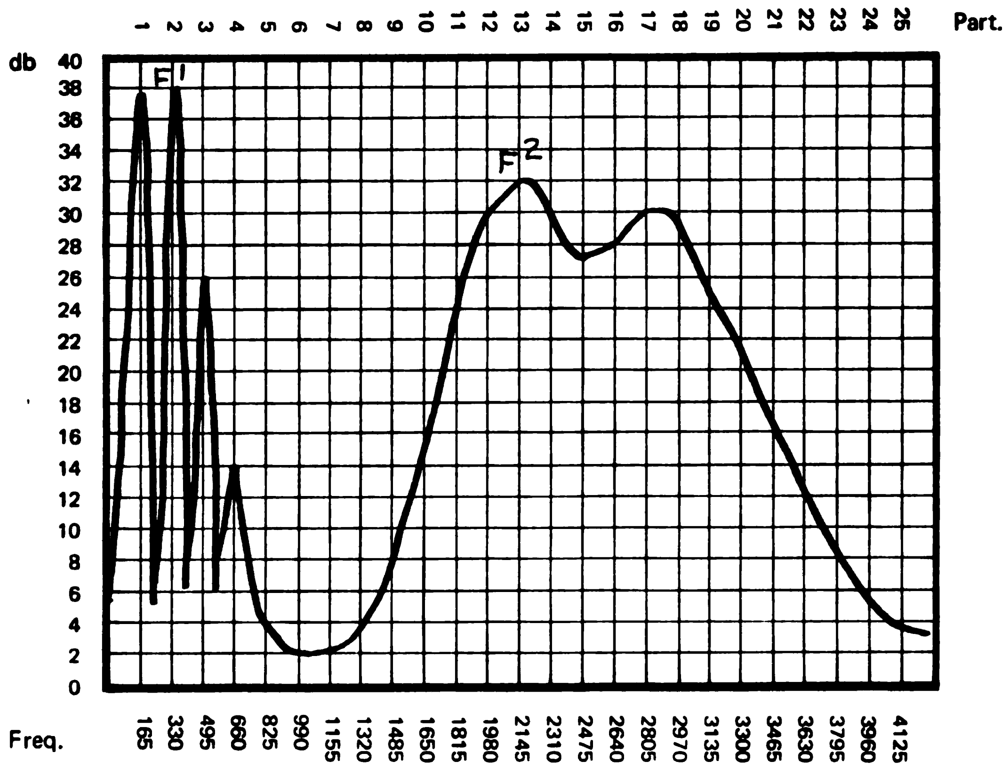

Figure 30.--Spectrograph of high school subject 4 singing the vowel [i] at e-165 Hz.

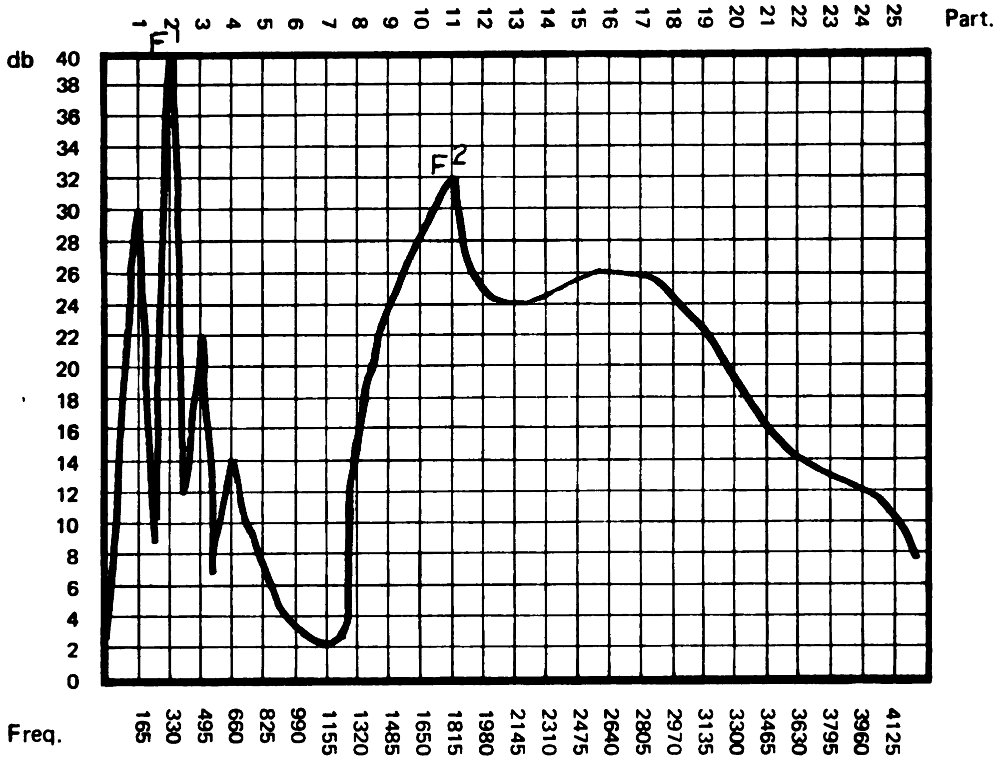

Figure 31.--Spectrograph of high school subject 10 singing the vowel [i] at 3-165 Hz.

thirteenth partial (2145 Hz) for high school subjects 3 and 4, with decibel readings of 32 recorded for both subjects.

4. A prominent energy region above F^2 is present in all three spectrograms. It appears as an energy peak at approximately the seventeenth partial (2805 Hz) at 26 to 30 dB with a gradual decrease to 20, 3.5, and 9 dB at the twenty-fifth partial (4125 Hz) for high school subjects 3, 4, and 10, respectively.

Figures 32 through 34 are spectrographs showing the formant behavior of university subjects singing the vowel [i] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 34 to 36 dB.

2. F^1 occurs on the second partial (330 Hz) for all three subjects. Decibel readings are 36, 40, and 38, respectively, for university subjects 1, 3, and 4.

3. F^2 occurs on the eleventh partial (1815 Hz) for all three subjects. Decibel readings were 30 and 28 for university subjects 1 and 4, respectively, with university subject 3 registering a much lower F^2 intensity of 20 dB.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region ranges from the thirteenth partial (2145 Hz) to an energy peak at the nineteenth partial (3135 Hz) at 23 and 26 dB for university subjects 1 and 3, respectively. The energy peak occurs at approximately the twenty-second partial (3630 Hz) at 19.5 dB for university subject 4. All three subjects show sharp decreases in intensity through the twenty-fifth partial (4125 Hz) after the energy peak occurs.

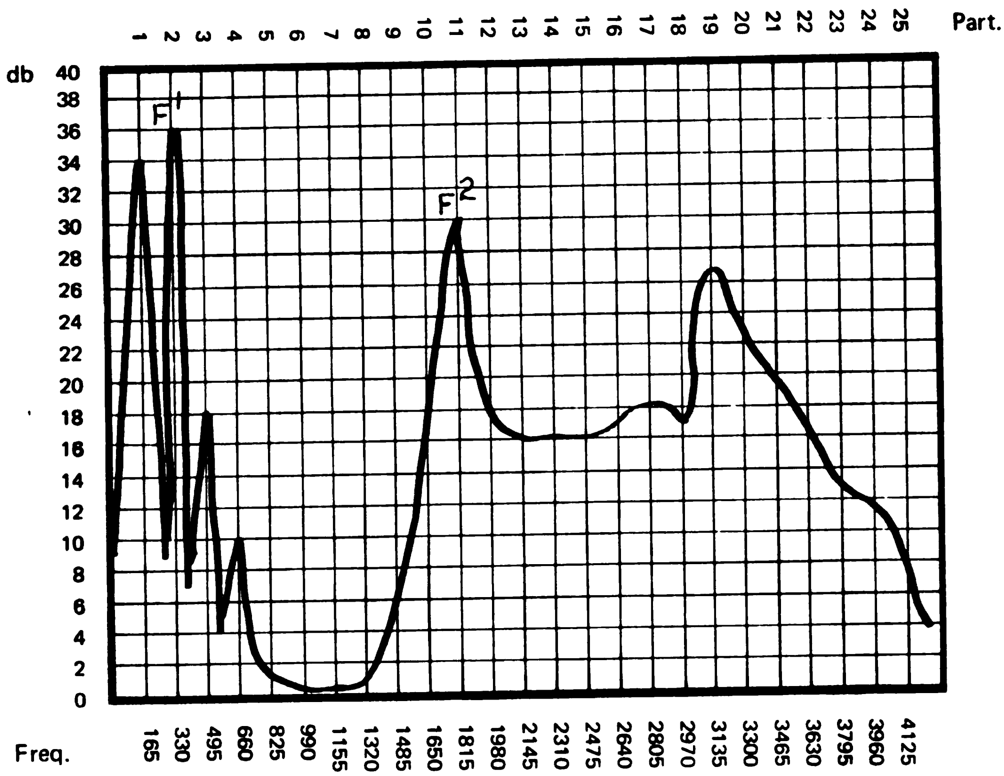

Figure 32.--Spectrograph of university subject 1 singing the vowel [i] at e-165 Hz.

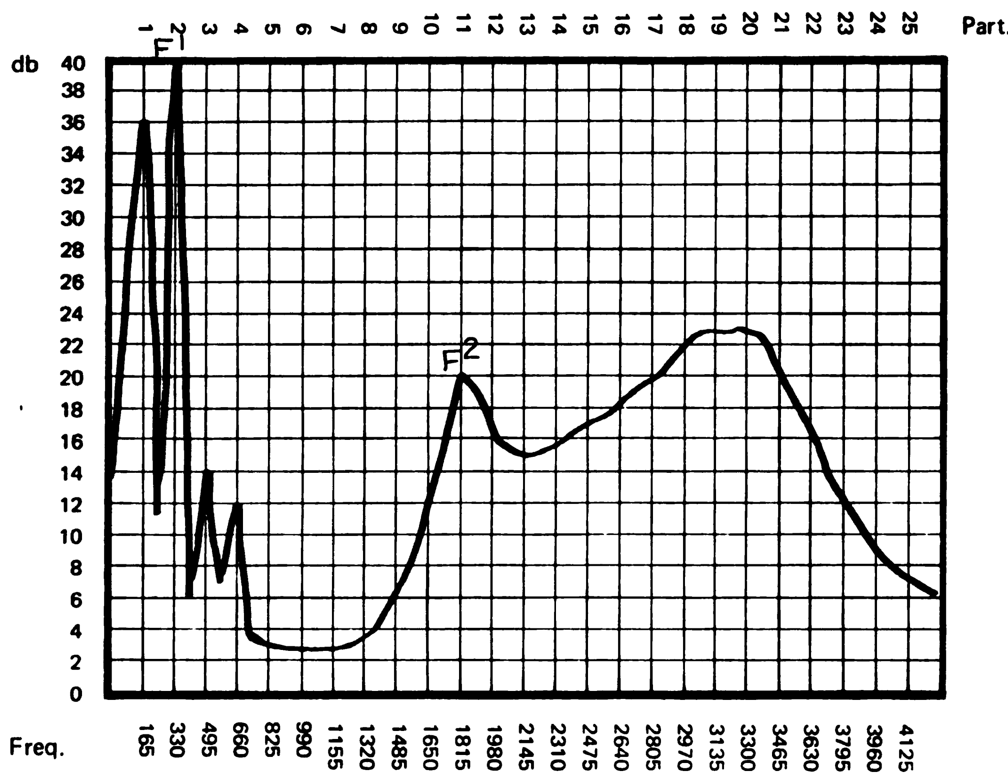

Figure 33.--Spectrograph of university subject 3 singing the vowel [i] at e-165 Hz.

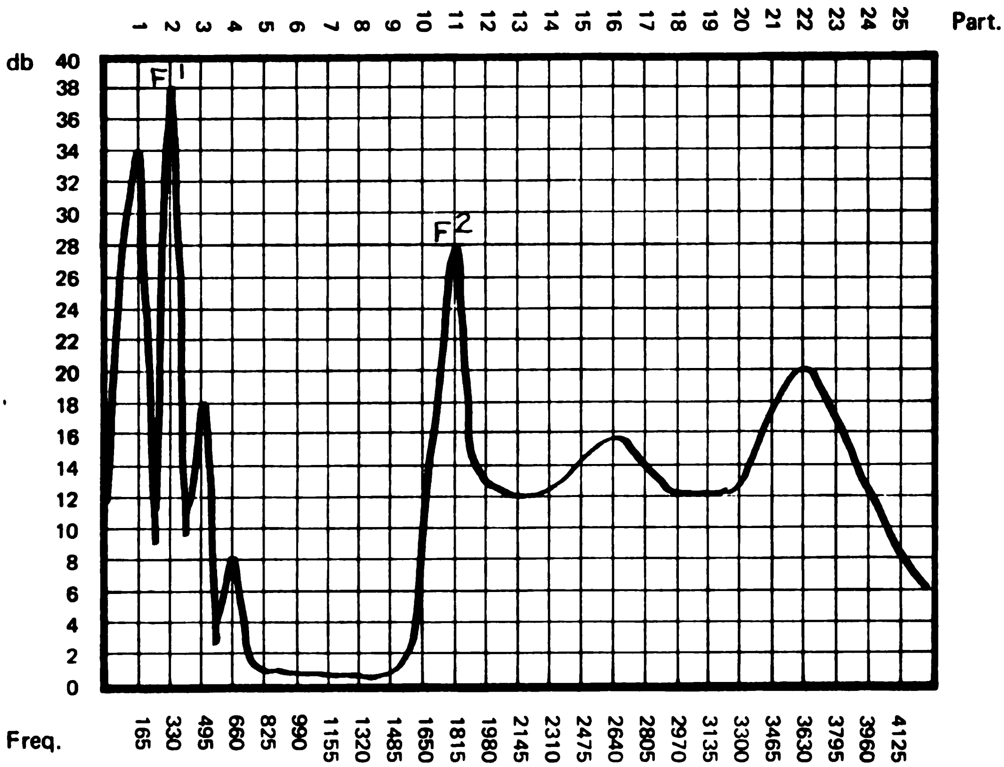

Figure 34.--Spectrograph of university subject 4 singing the vowel [i] at e-165 Hz.

Figures 35 through 38 are spectrographs showing the formant behavior of mature subjects singing the vowel [i] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 28 to 34 dB.

2. F^1 occurs on the second partial (330 Hz) for all four subjects. Decibel readings are 36, 40, 40, and 38, respectively, for mature subjects 1, 3, 4, and 10.

3. F^2 occurs on the eleventh partial (1815 Hz) for all four subjects. Decibel readings are 30, 26, 28, and 28, respectively, for mature subjects 1, 3, 4, and 10.

4. A prominent energy region above F^2 is present in all four spectrograms. It appears as two energy peaks covering partials from the fourteenth (2310 Hz) to twenty-first (3465 Hz) at between 23 and 29 dB. All subjects show a sharp decrease in intensity to 0 dB at the twenty-fifth partial (4125 Hz) after the second peak in this energy region occurs.

A Comparison of All Subjects Singing the Vowel [i] at e-165 Hz

1. The intensities of the fundamental range from 28 to 38 dB.

2. F^1 occurs on the second partial (330 Hz) for all subjects with decibel readings ranging from 36 to 40.

3. F^2 occurs on the thirteenth partial (2145 Hz) for high school subjects 3 and 4, with decibel readings of 32 for each subject. F^2 occurs on the eleventh partial (1815 Hz) for all other subjects with decibel readings ranging from 26 to 32. Although university subject 3 shows a very strong fundamental and F^1 intensity, his

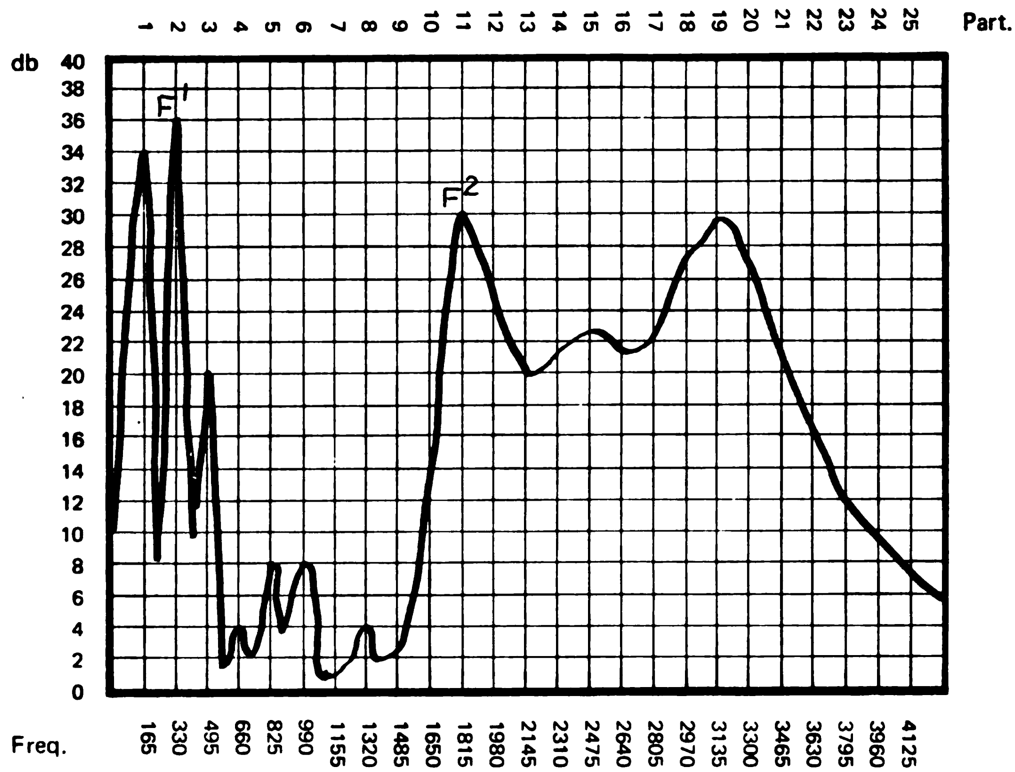

Figure 35.--Spectrograph of mature subject 1 singing the vowel [i] at e-165 Hz.

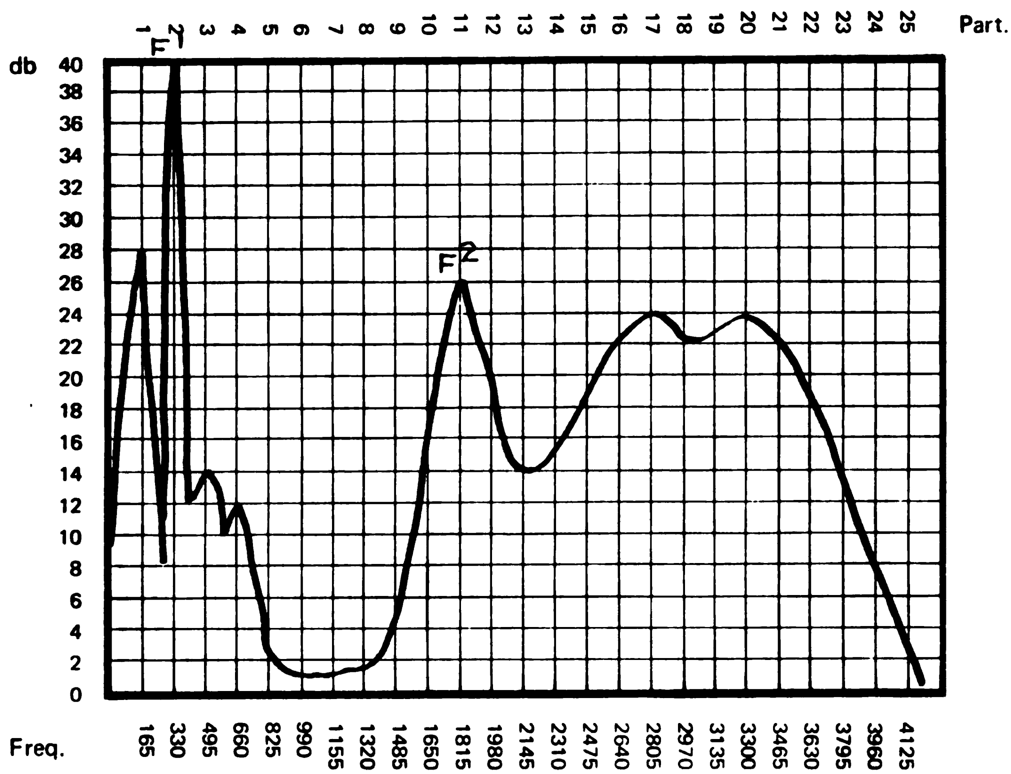

Figure 36. Spectrograph of mature subject 3 singing the vowel [i] at e-165 Hz.

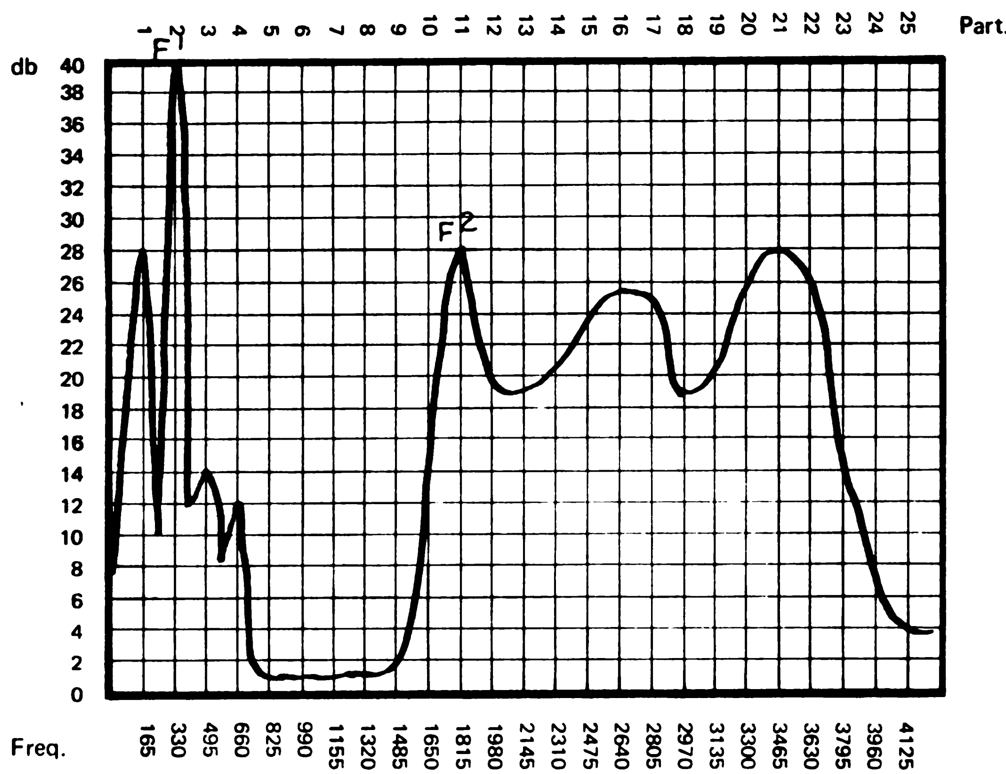

Figure 37.--Spectrograph of mature subject 4 singing the vowel [i] at e-165 Hz.

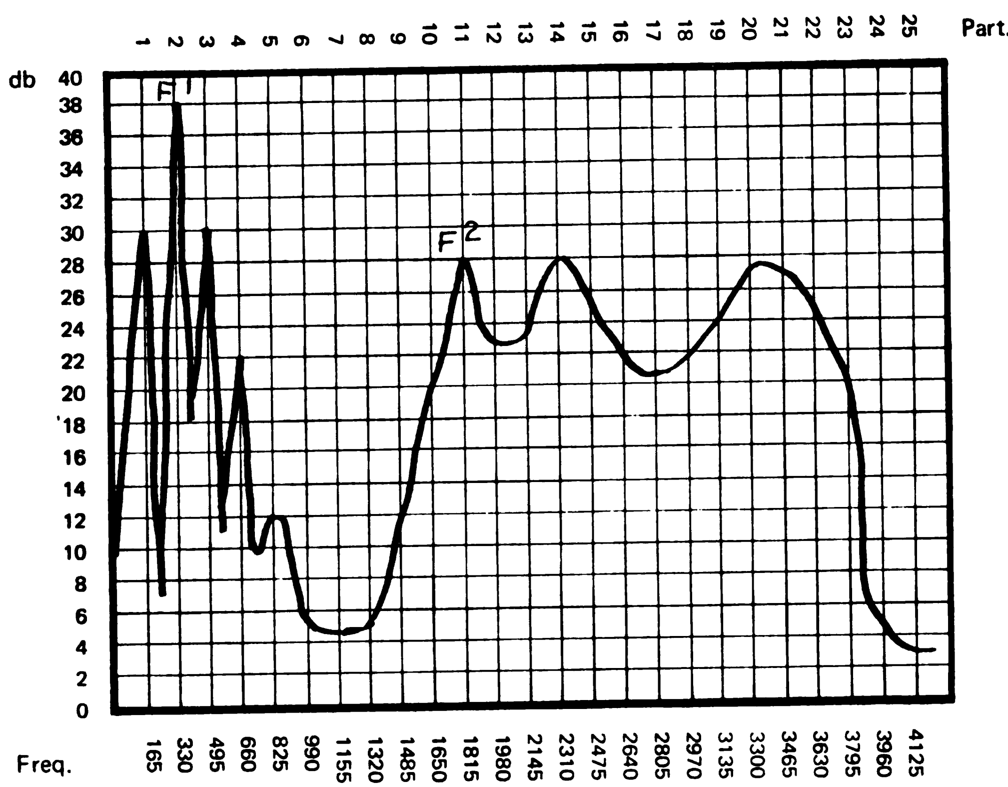

Figure 38.--Spectrograph of mature subject 10 singing the vowel [i] at e-165 Hz.

decibel reading for F^2 is only 20 dB, considerably lower than all other subjects.

4. A prominent energy region above F^2 is present in all spectrograms. It appears as one or two energy peaks covering partials from the fourteenth (2310 Hz) to the twenty-second (3630 Hz) at between 23 and 30 dB. All subjects show a decrease in intensity through the twenty-fifth partial (4125 Hz) after the last energy peak occurs.

Vowel [o] at Pitch e-165 Hz

Figures 39 through 41 are spectrographs showing the formant behavior of high school subjects singing the vowel [o] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 28 to 33 dB.

2. F^1 occurs on the third partial (495 Hz) for all three subjects. Decibel readings were 38, 38, and 40, respectively, for high school subjects 3, 4, and 10.

3. F^2 occurs on the fourth partial (660 Hz) for high school subject 3, with a decibel reading of 34. F^2 occurs on the fifth partial (825 Hz) for high school subjects 4 and 10, with decibel readings of 32 for each subject.

4. A region of intensity was present in all three spectrograms. This region is relatively weak in intensity, ranging from the eleventh partial (1815 Hz) to approximately the twenty-second partial (3630 Hz) at 16 to 4 dB.

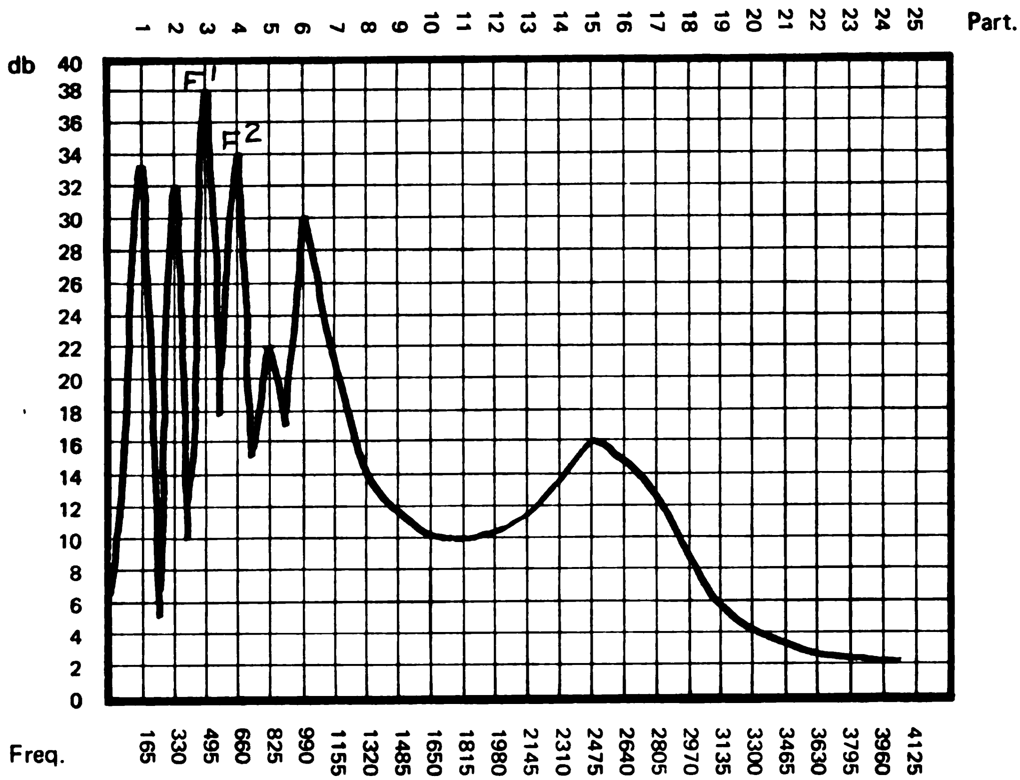

Figure 39.--Spectrograph of high school subject 3 singing the vowel [o] at e-165 Hz.

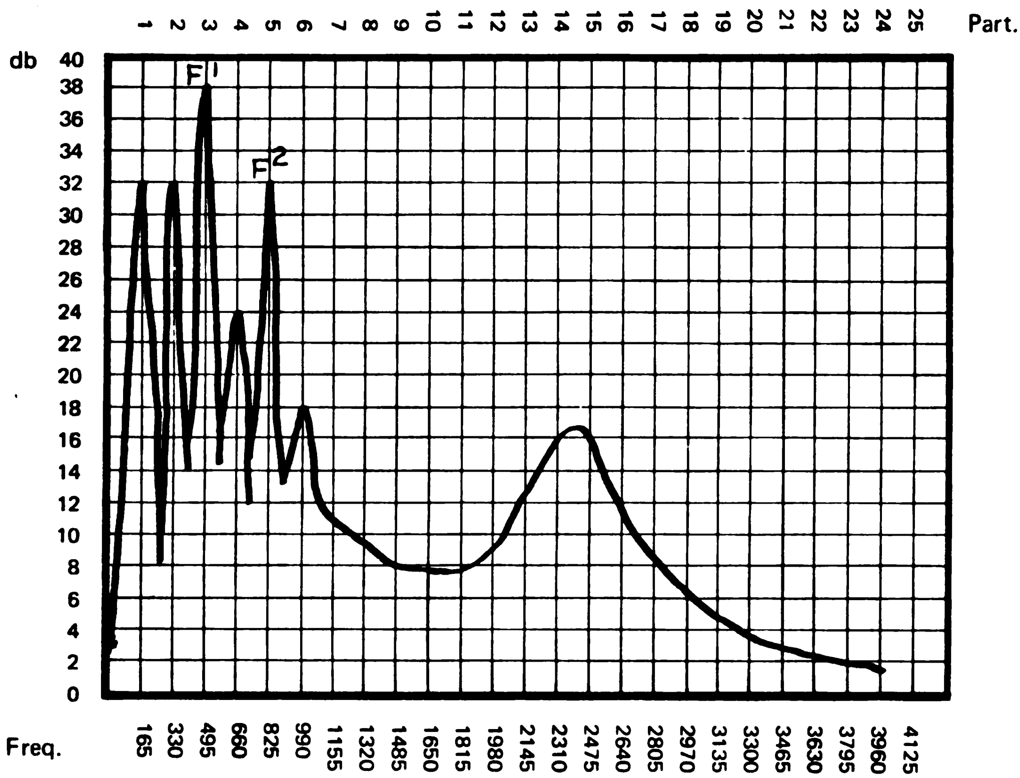

Figure 40.--Spectrograph of high school subject 4 singing the vowel [o] at e-165 Hz.

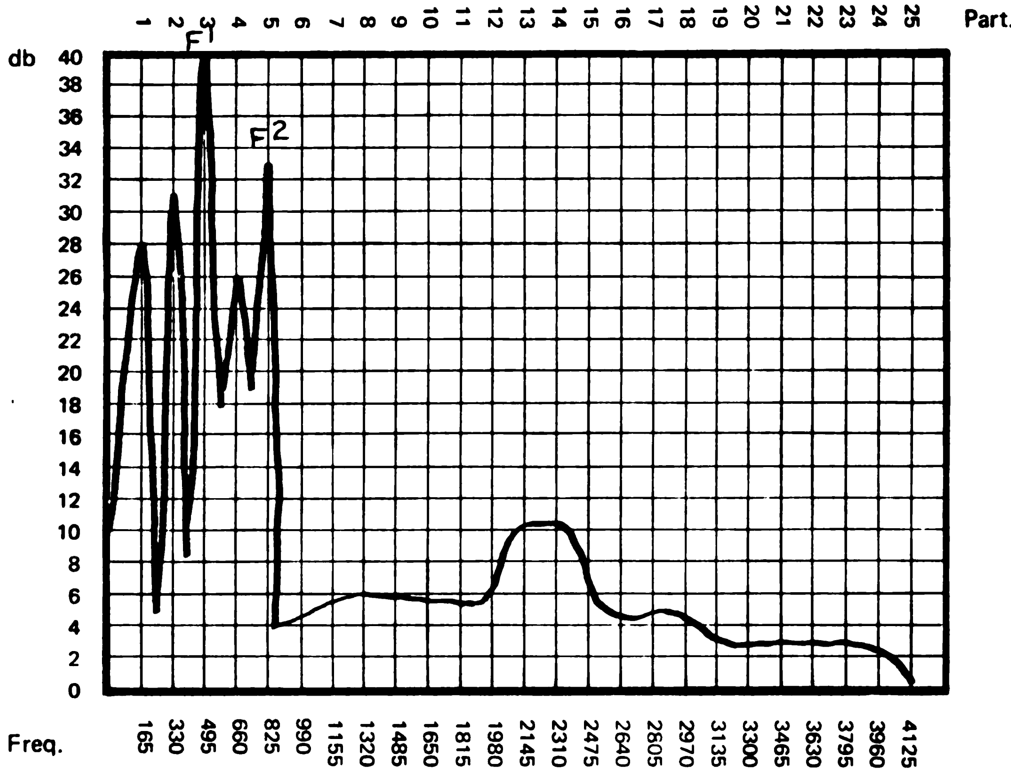

Figure 41.--Spectrograph of high school subject 10 singing the vowel [o] at e-165 Hz.

Figures 42 and 43 are spectrographs showing the formant behavior of university subjects singing the vowel [o] at e-165 Hz, and include the following information:

1. The intensities of the fundamentals for the two subjects are 30 and 32 dB.

2. F^1 occurs on the third partial (495 Hz) for both subjects, with both decibel readings at 40.

3. F^2 occurs on the fourth partial (660 Hz) for university subject 1, with a decibel reading of 38. F^2 occurs on the fifth partial (825 Hz) for university subject 4, with a decibel reading of 34.

4. A region of intensity is present in both spectrograms. This region is relatively weak in intensity, ranging from the seventh partial (1155 Hz) to approximately the twenty-second partial (3630 Hz) at 16 to 4 dB.

Figures 44 through 46 are spectrographs showing the formant behavior of mature subjects singing the vowel [o] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 24 to 30 dB.

2. F^1 occurs on the third partial (495 Hz) for all three subjects. Decibel readings are 38, 38, and 40, respectively, for mature subjects 3, 4, and 10.

3. F^2 occurs on the fourth partial (660 Hz) for all three subjects. Decibel readings are 32 for all three subjects.

4. A prominent region of intensity is present in all three spectrograms. This region ranges from the fourteenth partial (2310 Hz) to the twenty-second partial at 4 to 21 dB for mature subjects 3 and 4.

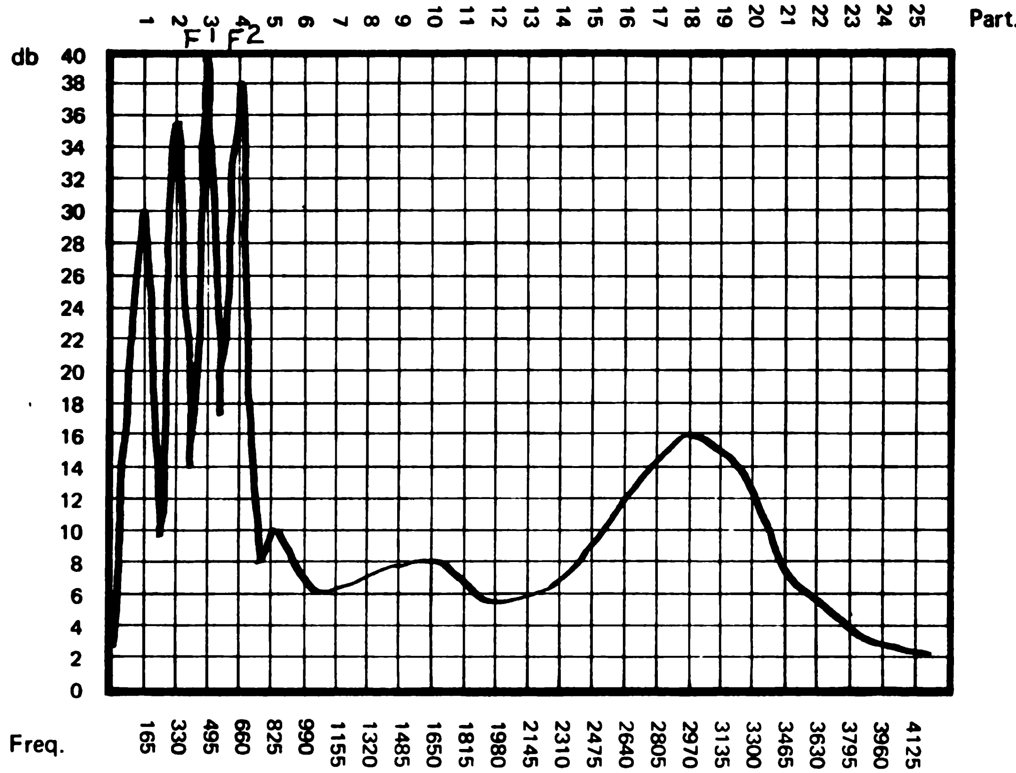

Figure 42.--Spectrograph of university subject 1 singing the vowel [o] at e-165 Hz.

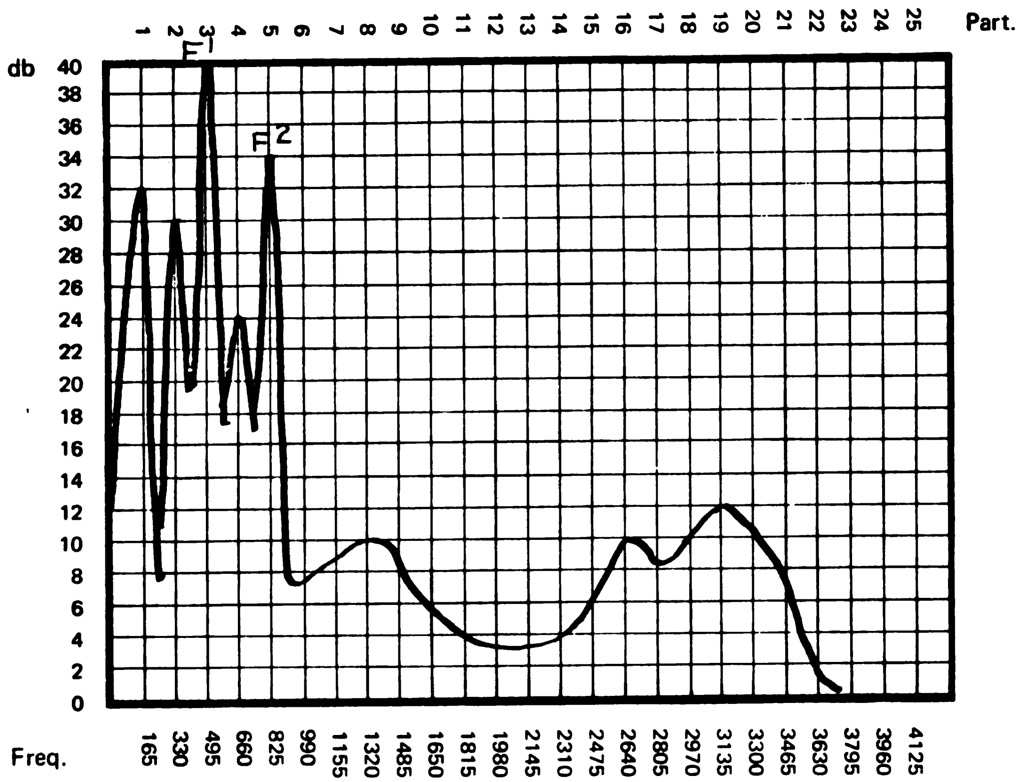

Figure 43.--Spectrograph of university subject 4 singing the vowel [o] at e-165 Hz.

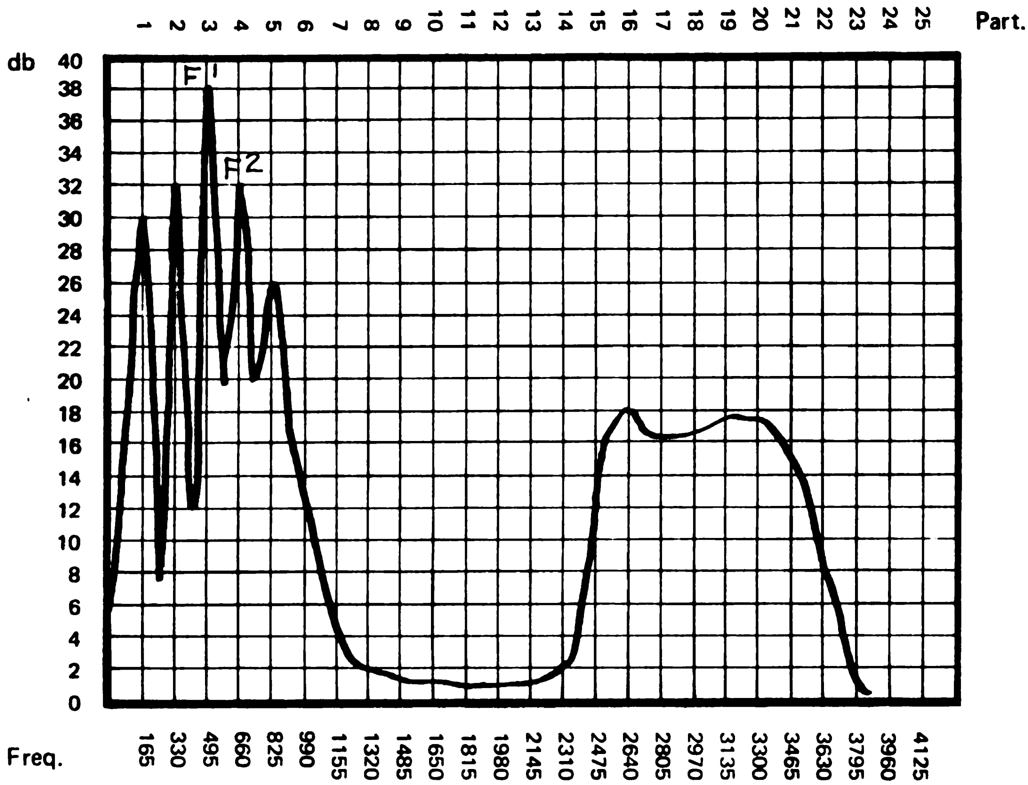

Figure 44.--Spectrograph of mature subject 3 singing the vowel [o] at e-165 Hz.

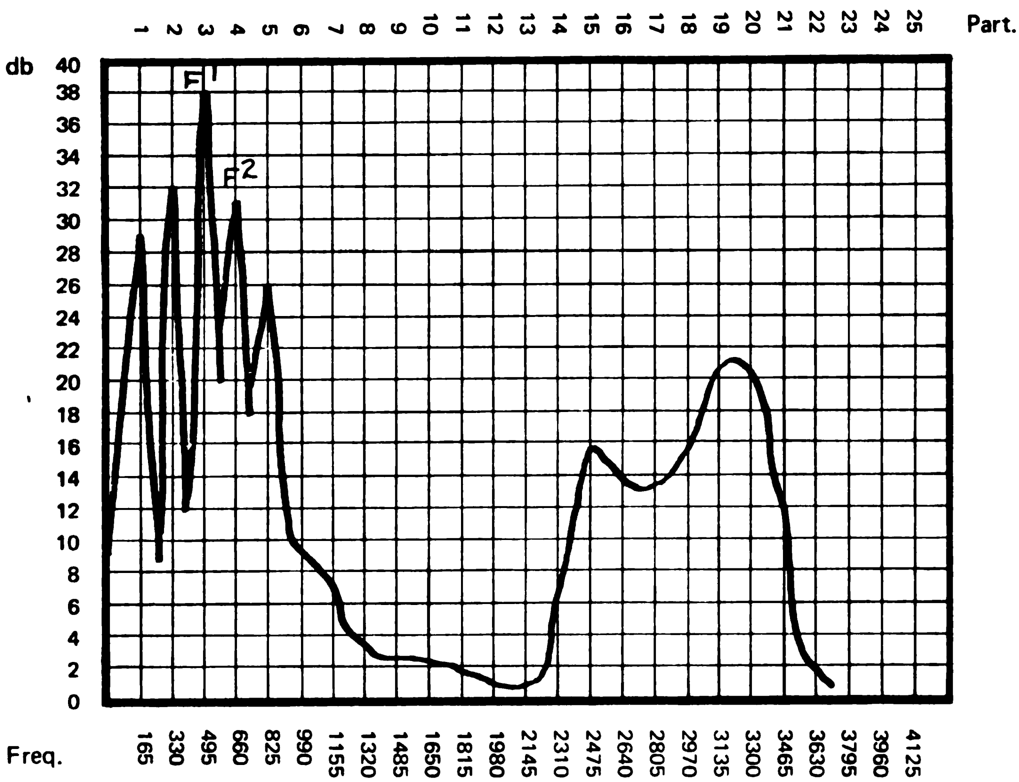

Figure 45.--Spectrograph of mature subject 4 singing the vowel [o] at e-165 Hz.

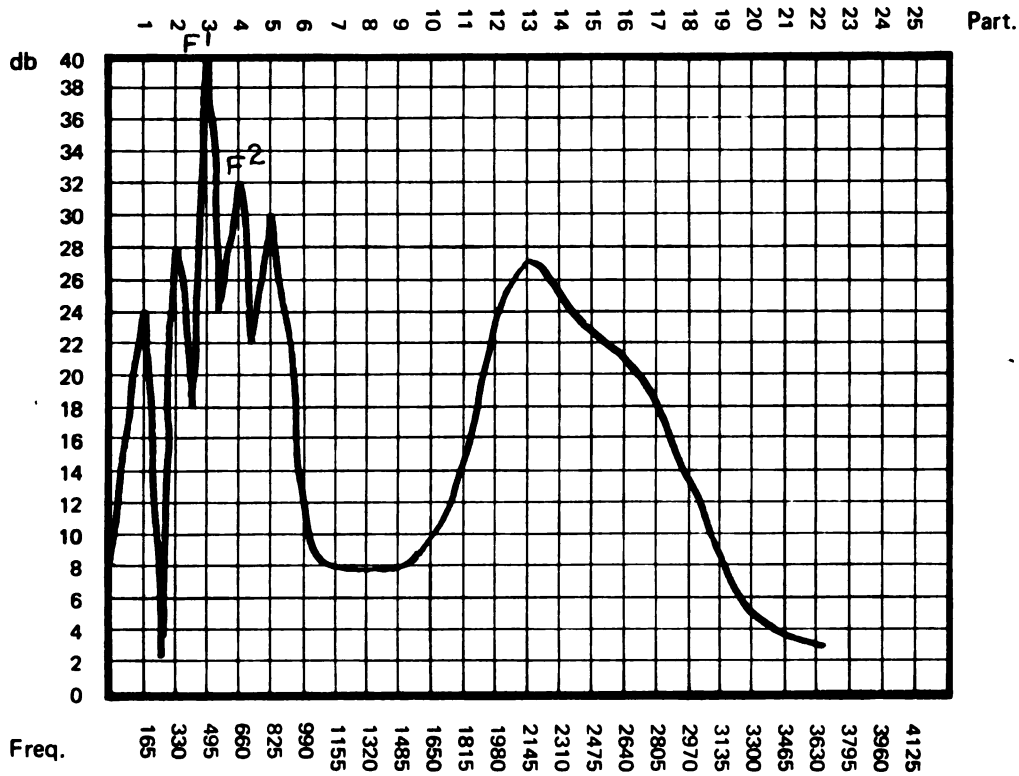

Figure 46.--Spectrograph of mature subject 10 singing the vowel [o] at e-165 Hz.

The region of intensity ranges from the tenth partial (1650 Hz) to the twenty-second partial (3465 Hz) at 8 to 28 dB for mature subject 10.

A Comparison of All Subjects Singing the Vowel [o] at e-165 Hz

1. The intensities of the fundamental range from 24 to 33 dB.

2. F^1 occurs on the third partial (495 Hz) for all subjects. Decibel readings range from 38 to 40.

3. F^2 occurs on the fifth partial (825 Hz) for high school subjects 4 and 10, and university subject 4, with decibel readings ranging from 32 to 34. F^2 occurs on the fourth partial (660 Hz) for all other subjects with decibel readings ranging from 32 to 38.

4. A region of intensity is present in all spectrograms. This region is relatively weak in intensity for high school and university subjects. However, a prominent region of intensity is present in the spectrograms of the mature voices, ranging from the twelfth partial (1980 Hz) to the twenty-second partial (3630 Hz) at 8 to 28 dB.

Vowel [u] at Pitch e-165 Hz

Figures 47 and 48 are spectrographs showing the formant behavior of high school subjects singing the vowel [u] at e-165 Hz, and include the following information:

1. The intensities of the fundamentals are 32 and 34 dB.

2. F^1 occurs on the second partial (330 Hz) for both subjects. Decibel readings were 38 for high school subject 3, and 40 for high school subject 10.

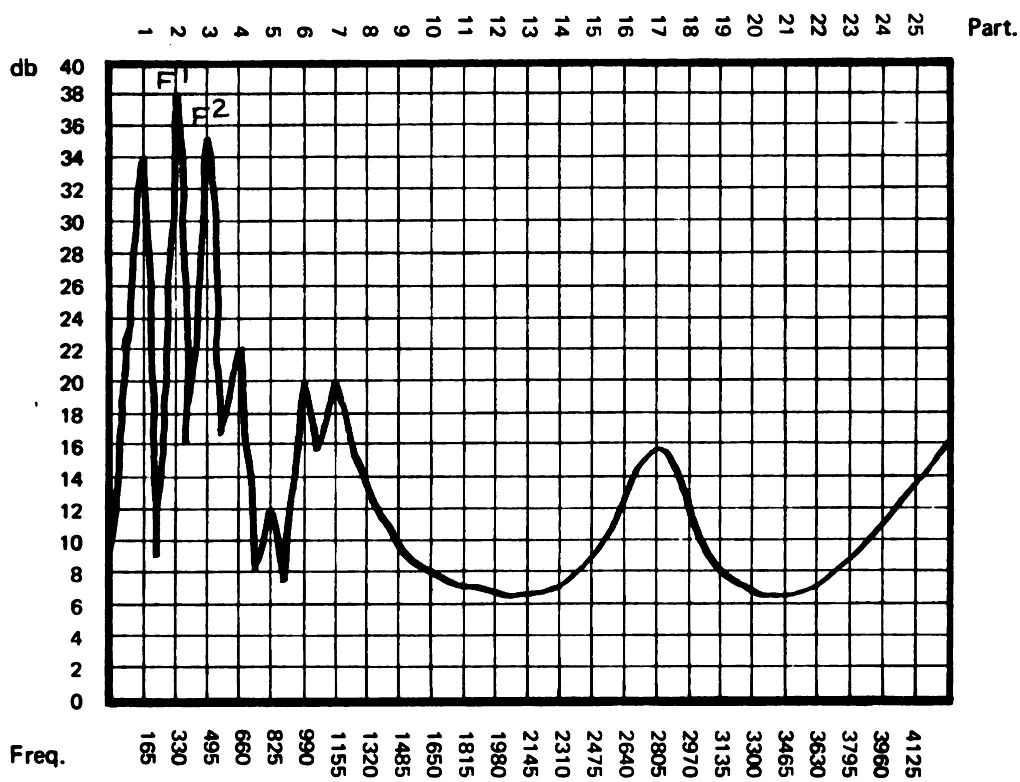

Figure 47.--Spectrograph of high school subject 3 singing the vowel [u] at e-165 Hz.

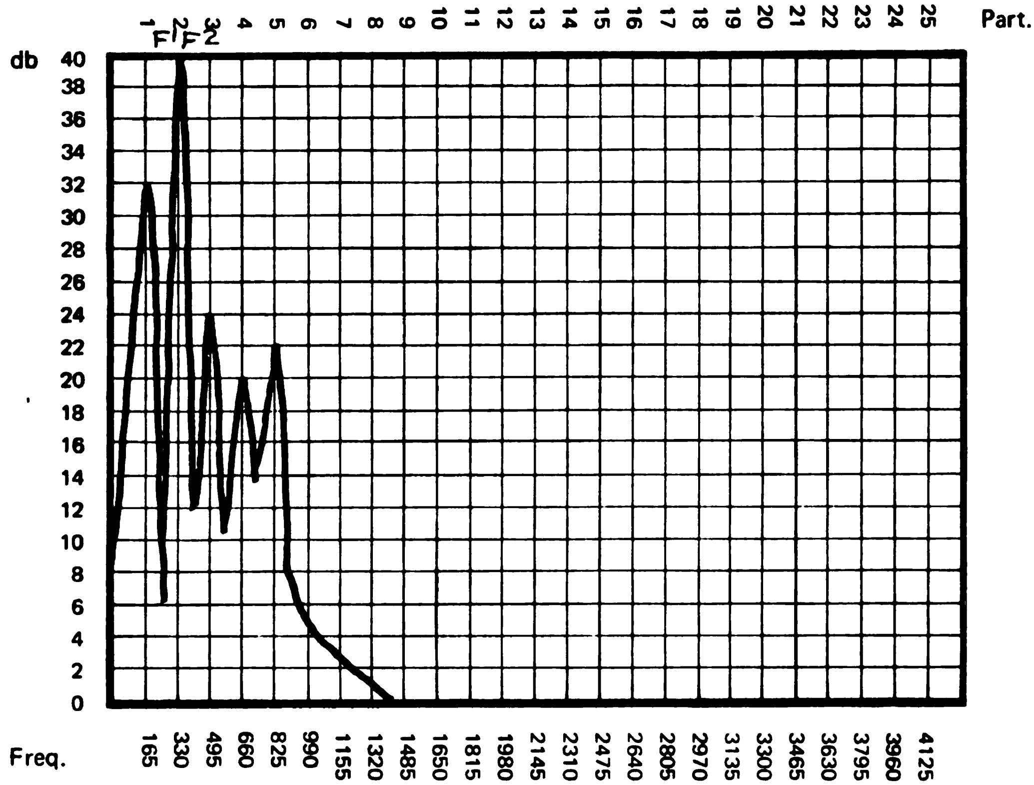

Figure 48.--Spectrograph of high school subject 10 singing the vowel [u] at e-165 Hz.

3. F^2 occurs on the third partial (495 Hz) for high school subject 3 at 35 dB. F^2 appears to be combined with F^1 for high school subject 10 at 40 dB.

4. A weak region of intensity is present in the spectrogram of high school subject 3. This region ranges from the eighth partial (1320 Hz) to the twenty-fifth partial (4125 Hz) at approximately 4 to 14 dB. No region of intensity above F^2 is present in the spectrogram of high school subject 10.

Figures 49 and 50 are spectrographs showing the formant behavior of university subjects singing the vowel [u] at e-165 Hz, and include the following information:

1. The intensities of the fundamental are 36 dB for both subjects.

2. F^1 occurs on the second partial (330 Hz) with decibel readings at 40 for both subjects.

3. F^2 appears to be combined with F^1 for both subjects at 40 dB.

4. A weak region of intensity above F^2 is present in both spectrograms. It ranges from the twelfth partial (1980 Hz) to the nineteenth partial (3135 Hz) at approximately 2 to 9 dB.

Figures 51 through 53 are spectrographs showing the formant behavior of mature subjects singing the vowel [u] at e-165 Hz, and include the following information:

1. The intensities of the fundamental range from 28 to 30 dB.

2. F^1 occurs on the second partial (330 Hz) for all three subjects. Decibel readings are 40, 40, and 38, respectively, for mature subjects 3, 4, and 10.

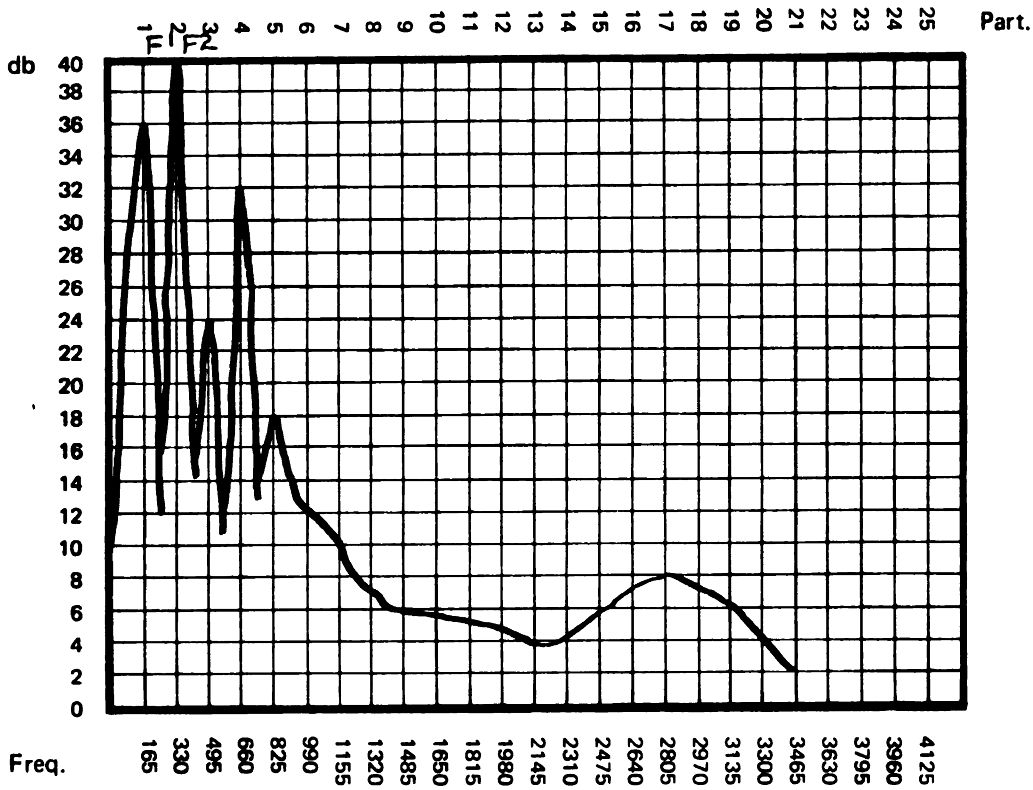

Figure 49.--Spectrograph of university subject 1 singing the vowel [u] at e-165 Hz.

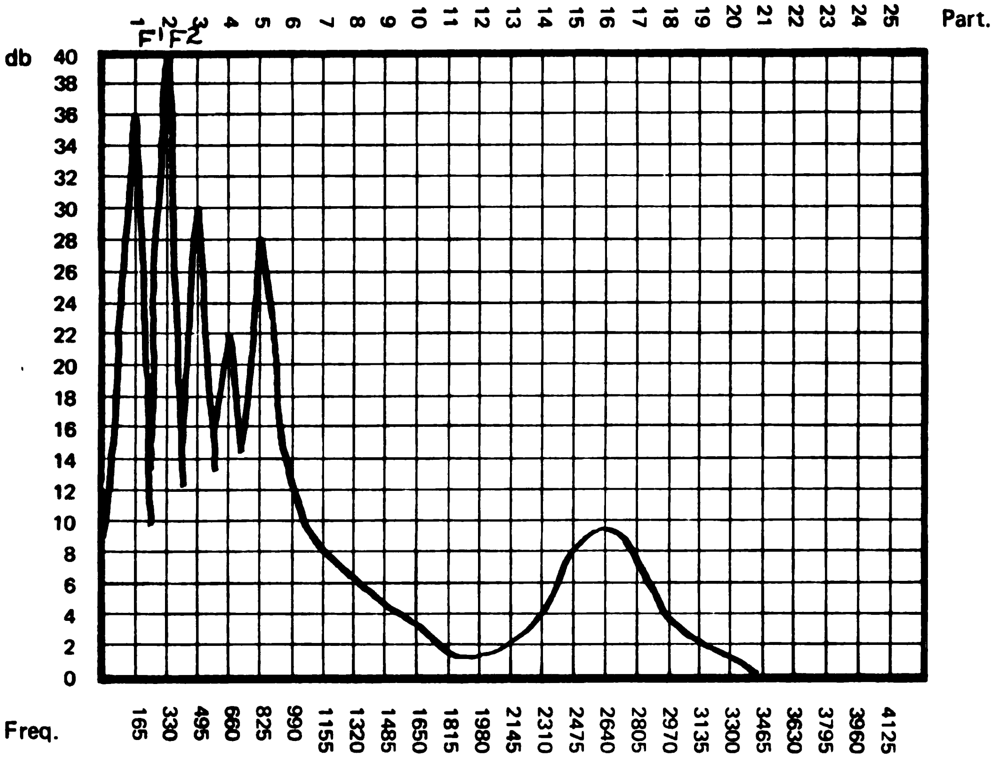

Figure 50.--Spectrograph of university subject 3 singing the vowel [u] at e-165 Hz.

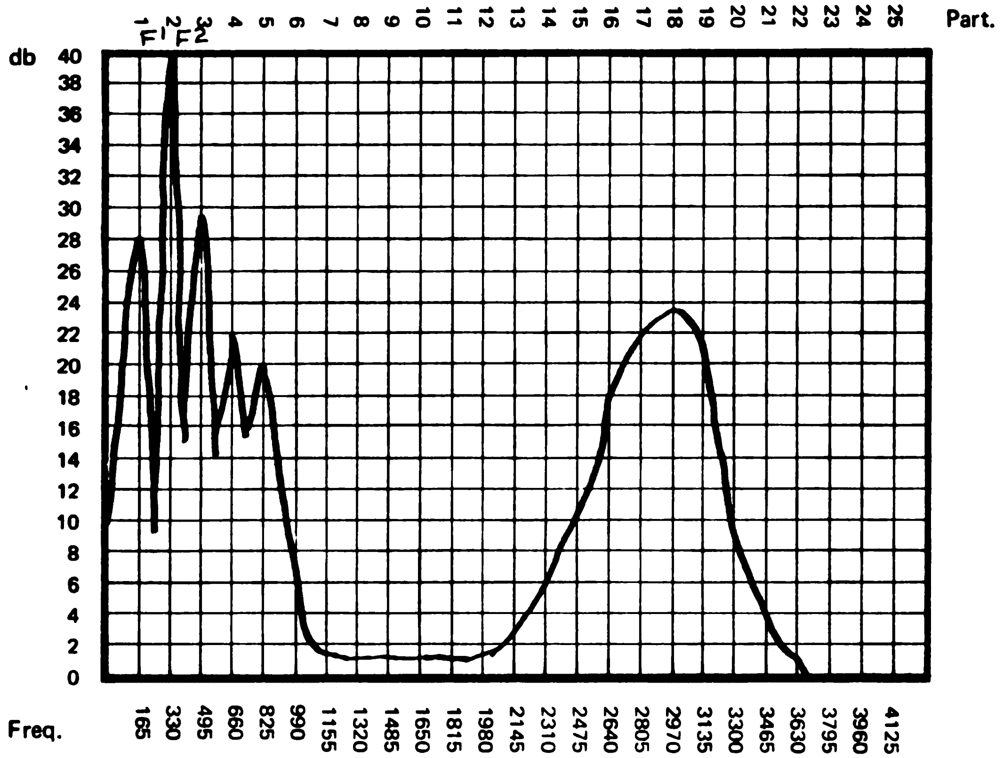

Figure 51.--Spectrograph of mature subject 3 singing the vowel [u] at e-165 Hz.

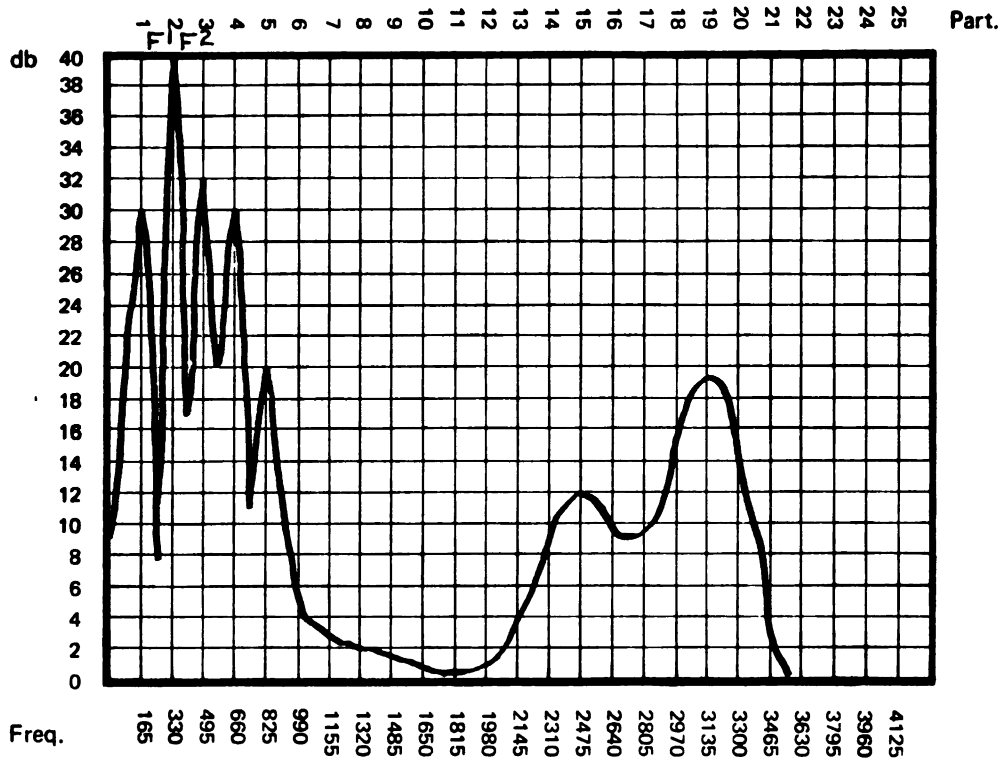

Figure 52.--Spectrograph of mature subject 4 singing the vowel [u] at e-165 Hz.

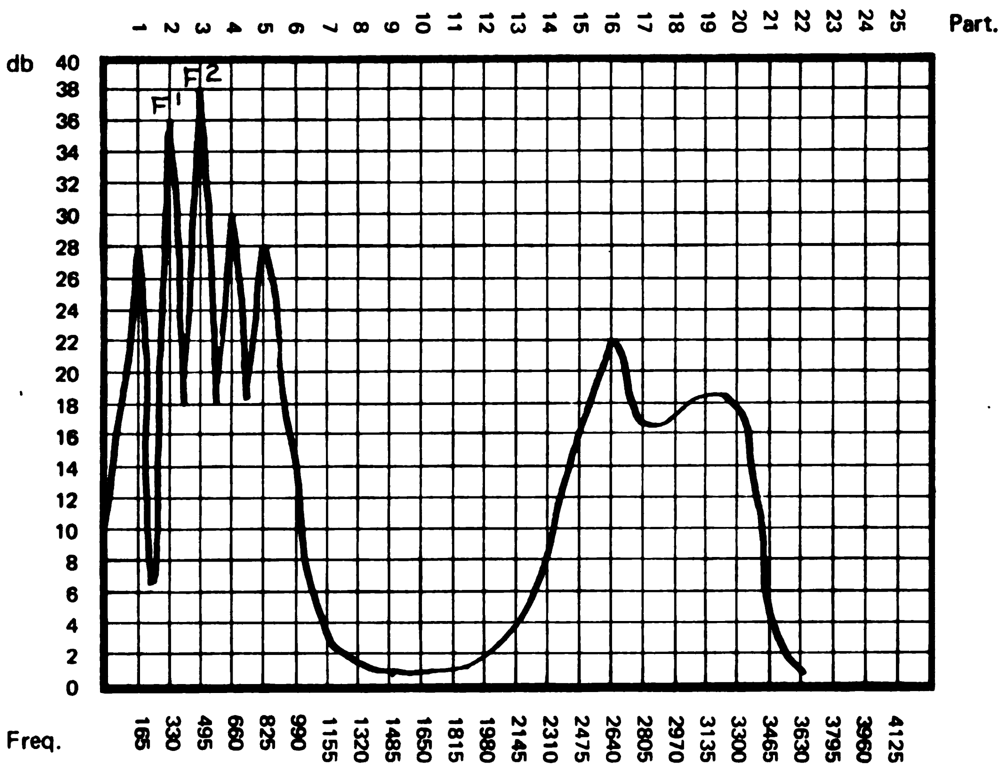

Figure 53.--Spectrograph of mature subject 10 singing the vowel [u] at e-165 Hz.

3. F^2 appears to be combined with F^1 at 40 dB for mature subjects 3 and 4. F^2 occurs on the third partial (495 Hz) with a decibel reading of 38 for mature subject 10.

4. A prominent region of intensity above F^2 is present in all three spectrograms. It ranges from the thirteenth (2145 Hz) to the twenty-first partial (3465 Hz) for all three subjects. Decibel readings range from 4 to approximately 24.

A Comparison of All Subjects Singing the Vowel [u] at e-165 Hz

1. The intensities of the fundamental range from 28 to 36 dB.

2. F^1 occurs on the second partial (330 Hz) for all subjects. Decibel readings range from 38 to 40.

3. F^2 occurs on the third partial (495 Hz) for high school subject 3 and mature subject 10 at 35 and 38 dB, respectively. F^2 appears to be combined with F^1 for all other subjects at 40 dB.

4. A weak region of intensity above F^2 is present in high school and university subjects; however, no consistent pattern is evident among subjects. The mature subjects show a more prominent region of intensity.

Vowel [a] at Pitch b-246 Hz

Figures 54 and 55 are spectrographs showing the formant behavior of high school subjects singing the vowel [a] at b-246 Hz, and include the following information:

1. The intensities of the fundamentals are 28 and 32 dB.

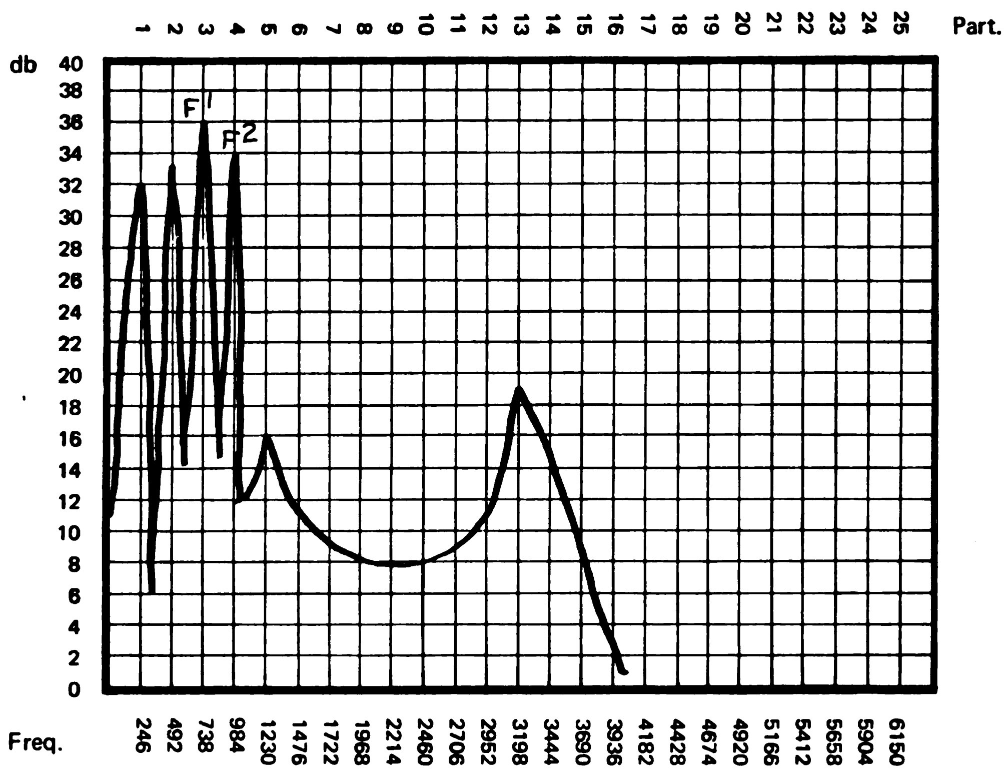

Figure 54.--Spectrograph of high school subject 5 singing the vowel [a] at b-246 Hz.

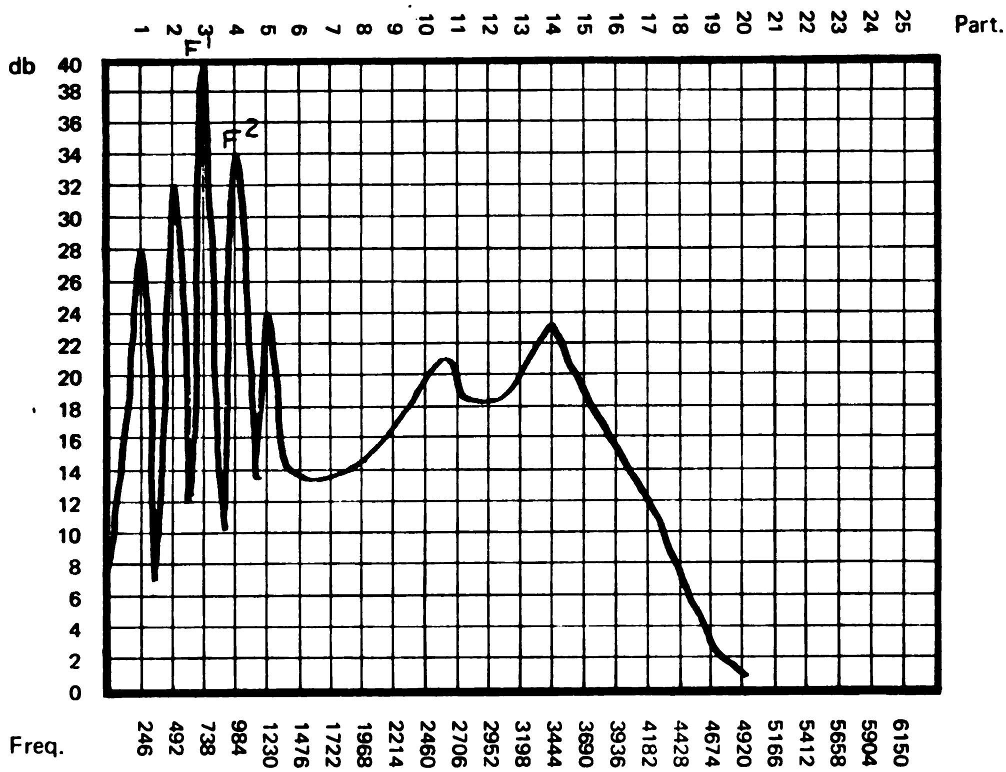

Figure 55.--Spectrograph of high school subject 10 singing the vowel [a] at b-246 Hz.

2. F^1 occurs on the third partial (738 Hz) for both subjects. Decibel readings are 36 and 40, respectively, for high school subjects 5 and 10.

3. F^2 occurs on the fourth partial (984 Hz) at 34 dB for both subjects.

4. A prominent energy region above F^2 is present in both spectrograms. This energy region ranges from the sixth partial (1476 Hz) for both subjects, with decibel readings ranging from approximately 4 to 22.

Figures 56 and 57 are spectrographs showing the formant behavior of university subjects singing the vowel [a] at b-246 Hz, and include the following information:

1. The intensities of the fundamentals are 32 and 33 dB.

2. F^1 occurs on the third partial (738 Hz) for both subjects. Decibel readings are 33 and 32, respectively, for university subjects 3 and 9.

3. F^2 occurs on the fourth partial (984 Hz) at 34 dB for both subjects.

4. A prominent energy region above F^2, with a strong peak at the twelfth partial (2952 Hz), is present in both spectrograms. This energy region ranges from the eighth partial (1968 Hz) to the seventeenth partial (4182 Hz) for both subjects. The intensity peak at the twelfth partial ranges from 15 to 28 dB.

Figures 58 through 60 are spectrographs showing the formant behavior of mature subjects singing the vowel [a] at b-246 Hz, and include the following information:

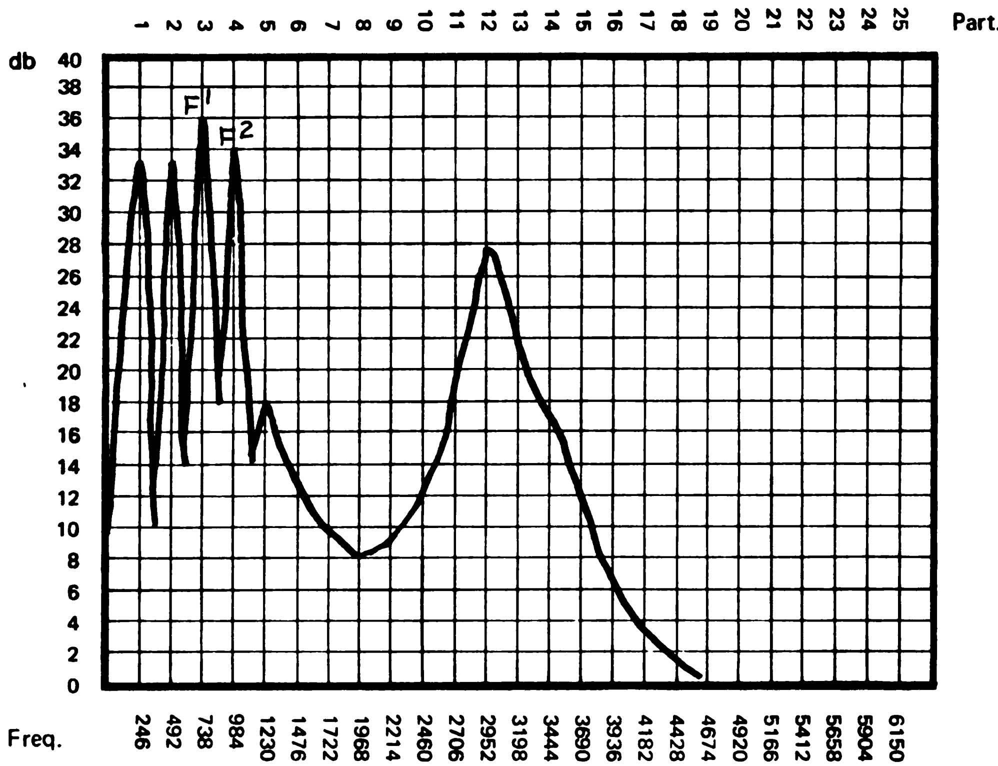

Figure 56.--Spectrograph of university subject 3 singing the vowel [a] at b-246 Hz.

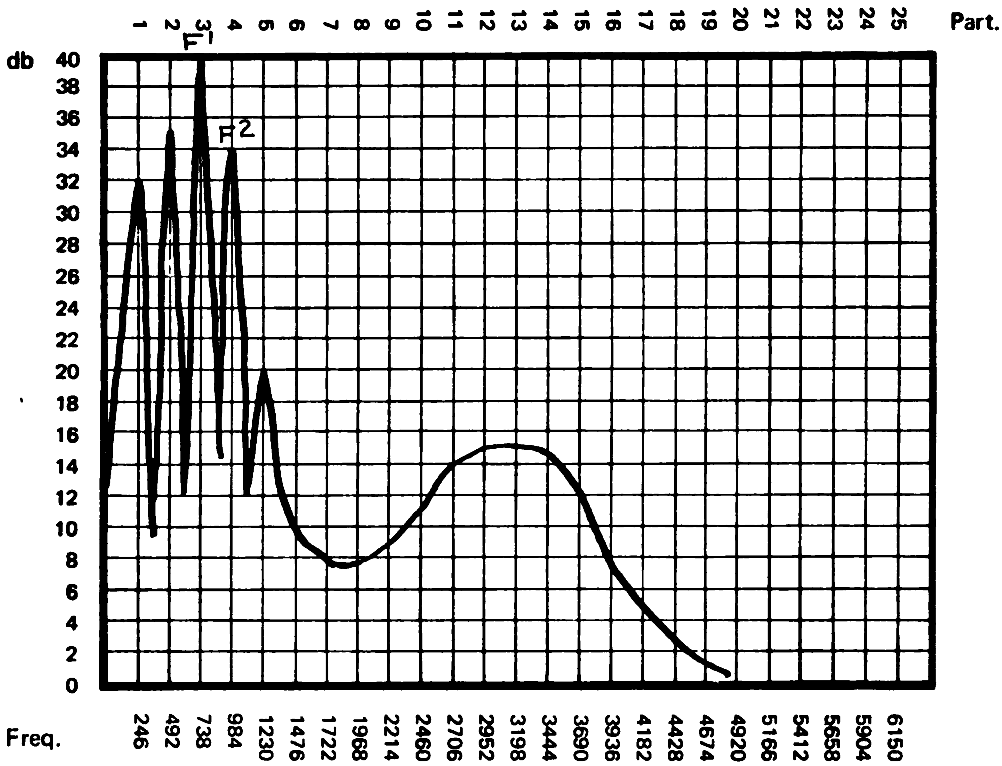

Figure 57.--Spectrograph of university subject 9 singing the vowel [a] at b-246 Hz.

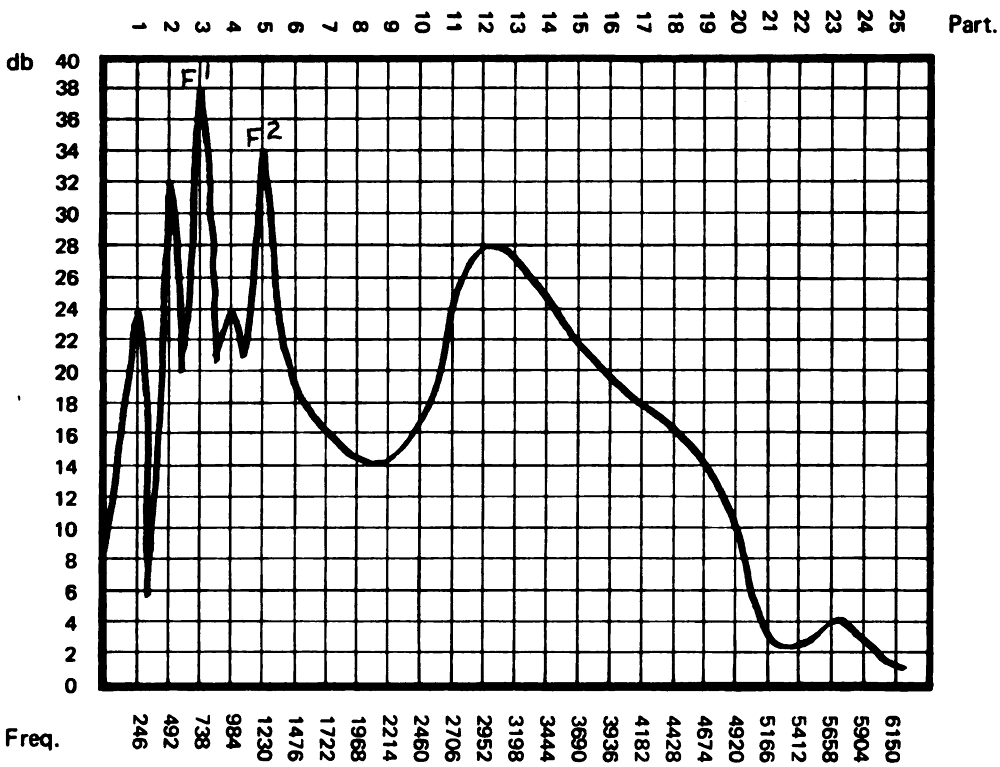

Figure 58.--Spectrograph of mature subject 3 singing the vowel [a] at b-246 Hz.

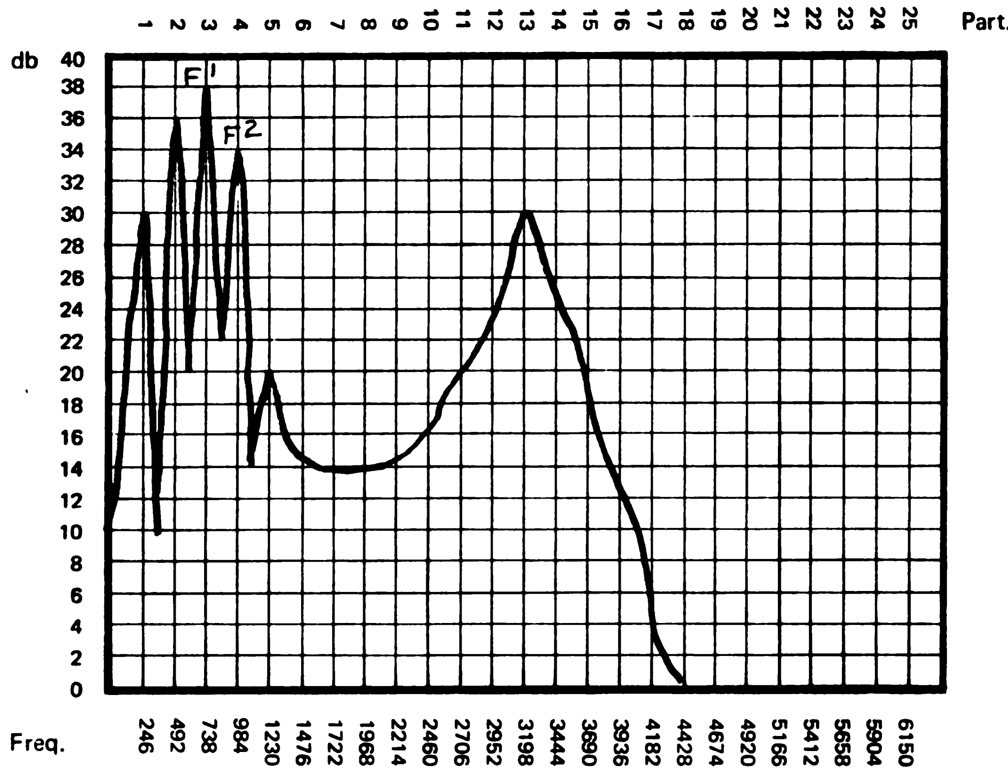

Figure 59.--Spectrograph of mature subject 4 singing the vowel [a] at b-246 Hz.

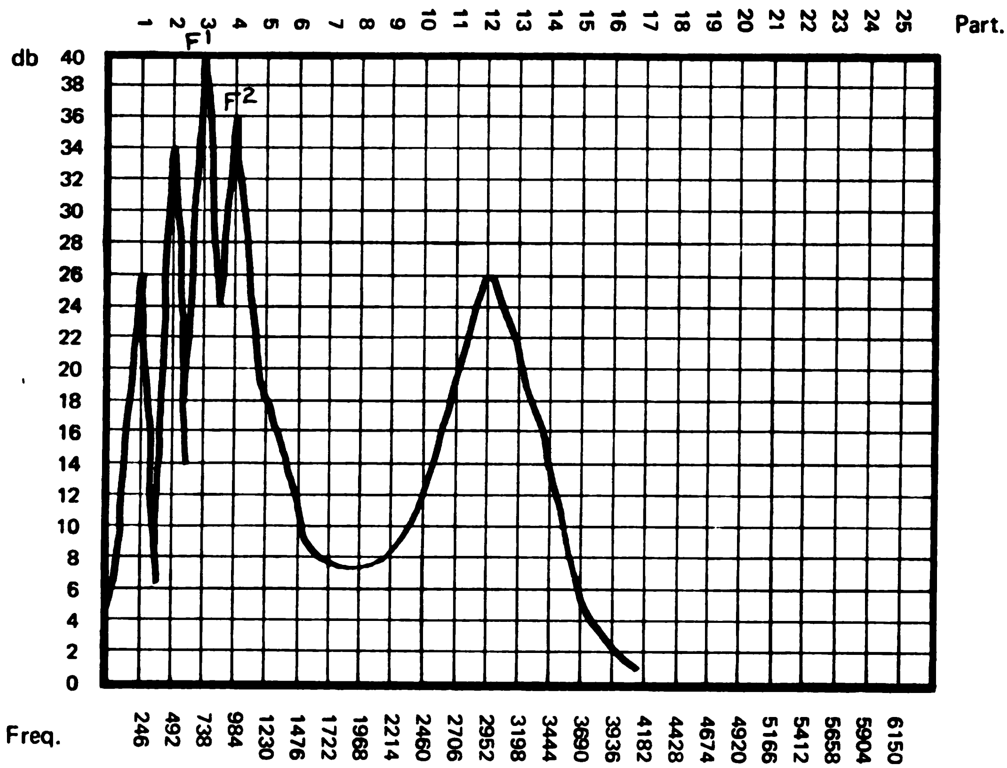

Figure 60.--Spectrograph of mature subject 10 singing the vowel [a] at b-246 Hz.

1. The intensities of the fundamental range from 24 to 30 dB.

2. F^1 occurs on the third partial (738 Hz) for all three subjects. Decibel readings are 38, 38, and 40, respectively, for mature subjects 3, 4, and 10.

3. F^2 occurs on the fourth partial (984 Hz) for mature subjects 4 and 10 with decibel readings at 34 and 36, respectively. F^2 occurs on the fifth partial (1230 Hz) for mature subject 3 with a decibel reading of 34.

4. A prominent energy region above F^2, with a strong peak at the twelfth partial (2952 Hz), is present in all three spectrograms. This energy region ranges from the eighth partial (1968 Hz) to the seventeenth partial (4182 Hz) for all three subjects. The intensity peak at the twelfth partial ranges from 26 to 30 dB.

A Comparison of All Subjects Singing the Vowel [a] at b-246 Hz

1. The intensities of the fundamental range from 24 to 33 dB.

2. F^1 occurs on the third partial (738 Hz) for all subjects. Decibel readings range from 32 to 40.

3. F^2 occurs on the fifth partial (1230 Hz) for mature subject 3 with a decibel reading of 34. F^2 occurs on the fourth partial (984 Hz) for all other subjects with decibel readings ranging from 34 to 36.

4. A prominent energy region above F^2, with a strong peak at the twelfth partial (2952 Hz), is present in nearly all spectrograms of university and mature subjects. This energy region ranges from the eighth partial (1968 Hz) to the seventeenth partial (4182 Hz).

The intensity peak at the twelfth partial ranges from 15 to 30 dB. This energy region for both high school subjects ranges from the sixth partial (1476 Hz) to the seventeenth partial (4182 Hz), with decibel readings ranging from approximately 4 to 22.

Vowel [e] at Pitch b-246 Hz

Figures 61 through 63 are spectrographs showing the formant behavior of high school subjects singing the vowel [e] at b-246 Hz, and include the following information:

1. The intensities of the fundamental range from 30 to 34 dB.

2. F^1 occurs on the second partial (492 Hz) for all three subjects. Decibel readings are 40, 40, and 36, respectively, for high school subjects 4, 9, and 10.

3. F^2 occurs on the sixth partial (1476 Hz) for all three subjects. Decibel readings are 32, 32, and 36, respectively.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region extends from F^2 to approximately the fifteenth partial (3690 Hz) at 16 to 29 dB.

Figures 64 and 65 are spectrographs showing the formant behavior of university subjects singing the vowel [e] at b-246 Hz, and display the following information:

1. The intensities of the fundamentals are 33 and 34 dB.

2. F^1 occurs on the second partial (492 Hz) for both subjects. Decibel readings are 40 and 38, respectively, for university subjects 3 and 9.

3. F^2 occurs on the sixth partial (1476 Hz) at 34 dB for both subjects.

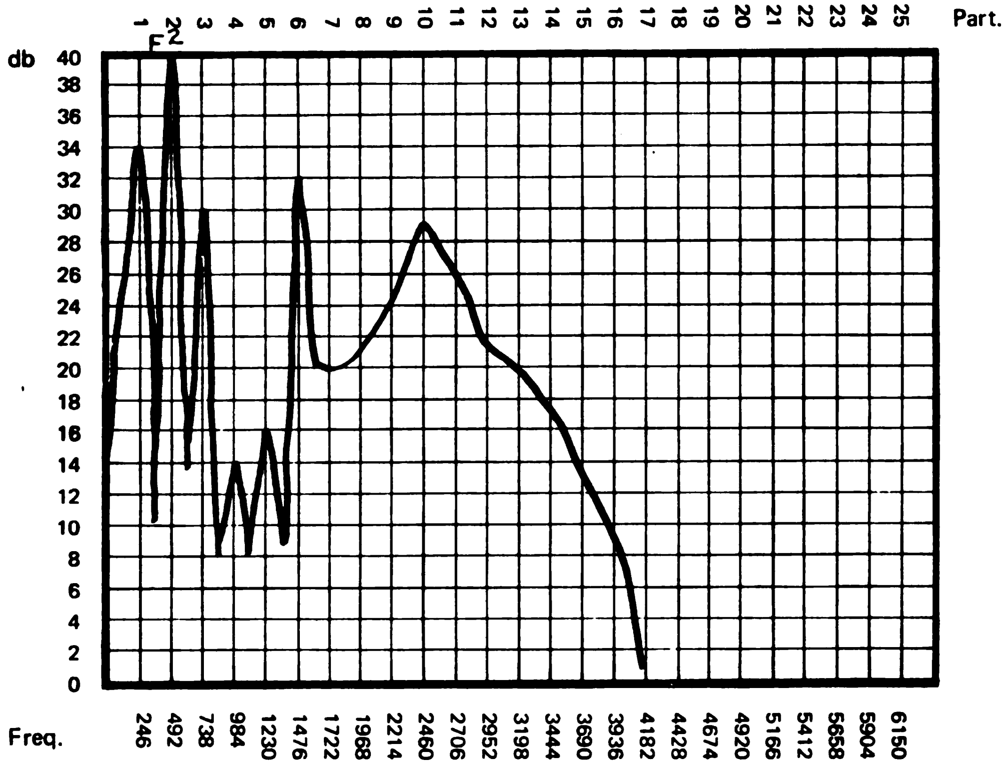

Figure 61.--Spectrograph of high school subject 4 singing the vowel [e] at b-246 Hz.

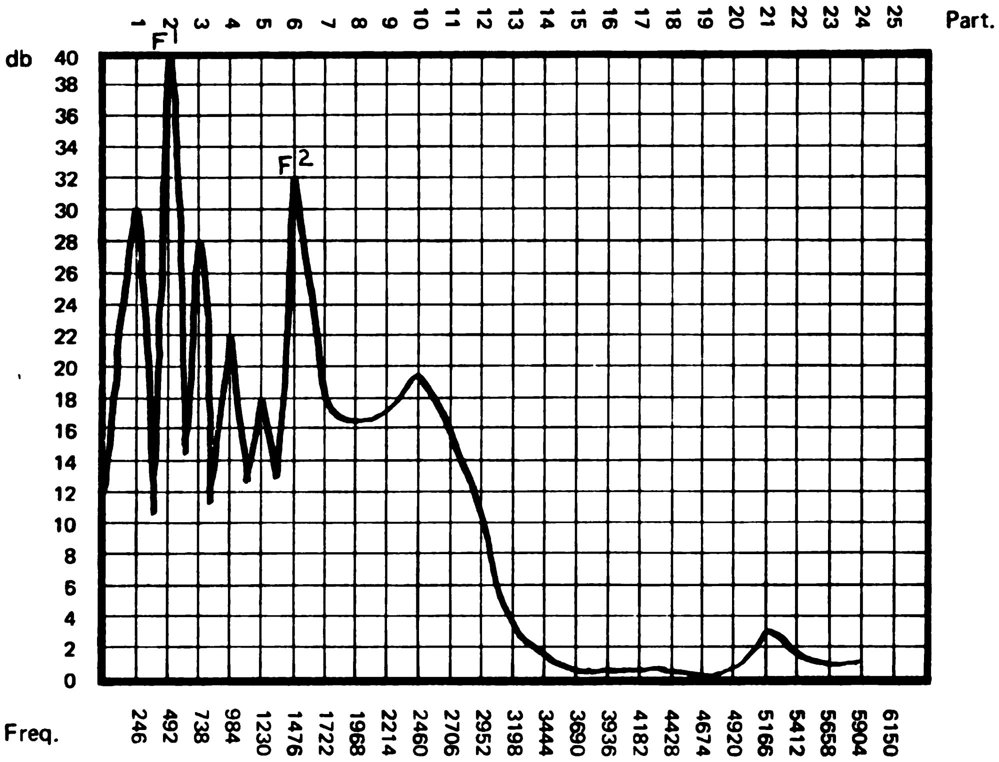

Figure 62.--Spectrograph of high school subject 9 singing the vowel [e] at b-246 Hz.

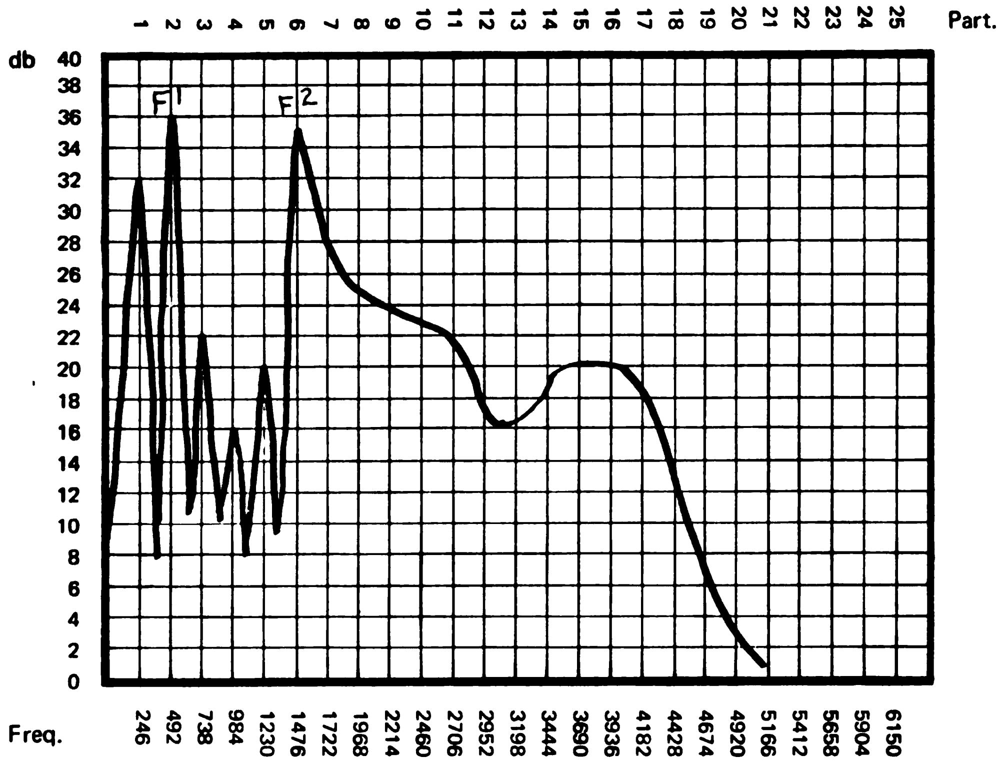

Figure 63.--Spectrograph of high school subject 10 singing the vowel [e] at b-246 Hz.

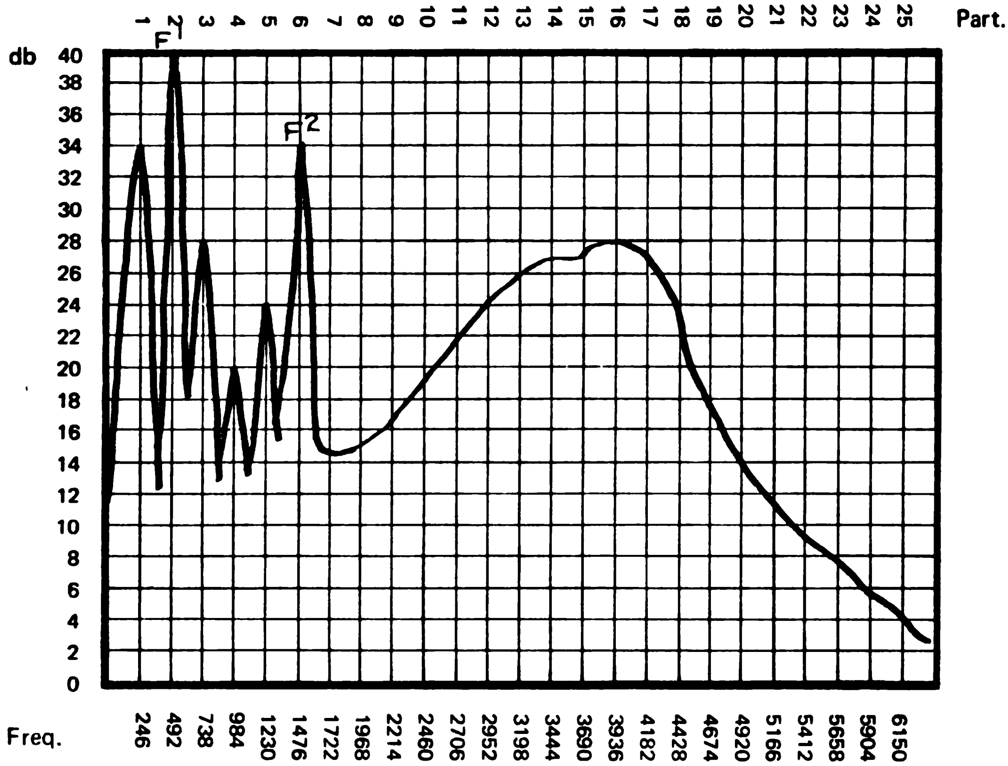

Figure 64.--Spectrograph of university subject 3 singing the vowel [e] at b-246 Hz.

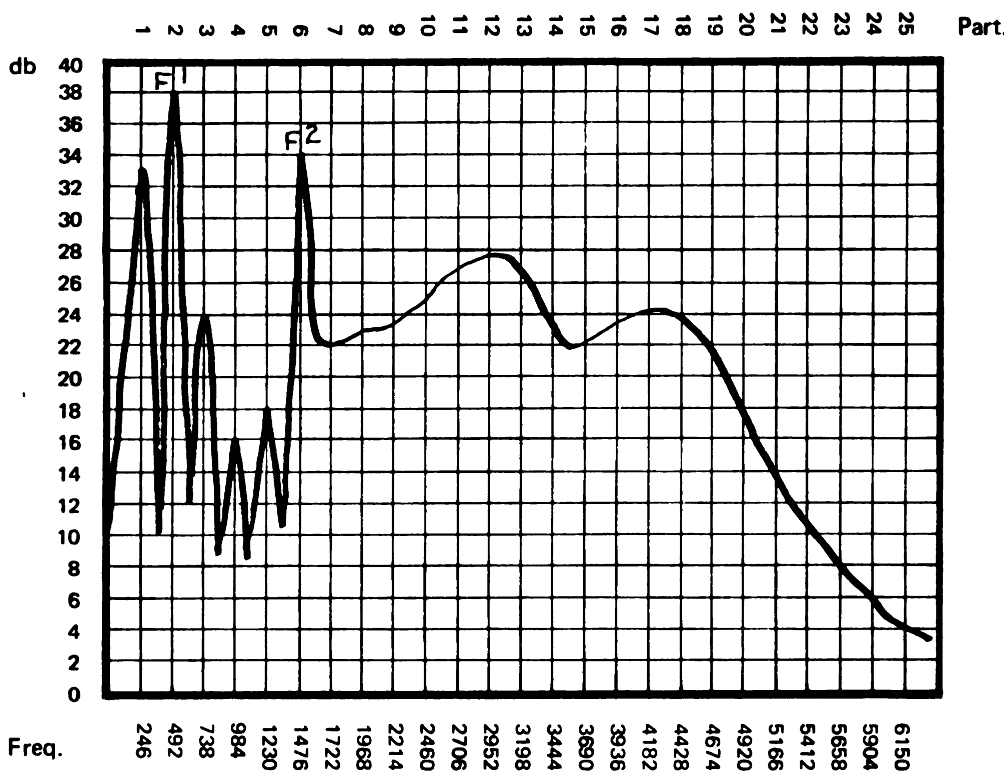

Figure 65.--Spectrograph of university subject 9 singing the vowel [e] at b-246 Hz.

4. A prominent energy region above F^2 is present in both spectrograms. This energy region extends from the eighth partial (1968 Hz) to the twenty-first partial (5166 Hz) at approximately 16 to 28 dB.

Figures 66 through 68 are spectrographs showing the formant behavior of mature subjects singing the vowel [e] at b-246 Hz, and display the following information:

1. The intensities of the fundamental range from 24 to 28 dB.

2. F^1 occurs on the second partial (492 Hz) for all three subjects. Decibel readings are 36, 32, and 38, respectively, for mature subjects 3, 9, and 10.

3. F^2 occurs on the sixth partial (1476 Hz) for all three subjects, with decibel readings at 36, 38, and 34, respectively.

4. A prominent energy region is present in all three spectrograms. This energy region extends from the eighth partial (1968 Hz) to the seventeenth partial (4182 Hz), with decibel readings ranging from 20 to 32. Mature subjects 9 and 10 show strong intensity peaks on the ninth partial (2214 Hz) at 32 dB.

A Comparison of All Subjects Singing the Vowel [e] at b-246 Hz

1. The intensities of the fundamental range from 24 to 34 dB.

2. F^1 occurs on the second partial (492 Hz) for all subjects. Decibel readings range from 32 to 40.

3. F^2 occurs on the sixth partial (1476 Hz) for all subjects with decibel readings ranging from 32 to 38.

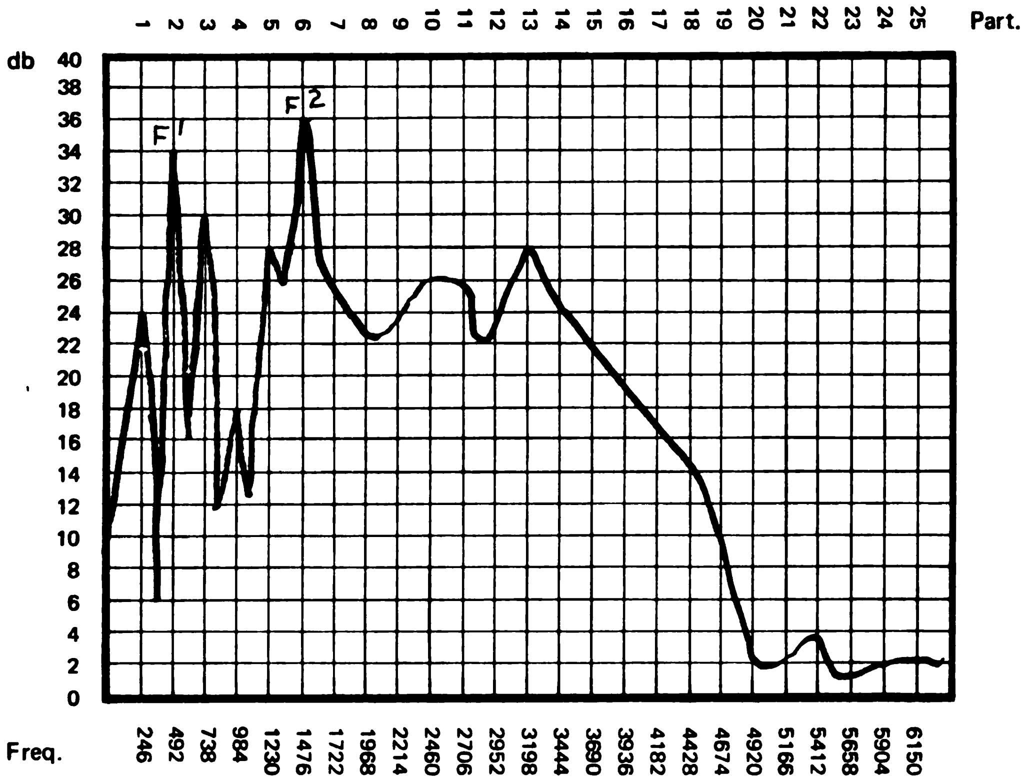

Figure 66.--Spectrograph of mature subject 3 singing the vowel [e] at b-246 Hz.

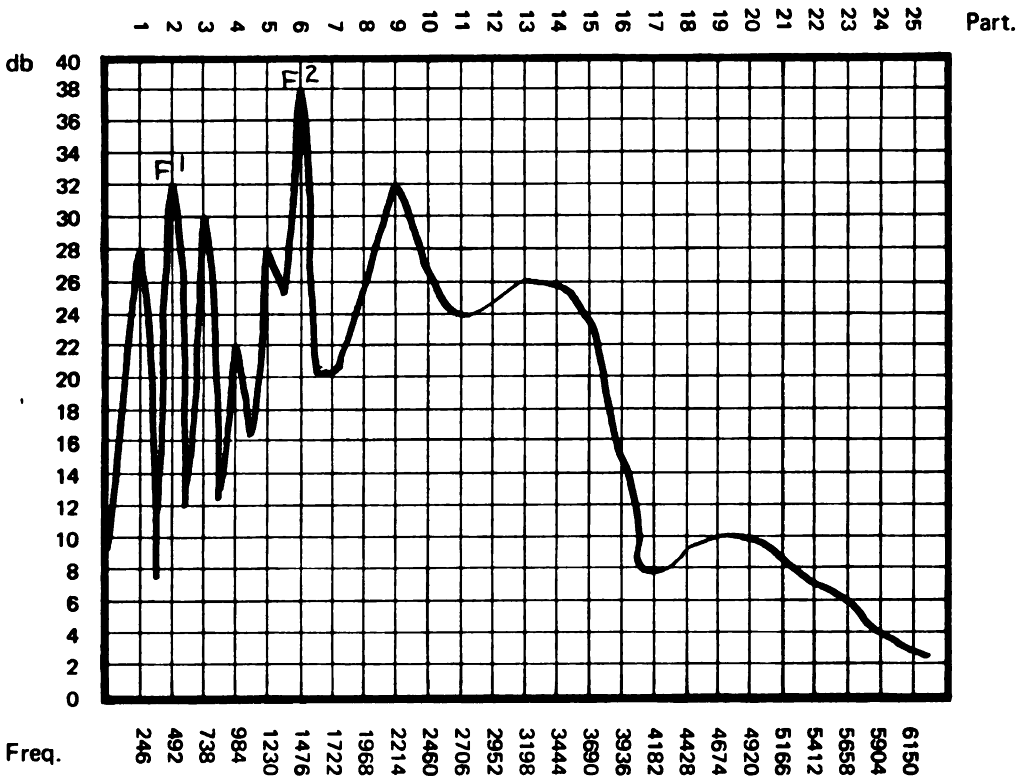

Figure 67.--Spectrograph of mature subject 9 singing the vowel [e] at b-246 Hz.

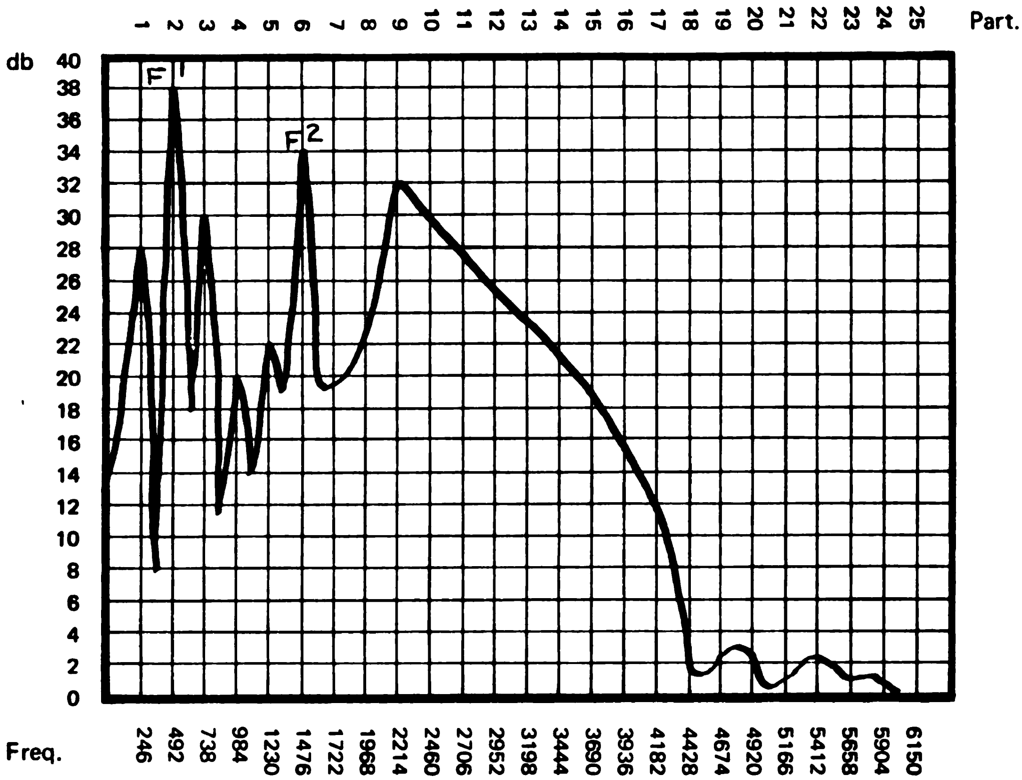

Figure 68.--Spectrograph of mature subject 10 singing the vowel [e] at b-246 Hz.

4. A prominent region of energy is present in all spectrograms. Although this energy region is not consistent for all subjects, it extends from approximately the eighth partial (1968 Hz) to the seventeenth partial (4182 Hz), with decibel readings ranging from 16 to 32. Mature subjects 9 and 10 show strong intensity peaks on the ninth partial (2214 Hz) at 32 dB.

Vowel [i] at Pitch b-246 Hz

Figures 69 and 70 are spectrographs showing the formant behavior of high school subjects singing the vowel [i] at b-246 Hz, and display the following information:

1. The intensities of the fundamentals are 38 and 40 dB.

2. F^1 is absorbed by the fundamental for both subjects at 38 and 40 dB.

3. F^2 appears as a prominent region of energy for both subjects, ranging from an intense peak on the seventh partial (1722 Hz) to the twelfth partial (2952 Hz). Decibel readings on the seventh partial are 38 for both subjects.

4. A prominent energy region above F^2 is present in both spectrograms. This energy region extends from the twelfth partial (2952 Hz) to the seventeenth partial (4182 Hz) at approximately 20 to 32 dB. Both subjects show intense peaks on the fifteenth partial (3690 Hz) at 28 to 30 dB.

Figures 71 and 72 are spectrographs showing the formant behavior of university subjects singing the vowel [i] at b-246 Hz, and display the following information:

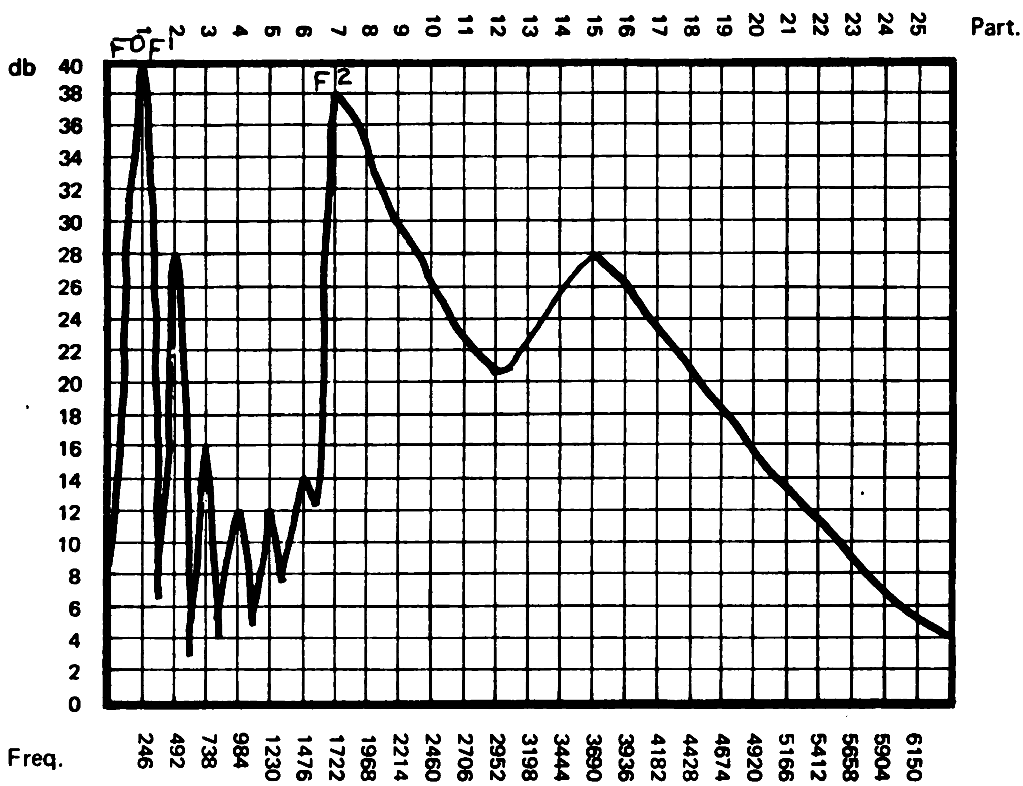

Figure 69.--Spectrograph of high school subject 9 singing the vowel [i] at b-246 Hz.

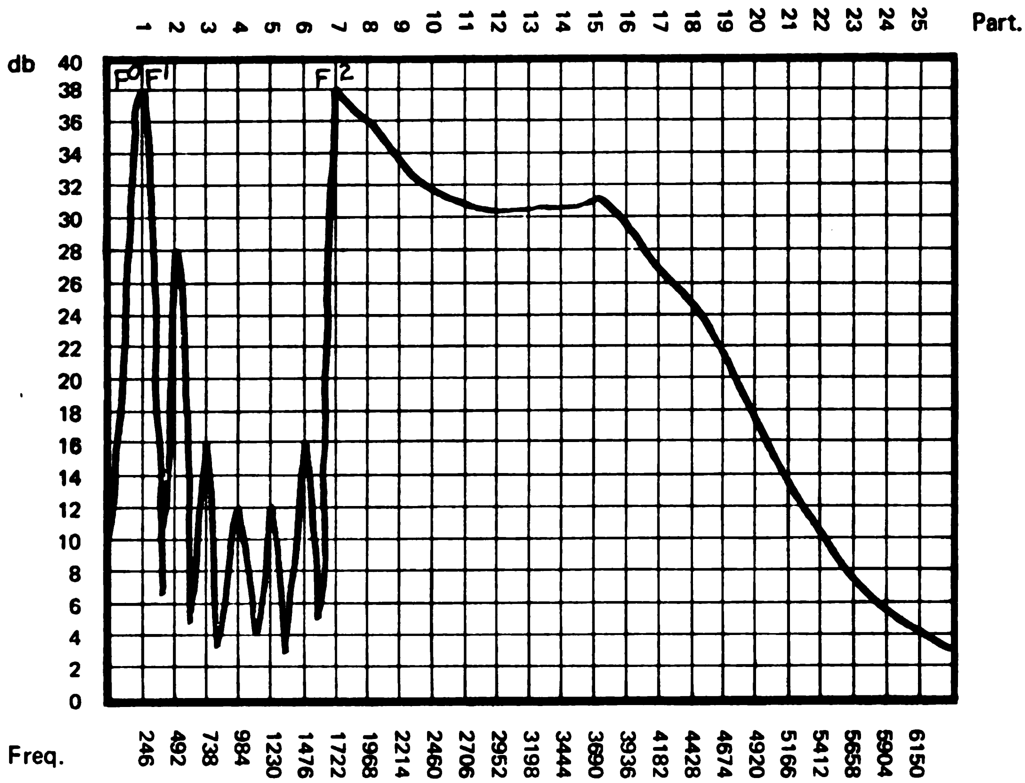

Figure 70.--Spectrograph of high school subject 10 singing the vowel [i] at b-246 Hz.

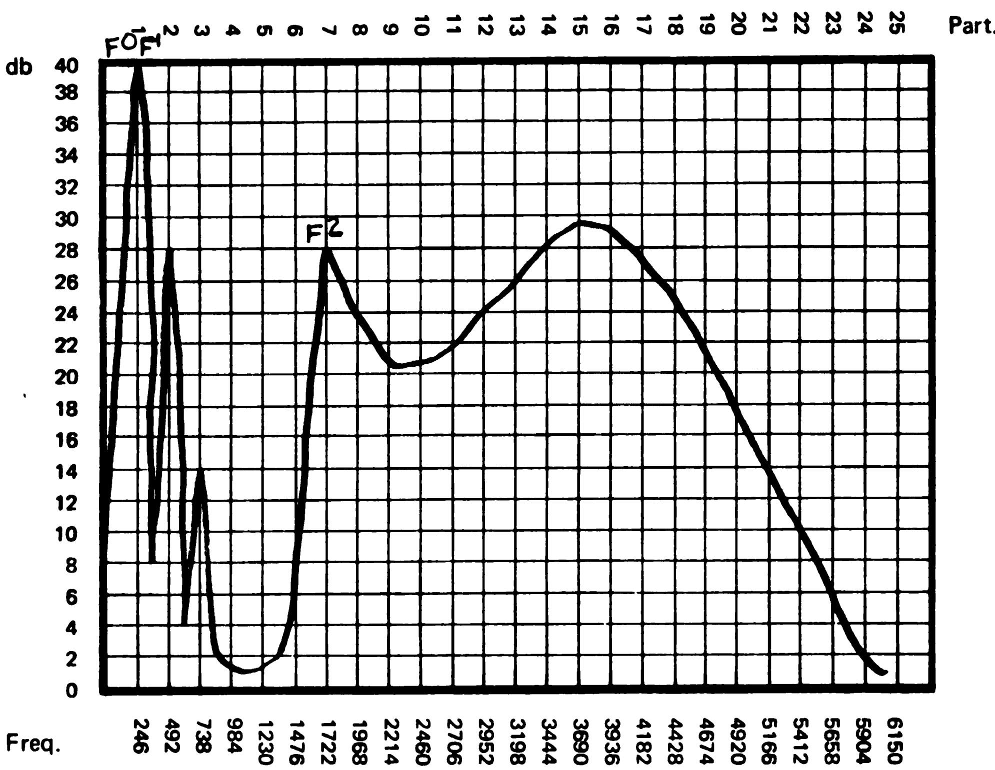

Figure 71.--Spectrograph of university subject 3 singing the vowel [i] at b-246 Hz.

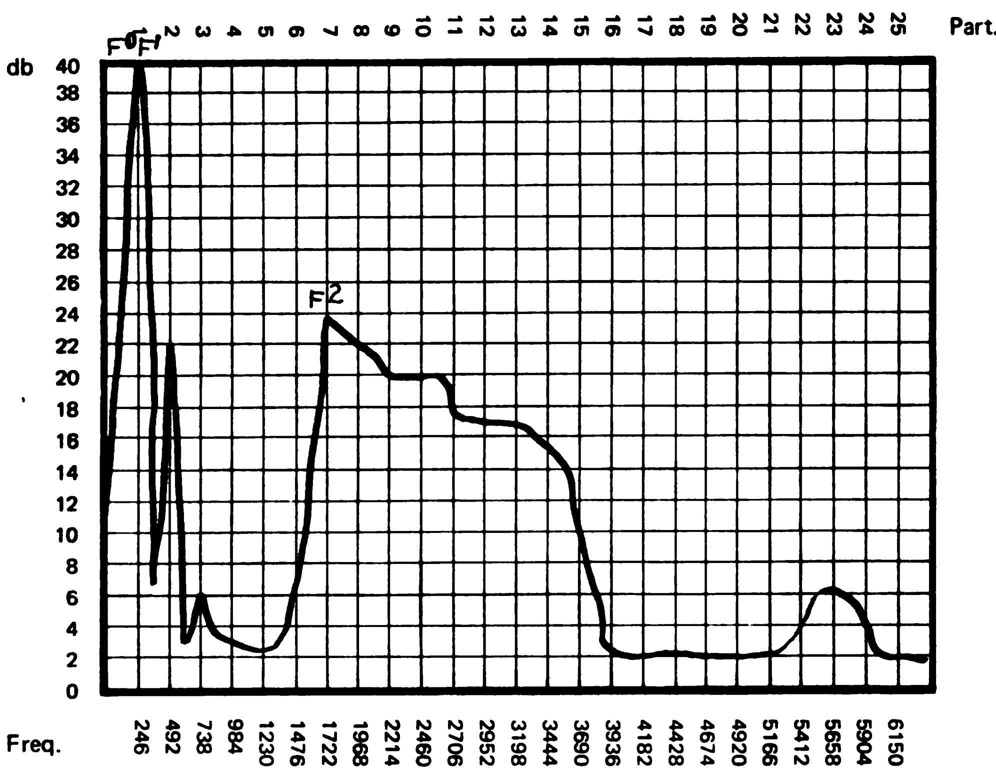

Figure 72. Spectrograph of university subject 9 singing the vowel [i] at b-246 Hz.

1. The intensity of the fundamental is 40 dB for both subjects.

2. F^1 is absorbed by the fundamental for both subjects at 40 dB.

3. F^2 appears as a prominent region of energy for both subjects, ranging from an intense peak on the seventh partial (1722 Hz) to the ninth partial (2214 Hz). Decibel readings on the seventh partial are 28 and 24, respectively, for university subjects 3 and 9.

4. A prominent energy region above F^2 is present in both spectrograms. This energy region extends from the ninth partial (2214 Hz) to the seventeenth partial (4182 Hz), with a strong intensity peak of 29 dB for university subject 3, occurring on the fourteenth partial (3444 Hz). The energy region extends from the ninth partial (2214 Hz) to the sixteenth partial (3936 Hz) for university subject 9, ranging from 10 to 20 dB.

Figures 73 through 76 are spectrographs showing the formant behavior of mature subjects singing the vowel [i] at b-246 Hz, and display the following information:

1. The intensities of the fundamental range from 34 to 38 dB.

2. F^1 is absorbed by the fundamental for all four subjects. Decibel readings are 34, 38, 32, and 36, respectively, for mature subjects 3, 4, 9, and 10.

3. F^2 occurs on the seventh partial (1722 Hz) for all four subjects. Decibel readings are 30, 28, 34, and 32, respectively.

4. Two additional energy peaks occur for all four subjects on the ninth partial (2214 Hz) and the thirteenth partial (3198 Hz).

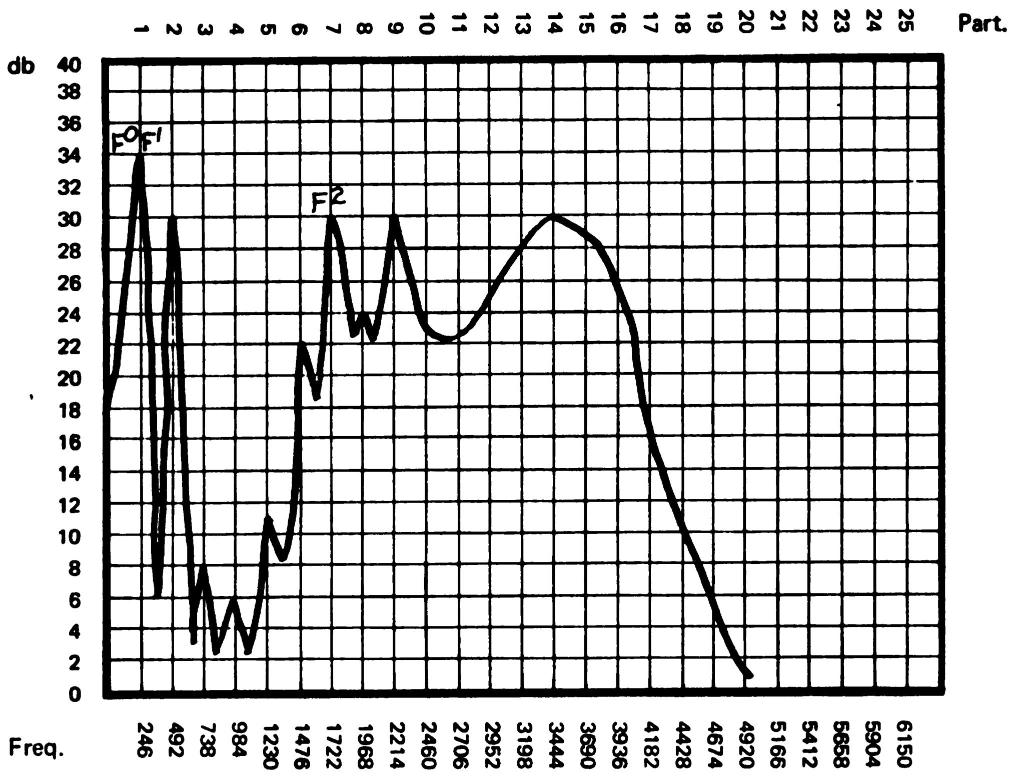

Figure 73.--Spectrograph of mature subject 3 singing the vowel [i] at b-246 Hz.

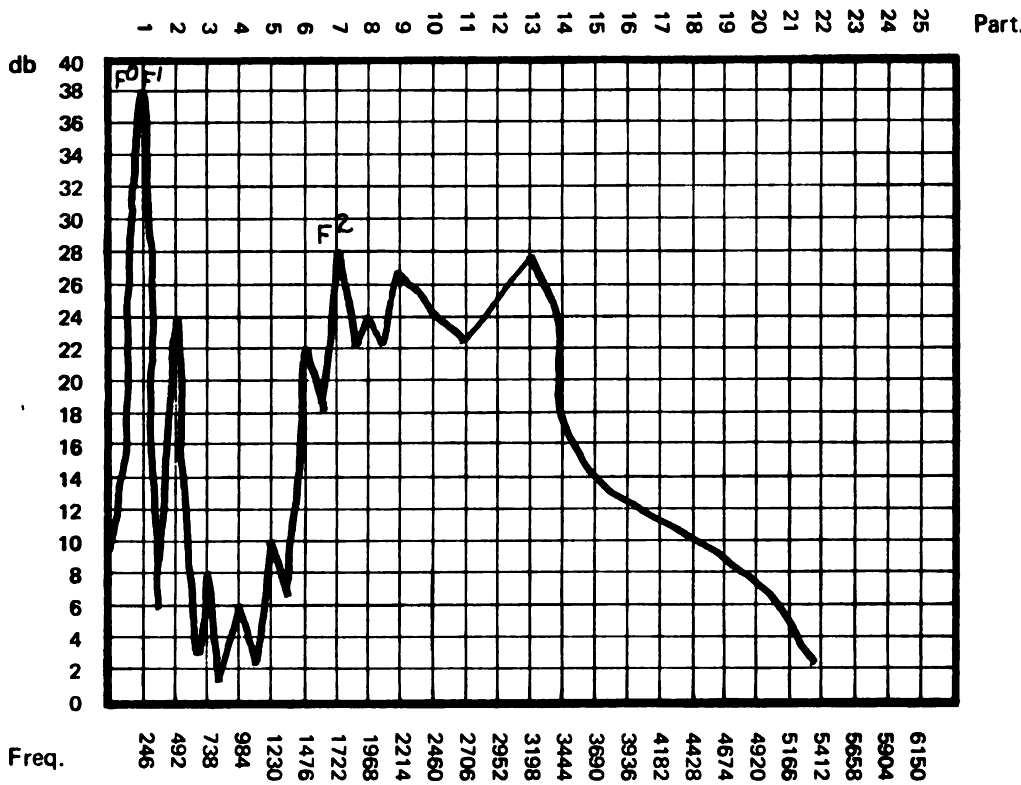

Figure 74.--Spectrograph of mature subject 4 singing the vowel [i] at b-246 Hz.

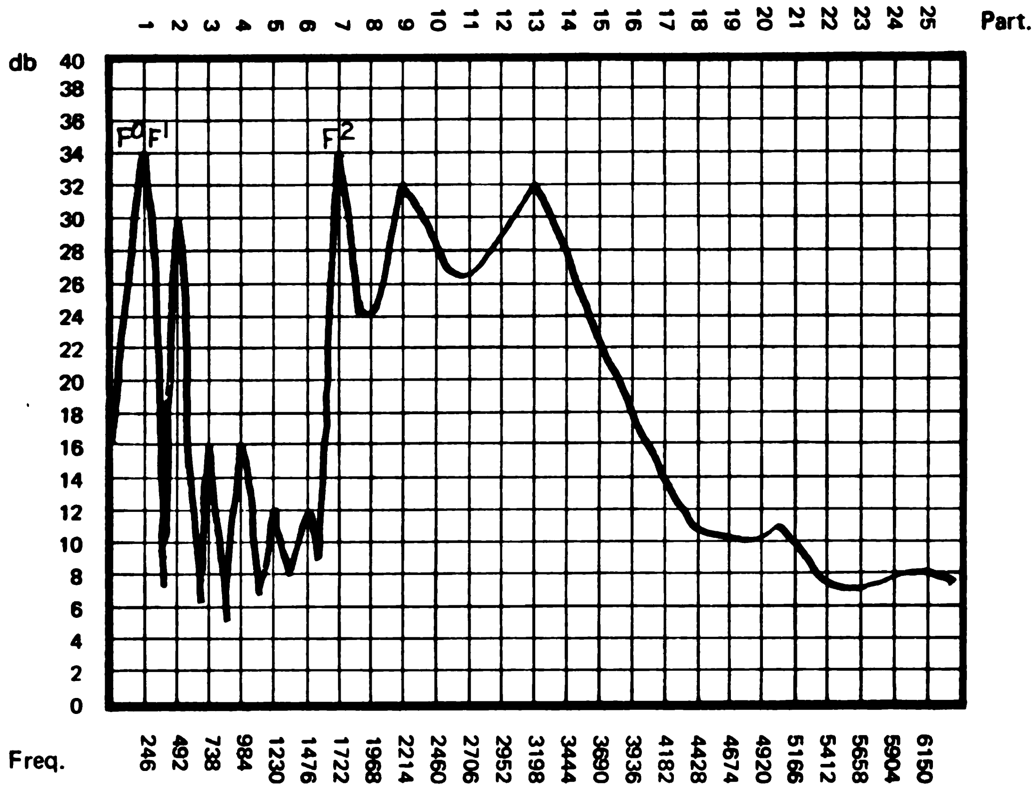

Figure 75.--Spectrograph of mature subject 9 singing the vowel [i] at b-246 Hz.

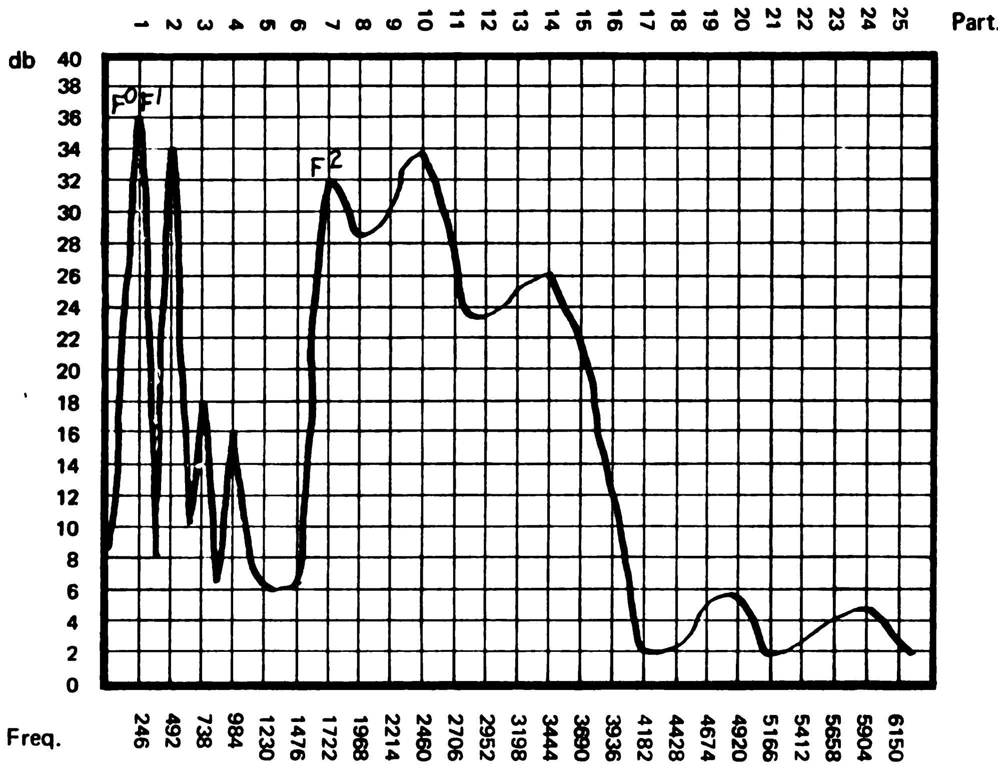

Figure 76.--Spectrograph of mature subject 10 singing the vowel [i] at b-246 Hz.

Decibel readings range from 28 to 33 on the ninth partial, and from 26 to 32 on the thirteenth partial.

A Comparison of All Subjects Singing the Vowel [i] at b-246 Hz

1. The intensities of the fundamental range from 34 to 40 dB.

2. F^1 is absorbed by the fundamental for all subjects.

3. F^2 occurs on the seventh partial (1722 Hz) for all subjects, with decibel readings ranging from 24 to 38. However, F^2 varied among subjects from a broad region of intensity for high school subjects, to a narrow intensity peak for mature subjects. F^2 shows greater intensity for high school subjects (38 dB) than that of the university or mature subjects.

4. A prominent energy region above F^2 is present in all spectrograms. This energy region ranges from the ninth partial (2214 Hz) to the seventeenth partial (4182 Hz) at 20 to 33 dB. Intensity peaks are present for all four mature subjects on the ninth partial (2214 Hz) at 28 to 33 dB, and on the thirteenth partial (3198 Hz) at 26 to 32 dB. Both high school subjects show intensity peaks on the fifteenth partial (3690 Hz) at 28 to 30 dB, and university subject 3 shows an intensity peak on the fourteenth partial (3444 Hz) at 29 dB.

Vowel [o] at Pitch b-246 Hz

Figures 77 and 78 are spectrographs showing the formant behavior of high school subjects singing the vowel [o] at b-246 Hz, and display the following information:

1. The intensities of the fundamentals are 30 and 32 dB.

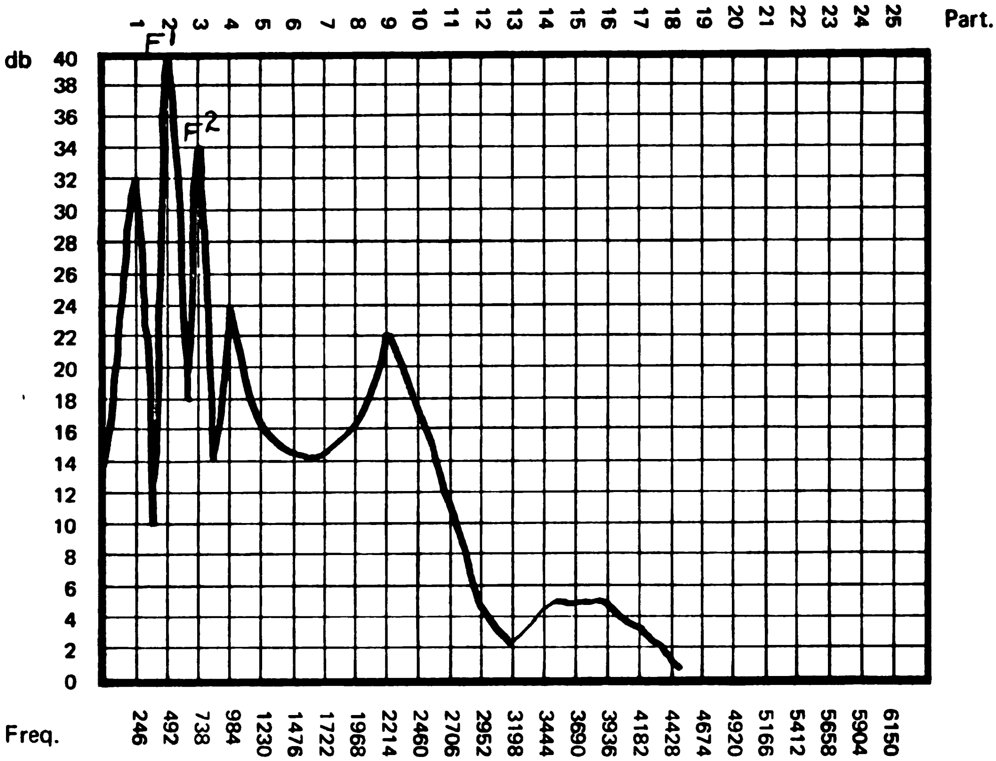

Figure 77.--Spectrograph of high school subject 4 singing the vowel [o] at b-246 Hz.

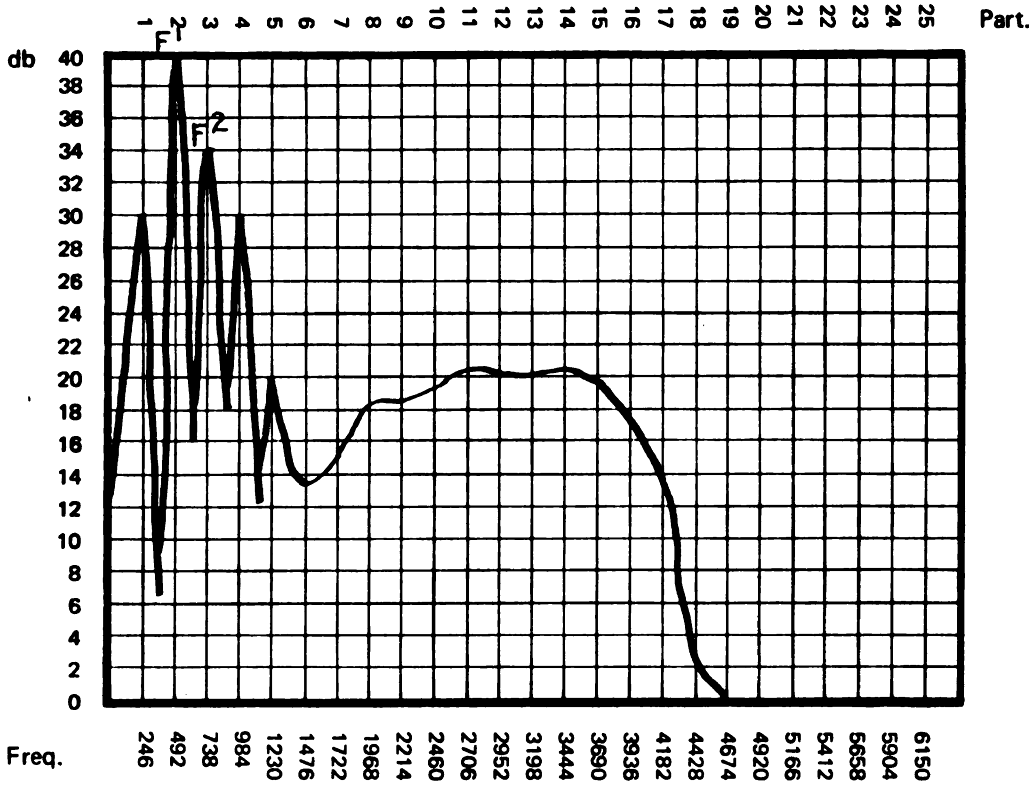

Figure 78.--Spectrograph of high school subject 10 singing the vowel [o] at b-246 Hz.

2. F^1 occurs on the second partial (492 Hz) at 40 dB for both subjects.

3. F^2 occurs on the third partial (738 Hz) at 34 dB for both subjects.

4. A prominent energy region above F^2 is present for high school subject 10, ranging from the seventh partial (1722 Hz) to the eighteenth partial (4428 Hz). Decibel readings range from 12 to 19. High school subject 4 shows an intensity peak on the ninth partial (2214 Hz) at 22 dB.

Figures 79 through 81 are spectrographs showing the formant behavior of university subjects singing the vowel [o] at b-246 Hz, and display the following information:

1. The intensities of the fundamental range from 32 to 34 dB.

2. F^1 occurs on the second partial (492 Hz) at 40 dB for all three subjects.

3. F^2 occurs on the third partial (738 Hz) for university subjects 3 and 9 at 36 and 34 dB, respectively. F^2 occurs on the fourth partial (984 Hz) at 38 dB for university subject 4.

4. A prominent energy region above F^2 is present in all three spectrograms. University subject 3 shows an energy region ranging from the ninth partial (2214 Hz) to the sixteenth partial (3936 Hz) at 16 to 32 dB. University subject 4 shows an energy region ranging from the tenth partial (2460 Hz) to the twenty-first partial (5166 Hz) at 8 to 21 dB. University subject 9 shows an energy region similar to that of university subject 3, but at 10 to 19 dB.

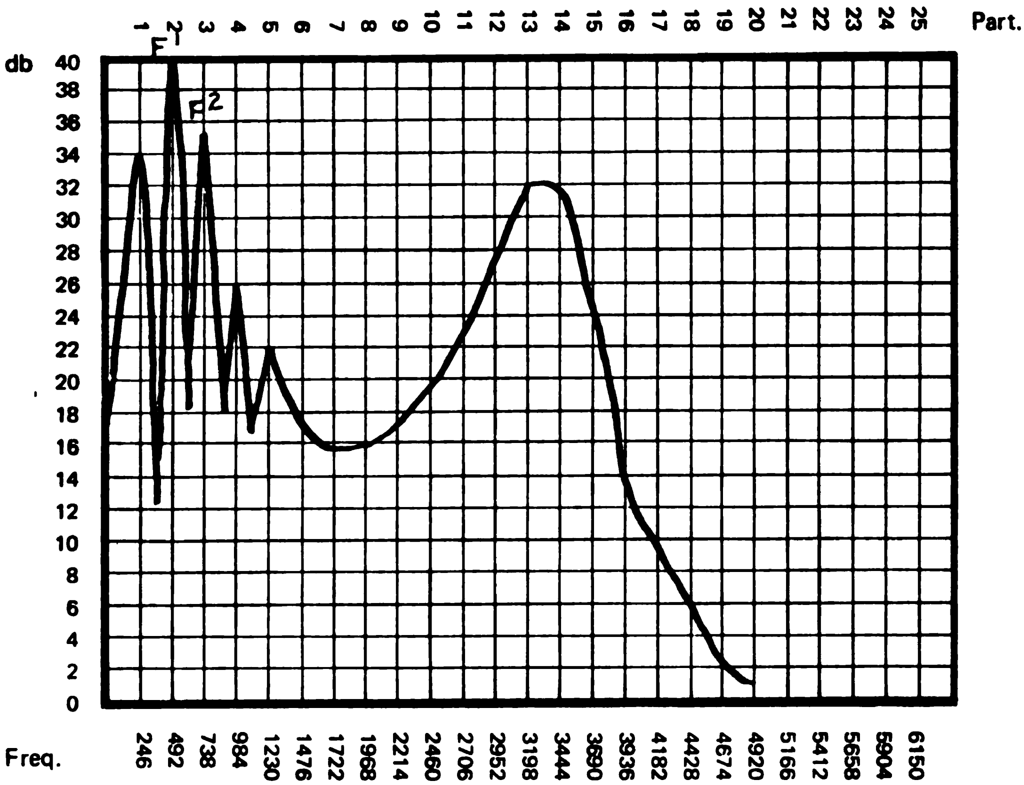

Figure 79.--Spectrograph of university subject 3 singing the vowel [o] at b-246 Hz.

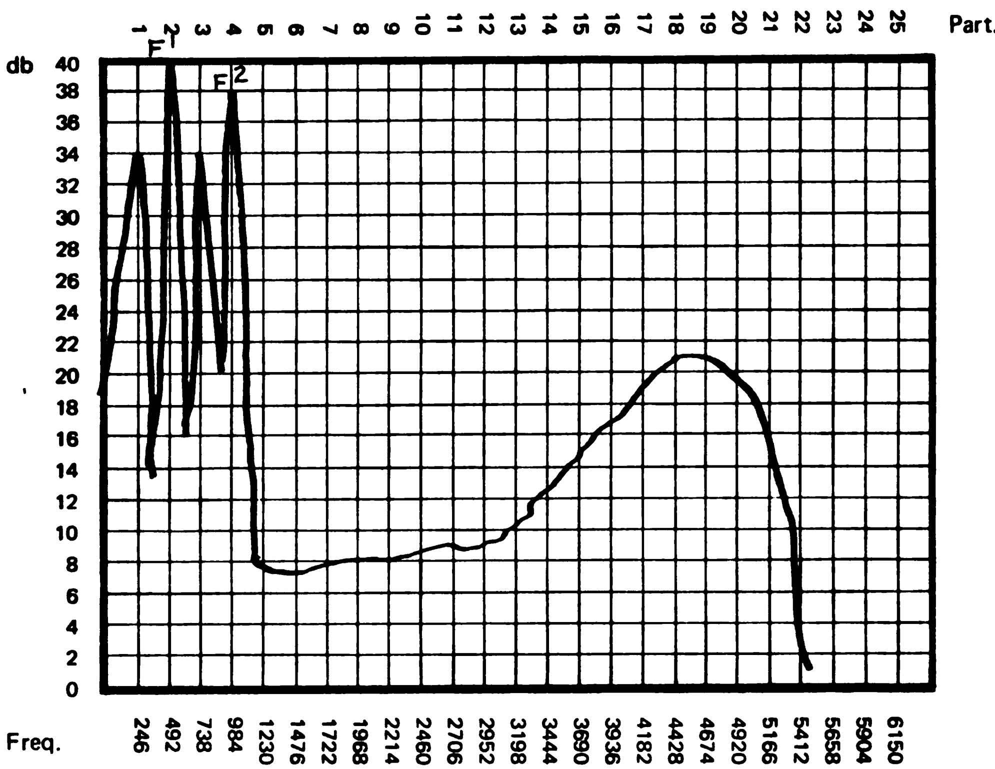

Figure 80.--Spectrograph of university subject 4 singing the vowel [o] at b-246 Hz.

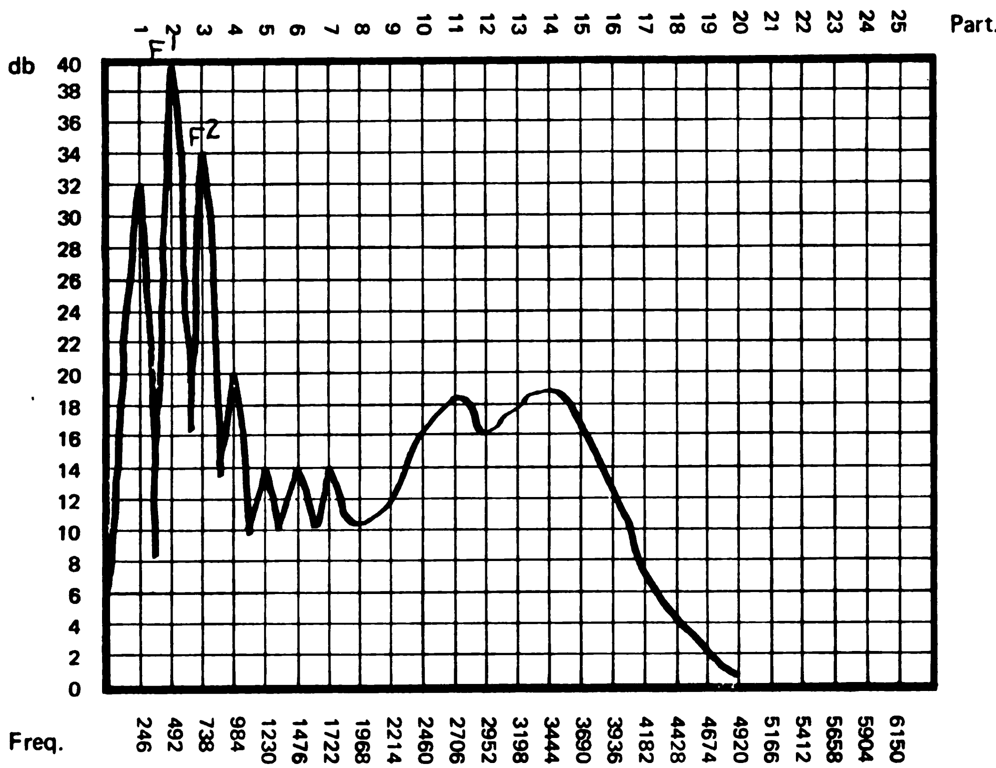

Figure 81.--Spectrograph of university subject 9 singing the vowel [o] at b-246 Hz.

Figures 82 through 85 are spectrographs showing the formant behavior of mature subjects singing the vowel [o] at b-246 Hz, and display the following information:

1. The intensities of the fundamental range from 26 to 28 dB.

2. F^1 occurs on the second partial (492 Hz) for all four subjects. Decibel readings are 38, 38, 34, and 40, respectively, for mature subjects 3, 4, 9, and 10.

3. F^2 occurs on the third partial (738 Hz) for mature subjects 3, 4, and 10. Decibel readings are 34, 32, and 36, respectively. F^2 occurs on the fourth partial (984 Hz) at 38 dB for mature subject 9.

4. A prominent energy region above F^2 is present in all four spectrograms. This energy region occurs from the ninth partial (2214 Hz) to the fifteenth partial (3690 Hz) with decibel readings ranging from 14 to 34.

A Comparison of All Subjects Singing the Vowel [o] at b-246 Hz

1. The intensities of the fundamental range from 26 to 34 dB.

2. F^1 occurs on the second partial (492 Hz) for all subjects with decibel readings ranging from 34 to 40.

3. F^2 occurs on the third partial (738 Hz) for all subjects except university subject 4 and mature subject 9. F^2 occurs on the fourth partial (984 Hz) for these two subjects at 38 dB. Subjects for whom F^2 occurs on the third partial show decibel readings from 32 to 36.

4. A prominent energy region above F^2 occurs for all subjects. This energy region is inconsistent, ranging from the

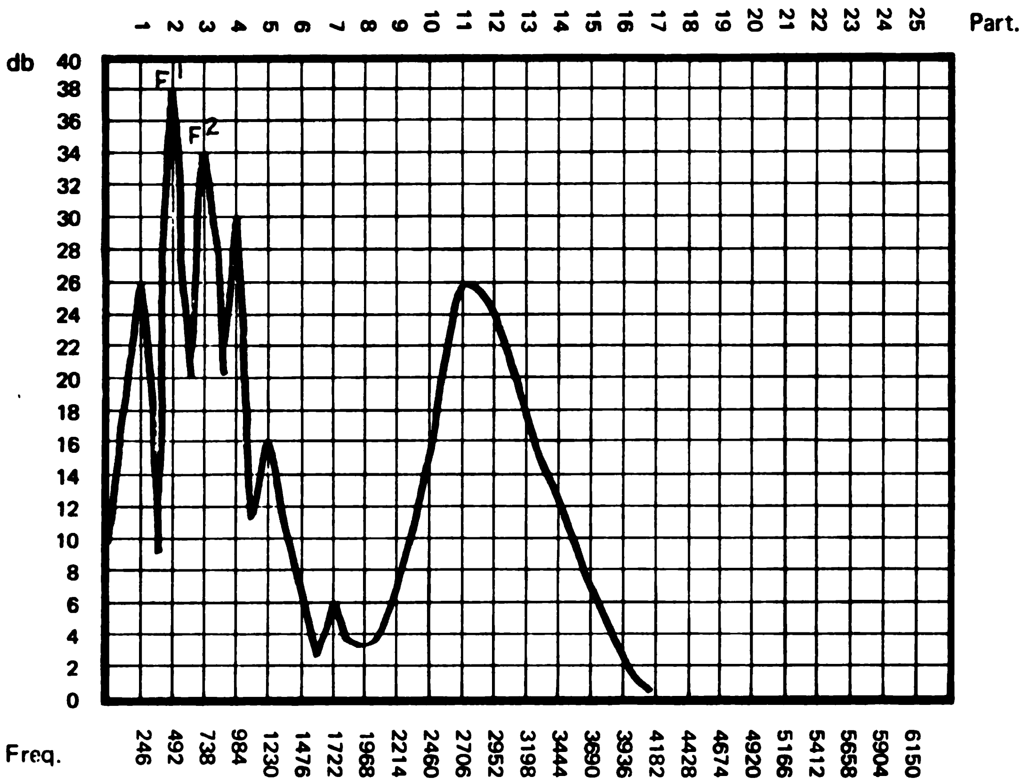

Figure 82.--Spectrograph of mature subject 3 singing the vowel [o] at b-246 Hz.

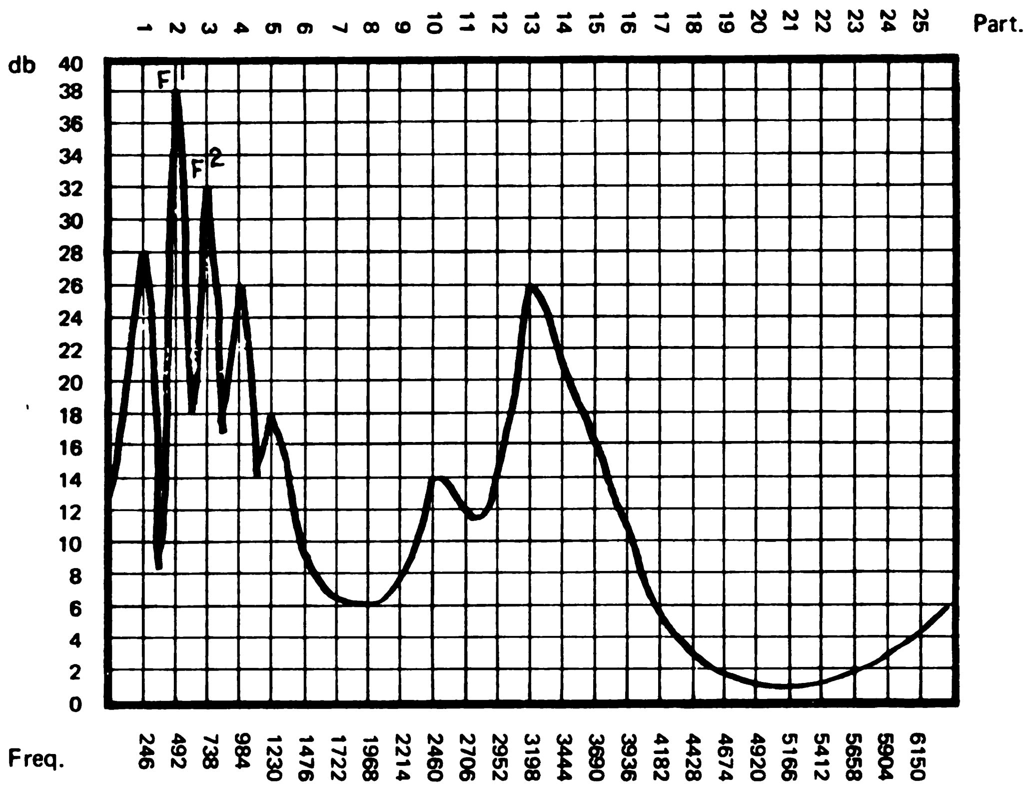

Figure 83.--Spectrograph of mature subject 4 singing the vowel [o] at b-246 Hz.

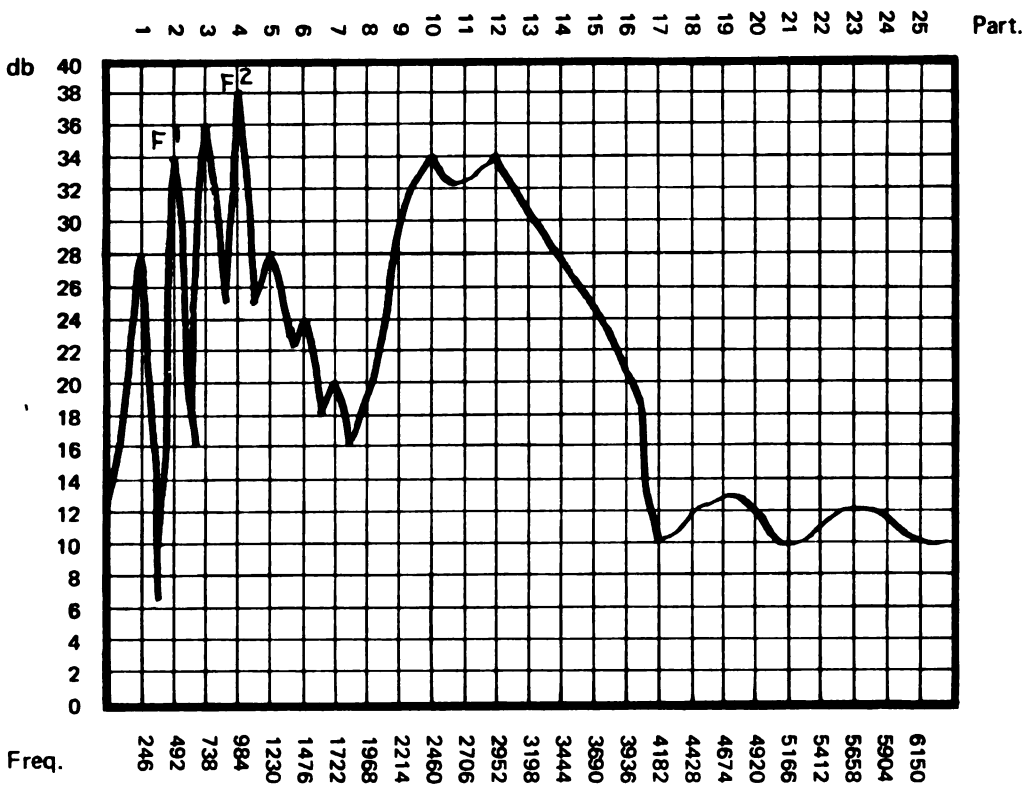

Figure 84.--Spectrograph of mature subject 9 singing the vowel [o] at b-246 Hz.

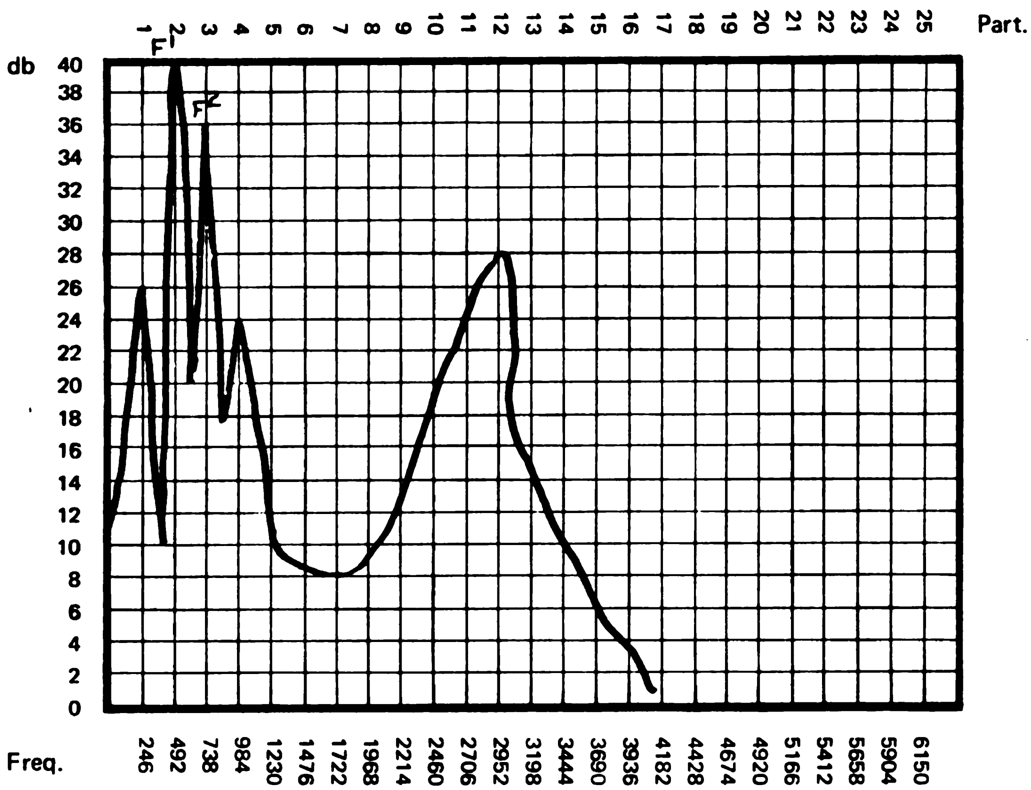

Figure 85.--Spectrograph of mature subject 10 singing the vowel [o] at b-246 Hz.

seventh partial (1722 Hz) to the twenty-first partial (5166 Hz) at 8 to 34 dB.

Vowel [u] at Pitch b-246 Hz

Figures 86 through 88 are spectrographs showing the formant behavior of high school subjects singing the vowel [u] at b-246 Hz, and display the following information:

1. The intensities of the fundamental range from 32 to 35 dB.

2. F^1 occurs on the second partial (492 Hz) for all three subjects. Decibel readings are 40, 38, and 38, respectively, for high school subjects 5, 9, and 10.

3. F^2 occurs on the third partial (738 Hz) for high school subjects 9 and 10. Decibel readings are 33 and 34, respectively. F^2 occurs on the fourth partial (984 Hz) at 34 dB for high school subject 5.

4. An energy region above F^2 occurs in all three spectrograms. This energy region is very weak and insignificant for high school subjects 9 and 10. The energy region ranges from the tenth partial (2460 Hz) to the eighteenth partial (4428 Hz) at 8 to 23 dB for high school subject 5.

Figures 89 and 90 are spectrographs showing the formant behavior of university subjects singing the vowel [u] at b-246 Hz, and display the following information:

1. The intensities of the fundamentals are 36 and 38 dB.

2. F^1 occurs on the second partial (492 Hz) for both subjects. Decibel readings are 34 and 38, respectively, for university subjects 4 and 9.

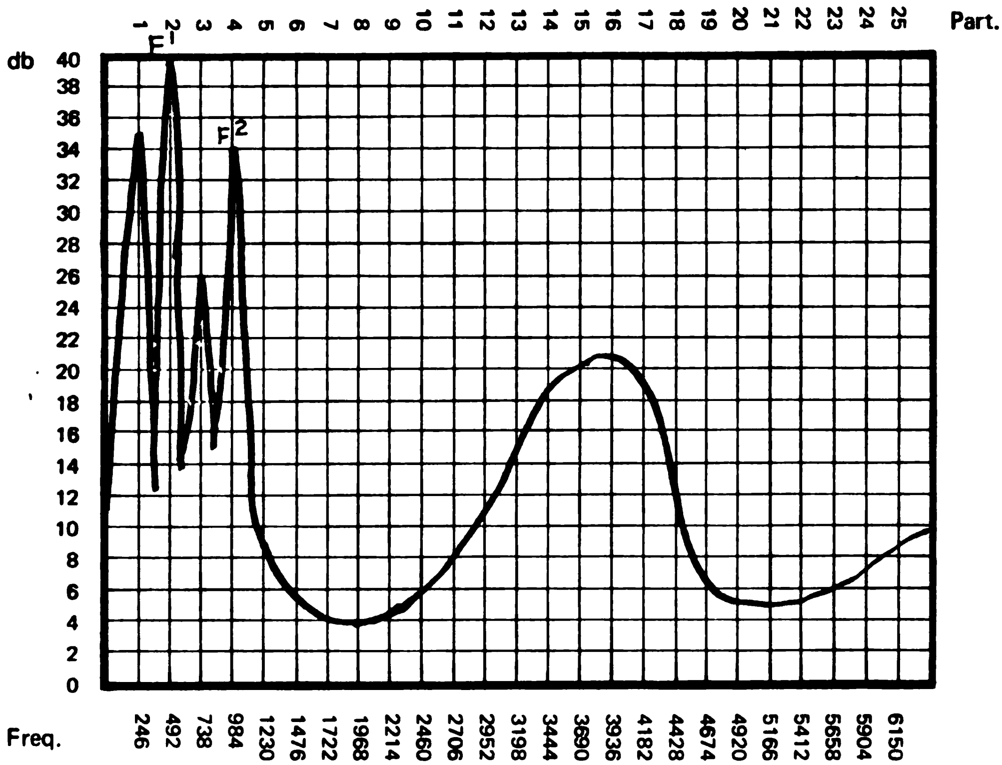

Figure 86.--Spectrograph of high school subject 5 singing the vowel [u] at b-246 Hz.

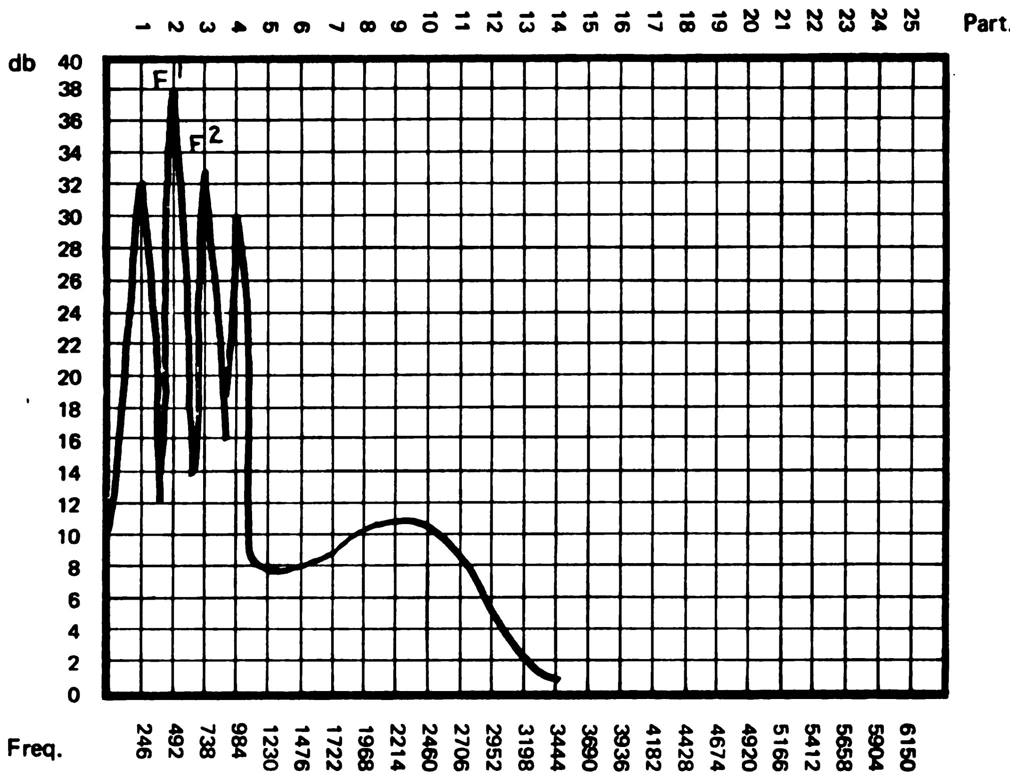

Figure 87.--Spectrograph of high school subject 9 singing the vowel [u] at b-246 Hz.

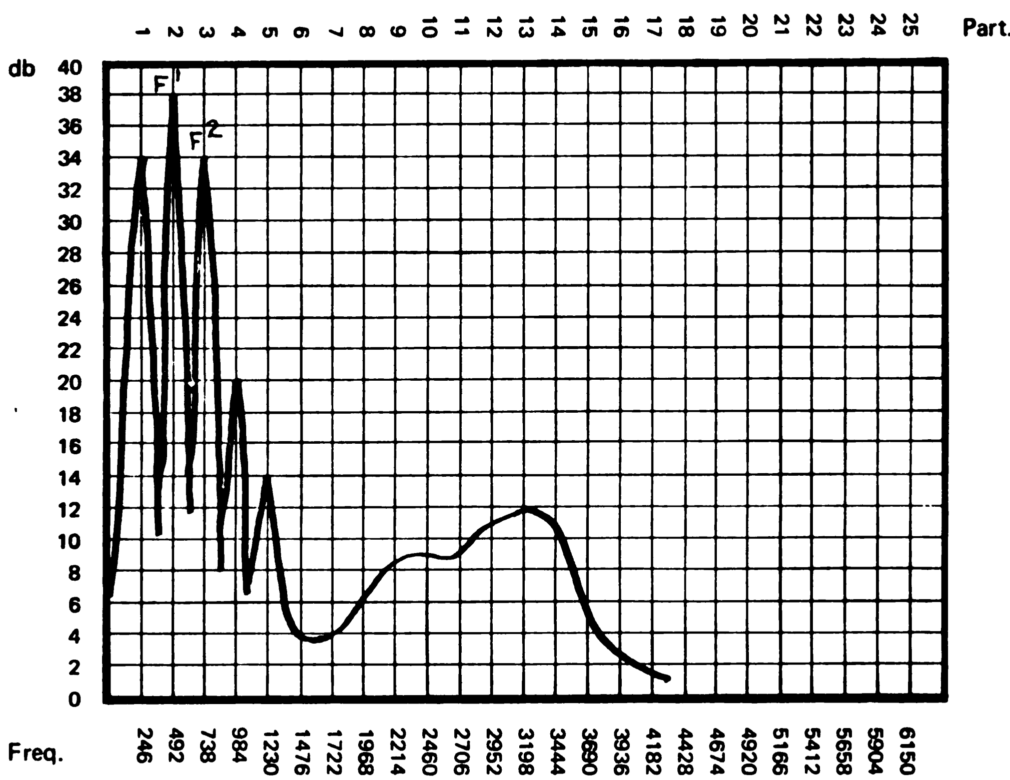

Figure 88.--Spectrograph of high school subject 10 singing the vowel [u] at b-246 Hz.

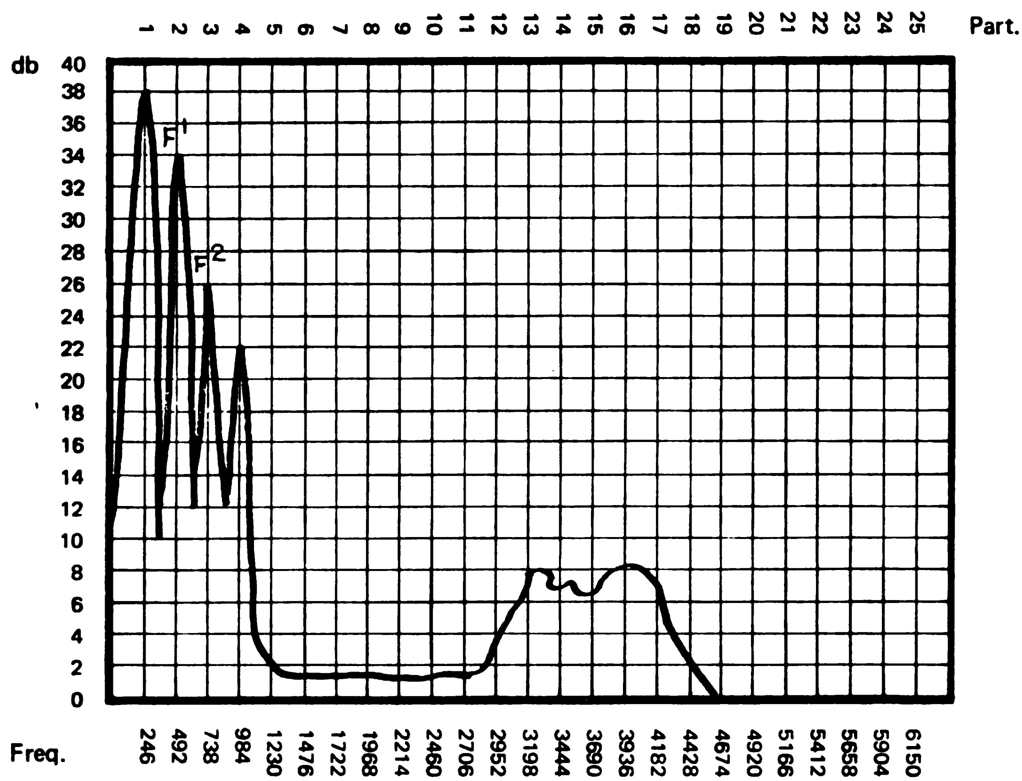

Figure 89.--Spectrograph of university subject 4 singing the vowel [u] at b-246 Hz.

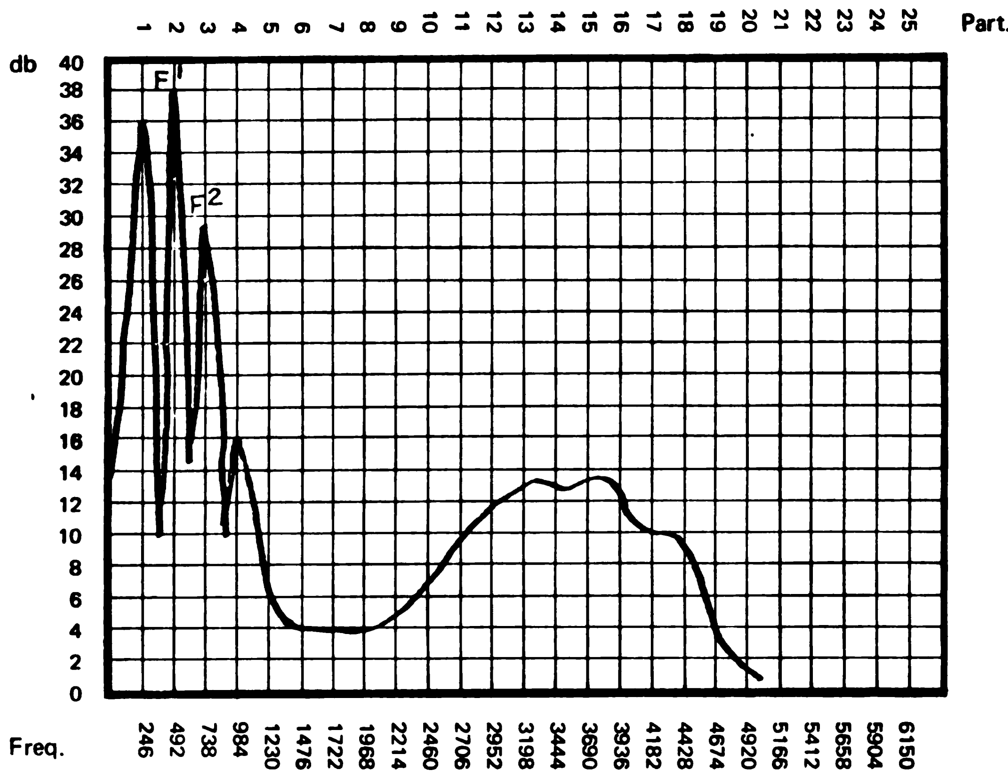

Figure 90.--Spectrograph of university subject 9 singing the vowel [u] at b-246 Hz.

3. F^2 occurs on the third partial (738 Hz) for both subjects. Decibel readings are 26 and 29, respectively.

4. A very weak energy region occurs in both spectrograms. This energy region is very insignificant, showing a decibel reading of 12 at the highest peak.

Figures 91 through 94 are spectrographs showing the formant behavior of mature subjects singing the vowel [u] at b-246 Hz, and display the following information:

1. The intensities of the fundamental range from 24 to 35 dB.

2. F^1 occurs on the second partial (492 Hz) for all four subjects. Decibel readings are 36, 36, 36, and 40, respectively, for mature subjects 3, 4, 9, and 10.

3. F^2 occurs on the third partial (738 Hz) for mature subjects 3, 4, and 10. Decibel readings are 30, 32, and 30, respectively. F^2 occurs on the fourth partial (984 Hz) at 40 dB for mature subject 9.

4. A prominent energy region above F^2 is present in all four spectrograms. Each subject shows a high intensity peak covering three different partials: the eleventh partial (2706 Hz), the twelfth partial (2952 Hz), and the thirteenth partial (3198 Hz). Decibel readings for the high intensity peaks range from 22 to 28.

A Comparison of All Subjects Singing the Vowel [u] at b-246 Hz

1. The intensities of the fundamental range from 24 to 38 dB.

2. F^1 occurs on the second partial (492 Hz) for all subjects with decibel readings ranging from 34 to 40.

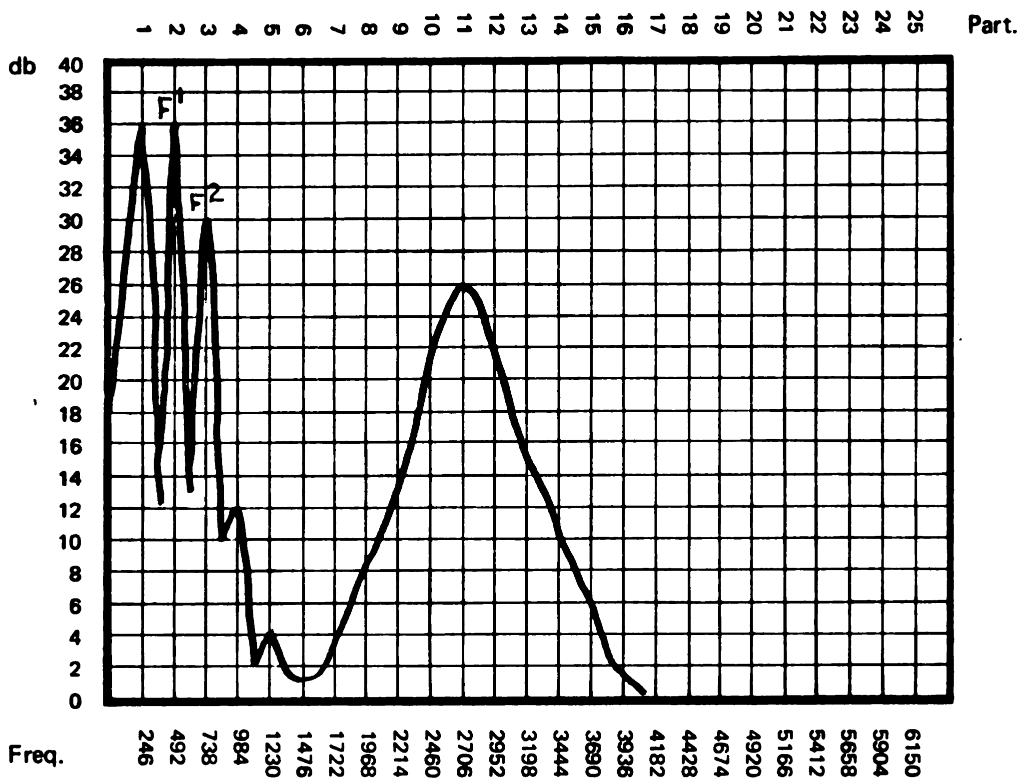

Figure 91.--Spectrograph of mature subject 3 singing the vowel [u] at b-246 Hz.

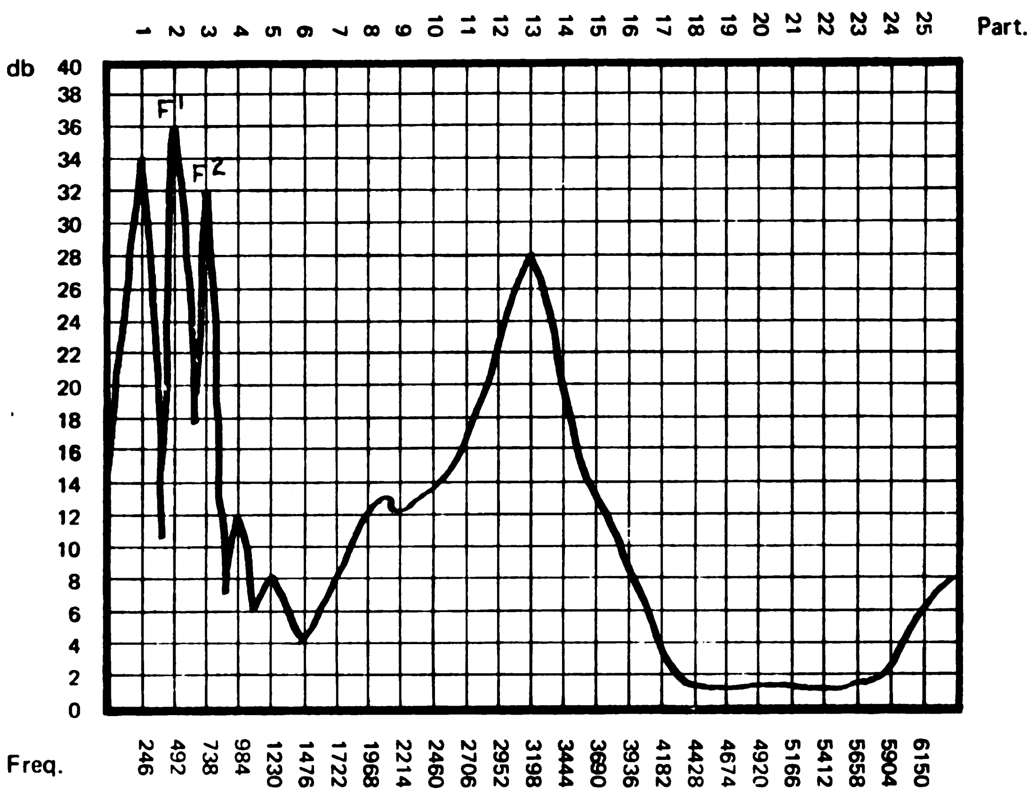

Figure 92.--Spectrograph of mature subject 4 singing the vowel [u] at b-246 Hz.

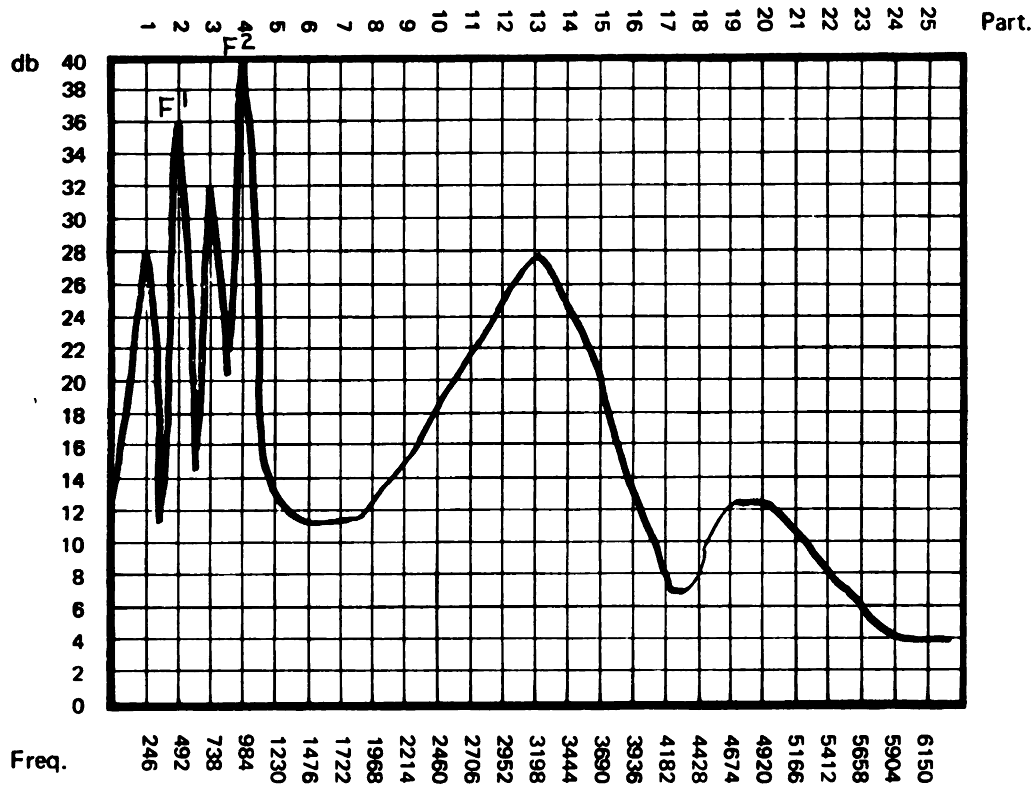

Figure 93.--Spectrograph of mature subject 9 singing the vowel [u] at b-246 Hz.

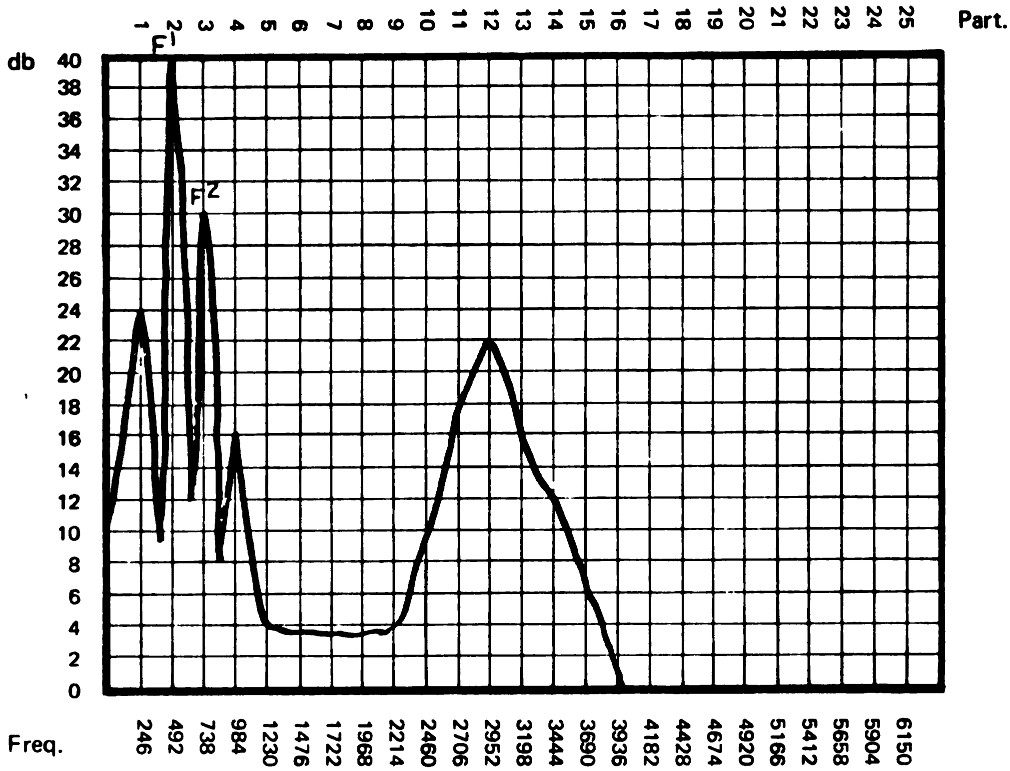

Figure 94.--Spectrograph of mature subject 10 singing the vowel [u] at b-246 Hz.

3. F^2 occurs on the third partial (738 Hz) for all subjects except high school subject 5 and mature subject 9. F^2 occurs on the fourth partial (984 Hz) for these two subjects at 34 and 40 dB, respectively. Decibel readings for the third partial range from 26 to 34.

4. An energy region is present above F^2 in all spectrograms. This energy region is very weak and insignificant for both university subjects and two of the high school subjects. The energy region for high school subject 5 ranges from the tenth partial (2460 Hz) to the eighteenth partial (4428 Hz) with a decibel reading of 23 at the highest intensity. Each mature subject shows a prominent energy region with an intensity peak covering three different partials: the eleventh partial (2706 Hz), the twelfth partial (2952 Hz), and the thirteenth partial (3198 Hz). Decibel readings for the high intensity peaks ranged from 22 to 28.

<u>Vowel [a] at Pitch $g^{\#}$-415 Hz</u>

Figures 95 and 96 are spectrographs showing the formant behavior of high school subjects singing the vowel [a] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamentals are 28 and 34 dB.

2. F^1 occurs on the second partial (830 Hz) at 38 dB for both subjects.

3. F^2 occurs on the third partial (1245 Hz) at 34 dB for both subjects.

4. A prominent energy region is present in both spectrograms. This energy region ranges from the sixth partial (2490 Hz)

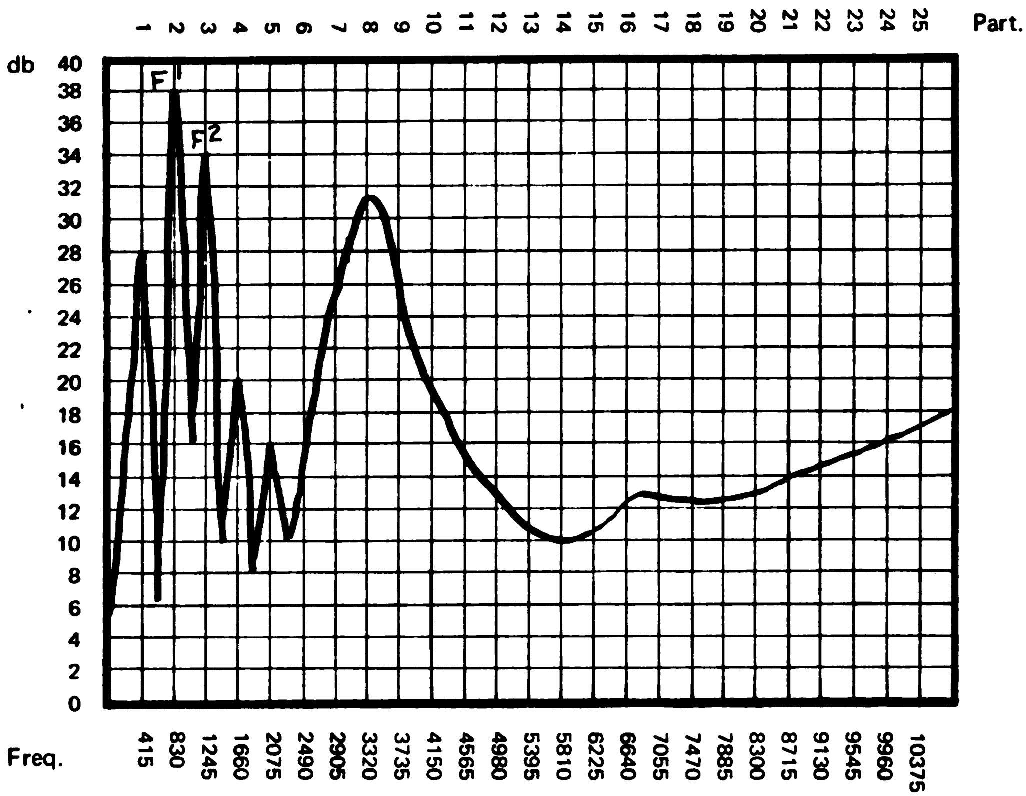

Figure 95.--Spectrograph of high school subject 9 singing the vowel [a] at g#-415 Hz.

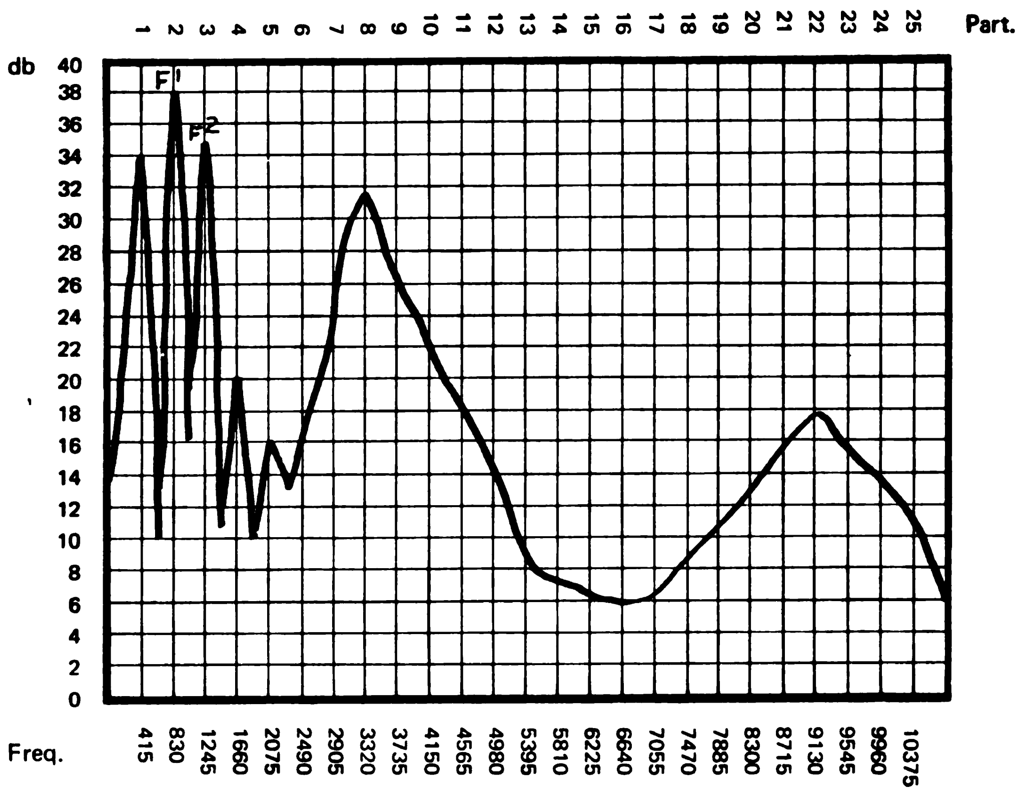

Figure 96.--Spectrograph of high school subject 10 singing the vowel [a] at g#-415 Hz.

to the twelfth partial (4980 Hz), showing a high intensity peak on the eighth partial (3320 Hz) at 31 dB for both subjects.

Figures 97 and 98 are spectrographs showing the formant behavior of university subjects singing the vowel [a] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamentals are 26 and 34 dB.

2. F^1 occurs on the second partial (830 Hz) for both subjects. Decibel readings are 40 and 38, respectively, for university subjects 3 and 9.

3. F^2 occurs on the third partial (1245 Hz) at 36 dB for university subject 9. F^2 appears to be combined with F^1 for university subject 3.

4. A prominent energy region above F^2 is present in both spectrograms. This energy region ranges from approximately the fifth partial (2075 Hz) to the twelfth partial (4980 Hz) at 14 to 24 dB for university subject 9, and 12 to 28 dB for university subject 3.

Figures 99 through 101 are spectrographs showing the formant behavior of mature subjects singing the vowel [a] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamental range from 26 to 36 dB.

2. F^1 occurs on the second partial (830 Hz) for all three subjects. Decibel readings are 38, 36, and 40, respectively, for mature subjects 4, 9, and 10.

3. F^2 occurs on the third partial (1245 Hz) for mature subjects 4 and 9. Decibel readings are 32 and 36, respectively. F^2 appears to be combined with F^1 for mature subject 10.

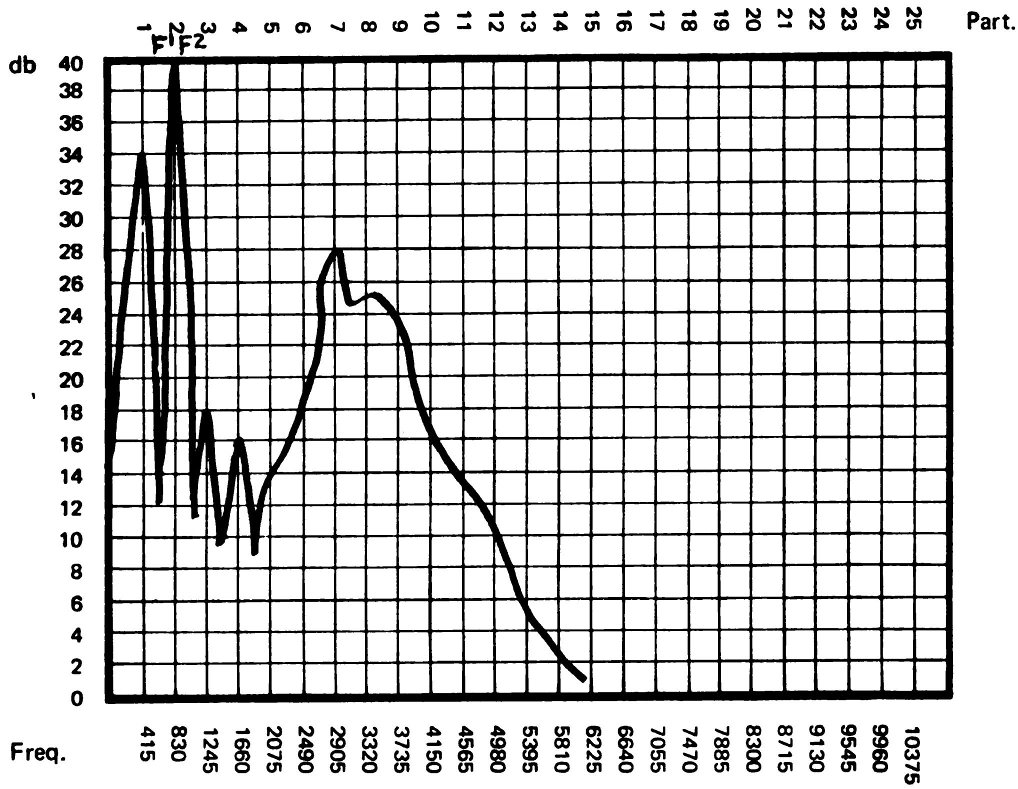

Figure 97.--Spectrograph of university subject 3 singing the vowel [a] at g#-415 Hz.

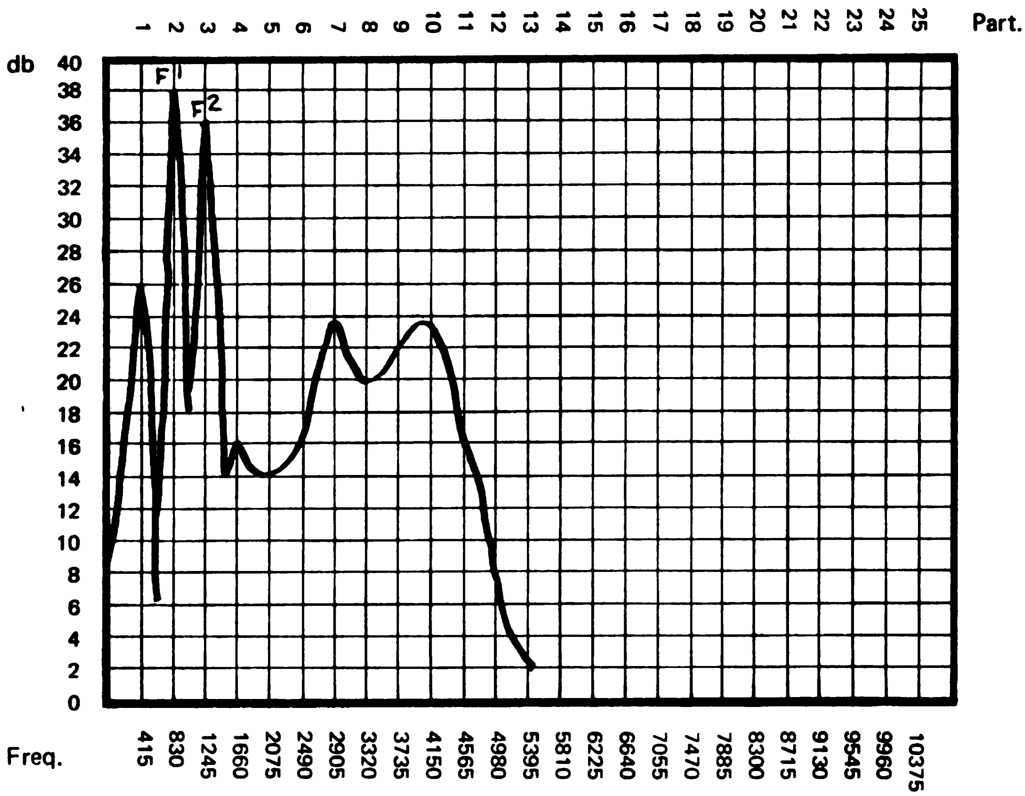

Figure 98.--Spectrograph of university subject 9 singing the vowel [a] at g#-415 Hz.

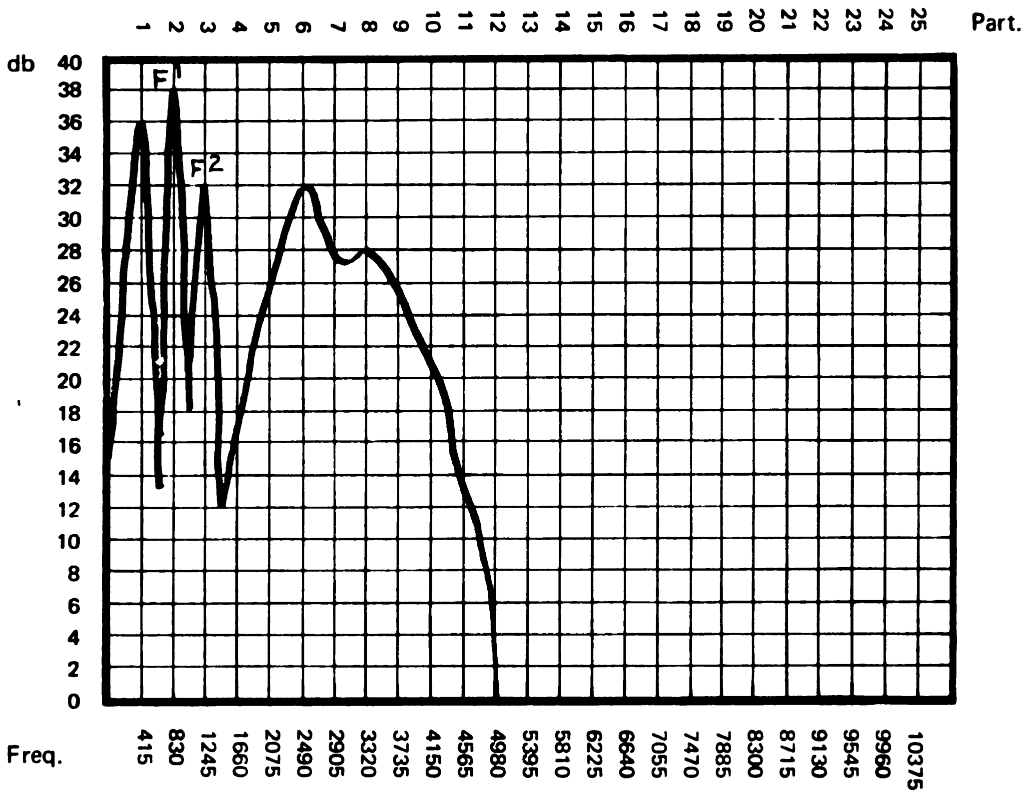

Figure 99.--Spectrograph of mature subject 4 singing the vowel [a] at g#-415 Hz.

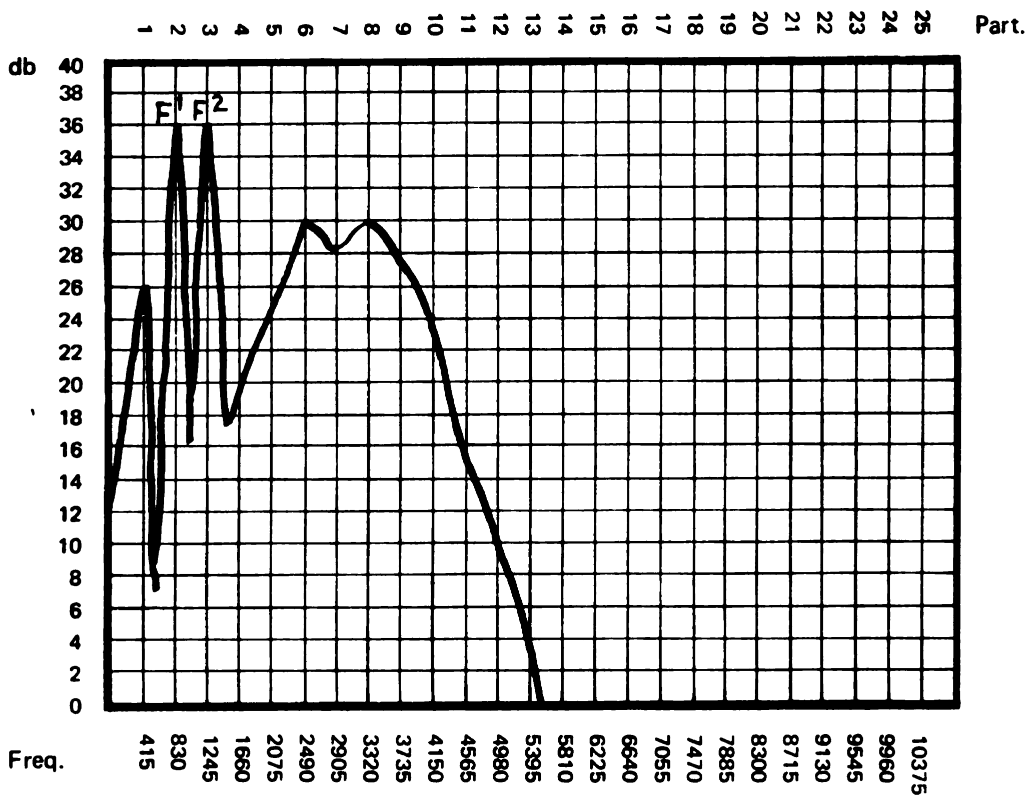

Figure 100.--Spectrograph of mature subject 9 singing the vowel [a] at $g^{\#}$-415 Hz.

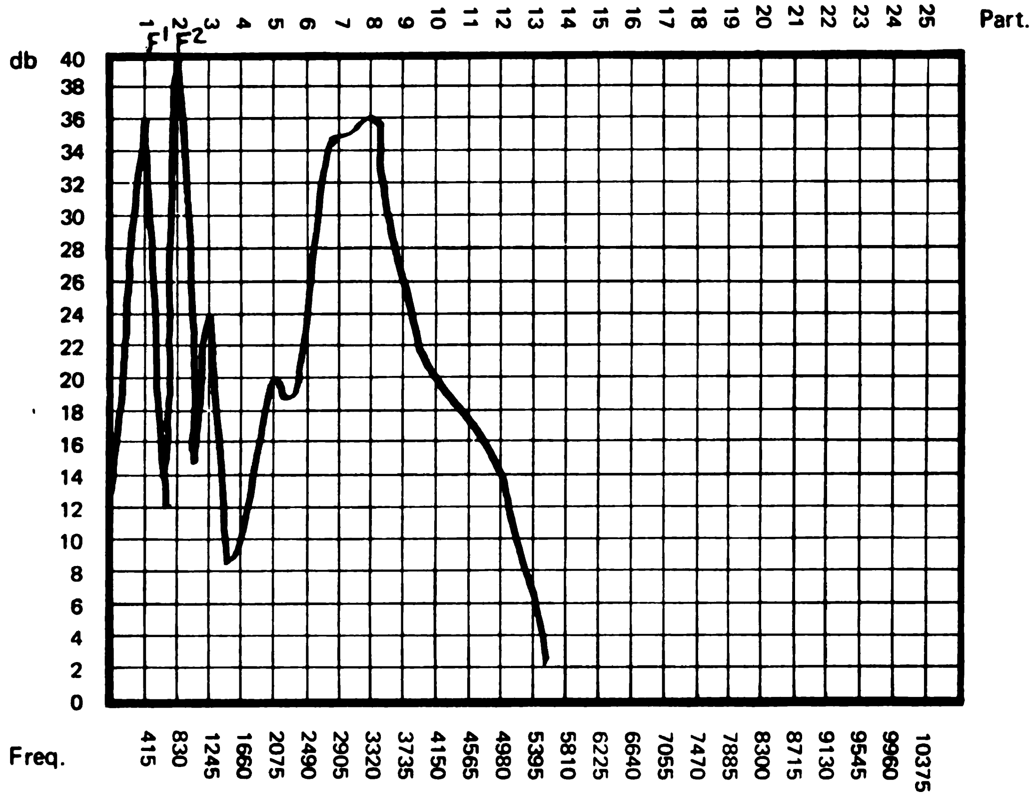

Figure 101.--Spectrograph of mature subject 10 singing the vowel [a] at g#-415 Hz.

4. A prominent region of energy above F^2 is present in all three spectrograms. This energy region ranges from the fifth partial (2075 Hz) to the eleventh partial (4565 Hz), with high intensity ranging from 30 to 36 dB.

A Comparison of All Subjects Singing the Vowel [a] at g#-415 Hz

1. The intensities of the fundamental range from 26 to 36 dB.

2. F^1 occurs on the second partial (830 Hz) for all subjects with decibel readings ranging from 36 to 40.

3. F^2 occurs on the third partial (1245 Hz) for all subjects except university subject 3 and mature subject 10. F^2 appears to be combined with F^1 for these subjects. Decibel readings for F^2 on the third partial range from 32 to 36.

4. A prominent energy region above F^2 is present in all spectrograms. This energy region is centered around the eighth partial (3320 Hz) with intensity peaks ranging from 24 to 36 dB.

Vowel [e] at Pitch g#-415 Hz

Figures 102 and 103 are spectrographs showing the formant behavior of high school subjects singing the vowel [e] at g#-415 Hz, and display the following information:

1. The intensities of the fundamentals are 32 and 36 dB.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the fourth partial (1660 Hz) for both subjects. Decibel readings are 38 and 40, respectively, for high school subjects 3 and 10.

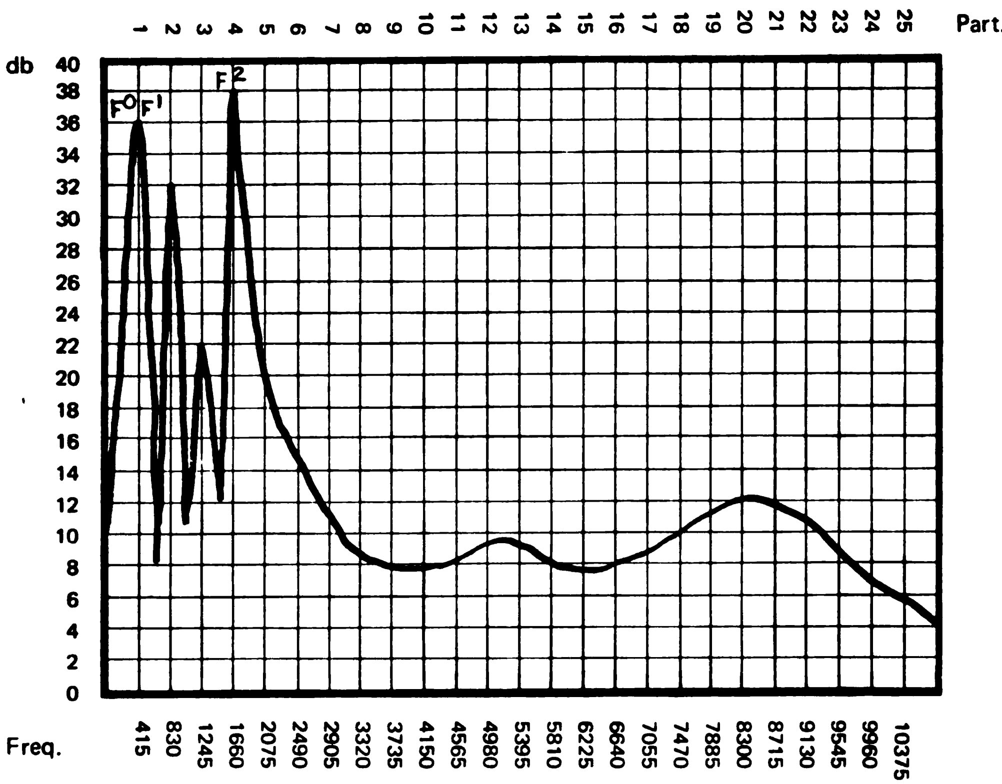

Figure 102.--Spectrograph of high school subject 3 singing the vowel [e] at g#-415 Hz.

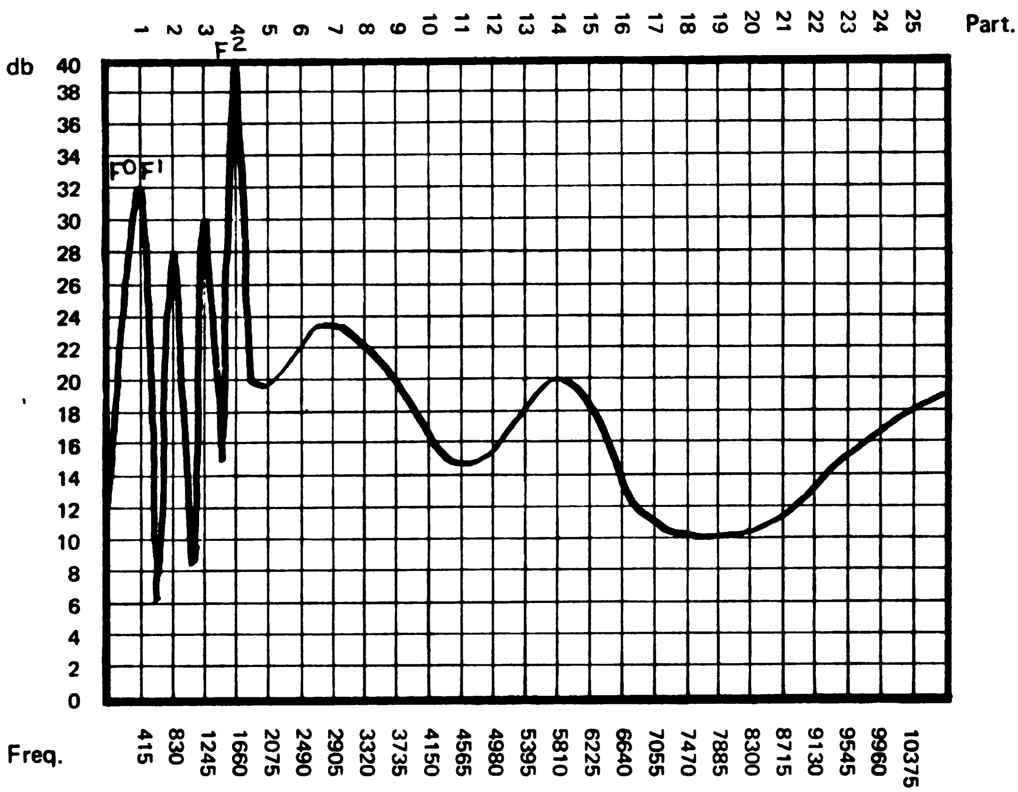

Figure 103.--Spectrograph of high school subject 10 singing the vowel [e] at g#-415 Hz.

4. A prominent energy region above F^2 is present in the spectrogram of high school subject 10. This energy region ranges from the fifth partial (2075 Hz) to well beyond 10,000 Hz at 10 to 23 dB. High school subject 3 shows a very weak and insignificant energy region, never exceeding 10 dB.

Figures 104 and 105 are spectrographs showing the formant behavior of university subjects singing the vowel [e] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamentals are 32 and 38 dB.
2. F^1 is absorbed by the fundamental for both subjects.
3. F^2 occurs on the fourth partial (1660 Hz) for both subjects. Decibel readings are 34 and 38, respectively, for university subjects 3 and 9.
4. A prominent energy region above F^2 is present in both spectrograms. This energy region ranges from the sixth partial (2490 Hz) to the twelfth partial (4980 Hz) at 22 to 30 dB.

Figures 106 through 108 are spectrographs showing the formant behavior of mature subjects singing the vowel [e] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamental range from 30 to 38 dB.
2. F^1 is absorbed by the fundamental for all three subjects.
3. F^2 occurs on the fourth partial (1660 Hz) at 36 dB for all three subjects.
4. A prominent energy region above F^2 is present in all three spectrograms. This energy region ranges from the sixth partial (2490 Hz) to the tenth partial (4150 Hz) at 22 to 34 dB.

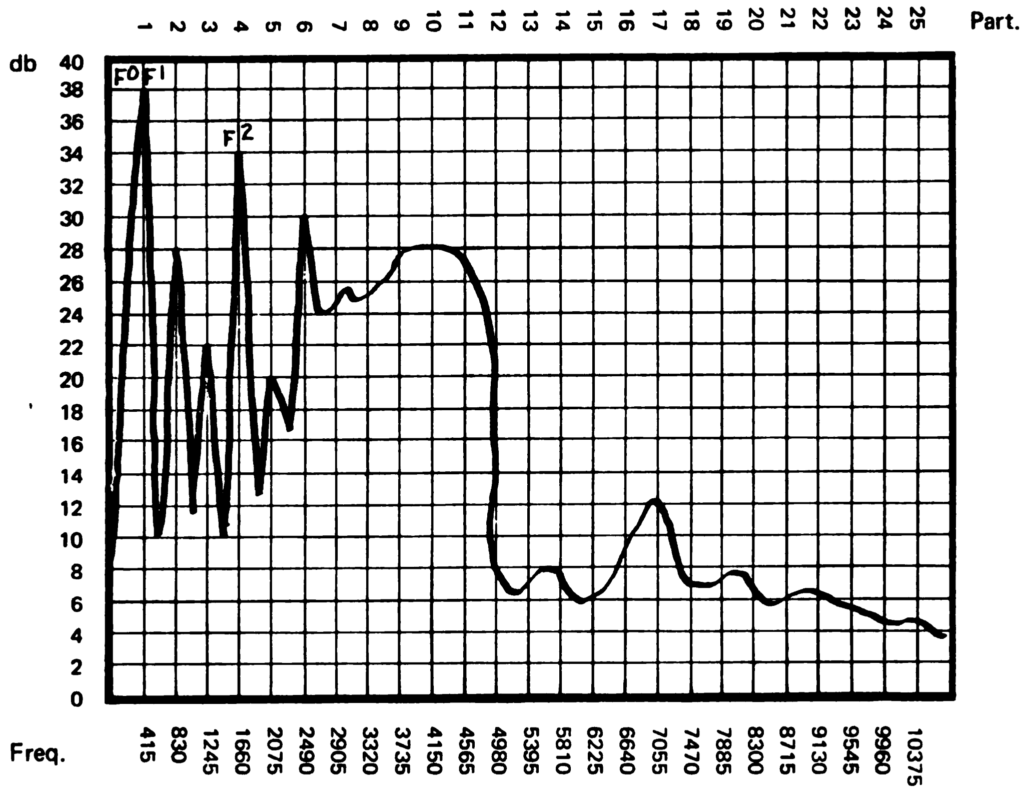

Figure 104.--Spectrograph of university subject 3 singing the vowel [e] at g#-415 Hz.

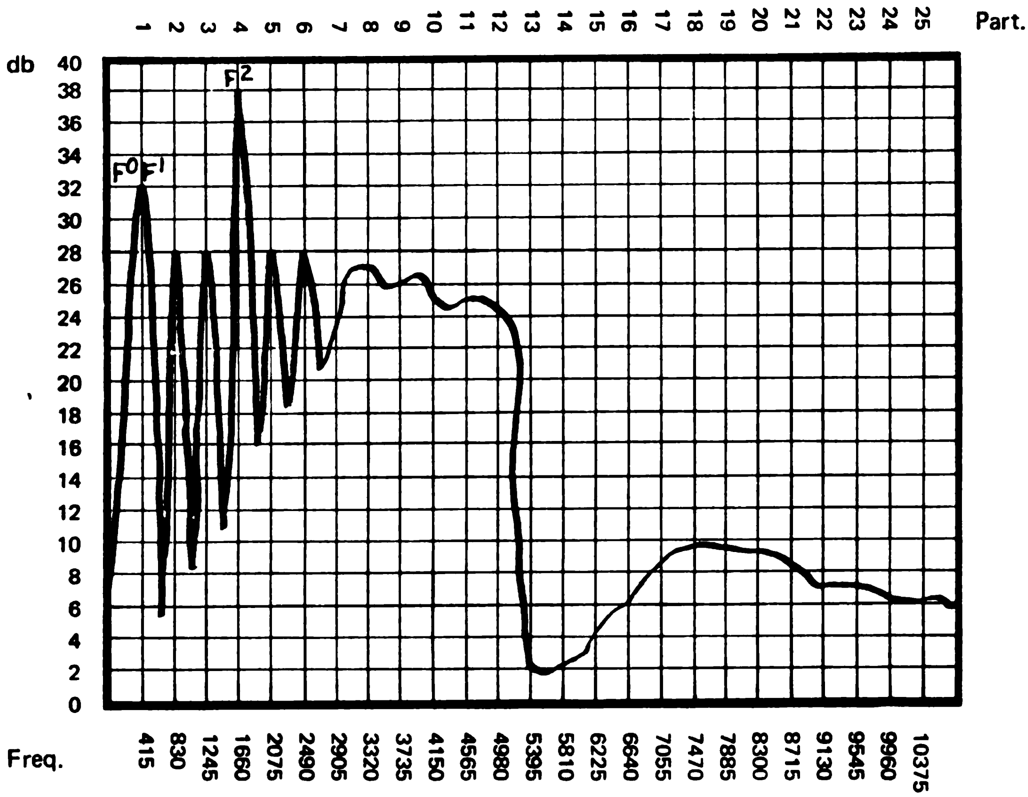

Figure 105.--Spectrograph of university subject 9 singing the vowel [e] at g#-415 Hz.

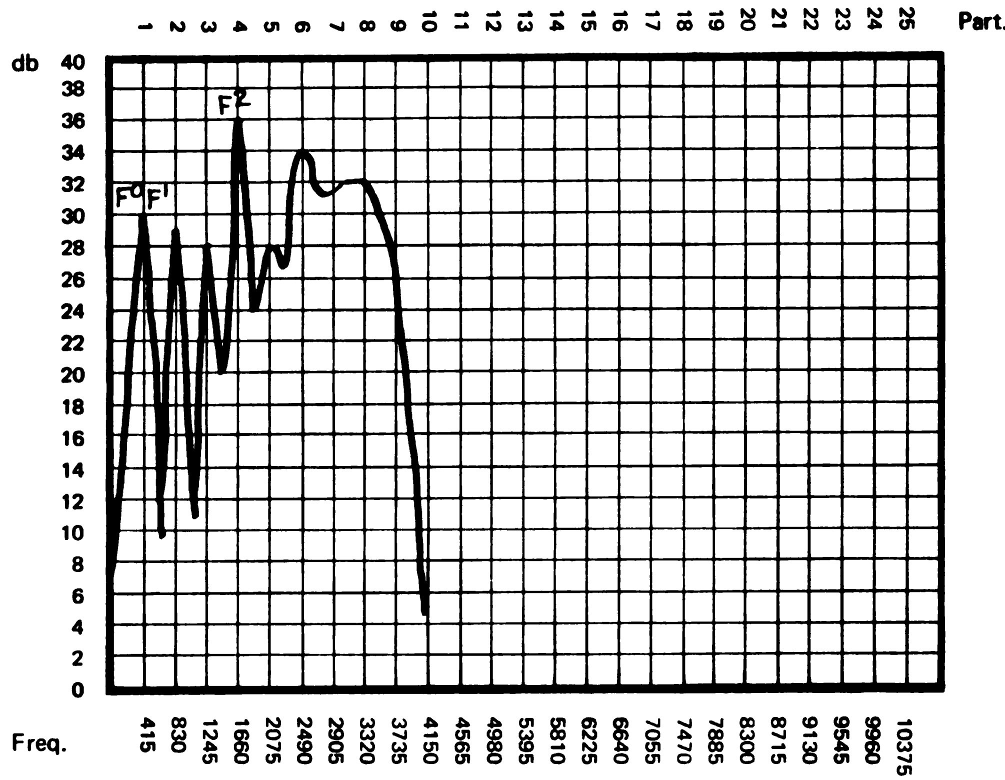

Figure 106.--Spectrograph of mature subject 3 singing the vowel [e] at g#-415 Hz.

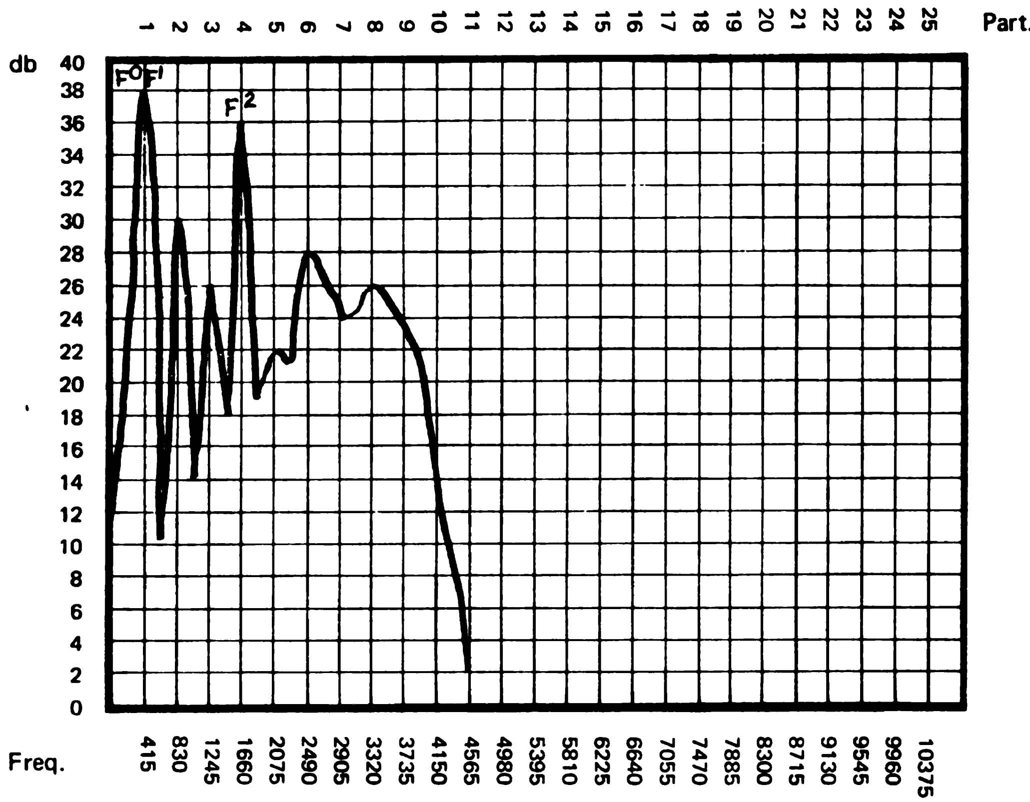

Figure 107.--Spectrograph of mature subject 4 singing the vowel [e] at g#-415 Hz.

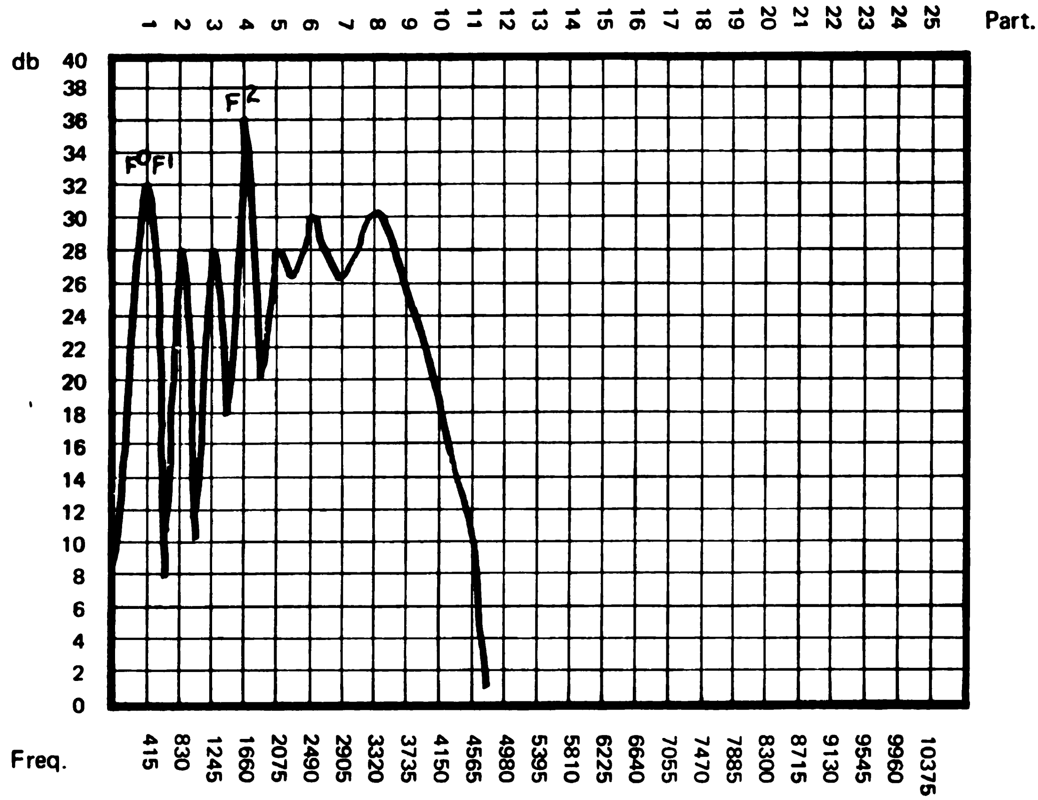

Figure 108.--Spectrograph of mature subject 9 singing the vowel [e] at g#-415 Hz.

A Comparison of All Subjects Singing the Vowel [e] at g#-415 Hz

1. The intensities of the fundamental range from 30 to 38 dB.

2. F^1 is absorbed by the fundamental for all subjects.

3. F^2 occurs on the fourth partial (1660 Hz) for all subjects. Decibel readings range from 34 to 40.

4. High school subject 10 shows a region of energy above F^2 covering over twenty partials at 10 to 23 dB. All university and mature subjects show a prominent energy region above F^2. This energy region ranges from approximately the sixth partial (2490 Hz) to the twelfth partial (4980 Hz). Decibel readings at peak intensities range from 22 to 34.

Vowel [i] at Pitch g#-415 Hz

Figures 109 and 110 are spectrographs showing the formant behavior of high school subjects singing the vowel [i] at g#-415 Hz, and display the following information:

1. The intensities of the fundamentals are 36 and 40 dB.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the fourth partial (1660 Hz) at 23 dB for high school subject 9. F^2 occurs on the fifth partial (2075 Hz) at 36 dB for high school subject 10.

4. A prominent energy region is present in the spectrogram of high school subject 10. This energy region shows two high intensity peaks occurring on the sixth partial (2490 Hz) and the ninth partial (3735 Hz), both at 32 dB. An energy region above F^2 is not present in the spectrogram of high school subject 9.

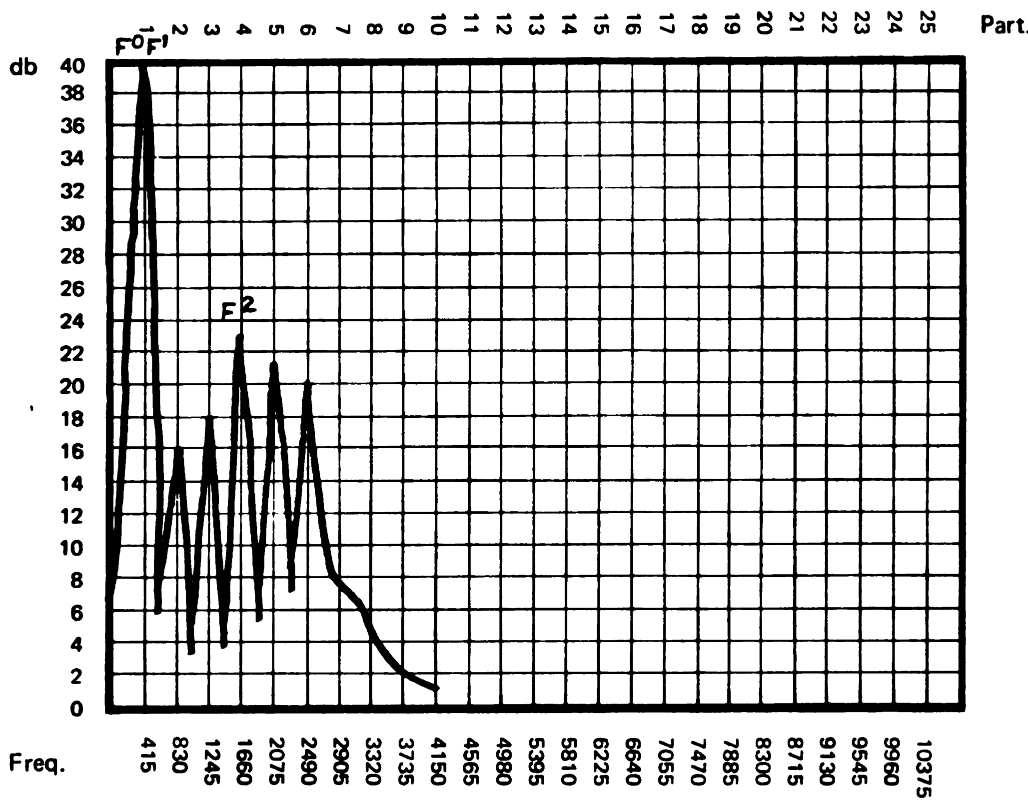

Figure 109.--Spectrograph of high school subject 9 singing the vowel [i] at g#-415 Hz.

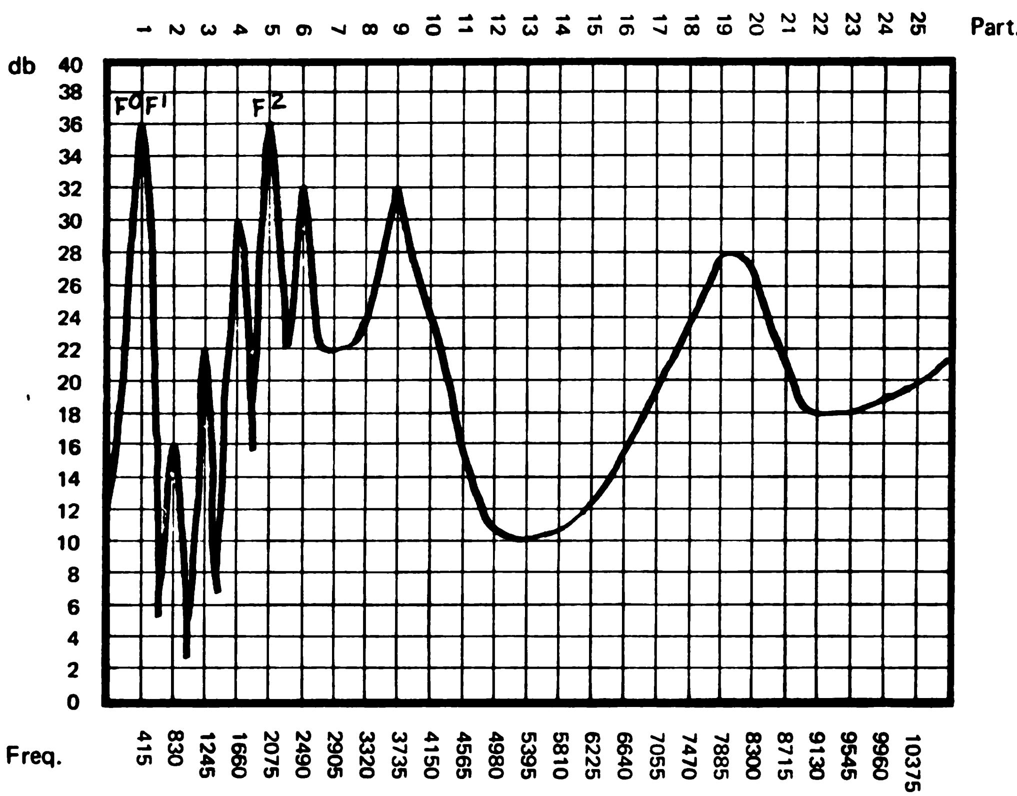

Figure 110.--Spectrograph of high school subject 10 singing the vowel [i] at g#-415 Hz.

Figures 111 and 112 are spectrographs showing the formant behavior of university subjects singing the vowel [i] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamentals are 40 dB for both subjects.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the fourth partial (1660 Hz) at 28dB for both subjects.

4. A prominent energy region above F^2 is present in the spectrograms of both subjects. University subject 1 shows high intensity peaks on the sixth partial (2490 Hz) and the tenth partial (4150 Hz) at 24 and 18 dB, respectively. University subject 3 shows a high intensity peak on the sixth partial at 26.5 dB.

Figures 113 through 115 are spectrographs showing the formant behavior of mature subjects singing the vowel [i] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamental range from 32 to 39 dB.

2. F^1 is absorbed by the fundamental for all three subjects.

3. F^2 occurs on the fourth partial (1660 Hz) for all three subjects. Decibel readings are 38, 32, and 38, respectively, for mature subjects 3, 4, and 9.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region ranges from the sixth partial (2490 Hz) to the eleventh partial (4565 Hz) with intensity peaks ranging from 22 to 32 dB.

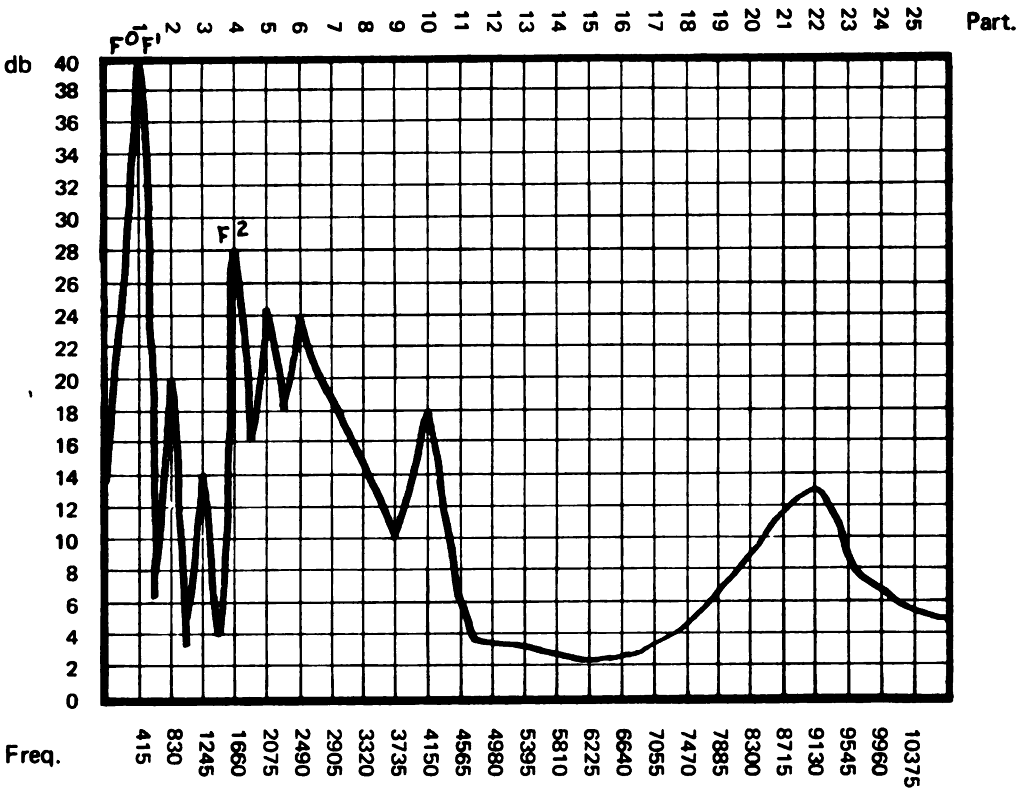

Figure 111.--Spectrograph of university subject 1 singing the vowel [i] at g#-415 Hz.

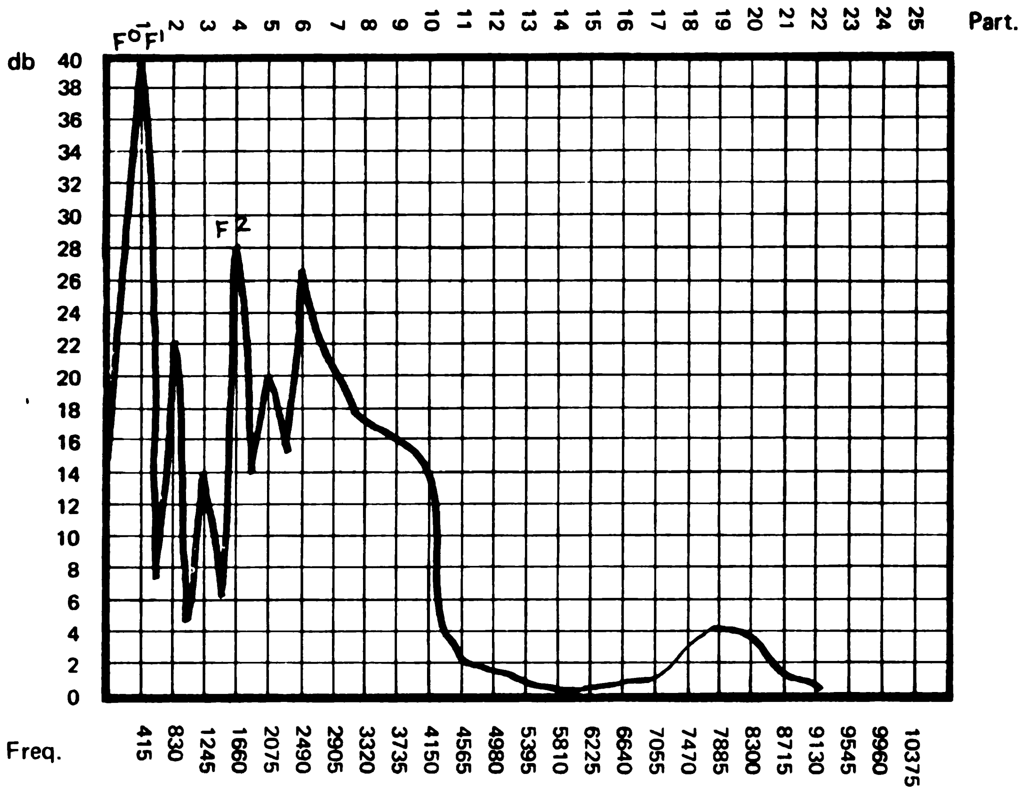

Figure 112.--Spectrograph of university subject 3 singing the vowel [i] at g#-415 Hz.

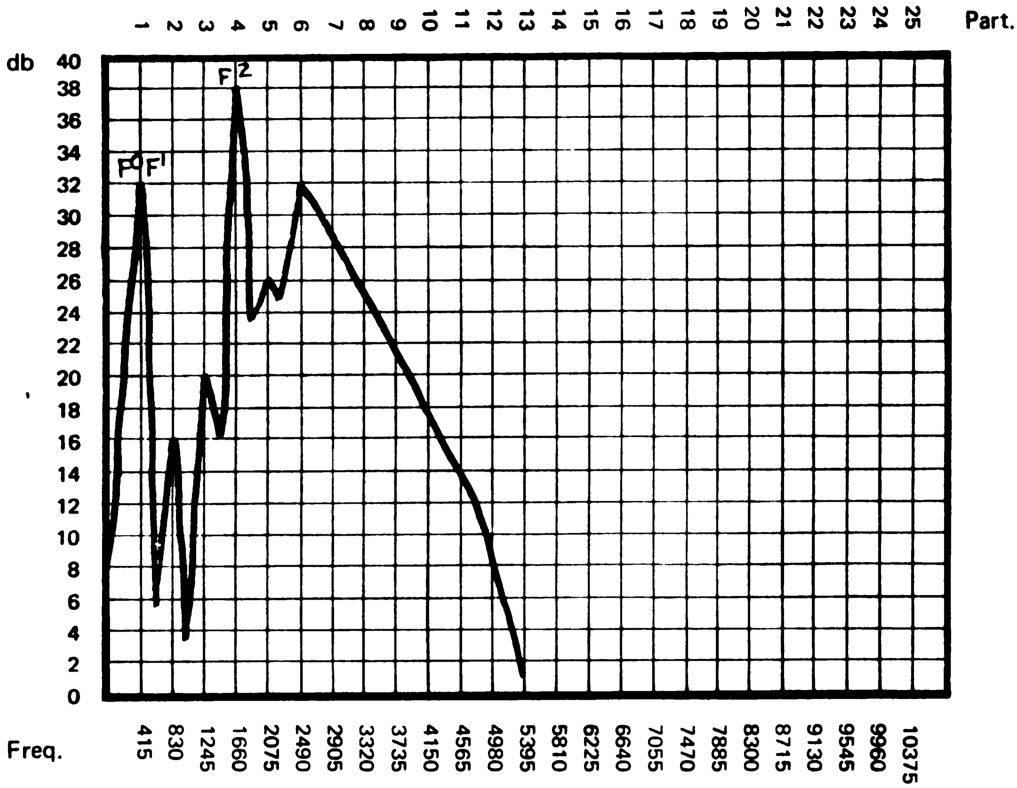

Figure 113.--Spectrograph of mature subject 3 singing the vowel [i] at g#-415 Hz.

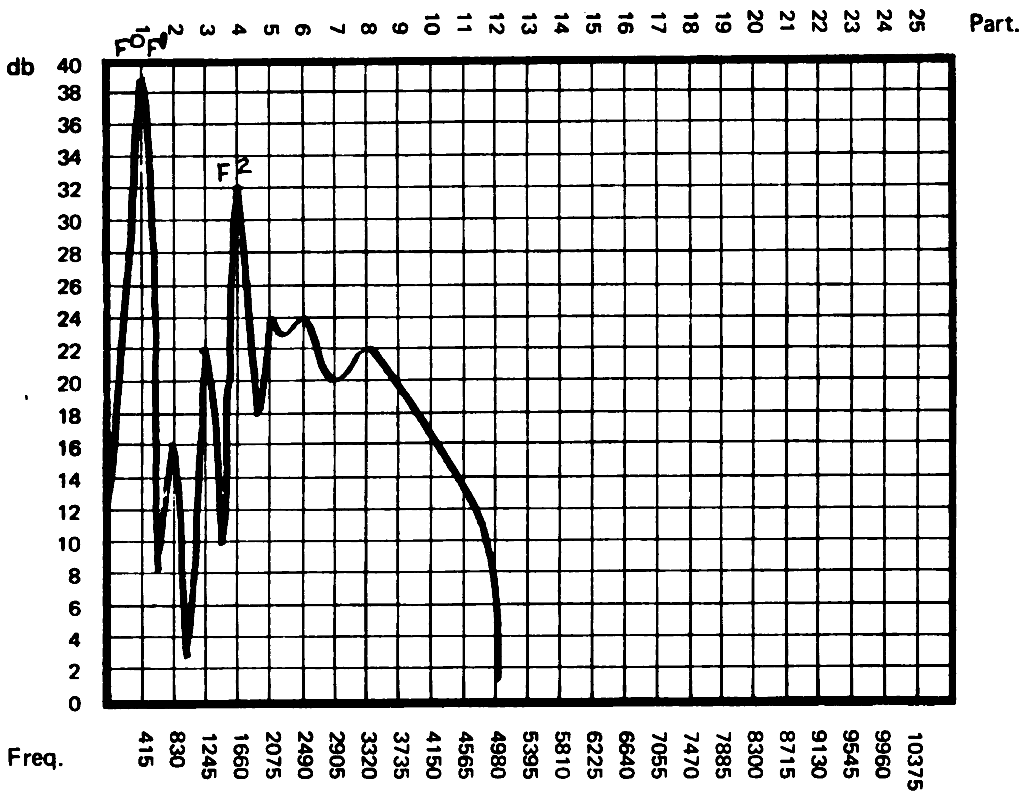

Figure 114.--Spectrograph of mature subject 4 singing the vowel [i] at g#-415 Hz.

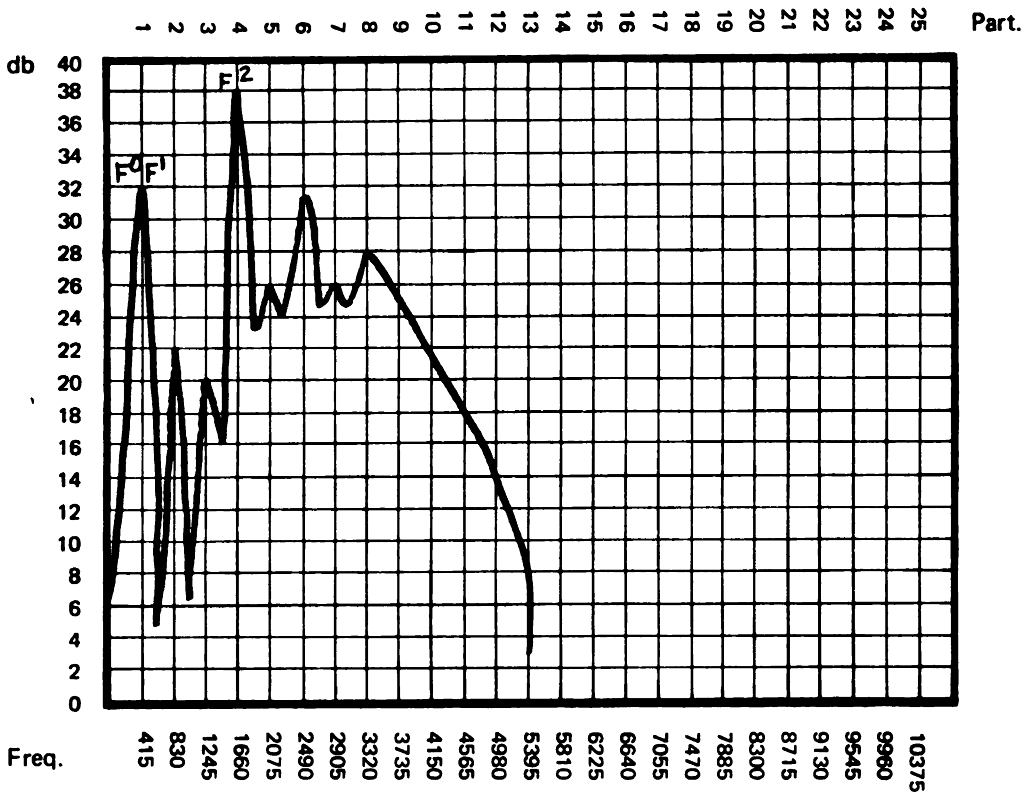

Figure 115.--Spectrograph of mature subject 9 singing the vowel [i] at g#-415 Hz.

A Comparison of All Subjects Singing the Vowel [i] at $g^{\#}$-415 Hz

1. The intensities of the fundamental range from 32 to 40 dB.

2. F^1 is absorbed by the fundamental for all subjects.

3. F^2 occurs on the fourth partial (1660 Hz) for all subjects except high school subject 10, with decibel readings ranging from 23 to 38. F^2 occurs on the fifth partial (2075 Hz) at 36 dB for high school subject 10.

4. A prominent region of energy above F^2 is present in all spectrograms except that of high school subject 9. This energy region ranges from approximately the sixth partial (2490 Hz) to the eleventh partial (4565 Hz) at 18 to 32 dB.

Vowel [o] at Pitch $g^{\#}$-415 Hz

Figures 116 and 117 are spectrographs showing the formant behavior of high school subjects singing the vowel [o] at $g^{\#}$-415 Hz, and display the following information:

1. The intensity of the fundamental is 34 dB for both subjects.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the second partial (830 Hz) for both subjects. Decibel readings are 38 and 40, respectively, for high school subjects 9 and 10.

4. A prominent region of energy above F^2 is present in both spectrograms. This energy region ranges from the sixth partial (2490 Hz) to the twenty-fifth partial (10375 Hz) at 11 to 26 dB.

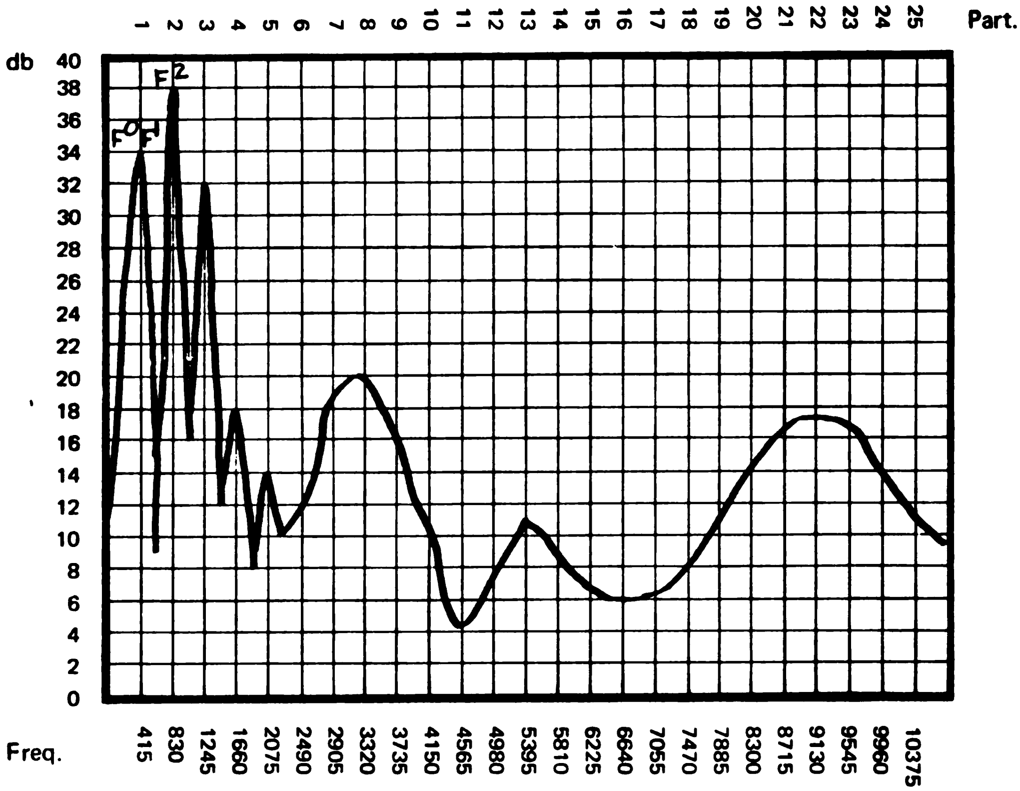

Figure 116.--Spectrograph of high school subject 9 singing the vowel [o] at g#-415 Hz.

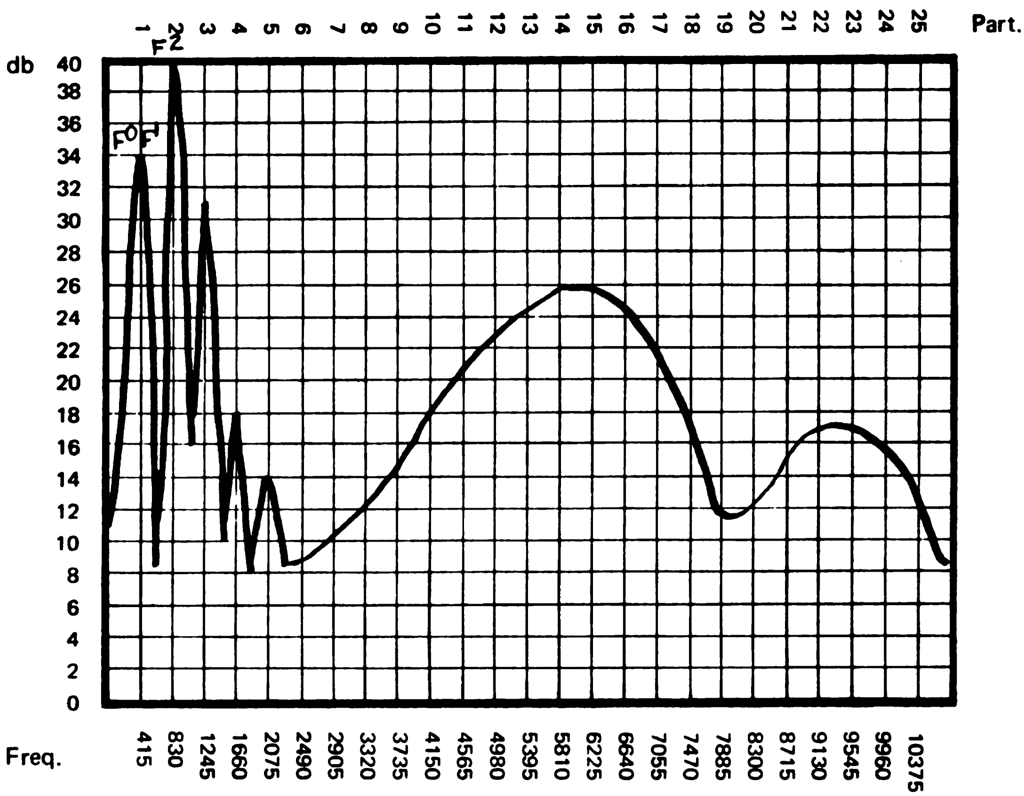

Figure 117.--Spectrograph of high school subject 10 singing the vowel [o] at g#-415 Hz.

Figures 118 and 119 are spectrographs showing the formant behavior of university subjects singing the vowel [o] at $g^{\#}$-415 Hz, and display the following information:

1. The intensity of the fundamental is 38 dB for both subjects.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the second partial (830 Hz) for both subjects. Decibel readings are 40 and 38, respectively, for university subjects 3 and 9.

4. A prominent energy region is present in both spectrograms. High intensity peaks occur on the seventh partial (2905 Hz) and the ninth partial (3735 Hz) for both subjects, with decibel readings ranging from 24 to 33.

Figures 120 through 122 are spectrographs showing the formant behavior of mature subjects singing the vowel [o] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamental range from 31 to 35 dB.

2. F^1 is absorbed by the fundamental for all three subjects.

3. F^2 occurs on the second partial (830 Hz) for all three subjects. Decibel readings are 34, 34, and 40, respectively, for mature subjects 3, 9, and 10.

4. A prominent energy region above F^2 is present in all three spectrograms. This energy region shows intensity peaks between the fifth partial (2075 Hz) and the eighth partial (3320 Hz), with decibel readings ranging from 22 to 32.

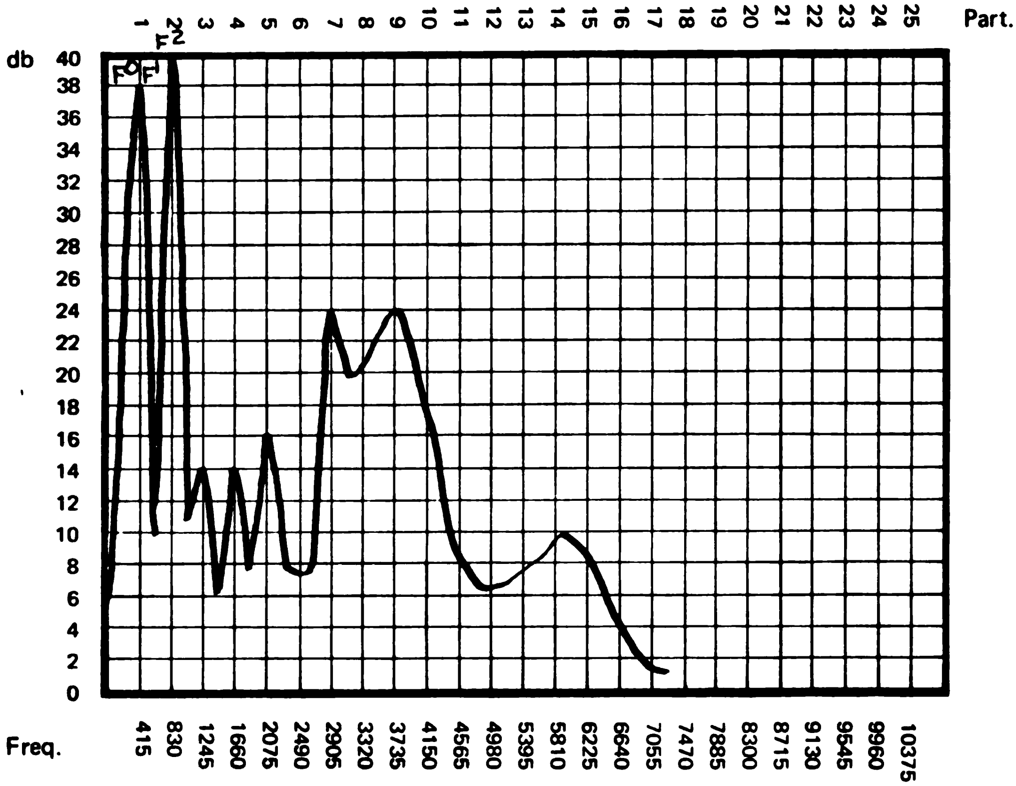

Figure 118.--Spectrograph of university subject 3 singing the vowel [o] at g#-415 Hz.

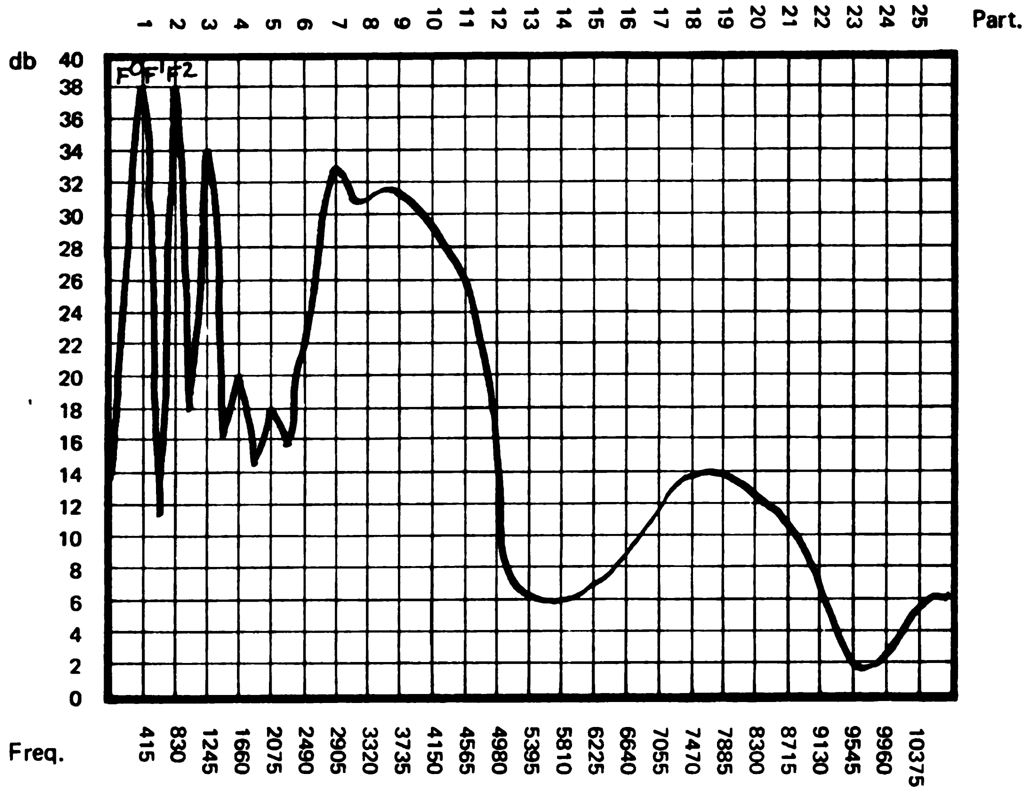

Figure 119.--Spectrograph of university subject 9 singing the vowel [o] at g#-415 Hz.

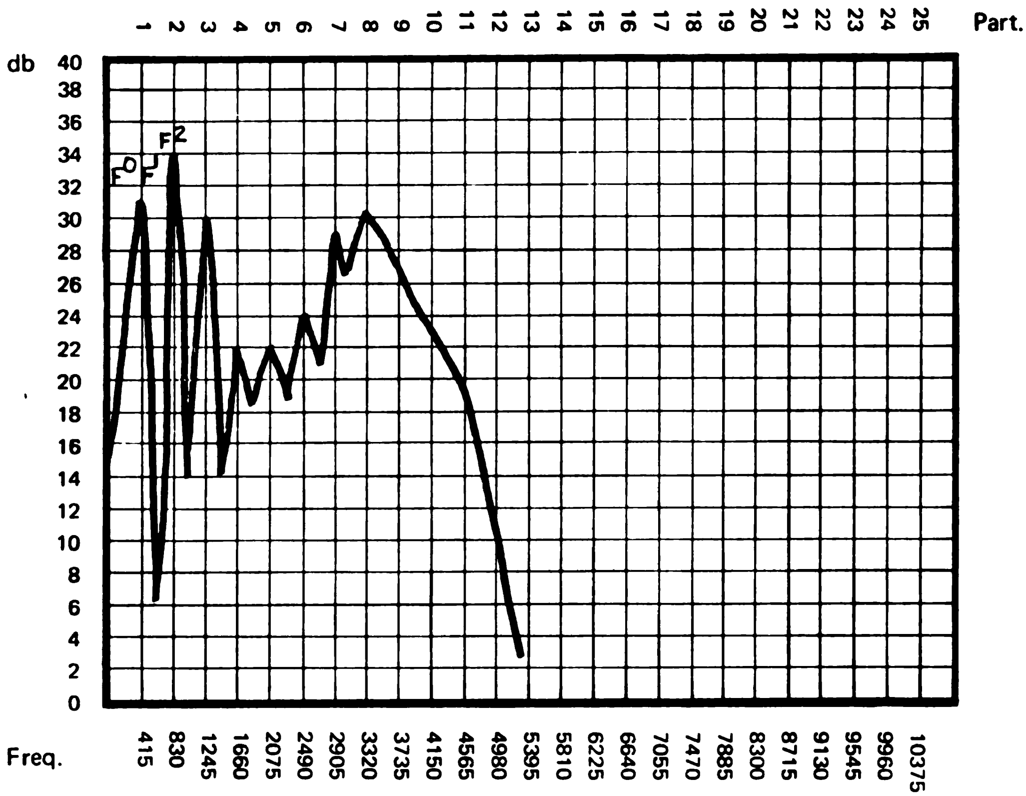

Figure 120.--Spectrograph of mature subject 3 singing the vowel [o] at g#-415 Hz.

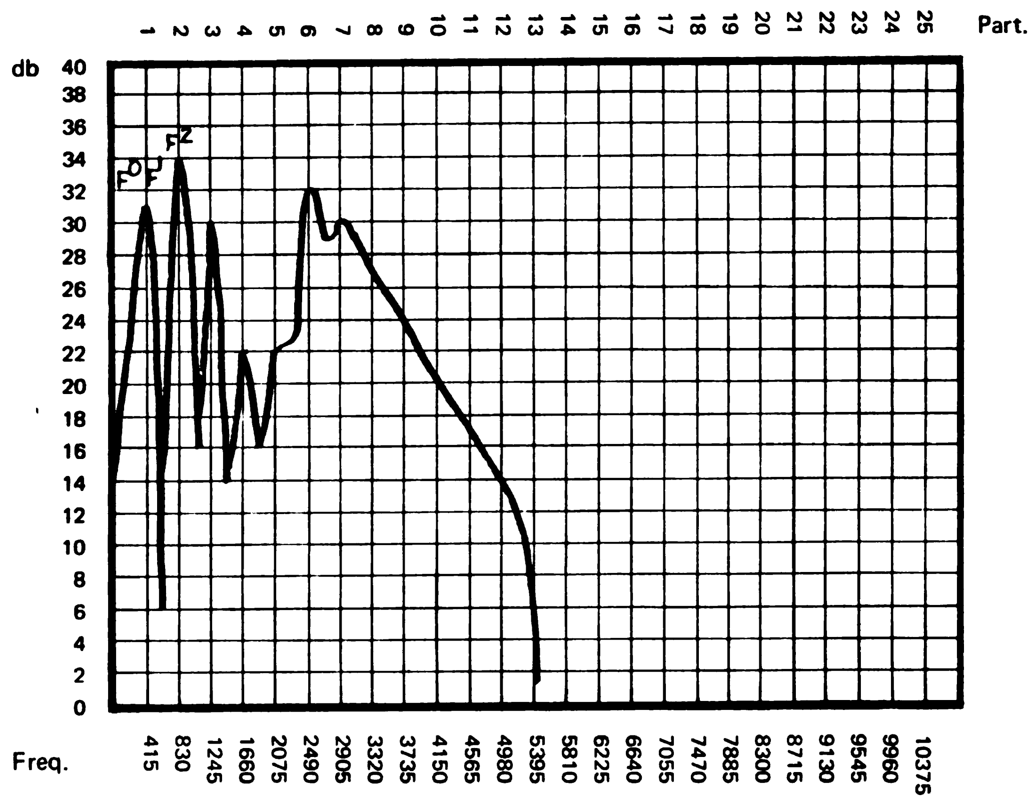

Figure 121.--Spectrograph of mature subject 9 singing the vowel [o] at g#-415 Hz.

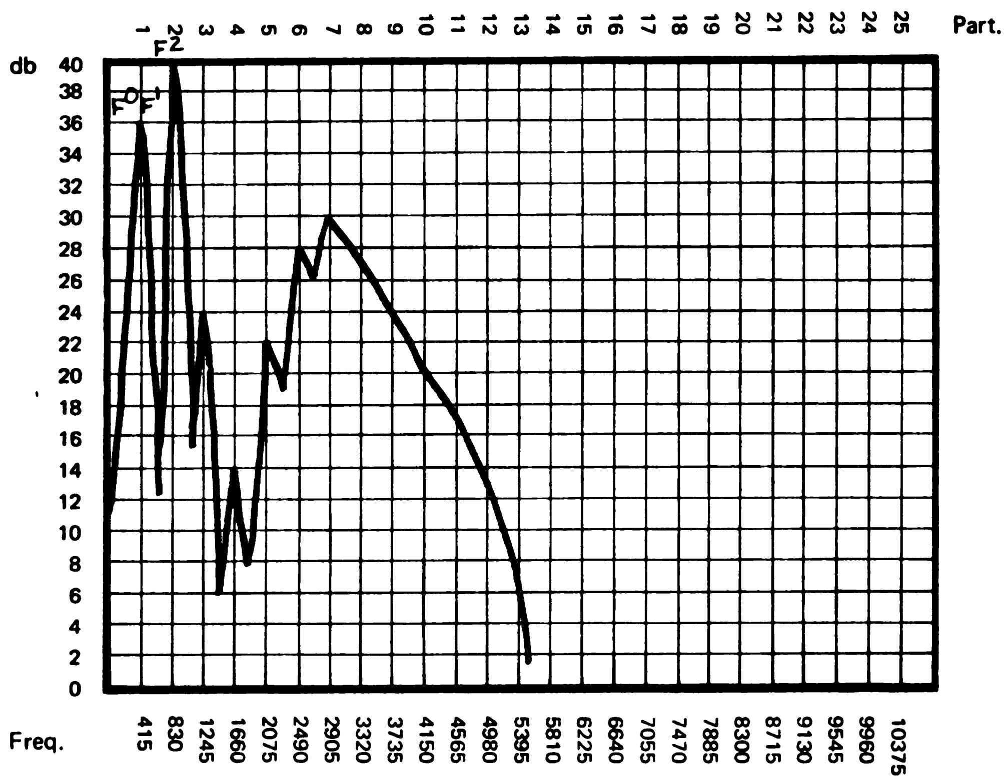

Figure 122.--Spectrograph of mature subject 10 singing the vowel [o] at g#-415 Hz.

A Comparison of All Subjects Singing the Vowel [o] at $g^{\#}$-415 Hz

1. The intensities of the fundamental range from 31 to 38 dB.

2. F^1 is absorbed by the fundamental for all subjects.

3. F^2 occurs on the second partial (830 Hz) for all subjects. Decibel readings range from 34 to 40.

4. A prominent energy region above F^2 is present in all spectrograms. A region of high intensity peaks ranging from the fifth partial (2075 Hz) to the ninth partial (3735 Hz) is registered by the university and mature subjects, with decibel readings ranging from 22 to 33. The high school subjects show an energy region from the sixth partial (2490 Hz) to the twenty-fifth partial (10375 Hz) at 11 to 26 dB.

Vowel [u] at Pitch $g^{\#}$-415 Hz

Figures 123 and 124 are spectrographs showing the formant behavior of high school subjects singing the vowel [u] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamentals are 38 and 40 dB.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the second partial (830 Hz) for both subjects. High school subject 9 shows a very low second formant of 22 dB, while high school subject 10 has a decibel reading of 38.

4. A prominent energy region above F^2 is present in the spectrogram of high school subject 10. High intensity peaks occur on the sixth partial (2490 Hz) and the eighth partial (3320 Hz) at 29 and 26 dB, respectively. In addition, a region of energy from the

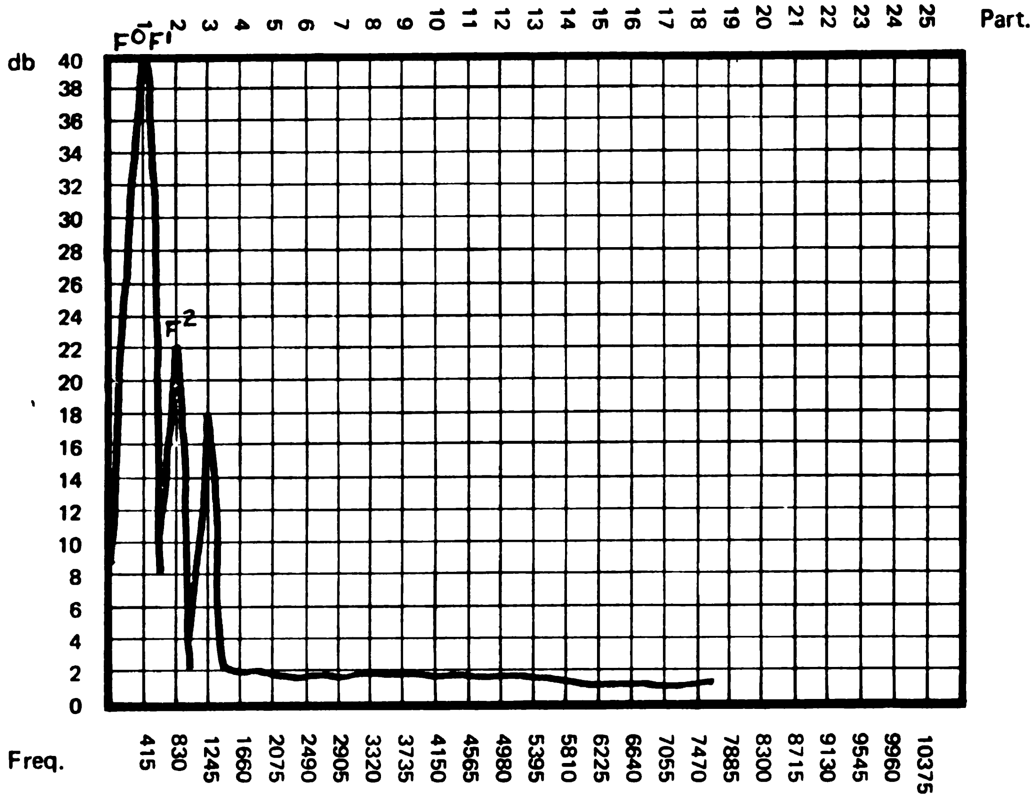

Figure 123.--Spectrograph of high school subject 9 singing the vowel [u] at g#-415 Hz.

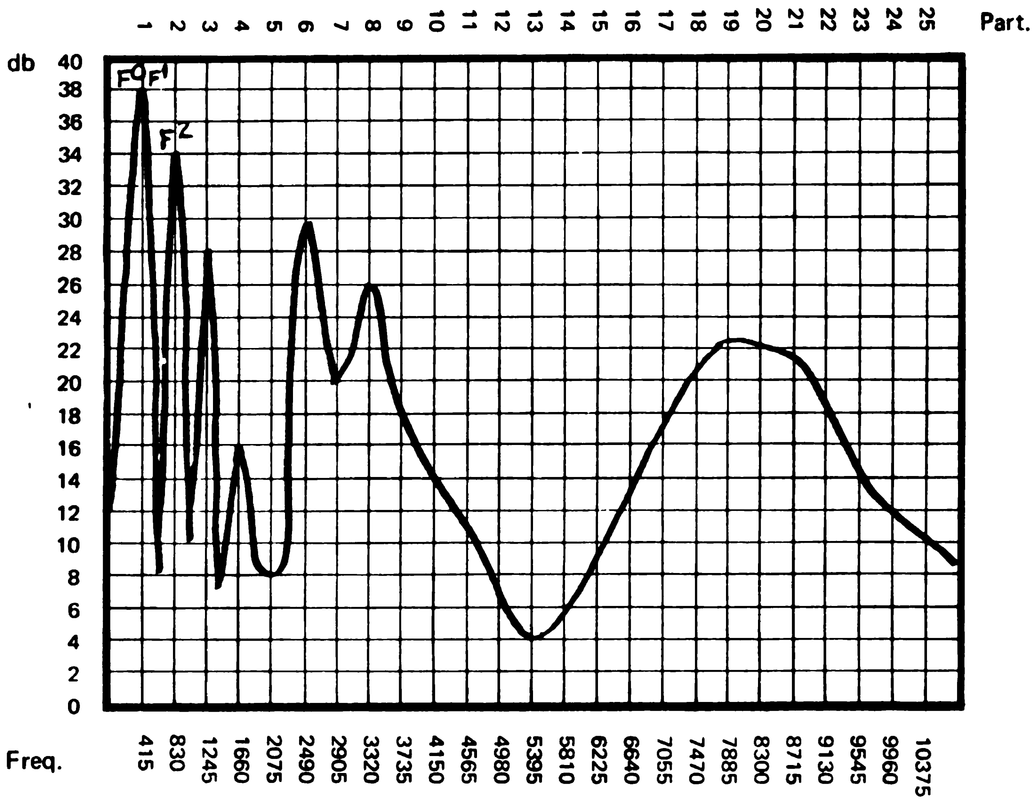

Figure 124.--Spectrograph of high school subject 10 singing the vowel [u] at g#-415 Hz.

fifteenth partial (6225 Hz) to beyond the twenty-fifth partial, with a maximum intensity of 27 dB, occurs in the spectrogram of high school subject 10. An energy region above F^2 is not evident in the spectrogram of high school scubject 9.

Figures 125 and 126 are spectrographs showing the formant behavior of university subjects singing the vowel [u] at $g^{\#}$-415 Hz, and display the following information:

1. The intensity of the fundamental is 40 dB for both subjects.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the second partial (830 Hz) for both subjects. Decibel readings are 40 and 36, respectively, for university subjects 3 and 9.

4. A prominent region of energy is present in the spectrogram of university subject 9. The energy region ranges from the fifth partial (2075 Hz) to the twelfth partial (4980 Hz) with a maximum decibel reading of 30. University subject 3 shows a very weak and insignificant region of energy above F^2.

Figures 127 and 128 are spectrographs showing the formant behavior of mature subjects singing the vowel [u] at $g^{\#}$-415 Hz, and display the following information:

1. The intensities of the fundamentals are 39 and 40 dB.

2. F^1 is absorbed by the fundamental for both subjects.

3. F^2 occurs on the second partial (830 Hz) for both subjects. Decibel readings are 30 and 34, respectively, for mature subjects 4 and 10.

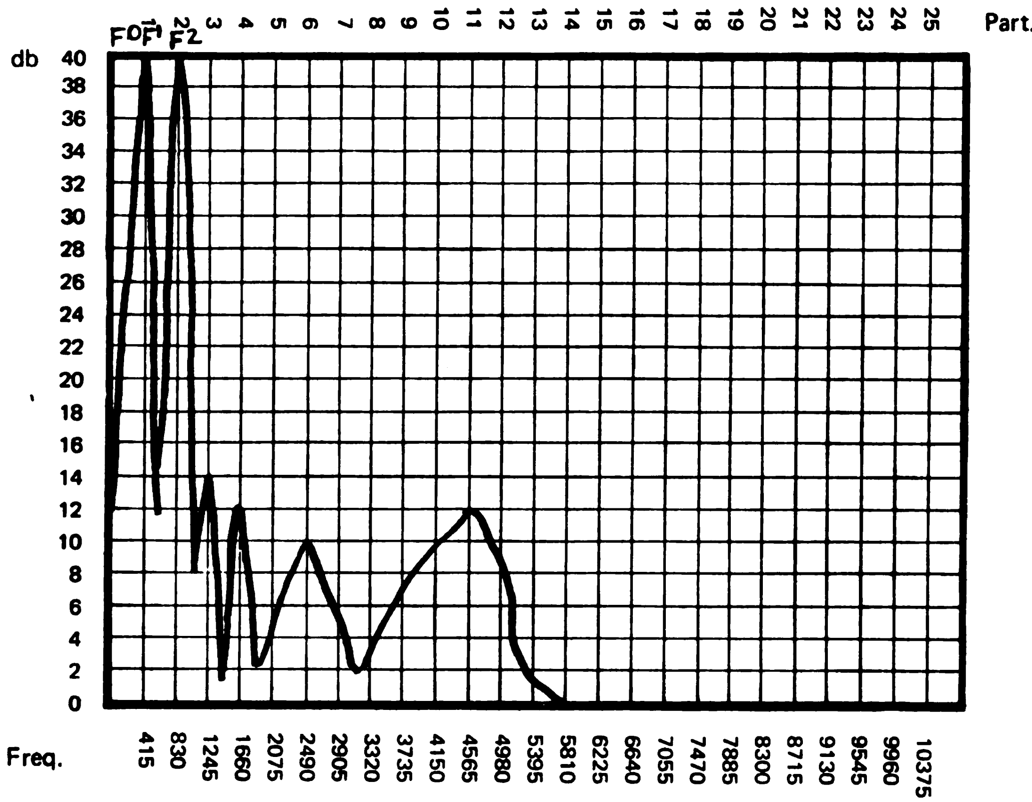

Figure 125.--Spectrograph of university subject 3 singing the vowel [u] at g#-415 Hz.

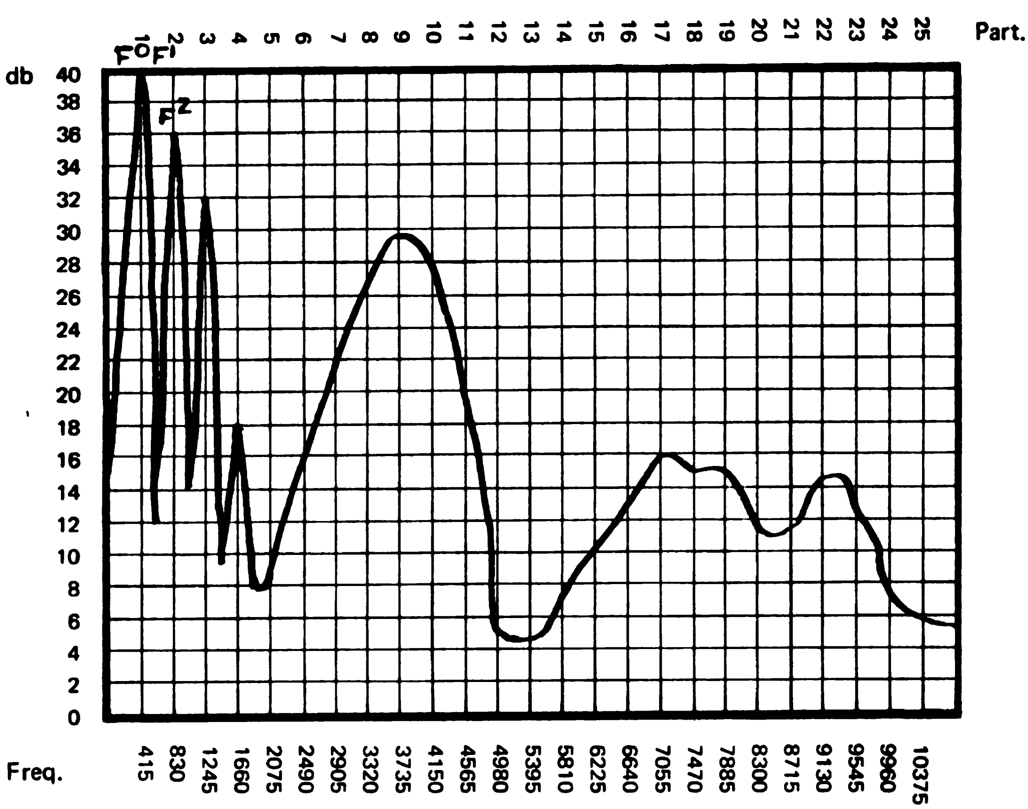

Figure 126.--Spectrograph of university subject 9 singing the vowel [u] at g#-415 Hz.

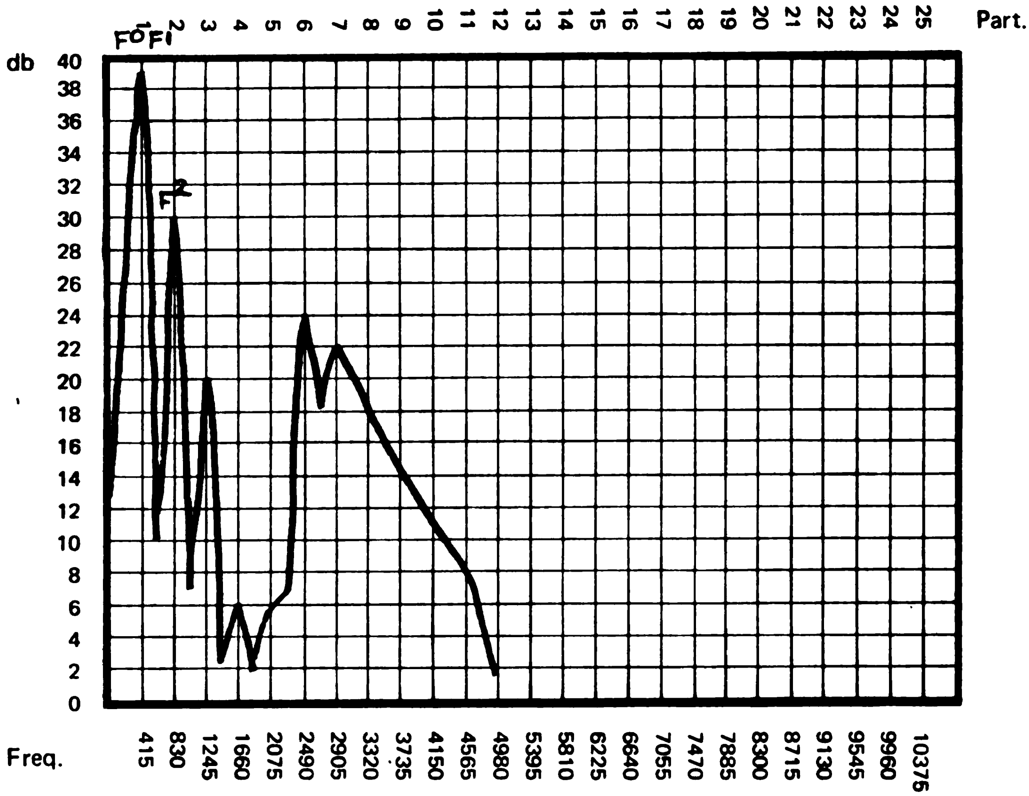

Figure 127.--Spectrograph of mature subject 4 singing the vowel [u] at g#-415 Hz.

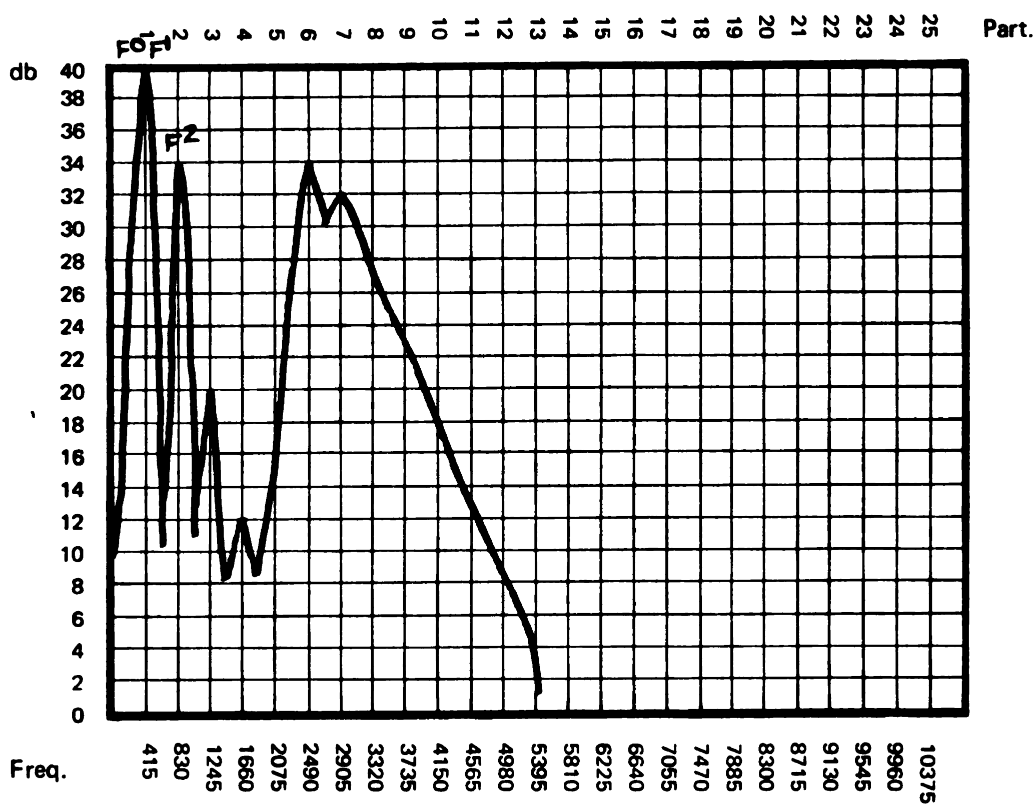

Figure 128.--Spectrograph of mature subject 10 singing the vowel [u] at g#-415 Hz.

4. A prominent energy region above F^2 is present in both spectrograms. Both subjects show intensity peaks on the sixth partial (2490 Hz) and the seventh partial (2905 Hz). Decibel readings range from 22 to 34.

A Comparison of All Subjects Singing the Vowel [u] at $g^{\#}$-415 Hz

1. The intensities of the fundamental range from 38 to 40 dB.

2. F^1 is absorbed by the fundamental for all subjects.

3. F^2 occurs on the second partial (830 Hz) for all subjects. Decibel readings range from 30 to 40 with the exception of high school subject 9, who shows a low second formant of 22 dB.

4. A prominent region of energy above F^2 is present in the spectrograms of most subjects, although mature subjects show the only similar patterns in this energy region. Both mature subjects show intensity peaks on the sixth partial (2490 Hz) and the seventh partial (2905 Hz) with decibel readings ranging from 22 to 34.

The data presented in this chapter reveal information concerning formant behavior. The following chapter will outline the conclusions concerning the formant behavior of the subjects studied in this investigation, relate the conclusions to that of previous research, and recommend suggestions for future research.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem of the study was to discover whether there are similar patterns of formant behavior in the spectra of sung vowels judged to be excellent in quality in tenor voices. The study attempted to discover the formants present in a given vowel, any similarity in patterns present, and compare the results with those of previous research.

The study included the vowels [a], [e], [i], [o], and [u]. The voices studied were high school, university, and mature tenor voices selected by qualified choral directors and applied voice teachers at various high schools, universities, and cities in Michigan. Thirty singers (10 high school voices, 10 university voices, and 10 mature voices) sang each vowel on the pitches e-165 Hz, b-246 Hz, and $g^{\#}$-415 Hz. The singers were recorded on the same equipment, at the same volume level, and the same distance from the microphone to insure differences in vocal quality which might have resulted from uneven signal strengths. The recording of each subject took place in an environment similar to that of a voice studio. The sample used for spectrographic analysis was selected by 20 adjudicators from the Michigan School Vocal Association's list of solo adjudicators.

For selecting the sample of voices to be analyzed, the taped samples were prepared in random order on separate tapes for each of the three pitches and for each of the age groups--a total of nine tapes. Aural instructions on the tape kept the adjudicator informed as to the sample, pitch, and vowel performed. Each adjudicator listened to only three tapes at one time to avoid any possible fatigue factor. The adjudication took place on three consecutive days for each adjudicator.

Only those vowel samples receiving a simple majority of excellent ratings (i.e., 11 or more), with no fair or poor ratings, were used for spectrographic analysis. The number of samples selected as excellent within a given age level varied according to vowel sound and pitch.

Selected samples were prepared into tape loops and converted into spectrographs at the Audiology and Speech Sciences Laboratory at Michigan State University. The spectrographs were analyzed and reproduced graphically, indicating the frequencies, intensities, and locations of the fundamental and first two formants for each subject selected.

Hoyt's Reliability Coefficient was calculated at the Computer Center at Michigan State University for each vowel selected at each of the three pitches to determine adjudicator reliability. The resulting print-out shows reliability scores (r) and standard error of measurement scores (SE).

Conclusions

Adjudicator evaluations were found to be highly consistent. Results showed reliability coefficients ranging from .9698 to .9819 for all vowels analyzed.

The relationships between the fundamental and F^1 were as follows:

1. For the vowel [a], F^1 had a frequency of 660 Hz on pitch e-165 Hz, 738 Hz on pitch b-246 Hz, and 830 Hz on pitch $g^{\#}$-415 Hz. F^1 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^1 increased as the fundamental frequency increased.

2. For the vowel [e], F^1 had a frequency of 495 Hz on pitch e-165 Hz, and 492 Hz on pitch b-246 Hz. F^1 was absorbed by the fundamental on pitch $g^{\#}$-415 Hz. F^1 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^1 remained approximately the same for all three pitches.

3. For the vowel [i], F^1 had a frequency of 330 Hz on pitch e-165 Hz, and was absorbed by the fundamental on pitches b-246 Hz and $g^{\#}$-415 Hz. The relative intensity of F^1 remained approximately the same for all three pitches. F^1 occurred on partial frequencies for all subjects analyzed.

4. For the vowel [o], F^1 had a frequency of 495 Hz on pitch e-165 Hz and 492 Hz for pitch -246 Hz. F^1 was absorbed by the fundamental on pitch $g^{\#}$-415 Hz. F^1 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^1 remained approximately the same for all three pitches.

5. For the vowel [u], F^1 had a frequency of 330 Hz for pitch e-165 Hz and 492 Hz for pitch b-246 Hz. F^1 was absorbed by the fundamental on pitch $g^{\#}$-415 Hz. F^1 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^1 remained approximately the same for all three pitches.

The relationships between the fundamental and F^2 were as follows:

1. For the vowel [a], F^2 had a frequency of 990 Hz on pitch e-165 Hz for all subjects except high school subject 3 and mature subject 3. F^2 occurred at 1155 Hz for these two subjects. F^2 had a frequency of 984 Hz on pitch b-246 Hz for all subjects except mature subject 3, who showed an F^2 frequency of 1230 Hz. F^2 had a frequency of 1245 Hz on pitch $g^{\#}$-415 Hz for all subjects except university subject 3 and mature subject 10. F^2 appeared to be combined with F^1 (830 Hz) for these subjects. F^2 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^2 remained the same for all three pitches.

2. For the vowel [e], F^2 had a frequency of 1320 Hz for mature subject 4, 1485 Hz for mature subjects 3 and 10, 1650 Hz for high school subject 10 and both university subjects, and 1815 Hz for high school subjects 3 and 4 and mature subject 1 on pitch e-165 Hz. F^2 had a frequency of 1475 Hz on pitch b-246 Hz and 1660 Hz on pitch $g^{\#}$-415 Hz. F^2 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^2 remained approximately the same for all three pitches.

3. For the vowel [i], F^2 had a frequency of 1815 Hz on pitch e-165 Hz for all subjects except high school subjects 3 and 4. F^2 occurred at 2145 Hz for these two subjects. F^2 had a frequency of 1722 Hz for all subjects on pitch b-246 Hz. F^2 had a frequency of 1660 Hz on pitch $g^{\#}$-415 Hz for all subjects except high school subject 10, who showed an F^2 frequency of 2075 Hz. F^2 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^2 increased slightly as the fundamental frequency increased.

4. For the vowel [o], F^2 had a frequency of 660 Hz for all subjects except high school subjects 4 and 10, and university subject 4 on pitch e-165 Hz. F^2 occurred at 825 Hz for these three subjects. F^2 had a frequency of 738 Hz for all subjects except university subject 4 and mature subject 9 on pitch b-246 Hz. F^2 occurred at 984 Hz for these two subjects. F^2 had a frequency of 830 Hz on pitch $g^{\#}$-415 Hz for all subjects. F^2 occurred on partial frequencies for all subjects analyzed. The relative intensity of F^2 increased slightly as the fundamental frequency increased.

5. For the vowel [u], F^2 appeared to be combined with F^1 (330 hz) for all subjects except high school subject 3 and mature subject 10 on pitch e-165 Hz. F^2 occurred at 495 Hz for these two subjects. F^2 had a frequency of 738 Hz on pitch b-246 Hz for all subjects except high school subject 5 and mature subject 9. F^2 occurred at 984 Hz for these two subjects. F^2 had a frequency of 830 Hz for all subjects on pitch $g^{\#}$-415 Hz. F^2 occurred on partial frquencies for all subjects analyzed. The relative intensity of F^2 remained approximately the same for all three pitches.

The relationships between F^1 and F^2 were as follows:

1. For the vowel [a], the relative intensity of F^1 increased slightly as the fundamental frequency increased, while F^2 remained constant for all three pitches.

2. For the vowel [e], F^1 was absorbed by the fundamental as the pitch increased, while the relative intensity of F^2 remained the same for all three pitches.

3. For the vowel [i], F^1 was absorbed by the fundamental and the intensity of F^2 increased slightly as the fundamental frequency increased.

4. For the vowel [o], F^1 was absorbed by the fundamental and the intensity of F^2 increased slightly as the fundamental frequency increased.

5. For the vowel [u], F^1 was absorbed by the fundamental as the fundamental frequency increased, while the intensity of F^2 remained constant for all three pitches.

Formants occurred on partial frequencies for all subjects. This was true, even though formants occasionally occurred on different partials for a given vowel or pitch.

F^1 was consistent in location for all subjects on all vowels and pitches. Not one variation occurred in the study.

F^2 was not as consistent in location, especially on the lower pitches. The location of F^2 differed for two subjects singing the vowel [a] at e-165 Hz. F^2 occurred on four different frequencies for the vowel [e] at e-165 Hz. The location of F^2 differed for two subjects singing the vowel [i], three subjects singing the vowel [o], and one subject singing the vowel [u] at e-165 Hz. For pitch b-246 Hz, the location of F^2 differed for one subject singing the vowel [a], two subjects singing the vowel [o], and two subjects singing the vowel [u]. There was total consistency in location of F^2 for the vowels [e] and [i] at b-246 Hz. For pitch $g^{\#}$-415 Hz, the location of F^2 differed for two subjects singing the vowel [a] and one subject singing the vowel [i]. All subjects were consistent in the location of F^2 for the vowels [e], [o], and [u] at $g^{\#}$-415 Hz. Thus, only 17, out of 120 vowels analyzed, differed in formant location.

There was little indication that the age of the singer created basic differences in formant behavior. Formant intensities were relatively similar for all subjects. There was a noticeable variation in the intensities of the fundamentals, especially between high school and mature subjects.

A prominent region of energy above F^2 was present in most spectrograms. This energy region was not consistent among subjects and failed to be as prominent as either F^1 or F^2.

Results Related to Previous Research

The present investigation found that formants always occurred on partial frequencies. This disagrees with Appelman[53] but corroborates the findings of Jones[54] and Wash.[55] Sullivan[56] found the formants to be in the same general location, but not exactly related to partials in all cases.

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[53]Appelman, op. cit. [54]Jones, op. cit.

[55]Wash, op. cit. [56]Sullivan, op. cit.

The formant locations and frequencies in the present investigation agree with those found by Wash for the vowels [a], [i], and [u]. Wash found the intensity of F^2 remained constant at lower pitches and increased as the pitch increased. The present findings disagree in that (1) for the vowel [a], the intensity of F^2 remained constant for all three pitches, and (2) for the vowel [u] the intensity of F^2 remained constant for all three pitches. F^2 did increase slightly in intensity as the fundamental frequency increased for the vowel [i].

The fixed formants for vowels, without regard to fundamental pitch, given by Appelman do not agree with the locations found in the present investigation. For example, Appelman states that for the vowel [a], F^1 is 700 Hz and F^2 is 1200 Hz. While some subjects showed F^1 and F^2 frequencies in this general range, the majority of subjects registered F^1 and F^2 frequencies that varied over 100 Hz or more with the frequencies of Appelman.

Recommendations for Future Research

The present study dealt with three different age levels, five vowels, and three pitches. Due to the magnitude of Chapter IV, it is recommended that future research be limited to one age level at a time.

Previous studies dealt with professional or mature subjects. Based on the results of this study, it is recommended that more research be initiated dealing with younger voices in all voice classifications.

The present study dealt with vowels judged to be excellent. It is recommended that carefully controlled research be initiated comparing the formant behavior of vowels judged to be poor with vowels judged to be excellent.

As far as is known, this is the first study of its kind dealing with the tenor voices. It is recommended that research be continued with the tenor voice and expanded to include all voice classifications, vowels, and pitches.

Due to the opinions of previous researchers and the lack of consistency of the patterns registered, the present investigation did not deal with the third formant. Future research in this area will be difficult until more sophisticated measuring devices are invented. Part of the present problem is the fact that the Bruel and Kjaer 2107 frequency analyzer scans each of the six spectrum scanning stages in the same amount of time. The analyzer is very accurate in the first two stages (20 to 63 Hz, and 63 to 200 Hz). However, the fourth stage (630 to 2000 Hz) and fifth stage (2000 to 6300 Hz) are not measured as accurately since a wider range of frequencies is measured in the same amount of time taken to measure stage one. This accounts for the lack of clarity in energy regions above F^2.

The present investigation dealt with the solo voice. Choral educators are constantly working for vowel unity and achieve success in this area by utilizing vocal exercises in unison. The design of this investigation could easily be applied to a unison choral sound for a thorough analysis of formant behavior. Music educators might benefit from exploring and utilizing the scientific equipment and research available to them.

APPENDICES

APPENDIX A

VOICE EXPERIMENT

APPENDIX A

VOICE EXPERIMENT

A. Adjudicator Information

Name:
Title:
Place of Employment:

B. Preliminary Information

Time of Test: 9 minutes
Materials Needed: pencil, test paper, earphones
Listening Level on Volume Dial: Earphones - 3
Speakers - 7
Tape Speed: 7-1/2 ips.

C. Instructions: Put the earphones on and start the tape for complete instructions.

TEST

	Most Natural Sound	Degree of Difference
Sample 1:	____ 1 (A)	____ A great deal of difference
	____ 1 (B)	____ A moderate difference
	____ Equal	____ Very little difference
Sample 2:	____ 2 (A)	____ A great deal of difference
	____ 2 (B)	____ A moderate difference
	____ Equal	____ Very little difference
Sample 3:	____ 3 (A)	____ A great deal of difference
	____ 3 (B)	____ A moderate difference
	____ Equal	____ Very little difference
Sample 4:	____ 4 (A)	____ A great deal of difference
	____ 4 (B)	____ A moderate difference
	____ Equal	____ Very little difference

(REMOVE EARPHONES)

Sample 5:	____ 5 (A)	____	A great deal of difference
	____ 5 (B)	____	A moderate difference
	____ Equal	____	Very little difference
Sample 6:	____ 6 (A)	____	A great deal of difference
	____ 6 (B)	____	A moderate difference
	____ Equal	____	Very little difference
Sample 7:	____ 7 (A)	____	A great deal of difference
	____ 7 (B)	____	A moderate difference
	____ Equal	____	Very little difference
Sample 8:	____ 8 (A)	____	A great deal of difference
	____ 8 (B)	____	A moderate difference
	____ Equal	____	Very little difference

Please express your preference for listening to the tape through either earphones or speakers. Check below:

____ Earphones

____ Speakers

APPENDIX B

LETTER TO DIRECTORS

APPENDIX B

LETTER TO DIRECTORS

Dear ____________________:

I am asking your assistance in gathering data for my doctoral dissertation concerning the study of quality in tenor voices. This is an acoustical study entitled, "The Formant Behavior of Vowels in Selected Tenor Voices."

There is presently little scientific research available to choral and applied voice teachers that gives them a concrete basis on which to judge vowel quality. It is the purpose of this study to discover formant patterns present in high school, university, and mature tenor voices that may lead to positive judgments regarding quality in all voices.

I am requesting that you recommend any high school, college, or professional tenors that you consider to be exceptionally excellent voices. The data to be collected could be gathered in the course of one day (or evening) on your campus. The data to be collected consists of a selected voice singing the five basic vowels on three different pitches, covering lower voice, middle voice, and upper voice. This would require approximately 20 minutes of each individual selected for the study.

I would appreciate hearing from you in the very near future. Please indicate your reactions to this study, your willingness to cooperate, names or number of students willing and qualified to participate, and a suggested date and time that would be convenient for me to come to your campus to collect the data.

It would be especially helpful if you would send me the names and addresses of any professional tenors throughout the state that you consider truly excellent performers. I anticipate some problems in lining up an adequate sample in this category.

Your assistance in this matter is greatly appreciated. I look forward to your reply in the near future.

Sincerely,

Paul W. Schultz

APPENDIX C

ADJUDICATOR'S INSTRUCTIONS

APPENDIX C

ADJUDICATOR'S INSTRUCTIONS

As you listen to the tapes you will hear tenor voices singing the five basic vowels at three different pitch levels. Each vowel will last for six seconds and will be repeated after a pause of three seconds. There will be ten different voices performing each vowel at each of the three pitches.

After you hear a given vowel and its repetition by an individual voice, you will indicate your judgment of the quality of that voice according to the following rating scale: (1) Excellent, (2) Good, (3) Fair, (4) Poor. Please make a prompt judgment, place it in the appropriate square on the answer sheet, and do not change your judgment once you have recorded it on the answer sheet.

Please disregard all clicks or noises on the tape that are not a part of the vowel production. Make your judgement on the steady state portion of the vowel. Do not consider the attack or release of that vowel. Any vowel produced at the pitch g#-415 Hz that is, in your opinion, sung falsetto will be rated as Poor. Aural instructions will guide you on the tape as to vowel sound, pitch, and sample letters.

High school, university, and mature tenor voices are used in this study. Evaluate each category based upon your experience and musical values. Use your own standards for each level but, under no circumstances, will you compare the three levels.

Instruction will be given as to the operation of the tape recorder and changing of tapes. Once you begin a tape, do not stop it under any circumstances. You will complete three tapes at this sitting, and the remainder on two separate days.

Vowels are indicated on the answer sheet according to the International Phonetic Alphabet as follows:

[a] as in calm
[e] as in pay
[i] as in beet
[o] as in tone
[u] as in boot

APPENDIX D

ADJUDICATOR MASTER SCORE CHARTS

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: e-165 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	2	3	2	2	2	2	1
2	3	2	1	1	3	3	2	2	2	1
3	2	1	2	1	4	3	2	4	2	1
4	2	2	1	1	3	2	2	2	2	1
5	3	2	1	2	4	3	2	4	1	1
6	2	2	2	2	4	3	2	3	1	1
7	2	2	2	1	4	3	2	4	2	2
8	2	2	2	1	3	3	3	3	2	1
9	3	2	2	1	3	2	1	2	1	2
10	3	3	2	1	3	3	3	3	2	1
11	3	3	1	2	4	3	2	3	2	1
12	3	2	1	1	4	4	2	4	1	1
13	2	3	1	2	3	2	3	4	2	2
14	2	3	1	1	3	3	2	3	2	1
15	3	3	1	2	4	4	3	4	2	2
16	3	3	1	2	4	3	3	4	2	1
17	2	2	1	1	3	3	2	3	1	1
18	3	2	2	2	4	3	2	4	2	1
19	2	3	1	1	3	3	2	3	2	1
20	3	3	1	2	4	4	3	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: e-165 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	3	1	1	2	2	2	2	2	1
2	2	2	1	1	2	2	2	2	2	1
3	2	2	2	2	3	4	3	3	2	1
4	2	2	1	1	3	2	2	2	2	1
5	3	2	1	2	4	3	3	2	3	1
6	2	2	1	1	3	3	2	2	2	1
7	4	3	1	1	4	4	3	3	2	2
8	3	2	2	2	3	3	4	3	3	1
9	2	3	2	2	2	3	2	3	2	1
10	3	4	2	1	3	3	3	3	2	1
11	3	3	1	2	2	3	3	3	2	1
12	4	4	1	2	4	4	2	4	2	1
13	3	2	2	1	3	3	3	4	2	1
14	2	3	1	1	3	4	2	3	2	1
15	3	3	2	1	4	4	3	4	3	2
16	3	4	1	1	4	4	3	3	3	1
17	2	3	1	1	3	3	3	3	3	1
18	4	3	2	2	3	4	4	3	3	1
19	2	2	1	1	3	3	3	3	2	1
20	4	3	2	2	4	4	3	4	3	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: e-165 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	1	2	2	3	2	2	1
2	2	2	1	2	3	2	3	2	1	1
3	2	2	2	1	3	3	2	4	2	1
4	2	2	1	1	3	2	3	2	1	1
5	3	3	1	2	2	3	4	3	2	1
6	3	2	2	1	3	3	2	3	2	1
7	2	2	1	1	2	2	3	3	2	1
8	2	3	1	2	3	4	4	4	2	1
9	3	3	1	1	3	2	3	2	2	1
10	2	3	2	2	3	3	4	3	2	1
11	2	3	1	1	2	3	4	3	2	1
12	3	4	2	1	2	4	4	4	2	2
13	2	4	2	2	2	3	4	3	1	1
14	2	3	1	2	2	3	4	3	2	1
15	3	4	2	1	3	4	4	4	2	2
16	3	3	1	2	3	4	4	4	2	1
17	2	3	1	1	2	3	3	3	1	1
18	3	4	2	1	3	3	4	4	2	1
19	2	2	1	1	2	3	3	4	2	1
20	3	3	2	1	3	4	3	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: e-165 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	3	1	2	2	2	1	2	2	1
2	1	3	1	1	3	2	2	3	3	1
3	1	2	1	2	4	2	2	3	4	1
4	1	2	2	1	3	2	1	2	2	1
5	2	3	1	2	3	2	1	3	2	1
6	2	2	2	1	4	2	2	2	2	1
7	1	4	2	1	3	2	2	3	2	1
8	2	2	2	1	3	3	2	3	2	1
9	1	2	2	1	3	2	2	3	2	2
10	2	4	2	1	4	3	2	4	3	1
11	2	3	1	2	4	3	2	4	2	1
12	2	4	1	1	3	4	3	4	2	1
13	2	3	1	1	4	2	2	4	2	1
14	2	3	1	1	3	2	2	4	2	1
15	2	4	1	2	4	3	2	4	3	1
16	2	4	1	1	4	3	3	4	3	1
17	2	3	1	1	3	2	2	3	3	1
18	2	4	2	1	4	3	2	4	2	2
19	1	3	1	1	3	2	2	3	2	1
20	2	4	2	2	4	4	3	4	3	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [u]
Pitch: e-165 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	2	2	3	3	2	2	2	1
2	3	3	1	3	2	3	3	3	3	1
3	2	4	1	3	3	3	2	3	2	1
4	2	3	1	2	3	2	3	2	2	1
5	2	3	1	2	2	2	2	2	3	1
6	3	2	2	2	2	3	2	3	2	1
7	2	2	1	2	2	2	3	2	2	1
8	2	2	2	3	3	4	3	4	3	1
9	2	3	2	3	3	3	2	2	2	1
10	3	3	1	3	4	3	4	3	3	2
11	3	3	1	3	3	3	2	2	2	1
12	3	3	1	4	4	4	2	2	3	1
13	2	3	1	2	3	4	2	3	2	1
14	2	3	1	3	4	3	2	3	2	1
15	3	3	2	4	4	4	3	3	3	1
16	3	3	1	4	3	4	3	3	2	1
17	2	2	1	3	3	3	2	3	2	1
18	3	2	2	4	4	4	4	3	3	1
19	2	3	1	2	3	3	2	2	2	1
20	3	4	2	4	3	4	4	3	3	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: e-165 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	2	1	2	2	2	3	1	2
2	1	4	3	2	4	3	2	4	1	2
3	2	3	3	2	2	3	2	4	2	3
4	1	2	2	1	3	3	1	3	1	2
5	2	4	2	1	3	3	1	4	1	2
6	2	3	2	2	3	2	2	4	1	2
7	1	3	3	1	2	3	2	4	2	3
8	1	3	2	2	4	2	2	4	2	2
9	2	3	2	1	2	2	2	3	1	3
10	1	3	3	1	4	2	2	4	2	3
11	2	3	3	1	3	3	1	4	1	3
12	2	4	3	2	2	3	3	4	1	3
13	1	4	3	1	4	2	3	4	1	4
14	1	3	3	1	2	2	2	4	1	3
15	1	4	3	2	3	3	3	4	2	3
16	1	3	3	1	4	3	2	4	1	3
17	1	3	2	1	2	3	2	3	1	2
18	2	4	3	1	3	3	2	4	2	3
19	1	3	3	2	3	3	2	3	1	2
20	2	4	4	1	3	3	2	4	1	3

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: e-165 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	1	2	2	2	2	2	2
2	2	2	1	1	2	2	2	2	4	3
3	1	3	1	2	2	4	2	2	3	4
4	1	2	1	1	2	3	2	3	2	2
5	1	4	2	2	2	4	4	2	4	4
6	2	3	1	2	3	3	2	3	3	2
7	1	3	1	1	2	3	2	2	3	2
8	1	2	2	1	3	4	2	3	2	4
9	1	2	1	2	3	3	3	3	2	3
10	1	3	2	1	3	3	2	2	3	3
11	1	2	2	2	3	4	3	2	2	3
12	2	2	2	2	4	4	4	4	3	4
13	1	2	1	1	4	3	3	3	2	2
14	1	2	1	1	3	4	3	3	2	2
15	2	3	2	1	4	4	4	3	3	4
16	2	3	3	1	4	4	4	3	3	3
17	1	2	2	1	3	3	2	2	2	3
18	1	3	3	1	4	4	3	3	3	4
19	1	2	3	1	3	3	2	2	2	2
20	2	3	3	1	3	4	4	3	4	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: e-165 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	3	2	1	2	3	2	2	2	2
2	1	2	1	1	3	4	1	4	2	2
3	2	4	2	1	2	2	2	4	2	3
4	1	2	1	1	3	3	3	2	2	2
5	2	3	1	1	2	3	2	4	3	3
6	1	2	2	2	2	3	2	3	3	3
7	2	2	1	2	3	2	2	2	3	2
8	1	2	2	2	3	2	3	2	2	2
9	1	2	1	1	3	3	2	3	2	2
10	2	3	1	1	4	3	2	4	2	3
11	1	3	1	1	3	3	3	4	2	2
12	2	3	1	2	4	4	3	3	3	4
13	1	4	1	1	3	4	2	4	2	2
14	1	3	1	2	3	4	2	3	2	3
15	1	4	2	1	4	4	3	4	3	3
16	2	4	1	2	4	4	3	4	4	3
17	1	3	1	1	2	3	3	3	3	2
18	2	3	2	2	3	4	3	3	4	3
19	1	2	1	1	3	3	2	3	3	2
20	2	3	1	2	4	3	3	4	4	3

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: e-165 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	1	2	2	2	3	1	2
2	1	2	3	1	2	3	3	3	1	2
3	1	4	3	1	3	4	2	4	2	2
4	1	2	2	1	3	2	1	3	1	2
5	1	2	4	2	3	3	2	4	1	2
6	2	2	2	2	3	2	2	3	2	2
7	2	2	3	1	3	2	3	4	2	3
8	2	3	3	1	3	3	3	4	2	2
9	1	2	2	2	3	3	2	3	1	3
10	1	3	4	1	3	3	2	4	2	3
11	1	3	3	1	2	3	3	4	1	2
12	2	3	2	2	4	4	3	4	2	4
13	2	2	4	2	3	2	3	4	1	3
14	1	2	3	2	3	2	3	4	2	3
15	1	3	4	1	3	3	3	4	2	4
16	2	3	4	1	3	4	3	4	2	4
17	1	2	3	1	2	3	3	3	2	2
18	2	3	3	2	4	3	3	4	2	3
19	1	3	2	1	3	2	2	3	2	2
20	2	3	3	1	3	3	4	4	2	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [u]
Pitch: e-165 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	3	1	1	2	2	2	4	2	2
2	2	2	1	2	4	3	2	4	2	1
3	1	3	1	2	4	4	2	4	1	3
4	1	2	1	2	3	2	3	3	1	2
5	1	3	2	2	3	3	2	4	2	2
6	2	3	2	3	2	2	2	3	1	2
7	1	2	1	2	3	4	3	3	2	2
8	1	3	1	2	3	3	3	4	2	2
9	1	2	1	2	2	3	3	3	1	3
10	2	3	2	2	3	3	3	4	1	2
11	1	3	2	2	3	4	2	4	1	3
12	2	4	2	3	4	4	4	4	2	3
13	1	4	1	3	3	2	2	4	2	2
14	1	3	1	3	2	3	3	4	1	3
15	1	4	2	3	4	4	3	4	2	3
16	2	4	1	3	3	4	4	4	2	3
17	1	3	1	2	3	3	2	3	1	2
18	2	3	2	3	3	4	3	4	2	3
19	1	2	1	2	3	3	3	3	2	2
20	1	3	2	3	4	3	4	4	2	3

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: e-165 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	1	1	1	2	1	2	2	1
2	1	2	1	1	2	3	1	2	2	1
3	2	2	2	1	1	3	1	3	2	2
4	1	2	1	1	2	2	2	2	2	1
5	2	2	1	2	2	3	1	3	2	2
6	1	2	2	2	1	2	1	3	2	2
7	2	2	2	1	2	3	1	3	4	1
8	1	2	1	2	2	3	2	3	2	2
9	1	2	2	1	2	3	1	2	4	1
10	1	2	1	2	2	3	2	3	3	1
11	1	2	1	1	2	3	1	3	2	1
12	2	3	1	1	3	2	1	4	4	1
13	1	1	2	1	3	2	2	3	4	2
14	1	2	1	2	2	2	1	3	4	1
15	2	2	2	1	2	3	1	4	4	1
16	2	2	1	1	2	3	1	3	4	2
17	1	2	1	1	2	2	1	3	3	1
18	2	2	1	2	3	3	2	4	4	2
19	1	2	1	2	2	3	1	3	3	1
20	2	3	2	1	3	4	1	4	4	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: e-165 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	1	1	2	2	1	2	2	1
2	1	2	1	1	2	2	1	2	2	1
3	1	2	1	1	2	3	2	2	3	1
4	1	2	1	1	2	2	1	2	2	1
5	2	2	2	1	3	4	2	3	4	1
6	2	2	1	2	2	3	1	3	2	1
7	1	2	2	2	3	2	2	3	3	1
8	2	2	2	1	3	4	2	3	2	1
9	2	2	2	1	3	3	2	3	2	2
10	1	3	1	2	3	4	2	3	4	2
11	1	3	1	2	2	3	2	3	3	2
12	1	3	1	1	4	4	3	4	4	2
13	1	2	2	2	4	4	3	4	4	1
14	1	2	1	1	3	4	2	3	4	2
15	2	3	1	2	4	4	3	4	4	1
16	1	3	1	2	4	4	2	3	4	1
17	1	2	1	1	3	3	1	2	3	1
18	2	3	2	1	4	4	3	4	4	1
19	1	2	1	1	3	3	2	2	2	1
20	2	3	2	2	4	4	2	4	4	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: e-165 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	1	2	2	2	3	2	1
2	1	1	1	1	2	2	2	3	3	1
3	1	2	1	1	2	3	2	2	2	1
4	1	1	1	1	2	2	2	2	2	1
5	1	2	1	2	2	4	3	4	4	2
6	2	2	2	2	2	3	2	3	2	1
7	2	2	1	1	3	3	2	3	4	2
8	2	2	1	1	2	4	2	3	3	1
9	1	2	1	1	3	3	2	3	2	2
10	1	2	1	1	3	4	3	4	4	1
11	1	1	1	2	2	4	2	4	2	2
12	2	1	1	1	3	4	3	4	4	2
13	2	2	2	1	3	4	2	4	3	1
14	1	1	2	1	2	3	2	4	4	2
15	2	1	2	2	3	4	3	4	3	1
16	1	2	1	2	4	4	3	4	4	1
17	1	2	1	1	3	4	3	3	2	1
18	2	3	1	2	3	4	3	4	3	1
19	1	2	1	1	3	3	3	3	3	1
20	2	2	1	2	3	4	4	4	4	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: e-165 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	2	3	2	2	1
2	2	1	1	1	1	2	2	2	2	1
3	1	1	1	1	2	2	2	3	2	1
4	2	1	1	1	2	2	3	2	3	1
5	2	2	1	1	2	3	3	4	3	2
6	2	2	1	2	2	2	2	3	2	1
7	2	2	1	1	2	3	3	4	2	1
8	3	2	1	1	2	3	2	4	2	2
9	2	2	1	1	2	3	2	3	3	1
10	1	2	1	2	2	3	3	4	3	1
11	3	2	1	1	2	4	3	4	2	1
12	3	1	1	1	2	3	3	4	3	2
13	2	3	1	1	3	3	2	4	3	1
14	2	2	1	1	3	2	3	4	3	1
15	2	3	2	2	3	3	3	4	4	1
16	2	2	2	1	3	3	4	4	4	1
17	1	2	1	1	2	3	3	4	3	1
18	2	3	1	2	3	4	3	4	3	2
19	1	2	1	1	2	2	3	3	4	1
20	3	3	1	2	3	4	3	4	4	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [u]
Pitch: e-165 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	2	2	2	2	1
2	2	2	1	1	2	3	2	2	2	1
3	1	2	1	1	1	3	2	2	2	2
4	2	2	1	1	2	2	3	2	2	1
5	2	4	2	1	2	4	4	4	3	2
6	2	2	1	1	2	2	2	2	2	2
7	1	3	1	1	2	3	2	2	4	2
8	2	2	2	1	2	4	2	3	3	1
9	2	2	2	1	3	3	2	3	3	1
10	1	3	1	2	2	4	4	3	3	1
11	1	3	1	1	2	4	3	4	3	1
12	2	2	1	1	3	4	2	4	4	1
13	1	2	2	1	3	4	3	4	4	2
14	1	3	2	1	3	3	3	3	4	1
15	2	3	1	2	3	4	3	4	4	1
16	2	3	2	1	3	4	4	4	4	1
17	1	2	1	1	3	3	3	2	3	1
18	2	4	2	2	3	4	3	4	4	1
19	2	2	1	1	2	3	2	3	3	1
20	2	3	2	1	3	4	4	3	3	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: b-246 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	3	2	2	1	3	2	3	2	1
2	1	3	2	2	1	3	2	2	1	1
3	3	3	4	2	1	4	4	2	1	2
4	2	2	2	2	1	3	2	2	2	1
5	3	3	2	2	1	2	3	3	2	1
6	2	3	2	3	2	2	3	3	2	1
7	2	3	3	2	1	4	3	2	2	1
8	2	3	2	2	1	4	3	3	2	1
9	3	2	2	2	1	3	3	2	2	1
10	3	3	3	3	2	3	3	2	2	1
11	3	3	3	3	1	3	2	2	2	1
12	3	4	3	3	1	4	4	3	2	1
13	2	4	3	2	1	4	3	3	1	1
14	2	3	2	3	2	4	3	3	2	1
15	3	3	3	3	1	4	3	4	2	1
16	3	4	3	2	2	4	4	3	2	1
17	2	2	2	2	1	3	2	2	1	1
18	3	3	2	3	1	4	4	4	2	1
19	2	2	2	2	1	4	3	3	1	2
20	3	3	3	3	2	4	4	3	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: b-246 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	2	1	2	2	3	1	1
2	1	1	3	1	2	2	2	2	2	1
3	2	2	2	1	1	2	3	3	1	1
4	2	2	2	2	1	2	2	3	1	1
5	2	2	3	2	1	2	2	3	1	1
6	2	2	2	2	2	2	3	3	1	1
7	2	2	2	2	1	3	2	3	1	1
8	3	3	3	1	1	2	2	4	2	1
9	3	3	2	2	2	3	2	3	1	1
10	2	3	3	1	2	3	2	4	1	1
11	3	3	3	1	2	3	3	4	1	1
12	3	4	3	1	2	4	3	4	2	2
13	2	4	2	1	1	3	3	4	1	1
14	3	4	2	1	1	4	3	4	2	1
15	3	4	3	1	2	4	3	4	1	2
16	3	4	3	1	2	4	2	4	1	1
17	2	2	2	1	1	3	2	3	1	1
18	3	3	3	2	2	3	3	4	2	1
19	1	2	3	1	2	2	2	4	1	1
20	3	4	3	1	2	4	3	3	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: b-246 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	3	2	2	1	2	2	2	1	1
2	1	4	2	2	2	3	2	3	1	1
3	2	4	2	2	1	2	3	3	1	1
4	2	3	2	2	2	2	2	2	1	1
5	2	4	2	3	1	2	2	3	2	1
6	2	4	2	3	2	2	2	2	2	1
7	1	3	2	2	1	2	2	3	2	1
8	2	4	3	3	2	3	3	4	1	2
9	2	3	2	3	2	2	3	3	2	1
10	2	4	3	3	2	3	3	3	1	1
11	2	4	3	3	2	3	2	3	1	1
12	3	4	3	4	1	3	2	2	1	2
13	3	4	2	4	1	3	3	3	1	1
14	2	4	2	3	1	2	2	3	1	1
15	3	4	3	4	2	3	3	4	2	1
16	3	4	3	4	2	3	3	4	1	1
17	2	3	2	2	1	3	2	2	1	2
18	2	4	2	4	2	3	3	3	2	1
19	2	4	3	3	1	2	2	3	1	1
20	2	4	3	3	2	2	3	4	1	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: b-246 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	3	2	1	2	3	1	2	1	1
2	2	3	3	2	3	3	1	2	2	1
3	2	4	3	1	3	3	2	3	1	2
4	2	2	3	1	2	3	2	2	2	1
5	3	3	3	2	2	2	1	3	2	2
6	2	2	3	2	2	3	2	3	2	1
7	2	3	2	1	2	3	1	2	1	1
8	2	4	3	2	2	4	1	3	2	2
9	3	3	3	2	2	3	1	2	2	1
10	3	4	2	1	3	4	2	3	2	1
11	3	3	3	2	3	4	2	3	1	1
12	4	4	4	1	3	3	2	4	2	1
13	4	2	2	1	3	3	2	3	2	1
14	3	3	3	1	2	3	2	3	2	1
15	4	4	4	1	3	4	2	3	2	2
16	4	4	2	1	3	4	2	3	2	1
17	2	3	3	1	2	4	2	2	1	1
18	3	4	3	2	2	3	2	3	2	1
19	2	2	3	1	2	4	1	2	2	1
20	4	3	2	1	2	4	2	2	2	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [u]
Pitch: b-246 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	2	2	2	3	3	3	1	1
2	2	2	3	2	1	3	2	2	1	1
3	3	3	3	2	2	4	3	2	1	1
4	2	2	2	2	1	3	2	2	2	1
5	2	3	3	2	2	3	2	3	2	1
6	3	3	3	2	1	3	2	3	2	2
7	2	2	2	2	1	3	3	2	1	1
8	3	3	3	2	1	4	3	3	2	1
9	3	3	3	2	2	3	2	3	1	1
10	3	3	2	2	1	3	3	2	2	1
11	3	4	2	2	2	3	2	2	1	1
12	2	4	3	2	1	4	2	4	2	1
13	3	4	3	2	1	3	2	2	2	1
14	2	3	3	2	1	3	2	3	1	1
15	3	4	3	3	2	4	3	3	1	2
16	3	4	3	2	2	4	2	4	1	1
17	3	3	2	2	1	3	3	2	1	1
18	3	4	2	2	1	4	3	4	2	2
19	2	3	2	2	1	3	3	2	1	1
20	3	4	3	2	2	3	2	3	1	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: b-246 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	1	1	3	2	2	2	1	1
2	3	2	1	2	3	1	2	2	1	2
3	3	2	1	2	2	1	2	3	1	2
4	2	1	1	2	2	2	2	3	1	1
5	2	2	2	2	3	2	2	3	1	3
6	3	1	2	2	2	2	2	3	1	2
7	3	1	1	2	2	2	3	3	2	1
8	3	2	1	2	3	2	3	3	2	1
9	2	1	1	2	3	2	3	3	1	2
10	2	1	1	2	3	2	3	4	2	2
11	3	2	2	3	3	3	3	3	2	2
12	3	2	2	2	4	3	4	3	2	3
13	2	1	2	2	4	3	3	4	2	2
14	3	2	1	2	3	2	3	3	1	2
15	3	1	1	2	4	3	3	4	1	3
16	3	2	1	3	4	3	3	4	1	3
17	2	1	1	2	3	2	3	2	1	2
18	3	3	2	2	4	3	2	4	2	2
19	3	2	1	2	3	2	3	2	1	1
20	2	2	1	2	4	3	3	3	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: b-246 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	1	2	2	1	2	3	1	1
2	2	2	1	2	2	1	1	4	1	2
3	1	2	1	2	3	2	2	3	1	1
4	1	1	1	1	2	2	2	3	1	2
5	2	1	1	2	3	2	2	4	2	1
6	2	2	2	2	2	2	2	4	1	1
7	2	1	1	2	3	2	2	3	1	2
8	2	1	1	2	3	3	2	4	1	2
9	2	2	2	2	3	2	2	3	1	2
10	1	2	1	2	3	2	2	3	2	2
11	3	2	2	3	3	3	2	4	2	1
12	3	2	2	3	4	3	3	4	2	2
13	2	1	1	2	4	3	2	4	1	2
14	2	2	1	2	3	3	2	3	2	1
15	3	1	2	3	4	3	3	4	2	1
16	3	2	1	3	4	2	3	4	1	2
17	2	1	1	2	3	2	2	3	1	2
18	3	2	2	2	4	3	3	4	1	2
19	1	2	1	3	3	2	3	3	2	1
20	2	2	1	2	4	3	3	4	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: b-246 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	1	2	1	2	2	2	1	1
2	2	1	2	2	1	2	2	3	1	1
3	1	2	1	1	2	3	2	2	1	2
4	1	2	1	2	2	3	2	2	1	1
5	2	2	1	2	1	3	3	3	2	2
6	2	2	2	2	2	3	3	4	2	2
7	2	2	1	2	2	3	2	3	1	1
8	2	2	2	2	2	4	3	3	2	2
9	2	2	1	2	1	3	2	3	2	2
10	2	2	1	2	2	3	3	4	1	2
11	3	2	2	3	3	4	3	3	2	2
12	3	2	2	3	3	4	3	4	1	2
13	2	2	1	2	3	3	4	3	1	2
14	2	2	1	2	2	3	3	3	1	2
15	3	2	1	3	3	4	4	4	2	2
16	3	2	1	3	3	4	4	4	1	2
17	2	1	1	2	2	3	2	4	1	2
18	2	2	2	2	3	4	4	3	1	2
19	2	2	1	1	2	2	3	4	2	1
20	3	2	1	2	2	4	4	4	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: b-246 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	1	2	2	2	2	1	1
2	3	1	1	2	1	3	1	2	2	2
3	2	2	2	2	1	3	1	3	1	1
4	2	1	2	1	2	3	1	2	2	1
5	3	1	2	2	2	3	2	3	1	2
6	3	2	2	2	2	3	2	3	2	2
7	2	2	1	1	2	3	2	3	1	2
8	2	2	1	1	2	3	2	3	1	1
9	2	1	1	1	2	4	1	2	1	2
10	3	2	1	1	2	4	2	3	2	2
11	3	1	2	2	3	3	2	3	1	3
12	2	2	1	2	3	4	3	4	1	3
13	3	2	1	1	3	4	2	4	1	2
14	2	2	1	1	2	3	2	4	1	2
15	3	2	2	1	3	4	3	4	2	3
16	3	2	1	2	3	4	3	4	1	3
17	3	1	1	1	2	4	2	4	1	3
18	3	2	1	1	3	4	2	3	2	2
19	2	2	1	1	3	3	2	4	1	2
20	3	2	2	1	2	4	3	4	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [u]
Pitch: b-246 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	2	1	1	2	1	2	1	1
2	2	1	2	2	2	3	2	3	1	2
3	3	1	1	1	2	3	1	4	1	2
4	2	2	1	1	2	2	1	3	1	1
5	3	2	2	1	2	3	2	3	2	2
6	3	2	2	1	2	2	2	4	2	2
7	2	2	1	2	2	3	2	3	1	1
8	3	2	2	2	2	3	2	4	1	2
9	2	2	1	1	2	2	2	4	2	2
10	3	2	2	1	2	3	2	4	1	2
11	3	1	3	2	3	3	3	3	2	2
12	3	1	2	1	4	4	2	3	2	3
13	2	1	2	2	3	3	2	4	1	3
14	2	1	2	1	2	2	2	3	1	2
15	3	2	2	2	3	4	2	4	1	2
16	3	2	2	1	3	4	2	4	1	3
17	2	2	2	1	2	2	2	4	1	3
18	2	2	1	2	3	4	2	4	2	2
19	2	1	2	1	3	4	2	3	1	2
20	3	2	1	2	3	4	2	4	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: b-246 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	2	1	2	2	2	1
2	2	2	1	1	2	1	2	2	1	1
3	2	2	2	1	2	1	2	3	2	1
4	2	2	1	1	2	2	2	2	1	1
5	2	2	1	2	2	2	2	3	2	1
6	2	2	2	1	2	1	2	3	2	1
7	1	2	1	1	2	2	2	3	1	1
8	2	2	1	1	2	2	1	3	1	2
9	2	2	1	2	3	2	1	3	2	1
10	2	2	1	1	2	2	2	3	1	1
11	2	4	1	1	2	3	2	3	1	1
12	1	2	2	1	3	3	2	4	2	2
13	3	3	2	1	4	2	2	4	1	2
14	2	2	1	2	3	2	1	4	2	1
15	2	2	2	2	3	2	1	4	1	1
16	2	3	1	2	3	2	2	4	2	1
17	1	2	1	1	2	2	2	3	1	1
18	2	3	2	1	4	2	3	4	2	2
19	2	2	1	1	2	1	1	3	2	1
20	2	2	1	2	3	2	2	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: b-246 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	2	2	2	2	1	1
2	1	1	1	1	2	2	1	2	1	1
3	2	1	2	2	2	3	1	3	2	1
4	1	1	1	1	2	2	2	2	1	1
5	2	2	1	2	2	3	2	4	2	2
6	1	1	2	2	2	2	2	3	1	1
7	2	2	1	2	3	4	1	3	2	1
8	2	2	1	2	3	3	2	3	1	1
9	2	2	1	2	2	4	2	4	2	2
10	1	2	1	2	3	3	1	3	1	1
11	2	2	1	2	2	3	2	3	1	2
12	2	2	1	1	4	3	1	4	2	2
13	2	1	2	3	2	4	2	4	2	2
14	1	1	2	2	3	4	1	3	1	1
15	1	2	1	2	4	4	2	4	2	1
16	2	2	1	3	4	4	2	4	1	1
17	2	1	1	2	2	3	1	3	1	2
18	2	2	1	2	3	4	2	4	1	1
19	1	1	2	2	2	3	1	4	1	1
20	2	2	1	2	2	3	1	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: b-246 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	2	2	2	2	1	1
2	1	1	1	1	2	2	1	2	1	1
3	1	1	1	1	2	3	2	3	1	1
4	1	1	1	1	3	2	1	2	1	1
5	2	2	1	1	2	4	2	3	2	2
6	1	2	2	1	2	2	1	4	2	1
7	2	2	1	1	2	3	2	3	2	1
8	2	2	1	1	3	3	2	3	2	2
9	2	2	1	1	3	4	2	4	1	1
10	2	2	1	1	3	3	1	4	1	1
11	2	3	2	1	3	2	2	3	1	2
12	2	1	1	1	4	3	1	3	2	2
13	2	2	2	1	4	4	1	3	2	2
14	1	2	1	1	3	3	2	3	1	2
15	2	2	2	2	4	4	2	4	1	1
16	2	2	1	1	4	4	2	4	2	2
17	1	2	1	1	3	2	2	3	1	1
18	2	1	1	2	4	3	2	3	1	1
19	1	2	2	1	3	3	2	4	1	2
20	2	2	2	1	3	4	2	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: b-246 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	1	1	2	2	1	2	1	1
2	2	1	1	1	1	2	1	2	1	1
3	1	1	1	1	2	3	2	2	1	1
4	1	1	1	1	2	2	1	2	1	1
5	2	2	1	1	1	4	2	3	2	1
6	2	2	1	1	2	2	2	3	1	1
7	1	2	1	1	2	3	2	4	2	1
8	2	2	1	2	2	2	2	3	2	2
9	2	2	1	2	2	4	2	4	2	1
10	2	2	1	1	2	3	2	3	2	1
11	2	3	2	2	3	2	3	4	1	2
12	1	2	2	1	4	4	3	2	1	1
13	1	2	1	1	3	4	3	3	2	1
14	1	2	1	2	2	3	2	3	1	1
15	2	2	2	2	3	4	3	3	1	2
16	2	3	1	2	3	4	3	4	1	2
17	2	2	1	1	2	3	2	3	1	1
18	2	2	2	1	3	3	3	4	2	1
19	1	2	1	1	3	4	2	3	1	1
20	2	2	1	2	3	3	3	4	1	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [u]
Pitch: b-246 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	1	1	2	2	1	2	1	2
2	1	1	1	1	2	2	1	2	1	1
3	2	1	1	1	3	2	2	3	1	1
4	1	2	1	1	3	2	2	3	1	2
5	2	2	1	1	4	3	2	3	2	1
6	2	1	1	2	3	2	2	2	1	1
7	2	2	1	1	3	3	1	3	2	1
8	2	2	1	1	3	3	1	4	2	2
9	2	2	1	1	4	3	2	3	2	2
10	2	2	1	1	3	4	1	4	1	1
11	2	2	2	1	4	3	1	4	2	2
12	2	1	2	1	4	3	2	4	1	1
13	2	1	2	1	4	3	2	4	1	2
14	2	1	1	1	3	3	2	3	1	1
15	2	1	2	2	4	3	2	4	2	1
16	2	2	1	2	4	3	2	4	1	2
17	2	1	1	1	3	3	2	4	2	1
18	2	2	2	1	4	3	2	3	1	1
19	1	2	1	1	4	3	2	3	1	2
20	2	2	1	1	4	2	2	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: g#-415 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	3	2	2	2	2	2	3	2	2	1
2	3	4	3	2	3	3	2	4	1	1
3	3	4	4	2	4	3	2	3	1	1
4	3	2	4	2	3	4	2	4	1	1
5	4	4	3	2	3	3	3	3	1	1
6	3	4	3	2	3	4	2	3	1	2
7	4	2	3	2	2	3	2	3	2	1
8	3	3	3	3	4	4	2	4	2	1
9	3	3	3	3	4	3	2	3	2	1
10	4	3	4	3	3	4	2	4	1	1
11	4	4	4	3	3	4	3	4	1	1
12	4	4	4	3	4	4	3	4	1	2
13	4	4	4	3	4	4	3	3	2	1
14	3	4	4	2	3	4	2	3	1	1
15	4	4	4	3	4	4	3	3	1	2
16	4	3	4	2	4	4	3	4	1	1
17	3	2	3	2	3	4	3	3	1	1
18	4	4	4	4	4	4	3	3	2	1
19	3	3	3	2	3	3	2	3	1	1
20	4	4	3	3	4	4	3	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: g#-415 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	3	2	1	3	4	4	2	4	3	2
2	3	2	2	4	4	4	2	3	3	1
3	3	2	2	4	4	4	2	4	2	1
4	2	2	1	3	4	4	4	4	2	1
5	2	3	1	3	4	4	3	3	2	1
6	3	2	1	3	3	4	4	2	3	2
7	3	2	2	2	3	3	3	3	2	1
8	3	3	1	2	4	3	3	4	3	2
9	3	3	2	2	4	3	2	3	3	1
10	3	3	2	2	4	4	4	4	3	1
11	3	3	1	4	3	4	4	4	2	1
12	2	3	1	2	4	4	2	3	2	1
13	4	3	1	3	4	4	3	4	4	2
14	2	3	1	2	4	3	3	3	3	1
15	3	3	1	3	4	4	4	4	4	2
16	4	4	1	3	4	4	4	3	4	1
17	2	3	1	3	3	3	2	4	3	1
18	4	3	2	4	4	4	3	3	4	1
19	3	2	1	3	3	4	4	3	2	1
20	4	3	2	4	4	3	4	4	4	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [j]
Pitch: g#-415 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	3	2	3	3	4	3	4	4	2	1
2	3	2	2	2	4	2	3	3	1	1
3	3	2	3	3	4	2	4	3	1	1
4	2	2	4	2	4	4	4	4	2	1
5	2	3	2	4	2	2	2	4	1	1
6	2	3	3	2	4	3	3	4	2	1
7	2	2	2	1	3	2	3	3	2	1
8	3	3	3	2	3	3	4	4	1	1
9	4	4	3	3	3	3	4	3	2	2
10	3	3	3	4	4	3	4	4	1	1
11	4	4	3	2	4	4	4	4	1	1
12	3	3	3	2	4	4	4	4	1	1
13	3	4	2	2	4	2	3	4	2	1
14	3	4	2	2	3	2	4	4	1	1
15	4	4	3	2	4	4	4	4	1	2
16	4	4	2	3	4	4	4	4	1	1
17	2	3	2	2	3	2	3	4	1	1
18	4	3	4	2	3	4	4	4	2	1
19	3	3	2	2	2	3	4	4	1	1
20	4	3	3	3	4	4	4	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [ọ]
Pitch: g#-415 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	3	2	2	3	4	2	4	2	1
2	2	2	2	3	4	4	2	3	2	1
3	2	3	2	3	3	3	3	4	1	1
4	2	2	2	2	4	4	4	4	1	1
5	2	3	3	3	4	3	2	2	1	1
6	2	4	2	2	4	3	3	3	2	2
7	2	2	2	2	3	3	2	2	1	2
8	2	3	3	2	3	3	2	4	1	1
9	3	4	3	4	4	3	3	3	2	2
10	3	3	3	2	4	4	4	4	1	1
11	4	2	2	2	3	4	2	4	1	1
12	3	3	3	2	4	4	3	4	2	1
13	3	3	3	4	4	3	2	4	2	1
14	2	3	3	2	4	3	2	4	1	1
15	4	4	3	3	4	4	3	4	1	2
16	4	4	3	3	4	4	3	4	1	1
17	2	3	3	2	4	4	2	4	1	1
18	4	3	2	3	4	4	4	4	2	1
19	3	2	2	2	3	3	3	4	1	1
20	4	4	4	3	3	4	3	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [y]
Pitch: g#-415 Hz

Adjudicators	High School Subjects									
	1	2	3	4	5	6	7	8	9	10
1	3	3	2	3	3	3	2	4	1	1
2	2	4	3	3	3	4	2	2	2	1
3	4	4	3	3	2	2	3	2	2	2
4	2	2	4	4	4	4	4	4	1	1
5	4	4	2	2	2	3	2	2	1	1
6	2	3	2	2	2	2	3	3	1	1
7	3	3	4	2	4	3	3	4	2	1
8	3	3	2	3	3	2	2	3	2	2
9	3	3	4	4	4	4	4	2	1	2
10	3	4	2	4	4	4	4	2	1	1
11	3	4	2	4	4	3	4	2	1	1
12	4	4	4	4	4	4	4	3	1	1
13	4	4	2	4	3	2	2	2	1	1
14	3	4	2	4	3	2	4	2	1	1
15	4	4	3	4	4	3	3	3	1	2
16	4	4	3	4	4	3	3	3	2	1
17	3	4	2	2	3	3	4	2	1	1
18	4	4	4	4	4	3	4	3	1	2
19	2	3	4	3	4	3	2	3	1	1
20	4	3	3	4	4	3	4	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: g#-415 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	1	3	3	2	2	3	1	2
2	2	2	1	3	2	2	2	4	1	2
3	2	2	1	3	3	2	2	2	1	2
4	2	1	1	2	2	2	3	4	1	2
5	3	2	2	3	3	2	3	3	1	3
6	3	1	1	3	2	2	2	3	2	2
7	3	1	1	4	2	2	2	3	1	2
8	2	2	1	3	3	2	3	3	1	2
9	2	2	2	3	3	3	2	3	1	3
10	3	2	2	3	3	2	3	4	2	3
11	2	1	1	3	3	2	2	4	1	3
12	2	2	2	4	3	4	4	3	1	4
13	3	1	1	4	4	2	3	3	2	4
14	3	1	1	4	3	3	2	3	1	3
15	3	2	1	4	4	3	3	3	2	3
16	2	2	1	4	3	3	3	4	1	4
17	2	2	1	3	2	3	2	2	1	3
18	3	2	2	3	3	3	4	4	2	4
19	2	1	1	2	3	2	3	3	1	3
20	3	2	1	4	4	3	3	4	2	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: g#-415 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	1	2	2	2	2	2	1	2
2	1	2	1	1	2	2	3	4	1	4
3	1	2	1	2	3	3	2	3	1	4
4	1	1	1	1	3	2	2	4	1	3
5	2	2	2	2	4	2	3	3	2	4
6	2	2	2	1	3	3	3	4	2	3
7	2	2	1	2	3	2	2	3	1	3
8	2	2	2	2	4	2	3	4	1	3
9	2	1	1	1	4	3	3	3	2	3
10	1	1	1	2	3	2	2	4	2	3
11	2	1	2	2	3	3	3	4	2	3
12	3	2	2	4	3	3	4	4	1	4
13	2	1	2	3	4	3	3	4	1	4
14	2	2	1	2	4	2	4	4	1	3
15	3	1	2	3	4	3	3	4	2	4
16	3	2	1	3	4	3	4	4	1	3
17	1	2	1	2	3	3	2	4	1	4
18	3	2	2	3	4	3	4	4	1	4
19	2	1	1	2	3	3	2	4	1	3
20	3	2	1	3	4	4	4	4	2	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: g#-415 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	1	2	2	3	2	4	1	2
2	1	3	1	2	3	3	2	3	1	3
3	1	3	1	3	3	2	3	3	2	3
4	1	3	1	2	3	2	2	4	1	3
5	2	2	2	2	4	2	3	3	2	3
6	2	3	2	3	3	2	3	3	1	3
7	1	2	1	3	3	2	2	2	1	2
8	2	2	2	2	3	3	2	3	2	3
9	1	3	1	2	4	3	3	3	2	3
10	2	4	2	2	4	3	3	4	1	3
11	1	2	2	2	4	3	4	4	2	3
12	1	4	1	2	4	3	4	4	2	4
13	1	2	1	3	4	2	4	2	1	3
14	1	3	1	3	3	2	4	3	2	2
15	2	4	1	3	4	3	4	4	2	4
16	2	3	2	3	4	3	4	3	2	4
17	1	2	1	2	3	3	2	2	1	2
18	1	4	2	4	4	3	4	4	2	4
19	1	2	1	2	3	2	3	2	2	3
20	2	3	1	3	4	3	4	4	2	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [ɑ]
Pitch: $g^{\#}$-415 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	1	2	2	3	3	2	4	1	4
2	2	2	1	3	2	2	2	2	2	3
3	3	1	2	3	3	3	3	3	2	4
4	2	1	1	3	2	3	2	4	1	2
5	3	2	2	4	4	2	3	4	1	3
6	2	1	1	4	2	3	2	3	2	3
7	2	2	1	4	3	3	2	3	1	4
8	3	1	1	3	2	2	2	3	1	3
9	2	2	2	3	3	3	3	3	2	4
10	2	2	1	4	3	3	3	4	1	3
11	3	1	1	4	4	3	3	4	1	3
12	3	2	2	3	4	4	4	4	1	4
13	3	2	1	3	4	3	4	3	1	4
14	3	1	1	4	4	2	3	3	1	4
15	3	2	1	3	4	4	4	4	1	4
16	3	2	1	4	4	3	3	4	2	4
17	2	1	1	3	3	2	3	4	1	4
18	3	2	2	4	4	4	3	4	1	4
19	2	1	1	3	4	3	2	4	1	4
20	2	2	2	4	4	3	2	4	1	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [y]
Pitch: g#-415 Hz

Adjudicators	University Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	2	2	3	2	4	1	3
2	3	2	2	4	3	2	3	2	1	4
3	2	3	2	3	4	3	4	3	1	4
4	1	4	1	2	3	2	3	4	1	3
5	3	3	1	4	3	4	4	4	2	4
6	1	2	1	3	2	4	2	3	2	3
7	2	2	1	2	3	2	3	3	1	4
8	3	2	1	3	3	3	3	4	2	3
9	3	2	2	2	3	3	3	3	1	4
10	3	3	2	2	2	3	3	4	2	3
11	3	4	1	2	4	2	4	4	1	4
12	3	3	2	4	4	3	4	4	2	4
13	2	2	1	2	3	3	4	4	1	4
14	2	3	1	2	4	2	3	4	1	3
15	3	2	1	4	4	3	4	4	1	4
16	3	3	2	4	4	4	3	4	1	4
17	2	3	1	3	3	3	3	4	1	4
18	2	4	1	4	3	4	3	4	2	4
19	1	3	1	3	2	3	3	4	1	3
20	3	4	2	4	3	3	4	4	1	4

ADJUDICATOR MASTER SCORE CHART

Vowel: [a]
Pitch: g#-415 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	1	2	2	2	2	1	1
2	2	2	1	1	3	2	2	2	1	1
3	2	2	2	1	3	2	2	3	1	1
4	2	3	1	1	3	3	3	3	1	1
5	3	3	2	1	4	4	3	3	2	2
6	2	3	1	1	3	2	2	3	1	2
7	3	4	2	2	4	3	2	2	1	1
8	2	3	2	1	4	3	2	3	1	2
9	3	3	2	2	4	3	2	3	2	1
10	3	3	1	2	3	4	3	3	1	1
11	3	3	1	1	4	3	2	4	1	2
12	3	3	2	1	4	4	4	4	2	1
13	3	4	2	1	4	4	3	4	2	2
14	2	3	2	1	4	3	3	2	2	1
15	3	4	1	2	4	4	3	4	1	1
16	3	4	2	1	4	4	3	4	1	1
17	2	3	2	1	3	4	3	3	1	1
18	4	3	2	2	4	4	3	4	2	1
19	3	2	1	1	3	2	3	3	1	1
20	3	4	2	2	4	4	4	3	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [e]
Pitch: g#-415 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	1	2	2	2	1	1	1
2	2	2	1	1	2	1	2	1	2	1
3	2	3	1	1	3	1	2	1	1	1
4	2	3	1	1	3	1	2	2	1	1
5	3	3	2	2	4	2	2	2	2	2
6	2	3	2	2	3	1	1	2	2	2
7	2	4	2	2	4	1	1	2	1	1
8	2	2	2	2	3	2	2	1	2	1
9	2	2	1	1	3	2	2	1	2	1
10	2	3	1	1	4	2	2	2	1	2
11	3	3	1	2	3	2	1	2	1	2
12	3	2	2	1	4	2	1	3	1	2
13	3	4	2	2	4	3	1	2	2	1
14	2	2	1	1	4	2	1	2	1	2
15	3	4	1	1	4	2	2	2	1	1
16	3	4	1	2	4	2	2	3	1	2
17	2	2	1	1	3	1	2	2	1	1
18	3	4	2	1	4	2	2	3	2	2
19	2	3	1	1	3	2	1	2	1	2
20	3	3	1	2	4	2	2	3	1	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [i]
Pitch: g#-415 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	2	3	2	1	2	1	2
2	2	2	1	1	2	2	1	2	1	1
3	1	2	1	2	3	3	1	2	1	1
4	2	3	1	1	2	2	2	2	1	1
5	2	3	2	1	4	3	2	2	2	2
6	2	2	2	1	3	2	2	2	2	1
7	2	4	1	1	3	2	1	2	1	2
8	2	2	1	2	3	2	1	2	2	1
9	1	2	2	1	3	2	2	3	2	2
10	2	3	1	2	3	2	1	2	1	1
11	3	2	1	1	4	3	2	3	2	2
12	3	3	1	2	4	3	2	2	1	2
13	3	3	2	1	4	3	1	2	2	2
14	2	3	1	1	3	3	1	3	1	1
15	2	4	2	1	4	3	2	2	1	2
16	2	4	1	2	4	4	2	2	1	2
17	2	3	1	1	4	3	2	2	1	1
18	3	4	2	1	4	4	3	3	2	2
19	2	3	1	1	3	3	1	2	1	1
20	3	3	1	1	4	4	2	4	2	2

ADJUDICATOR MASTER SCORE CHART

Vowel: [o]
Pitch: g#-415 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	2	2	1	1	2	2	1	2	1	1
2	1	2	1	2	2	2	1	2	1	1
3	1	2	1	2	3	2	2	2	1	1
4	2	3	1	1	3	2	1	2	1	1
5	2	4	2	1	3	4	1	2	2	2
6	2	3	1	2	3	2	1	2	2	2
7	1	4	2	1	3	3	1	3	2	2
8	2	3	1	2	3	3	1	3	2	1
9	1	2	1	2	3	3	2	3	1	2
10	2	3	2	1	3	3	2	3	1	1
11	3	3	1	2	3	3	2	2	1	2
12	1	3	2	2	4	4	2	4	1	1
13	3	4	2	2	4	3	1	3	2	2
14	2	4	1	2	3	2	1	3	2	1
15	2	4	1	2	4	3	2	4	1	1
16	2	3	1	2	4	4	2	4	1	1
17	1	3	1	2	3	3	2	4	1	1
18	3	4	2	3	4	4	2	4	2	1
19	2	3	1	2	3	3	1	4	1	2
20	2	4	2	2	3	4	3	4	2	1

ADJUDICATOR MASTER SCORE CHART

Vowel: [ų]
Pitch: g#-415 Hz

Adjudicators	Mature Subjects									
	1	2	3	4	5	6	7	8	9	10
1	1	2	2	1	2	2	1	2	1	1
2	2	2	1	2	2	2	1	2	2	1
3	2	2	1	1	2	2	1	2	1	1
4	1	3	2	1	3	3	2	2	1	1
5	3	3	2	2	2	4	1	3	2	2
6	3	2	2	2	3	2	2	2	2	1
7	2	4	2	1	4	3	1	2	2	1
8	3	3	1	1	3	2	2	3	2	2
9	2	2	2	1	3	3	2	3	2	2
10	2	3	1	2	3	2	2	3	2	1
11	3	2	1	1	3	3	1	3	3	2
12	1	2	2	1	4	3	2	3	2	2
13	2	2	2	1	4	4	2	1	3	1
14	2	2	2	1	2	3	1	3	2	1
15	2	4	1	2	3	4	1	2	3	1
16	3	3	2	1	4	4	2	2	3	2
17	2	2	2	1	3	3	1	2	2	1
18	3	4	2	2	3	4	2	3	3	1
19	1	2	1	2	3	2	1	2	2	2
20	2	4	2	1	4	4	2	3	3	1

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