THE FORMANT BEHAVIOR OF THE VOWELS [a], [i], AND [u] IN BARITONE VOICES IN RELATION TO DIFFERENT VOICE RANGES

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This is to certify that the

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The Formant Behavior Of The Vowels /a/, /i/, And /u/
In Baritone Voices In Relation To Different
Voice Ranges

presented by

Nathaniel Hubert Wash

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of the requirements for

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ABSTRACT

THE FORMANT BEHAVIOR OF THE
VOWELS [ɑ], [i], AND [u] IN BARITONE VOICES
IN RELATION TO DIFFERENT VOICE RANGES

By

Nathaniel Hubert Wash

The Problem

The problem of the study was to determine formant characteristics of certain sung vowels preferred by auditors. Patterns of formant behavior considered were the comparative strengths of formants, their proximity to partial frequencies, and their distribution within the spectrum.

A high factor of agreement was expected among auditors in relation to the excellence of the vowels under study. If auditors agreed concerning the quality of the sung vowels, similarities of tonal spectra were expected.

The study included the vowels [ɑ], [i], and [u] sung on the pitches e 165 Hz., c 256 Hz., and e 330 Hz. by five singers with baritone voices judged to be of professional quality.

The Procedure

Tones in each sample, a specific vowel on a selected pitch, were recorded at similar intensities in an acoustically treated studio. The tape of samples in random order

was presented to twenty-two evaluators individually by means of a tape player and earphones. Evaluations concerned quality of tones and phonetic recognition of vowels. The three most highly preferred tones from each sample were processed on the tone analyzer. Spectrograms of tones were examined and reproduced on graphs indicating frequencies, intensities, widths, and locations of fundamentals and formants. Phonetic recognition and mean ratings of selected tones were tabulated and correlated with graphs for each sample.

Conclusions

Conclusions were based on mean readings of data for the tones in each sample.

1. For the vowel [ɑ] at 165 Hz. intensities were 20 db for F0, 30.2 db on partial four (660 Hz.) for F1, 31.3 db on partial six (990 Hz.) for F2, and 32.2 db centered on partial seventeen (2805 Hz.) for F3. For the vowel [ɑ] at 256 Hz. intensity was 14 db for F0, 30.7 db on partial two (512 Hz.) for F1, 32.3 db on partial four (1024 Hz.) for F2, and 28.8 db centered on partial ten (2560 Hz.) for F3. For the vowel [ɑ] at 330 Hz. intensities were 18 db for F0, 32.7 db on partial two (660 Hz.) for F1, 25.3 db on partial three (990 Hz.) for F2, and 34.7 db centered on partial eight (2640 Hz.) for F3.

2. For the vowel [I] at 165 Hz. intensities were 21.7 db for F0, 28.3 on partial two (330 Hz.) for F1, 30.3 db on partial ten (1650 Hz.) for F2, and 32 db centered on partial fifteen (2475 Hz.) for F3. For the vowel [i] at 256 Hz. intensities were 22.7 for F0, F1 was absorbed by F0, 28 db on

partial seven (1792 Hz.) for F2, and 31.7 db centered on partial eleven (2815 Hz.) for F3. For the vowel [i] at 330 Hz. intensities were 27 db for F0, F1 was absorbed by F0, 32.7 db on partial five (1650 Hz.) for F2, and 34 db centered on partial eight (2640 Hz.) for F3.

3. For the vowel [u] at 165 Hz. intensities were 24 db for F0, 32.7 db on partial three (495 Hz.) for F1, 23 db on partial six (990 Hz.) for F2, and 31.7 db centered on partial sixteen (2640 Hz.) for F3. For the vowel [u] at 256 Hz. intensities were 24.3 db for F0, 28.7 db on partial two (512 Hz.) for F1, 26.7 db on partial three (768 Hz.) for F2, and 34.3 db centered on partial eleven (2816 Hz.) for F3. For the vowel [u] at 330 Hz. intensities were 27.3 db for F0, F1 was absorbed by F0, 22.7 db on partial three (990 Hz.) for F2, and 36.3 db centered on partial eight (2640 Hz.) for F3.

(This written thesis and three public recitals constitute the dissertation requirements for the degree of Doctor of Philosophy in applied music, literature, and theory.)

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By

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CHAPTER I

INTRODUCTION

Purpose

The purpose of this study is to determine whether certain sung vowels selected by auditor preference have the same or similar patterns of formant behavior and to determine what those patterns may be.

Problem

The problem of the study is to determine whether the formants of vowels judged to be excellent are related to specific areas of frequency; and further, to determine the comparative strengths of the formants, their proximity to partial frequencies, and their distribution within the spectrum.

Hypothesis

1. There will be a high factor of agreement among the auditors in relation to the excellence of the vowels under study.

2. If hypothesis one is true, the tonal spectra of preferred vowels should reflect a uniformity of frequency distribution.

Terminology

Decibel, the smallest unit for measuring the loudness of sounds: abbreviated db.

Formant, an energy peak or band within the sound spectrum of a tone. The quality of a sound is determined by the relative strengths and positions of formants: abbreviated F, followed by a numberal which denotes the observable chronological order within a given spectrum.

Herz, a unit of frequency equal to one cycle per second: abbreviated Hz.

Spectrogram, a chart or diagram analysis of a sound spectrum.

Timbre, that specific characteristic of tone quality which is the result of partial strengths and distribution.

Experimental Design

To provide information for establishing the correlation between vowel formants and preference of sung vowel phonemes the following experimental design was developed:

1. Data showing the acoustic spectra (spectrograms) of the sung vowels under study.

2. Auditor recognition and evaluation of recorded vowels.

3. Auditor reliability coefficient.

Conditions necessary for the accomplishment of the experimental design are as follows:

1. Several vowel phonemes must be included in the study in order to determine the effects of different formant patterns on auditor preference.

2. Several pitch levels must be included in order to consider possible resultant acoustic effects.

3. Subjects must be chosen on the basis of their ability to sing vowels as prescribed.

4. Subjects must be recorded at similar volume levels to insure against differences in timbre which might result from non-uniform vocal signal strengths.

5. Recording room must be acoustically treated so that interference from resonant frequencies will not impair recorded data.

6. Auditors must be chosen who meet the requirements for membership in the National Association of Teachers of Singing, or who possess the master's degree and are engaged in teaching voice or choral music.

7. Material must be presented to auditors in such manner that as nearly as possible each tone may be judged individually.

8. Auditor judgment reliability must be tested by statistical design.

Delimitations of the Study

1. Collections of samples are taken in controlled clinical conditions as opposed to artistic performance conditions.

2. Singers with professional quality baritone voices are used as subjects in this study. From the recorded samples of a number of subjects, the three samples in each category with highest ratings by auditors are processed for tonal analysis on the Bruel and Kjaer analyzer.

3. The vowels [ɑ], [i], and [u] are chosen to

represent "high frontal," "low back," and "rounded" classifications. Each of them is sung at e 165 Hz., c 256 Hz., and e 330 Hz. respectively.

4. Auditors are selected from voice faculties of colleges and universities, teaching assistants, private teachers of voice, and choral directors.

Background of the Problem

As technology has advanced, providing special equipment for examining sound spectra, there have developed a number of claims concerning formant behavior, location of formants when associated with ideal vocal quality, and even differences in theories concerning the production of the various frequencies in question.

Seashore[1] stated early in his studies concerning beauty in singing that timbre is dependent primarily on the number of partials, their relative locations in the spectrum, and their relative strengths.

Erickson[2] found that timbre is affected by energy distribution among partials and by the presence or absence of certain partials. Further, he believed that subjective evaluation of quality in singing is necessary for the development of scientific evaluation.

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[1]Carl E. Seashore, Psychology of Music (New York: McGraw-Hill Book Company, Inc., 1938), p. 97.

[2]Carl I. Erickson, "The Basic Factors in the Human Voice," Psychological Monographs, XXXVI (February, 1927), 110-112.

Important findings from a study by Holmes[3] are that vocal quality depends upon the relationship between the fundamental and the characteristic frequency bands of sounds. He found that there was high agreement among judges in their evaluations of tone quality and that their evaluations of vocal sounds can be related to objective measurements.

Pertinent to the design of this study is information provided by Laase.[4] He noted that the intensity of the higher partials of a spoken vowel increases as the intensity of the tone increases. As the pitch is raised, the strength of the fundamental increases whereas the strength of the high partials decreases. Borchers[5] added to this the finding that the intensity of the fundamental decreases comparatively as the tone increases in energy.

Concerning frequency ratios between fundamental and formant, Gray and Wise[6] made the observation that there is a tendency for each formant frequency to rise as the frequency of fundamental rises. The authors concluded that different speech sounds are distinguished by the characteristic frequency

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

Reader:

Please disregard the information on page five and in the bibliography that refers to F. Lincoln P. Holmes. The source given is in error, and the correct source has not been found.

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regions. Partials which lie within those regions exhibit greater portions of the total energy of the sound than is reflected in the other components.

As early as 1942, Bartholomew indicated that there was a conflict of opinion as to the acoustical properties of sound, one theory being called the "harmonic" and the other the "formant." Of these theories he wrote:

> The harmonic theory states that the characteristic tone quality of an instrument is due entirely to the relationship among fundamental and upper partials, which relationship is supposed to remain unchanged no matter what the fundamental is. . . .
>
> The formant theory states that the characteristic tone quality of an instrument is due to the relative strengthening of what ever partial lies within a fixed region of the musical scale. This region is called a formant of the tone.[7]

Vennard[8] explained that eighty to ninety per cent of the harmonics of a vocal tone are proportioned by formants; only a small percentage are relative to the fundamental. William E. Castle[9] suggested that fundamental frequency, intensity, and duration have become important supplements or replacements for steady state formants under some listening conditions.

The citations offered above indicate that there are

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

[8]William Vennard, Singing, the Mechanism and the Technic (3d ed. rev.; Ann Arbor: Edwards Brothers, Inc., 1964), p. 107.

[9]William E. Castle, The Effect of Selective Narrow-Band Filtering on the Perception of Certain English Vowels (The Hague: Mouton & Co, 1964), p. 30.

differences of opinion concerning characteristic formant frequencies associated with the quality of tones. At the present time, information concerning the role of formants as quality characteristics is incomplete. There is no definitive study available for all representative human voice qualities and classes and for all of the usable pitch ranges.

The present study is one step toward gathering the information needed to build a completely comprehensive fund of knowledge concerning the role of the formants of the several vowels in producing quality characteristics and to discover, if possible, whether or not there does exist a systematic pattern of formant behavior.

It is not the purpose in this background survey to exhaust all sources which are concerned with formants as they affect timbre, but rather to give an overview. A number of writings deal only with spoken sounds. While these furnish helpful background information, their usefulness is limited. Considerations such as sustained pitch, duration of tone, and intensity, vary greatly between spoken and sung vowels.

Until the development of highly sophisticated electronic tone analyzers, a high degree of precision in effective tone analysis has not been possible. This investigation depends to a large extent on the accuracy and detail of spectrograms produced. In order to accomplish the goal, comparisons must be limited to identical vowels at identical pitches sung by similar voices at similar intensity levels.

In keeping with the scope of the present study, three works which pertain in some aspect directly to the problem at hand were chosen as being most relevant. These will be reviewed in Chapter II.

CHAPTER II

SURVEY OF RELATED LITERATURE

Three works are included in this review of closely related literature. From The Science of Vocal Pedagogy,[10] by Appelman, research which pertains to formant characteristics is reviewed, Sullivan[11] in his doctoral dissertation, examines timbre, vowel quality, vibrato rate, and intensity as related to total vocal quality. Of particular interest is formant behavior as it affects timbre. The reviewed section of the doctoral dissertation by Jones[12] treats formant characteristics of certain vowel sounds produced with closed velum.

Appelman discussed the creation of vowel formants as an important aspect of the laws that govern vocal sound. He reasoned:

> 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 characteristics to such tones. This reinforcement gives the partials greater energy at the

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[10] D. Ralph Appelman, The Science of Vocal Pedagogy (Bloomington: Indiana University Press, 1967), pp. 126-127, 224.

[11] Ernest G. Sullivan, "An Experimental Study of the Relationships between Physical Characteristics and Subjective Evaluation of Male Voice Quality in Singing" (unpublished Ph.D. dissertation, School of Music, Indiana University), pp. 105-167.

[12] J. Loren Jones, "A Cinefluorographic and Spectrographic Analysis of the Effect of Velum Positions on Sung Vowels" (unpublished D. M. Ed. dissertation, School of Music, Indiana University), pp. 52-244.

point of cavity resonance. These points of greater energy are called formants.

> In passing through the resonating systems 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 necessaryily 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.[13]

Appelman further stated that if the throat and oral cavities were unchanged but the fundamental pitch were lowered, vowel characteristics would be unchanged. The reason given was that there had not been an energy variation within each formant. A spectrograph was given of a bass voice dropping the octave from c 523 Hz. to c 251 Hz. This illustration showed the phenomenon of F1 being made up of the second and third partials during the singing of the higher pitch. On the lower pitch most of the energy of F1 was shown on partial five even though the fourth and sixth partials fell within the energy band of the vowel formants as shown for the higher pitch.

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[13] Appelman, pp. 126-127.

Another item of interest was the formant chart which appeared in the chapter on vowel migration. Appelman stated:

> In constructing the formant chart the migration characteristics of each vowel had to be evaluated. Considering only formant movement and disregarding formant band width and formant strength--the second formant moves twice the frequency interval for each vowel sound as does the first formant; e.g., in passing from [i] to [I] the second formant moves 100 cycles while the first moves 40; from [I] to [e]--the second formant, 100 cycles, the first, 45 cycles, etc. This characteristic formant movement may be observed in the back vowels as well as the frontal vowels.[14]

The Hz. deviations in the first and second formants were without reference to a fundamental pitch. This was true also in the chart which showed the first three formant frequencies of vowel phonemes. Different sets of figures were given for men and women singers. The statements and statistics cited suggested that the author subscribed to the "fixed formant theory."

Sullivan's purpose was to establish relationships between physical characteristics and subjective evaluation of male voice quality in singing. He was concerned with timbre, rate of vibrato, vowel quality, and total intensity.

A jury of voice teachers evaluated a number of male voices who were chosen to represent a wide range of quality. The general categories of trained and untrained singers were specified. Within each of these categories there were excellent voices, moderately good voices, and poor voices.

Of the samples recorded by the subjects, the pitches A# (234 Hz.) and F (347 Hz.) were selected for presentation

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[14]Appelman, p. 224.

to auditors using the method of paired comparisons. Vowels used were [ɑ], and [i], and [u].

Voices were recorded on tape by use of good equipment. Intensity levels were measured. Readings were taken of the sound characteristics of the studio. Tonal analysis was made by use of the Sona-Graph. Samples were played to jurors by means of tape recorder and speaker in the recording studio. Specific controls were these:

1. Dial settings were constant for all recording.

2. Subject to microphone distance was identical.

3. Samples were copied and brought to the same volume level.

4. Jurors' chairs were placed as nearly in front of the speaker as possible, rear chairs elevated.

Sullivan gave the following description of formant measurements:

> Formants were measured for location, intensity, and width. In many cases the location of the first two formants was so close together that they overlapped. Here it was difficult to determine by measurement alone the location of the formant peak. The phonetic transcriptions were consulted. The 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.[15]

Determinants of vowel characteristics were believed to be the locations of F1 and F2. Sullivan indicated that

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[15] Sullivan, pp. 46-47.

in the [ɑ] and [u] vowels only one peak was usually present. This was accounted for by considering that F1 and F2 were combined or that F2 was too weak to be observed. This made accurate measurement impossible. The first formant of the vowel [i] at both pitches always included the first two partials, and in five cases included the third.

The strongest formant above F2 was designated formant S. Of FS and its relation to vocal quality he stated:

> In the sonagrams of all the experimental tones, a region of strength at about 3,000 cps is apparent. This sometimes includes several formants which together cover as much width as 2,000 cps. A minute inspection of the sonagrams gave some hope that the characteristics of the strongest formant in this region would provide an index to vocal quality. The formant in this region has been designated as FS.[16]

The author stated further that an optimum location of FS and its intensity ratio to F1 apparently provided the highest correlation with jury preference. The vowel [ɑ] at the pitch A# (234 Hz.) was the only exception to the above in the coefficient of intensity relationship between F1 and FS. This same vowel at the pitch A# was rated higher as the intensity of the strongest formant increased.

No correlation was found between intensity above 4000 Hz. and jurors' evaluation of vocal quality with the exception of [i] at the pitch F. An inspection of the strongest formants above 4000 Hz. revealed no correlation with jury mean scores.

In a detailed analysis of the three vowels used in the

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[16] Ibid., p. 98.

study sung at the two pitches used, the following conclusions were drawn:

Vowel [ɑ] at Pitch A#

Six of the eight highest ranked tones had distinct F1 and F2 areas. Subjects who ranked high showed an average of 612 Hz. for F1. For F2 the average was 994 Hz. Quality was judged higher as the position of FS approximated 2700 Hz., and as FS was shown to be both stronger and wider.[17]

Vowel [ɑ] at Pitch F

F1 averaged 722 Hz. for all subjects. F2 averaged 1175 Hz. for preferred tones, only slightly higher than non-preferred. Quality was judged higher as the intensity of F1 was weaker. F2 was not computed. FS related closely to quality, its optimum location being at 2850 Hz. As the location of FS approximated 2850 Hz., tones were ranked higher in quality. Quality was rated higher as the width of FS approached 1525 Hz. The intensity of FS was positively related to quality.[18]

Vowel [i] at Pitch A#

Average frequencies for F1, 272 Hz., and F2, 1951 Hz. were not important in consideration of vocal quality. A weak F1 was preferred as was a narrow F2. Tones were judged higher in quality when F2 was stronger than F1. Optimum

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[17] Ibid., pp. 107-112.

[18] Ibid., pp. 116-121.

location for FS was about 2800 Hz. There was some correlation in frequency band width in the area of FS.[19]

Vowel [i] at Pitch F

The intensity of F1 had an inverse relationship to jury evaluation of quality. As F2 approached an intensity twice that of F1 the tone was rated higher in quality. The nearer FS approached 3000 Hz., the higher the tone was ranked. As in the previous section the width of FS showed no correlation to quality, but the band width in the region of FS showed a positive correlation with quality evaluation. Band width was more important to quality than the intensity of FS.[20]

Vowel [u] at Pitch A#

F1 and F2 were important only when they appeared as one combined peak instead of separate peaks. The combined peak spectra correlated with preferred tone quality. Optimum location of FS was 2500 Hz., but band width was insignificant. The stronger the formant above F2, the better the rating the tone received. In general, the ratio of intensity between FS and F1 was more significant than the ratio between FS and the fundamental.[21]

Vowel [u] at Pitch F

F1 and F2 were not significant. Location and width of FS showed a high correlation with jury preference. As

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[19] Ibid., pp. 125-132.

[20] Ibid., pp. 137-142.

[21] Ibid., pp. 145-151.

FS approached 2900 Hz., the tone was judged higher in quality. The sample was ranked higher when FS widened and when it was stronger in relation to the fundamental.[22]

General Conclusions Pertinent to the Present Study

1. The optimum location of FS varied according to vowel and pitch. The nearer FS was to this optimum, the higher the tone was judged in quality.

2. The strength of FS was most important for jury preference. The optimum strength was between one and two times that of F1 and stronger than the fundamental.

3. The tone was judged better in quality as F1 became weaker.

4. F2 was important only in consideration of the [i] vowel. Tone was rated higher as this formant became narrower.

5. Spectral energy above 4000 Hz. was not important in jury preference.

6. There was positive correlation between the intensity at which a tone was produced and its rank order of quality preference.

In the study by Jones the primary consideration was the effect of velar positions on the quality characteristics of sung vowels. To obtain data which allowed observation of positions of the velum during phonation, the technique of cinefluorography was used. Sung vowels were recorded on tape

[22]Ibid., pp. 154-161.

and copied to obtain equal sound level. Tapes of recorded vowels were then presented to auditors for their judgments of nasal quality, preference, and phoneme recognition.

There were seven subjects, each of whom successfully sang three vowel phonemes using three positions of the velum on two pitches. This produced eighteen groups of samples. Of particualr interest were the data available concerning vowel quality evaluations by the judges in relation to spectrographic information. Conclusions were these:

1. With one exception, judges strongly preferred non-nasal tones. The exception was the [ɑ] vowel at e 330 Hz., which was rated identically when sung with closed or slightly open velum.

2. A closed velum was more necessary for a preferred tone rating at the lower pitch of C 128 Hz.[23]

Vowels produced in position number 2, closed velum, were most highly preferred by auditors. Therefore, samples with a preferred rating of 90% or better in each of the six groups of samples produced with closed velums were examined to determine formant behavior. Comparison of auditor preference and sound spectrum charts indicated the findings which follow:

Vowel [ɑ] at Pitch 130 Hz.

1. Four subjects qualified.[24]

2. F1 was 650 Hz. for three subjects, 780 Hz. for

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[23]Jones, pp. 229, 230.

[24]Ibid., pp. 70, 73, 74, 76.

one subject.

3. F2 was 1040 Hz. for three subjects, and included from 1040 Hz. to 1170 Hz. for one subject.

4. F3 was 2600 Hz. for one subject, 2730 Hz. for three subjects.

Vowel [ɑ] at Pitch 330 Hz.

1. One subject qualified.[25]

2. F1 was 660 Hz.

3. F2 was 990 Hz.

Vowel [i] at Pitch 130 Hz.

1. Three subjects qualified.[26]

2. F1 was 260 Hz. for two subjects, 390 Hz. for one subject.

3. F2 was 1950 Hz., 2080 Hz., and 3250 Hz. respectively for the three subjects.

4. F3 was 2860 Hz., 2990 Hz., and 3250 Hz. respectively for the three subjects.

Vowel [i] at Pitch 330 Hz.

1. One subject qualified.[27]

2. F1 was 330 Hz.

3. F2 was 1650 Hz.

4. F3 was equal in strength on both 2970 Hz. and

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[25] Ibid., p. 103.

[26] Ibid., pp. 124, 129, 130.

[27] Ibid., p. 156.

3300 Hz.

Vowel [u] at Pitch 130 Hz.

1. One subject qualified.[28]
2. F1 was 260 Hz.
3. F2 was 780 Hz.
4. F3 was 2210 Hz.

Vowel [u] at Pitch 330 Hz.

No subject qualified for this group of tones.

Conclusions Concerning Related Research

The information given by Appelman raises the following questions which are significant to the present study:

1. What effect do pitch changes as indicated have upon formant band width?

2. Is the spectrograph used by this author sufficiently accurate to warrant drawing detailed conclusions?

3. What would be the effect of pitch changes other than the octave?

Research by both Jones and Sullivan showed that certain characteristics of specific tonal spectra may be correlated with auditor preference for certain vowels. Differences in the results of these two authors may be due in part to the fact that tonal analysis was accomplished on different equipment. This difference was reflected in the accuracy of the findings. Pitches used were different and did not give data reliable for detailed comparison between the two studies. Subjects were

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[28]Ibid., p. 183.

chosen differently. Those in the Sullivan study varied widely in singing ability, whereas Jones chose subjects on the basis of their professional vocal quality.

Since the present study was concerned with only those tones rated highest in quality by auditors, it seemed most logical to follow the experimental design of the Jones research. Subjects were chosen on a similar basis, and spectrographic analysis was accomplished on the same equipment. These conditions facilitated comparison of results.

CHAPTER III

EXPERIMENTAL PROCEDURES

To provide reliable information for the study, certain conditions were necessary. Subjects meeting specific qualifications were needed. Equipment had to provide data of sufficient accuracy and scope. The recording process had to be clinically controlled. The auditor environment had to be uniform. The preceding items are discussed in this section of the study.

Selection of Subjects

Since the purpose of the study was to determine characteristics of excellent tones, five singers with excellent baritone voices were chosen as subjects. The preliminary evaluations of the subjects were made by members of the National Association of Teachers of Singing who were acquainted with their performance abilities. Subjects were assigned the numbers one through five for identification.

Equipment for Recording, Analyzing, and Evaluating Tones

Equipment for recording tones was an Ampex model AG 440-4 recorder; tape speed was 7½ inches per second; frequency response was 40 to 15,000 Hz. ± 2 db. The microphone used was an Electro-Voice model 635 A; frequency response was 60 to 15,000 Hz. ± 2 db. Scotch music mastering tape number

206 was used; thickness was 2.08 mils.

The recording studio was located in the Speech Department of Michigan State University; ambient levels were at full octave filter settings; center frequencies were at the following sound pressure levels at .0002 microbar reference:

Hz.	31.5	63	250-8000
db	46	20	less than 10

Equipment for measuring intensity of tones was a Bruel and Kjaer model 2204 S sound level meter; response was ± 0 db from 2 to 20,000 Hz. at C weighting. Equipment for analyzing tones was a Bruel and Kjaer model 2107 tone analyzer; frequency response was linear from 2 to 40,000 Hz.; six stage spectrum scanning was employed as follows: 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.; frequency response accuracy was better than ± 1%; band pass characteristics were better than ± .5 db; signal shaping was accomplished through three weighted networks.

Used in conjunction with the tone analyzer was a Bruel and Kjaer model 2305 level recorder; frequency response 2 to 200,000 Hz. accurate to within 1 db; input signals from 5mV to 100 volts; selectable stylus and paper speeds.

Equipment for auditor evaluation of tones was a Roberts recorder model 770 X tape playback; frequency response 40 to 22,000 Hz. at 7½ inches per second. Earphones used were Superex model PRO-B; frequency response was from 18 to 22,000 Hz.; there were no volume or tone controls.

Recording the Tones

A distance of fourteen inches from subject to microphone was maintained by means of a string tied to a second microphone stand. At the end of the string was a button which the subject held against his chin. The microphone was placed approximately level with the mouth of each subject. During recording, level controls were monitored.

Since all subjects were singers capable of producing tones at the required intensity, it was decided that the vocal signal strengths would be similar for each sample. This was accomplished by means of a sound level meter located near the microphone during the recording of tones. Each subject sang a vowel tone of sufficient intensity to produce the desired reading on the sound level meter. By this means all tones recorded on the master tape were of similar intensity.

Recording Procedure

The overall scope of the experiment was explained to each subject. He was instructed in the order of procedure and given opportunity for practice. He was told to hold the position button against his chin and to sing with medium-high intensity as he adjusted the sound level meter to obtain the desired range. The proper pitch and vowel were designated; the tape recorder was started; the signal to sing was given; after six seconds the signal to stop singing was given; the recorder was stopped. There was a pause before the next sample. The procedure was followed for a total of nine samples from each subject. The vowels [ɑ], [i], and [u] were each sung on the pitches of 165 Hz., 256 Hz., and 330 Hz.

Preparation of Recorded Samples for Presentation to Auditors

From the master tape of recorded samples, two copies were made and edited identically by removing tone samples in order. Each strip of tape containing one tone was marked for direction and fastened by its leading end in correct sequence to a long strip of masking tape. The masking tape was marked with subject numbers, sample numbers, and tone numbers Extra copies of the tones contained in sample four, selected at random, were made for use as sample zero. One tone from each sample was selected at random to serve as an auditor reliability check. These tones were copied from the master tape, edited, and identified in the manner described above.

The first step in making the audition tape was to record all necessary announcements and instructions in correct sequence. Four seconds were allowed between announcements of items so that auditors would have time to evaluate tones. The middle thirty-one inches from each tape strip containing a recorded tone were clipped out and spliced into the announcement tape; this eliminated the attack and release. Samples and tones were arranged in random sequence.

Reliability Test

In each sample one pair of tones was repeated at random so that comparison of auditor responses might provide an index of reliability. All repetitions of tones were identical with the originals.

Selection of Auditors

Auditors were voice teachers and choral directors from colleges, universities, and secondary schools. A number of them qualified for membership in the National Association of Teachers of Singing. Several maintained private studios in addition to their college teaching. Those engaged in choral directing had attained a minimum of the master's degree in music.

Presentation of Audition Tape to Auditors

Each auditor was given a sheet instructing him in the procedure to be followed. He was asked to make a quality judgment of each tone, rating it on a scale of 1 to 5. Number 1 rated a tone as superior; 2, very good; 3, good; 4, above average; 5 average. The auditor was asked also to indicate by use of a key word or phonetic spelling the vowel phoneme that he had heard. Spaces on each evaluation sheet provided for auditor identification by number. Other information concerning him included place of employment, approximate age, and sex. The date and beginning sample number were marked on each sheet.

Instructions and a practice sample were placed at the beginning of the tape to familiarize auditors with the procedure. The audition tape was played for each auditor individually. All settings on the tape recorder were identical

for all playbacks. Because the earphones used had no provision for tone or volume control, the playback environment was equal for all auditors. The starting point of the tape was advanced with each new auditor so that each sample appeared first in its turn.

Selection of Tones for Spectrographic Analysis

In the search for criteria of quality it was decided that the three tones with highest auditor ratings in each sample would produce sufficient data for the scope of the present study. For that reason the first three highest-rated tones in each sample were prepared for processing on the tone analyzer.

Preparation of Tapes for Spectrographic Analysis

After the audition tape had been presented to all auditors, results were compiled to determine tones for analysis. The appropriate tape strips containing tones were removed, marked for identification, and formed into loops approximately thirty-one inches in length. Loops were placed on a pegboard in readiness for use in spectrographic processing.

Spectrography

Processing of the tape loops was done in the laboratory of the Michigan State University Speech Department. The technician made the proper connections between the tape recorder, the Bruel and Kjaer 2107 analyzer, and the 2305 level recorder. Switch selections were as follows:

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 second
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 second

Following the proper warm-up period, the tape loop was started, gain control was adjusted to 10 db, chart paper was set at point 0, and the graph was begun. After the spectrogram was made, the loop was returned to the correct peg and identifying information was copied onto the spectrogram. Each sample was processed in this manner.

Procedures described in this chapter have produced the following:

1. Taped recordings and spectrograms of the preferred vowel phonemes under study.

2. Subjective evaluations of auditors concerning preferred tones and phoneme recognition.

Procedures described above have provided sound spectrum charts and related auditor ratings of tones. Subjects capable of singing the desired tones have been selected carefully. The equipment used for recording, analyzing, and presenting tones to auditors has been of high quality. Tones have been recorded in controlled conditions. Samples have been arranged in random order for presentation to auditors. The tones selected by auditors have been processed on the analyzer. The following chapter will be a presentation of information thus derived.

CHAPTER IV

PRESENTATION OF DATA

Two classes of data are presented in this chapter: auditor evaluations of the quality of sung vowels, and the tonal spectra of those sung vowels.

The presentation is organized into nine sections, one for each of the three vowels performed on three different pitches. Each group is concerned with auditor evaluations and spectrograms of the three highest rated tones for a specific pitch and vowel. At the beginning of each group, information obtained from auditors is given. A graph of the spectrum of each tone follows. The order of presentation of tones corresponds with their order of auditor preference. Analysis of data concludes each group presentation.

The concluding section of the chapter is comprised of tables giving the mean ratings of auditors for all selected samples, phoneme recognition for all selected samples, auditor reliability information, and sound level readings for the selected tones.

Vowel [ɑ] at Pitch 165 Hz.

Phoneme Recognition by Auditors

Tone #1

[ɑ]	[ɒ]	[ʌ]	other
15	3	2	2

Consensus [ɑ]

Tone #2

[ɑ]	[ɒ]	[ɔ]	other
10	9	1	2

Consensus [ɑ]

Tone #3

[ɑ]	[ʌ]	other
21	1	0

Consensus [ɑ]

Auditor Judgment of Timbre

Tone #1

Mean 2.05
(Very good)

Tone #2

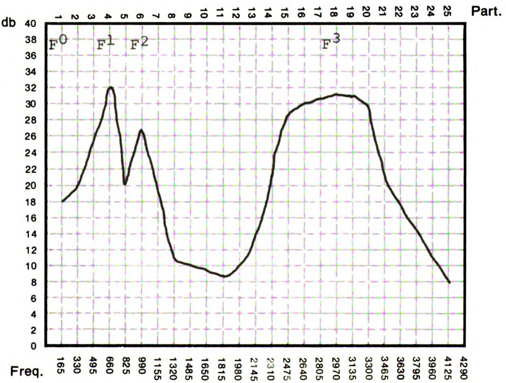
Mean 2.73
(Good)

Tone #3

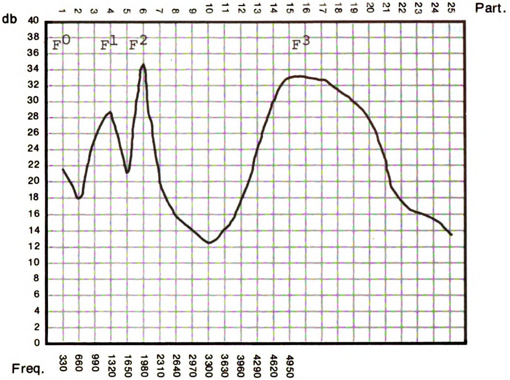
Mean 2.82
(Good)

Comparison of Sound Spectra

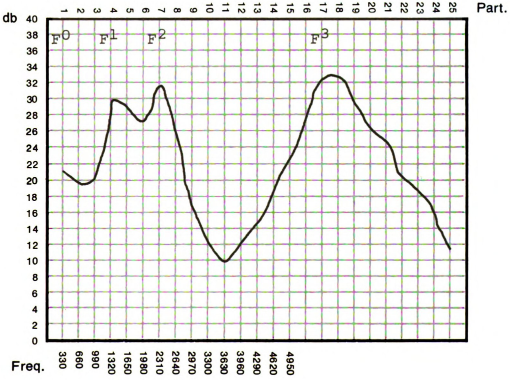
Tone #1



Tone #2


Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0 F1 F2 F3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950

Tone #3


Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0 F1 F2 F3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950

Interpretation of Data for the Three Tones:
Vowel [ɑ] at Pitch 165 Hz.

1. Auditor recognition of the [ɑ] vowel as sung by all subjects was 70%.

2. Auditor mean ratings of timbre ranged from 2.05 to 2.82, (from very good to good).

3. Sound levels at the time of recording were 92 db, 88.5 db, and 92 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 18 to 22 db. The highest scored tone had the lowest db reading for the fundamental pitch.

5. F1 showed an energy peak on the fourth partial (660 Hz.) for all tones. Decibel readings were 32, 28.5, and 30 respectively for tones #1, #2, and #3.

6. F2 showed an energy peak on the sixth partial (990 Hz.) for tones #1 and #2. Tone #3 showed the peak on partial seven (1155 Hz.). Decibel readings were 27, 35, and 32 respectively.

7. F3 appeared as a broad band of high intensity in all three tones. In tone #1 its width covered from the fifteenth partial (2475 Hz.) to the twentieth partial (3300 Hz.) at approximately 30.5 db. In tone #2 its width covered from the fourteenth partial (2310 Hz.) to the twentieth partial (3300 Hz.) at approximately 33 db. In tone #3 its width covered from the sixteenth partial (2640 Hz.) to the nineteenth partial (3135 Hz.) at approximately 33 db. The energy peak of this formant was centered at 2970 Hz. in tone #1, 2640 Hz. in tone #2, and 2805 Hz. in tone #3.

8. All tonal spectra contained a broad formant between 4000 to 10,000 Hz. Intensity readings were below 10 db.

Vowel [ɑ] at Pitch 256 Hz.

Phoneme Recognition by Auditors

Tone #1

[ɑ]	[ʌ]	[ɔ]	other
13	3	3	3

Consensus [ɑ]

Tone #2

[ɑ]	[ʌ]	[ɔ]	other
9	5	5	3

Consensus [ɑ]

Tone #3

[ɑ]	[ɒ]	[ɔ]	other
8	5	4	5

Consensus [ɑ]

Auditor Judgment of Timbre

Tone #1

Mean 1.8 (Very good)

Tone #2

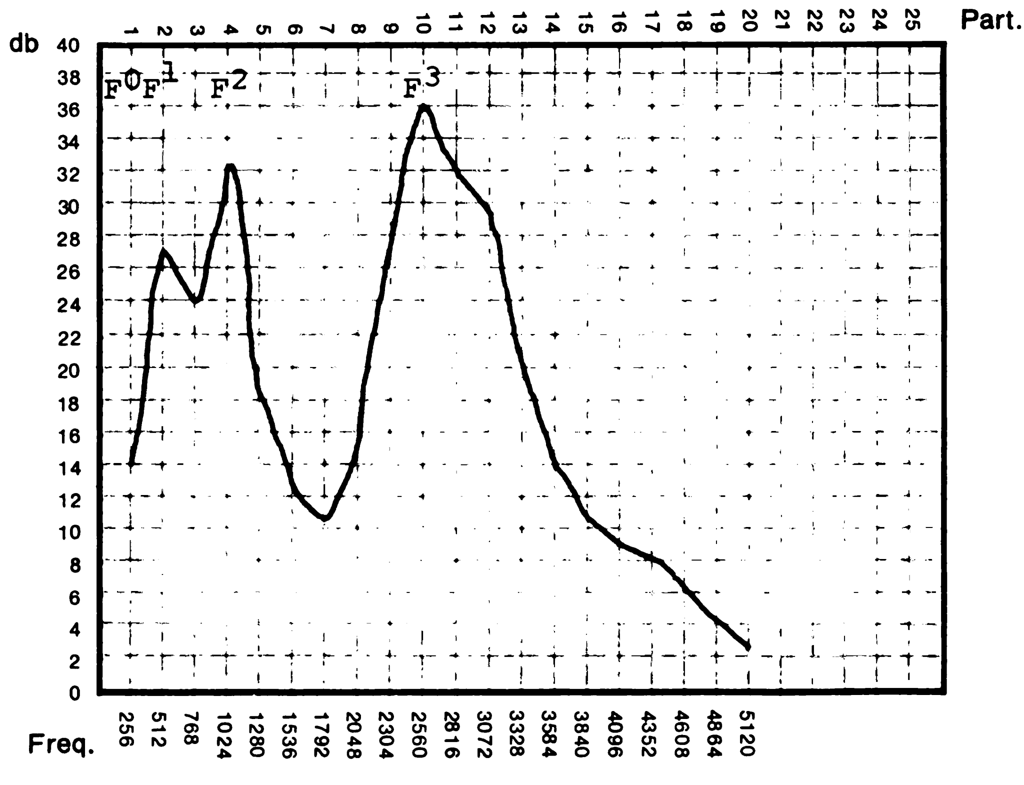
Mean 2.3 (Very Good)

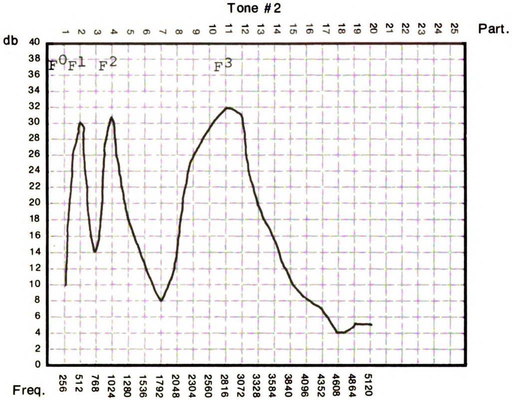
Tone #3

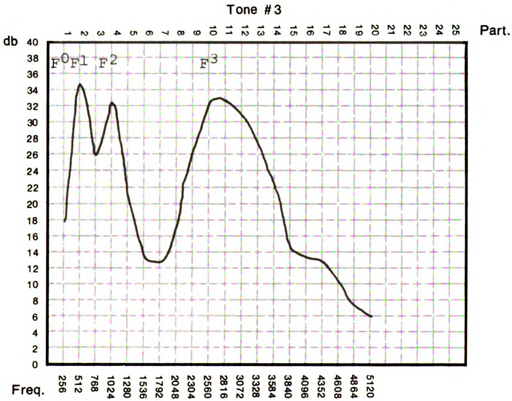
Mean 2.4 (Very good)

Comparison of Sound Spectra

Tone #1




Tone #2
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0 F1 F2 F3
Freq.
256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096 4352 4608 4864 5120


Tone #3
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0 F1 F2 F3
Freq.
256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096 4352 4608 4864 5120

Interpretation of the Data for the Three Tones:
Vowel [ɑ] at Pitch 256 Hz.

1. Auditor recognition of the [ɑ] vowel as sung by all subjects was 48.5%.

2. Auditor mean ratings of timbre ranged from 1.82 to 2.4 (very good).

3. Sound levels at the time of recording were 98.5 db, 102 db, and 95.5 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 10 to 18 db.

5. F1 showed an energy peak on the second partial (512 Hz.) for all tones.

6. F2 showed an energy peak on the fourth partial (1024 Hz.) for all tones. Decibel readings were 33, 31, and 33 db respectively.

7. F3 appeared as a broad band of high intensity in all three tones. In tone #1 its width covered from the ninth partial (2304 Hz.) to the twelfth partial (3072 Hz.) at approximately 28 db. Its width in tone #2 covered from the seventh partial (2310 Hz.) to the ninth partial (2970 Hz.) at approximately 30 db. Its width in tone #3 covered from the ninth partial (2304 Hz.) to the thirteenth partial (3328 Hz.) at approximately 28.5 db. The energy of this formant was centered at 2560 Hz. in tone #1, 2816 Hz. in tone #2, and 2560 Hz. in tone #3.

Vowel [ɑ] at Pitch 330 Hz.

Phoneme Recognition by Auditors

Tone #1				Tone #2				Tone #3			
[ɑ]	[ʌ]	[ɔ]	other	[ɑ]	[ʌ]	[o]	other	[o]	[ɑ]	[u]	other
11	3	3	5	5	5	4	8	7	6	2	7

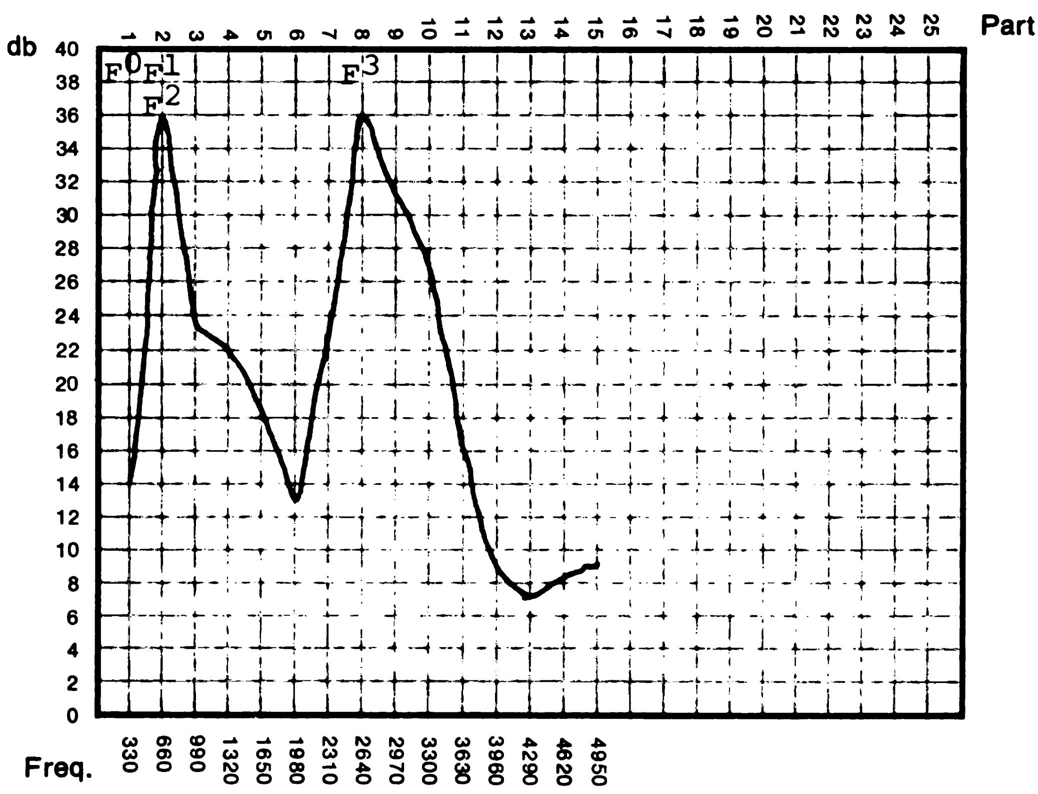
Consensus [ɑ] Consensus [ɑ] Consensus [o]

Auditor Judgment of Timbre

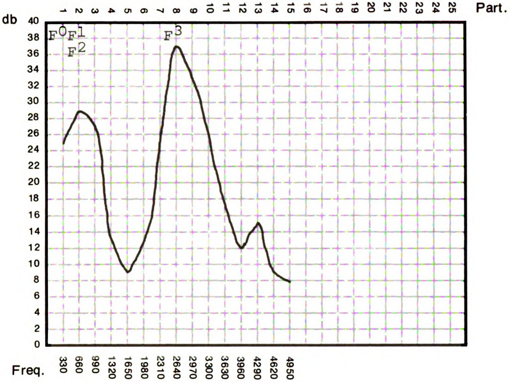
Tone #1	Tone #2	Tone #3
Mean 2.4 (Very good)	Mean 2.6 (Good)	Mean 3.6 (Above average)

Comparison of Sound Spectra

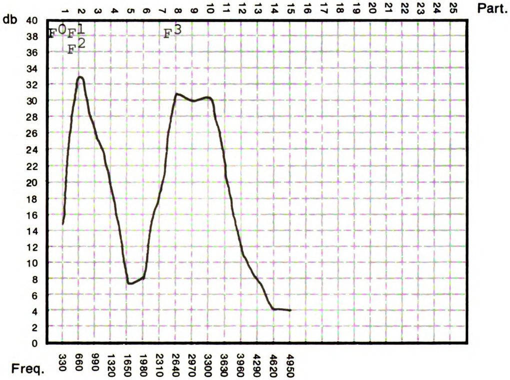
Tone #1



Tone #2


db
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F^0 F^1
F^2
F^3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950

Tone #3


db
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F^0 F^1
F^2
F^3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950

Interpretation of the Data for the Three Tones: Vowel [ɑ] at Pitch 330 Hz.

1. Auditor recognition of the [ɑ] vowel as sung by all subjects was 35%.

2. Auditor mean ratings of timbre ranged from 2.4 to 3 (from very good to good).

3. Sound levels at the time of recording were 106, 95.5, and 97 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 14 to 25 db. Tone #1, the most preferred, showed the lowest reading.

5. F1 showed an energy peak on the second partial (660 Hz.) for all tones. Decibel readings were 36, 29, and 33 respectively for tones #1, #2, and #3.

6. F2 appeared to be combined with F1 in all tones.

7. F3 appeared as a broad band of high intensity for all three tones. In tones #1 and #2 its width covered from the seventh partial (2310 Hz.) to the tenth partial (3300 Hz.) at an average reading of approximately 27 db. Peak energy on partial eight (2640 Hz.) was 36 db in tone #1 and 37 db in tone #2. In tone #3 the spectrum varied. The band covered from the eighth (2640 Hz.) to the tenth (3300 Hz.) partials. Partial eight, the highest by .5 db, was 31 db in intensity.

Vowel [i] at Pitch 165 Hz.

Phoneme Recognition by Auditors

Tone #1

[I]	[i]	[e]	other
12	7	2	1

Consensus [I]

Tone #2

[I]	[i]	[e]	other
10	8	2	2

Consensus [I]

Tone #3

[I]	[i]	[E]	other
13	5	2	2

Consensus [I]

Auditor Judgment of Timbre

Tone #1

Mean 2.3
(Very good)

Tone #2

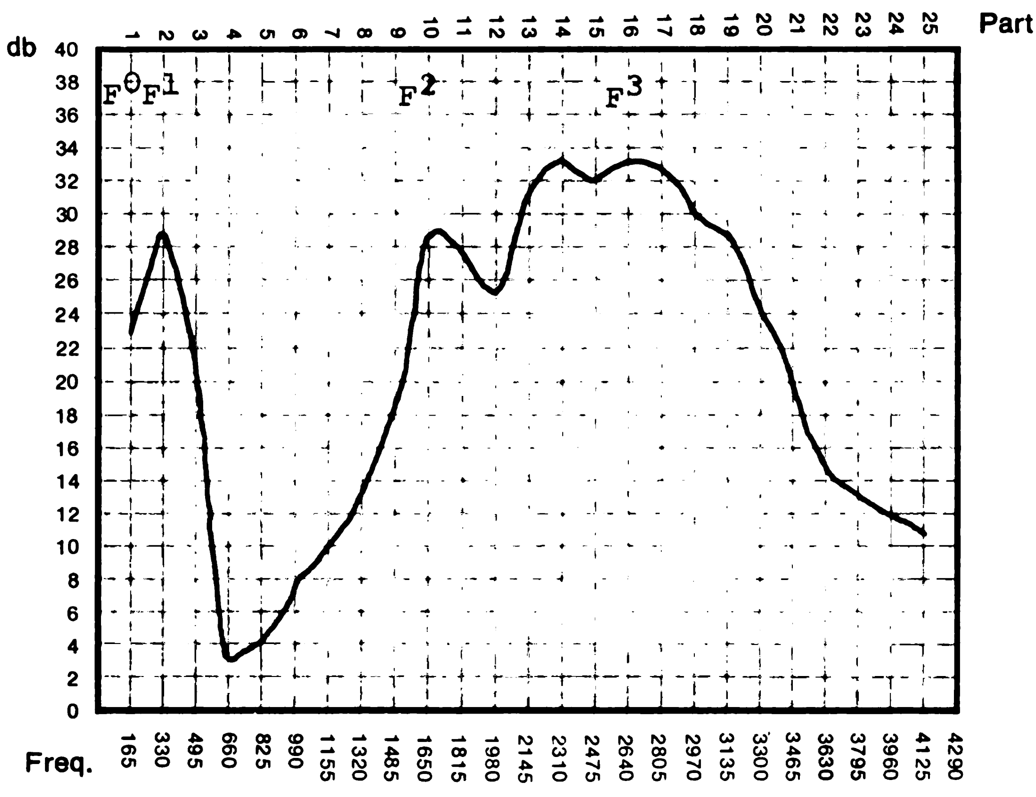
Mean 2.8
(Good)

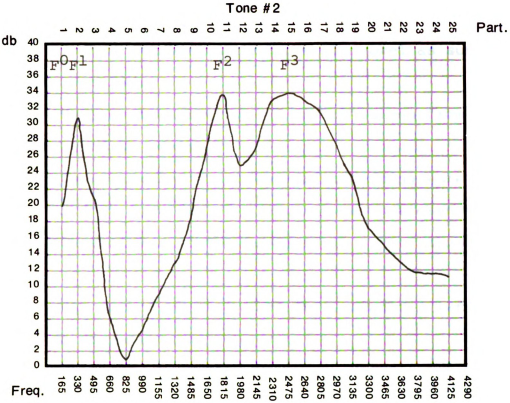
Tone #3

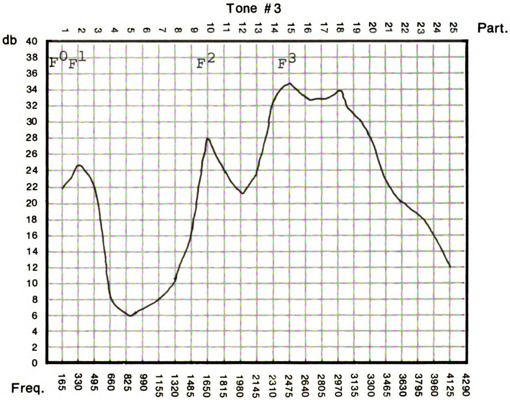
Mean 3.0
(Good)

Comparison of Sound Spectra

Tone #1




Tone #2
Part.
db
Freq.
F^0 F^1
F^2
F^3


Tone #3
Part.
db
Freq.
F^0 F^1
F^2
F^3

Interpretation of Data for the Three Tones: Vowel [i] at Pitch 165 Hz.

1. Auditor recognition of the [I] vowel as sung by all subjects was 53%.

2. Auditor mean ratings of timbre ranged from 2.27 to 3 (from very good to good).

3. Sound levels at the time of recording were 85 db, 90 db, and 87.5 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 20 to 23 db.

5. F1, second partial (330 Hz.), readings were 29, 31, and 25 db respectively.

6. F2 showed an energy peak on partial ten (1650 Hz.) in tones #1 and #3. Intensity levels for these two tones were 29 and 28 db. In tone #2 the second formant energy peak was on partial eleven (1815 Hz.) at a db reading of 34.

7. F3 appeared as a broad band of high intensity in all three tones. In tone #1 its width covered from the thirteenth partial (2145 Hz.) to the nineteenth partial (3135 Hz.) at approximately 31 db. In tone #2 its width, somewhat narrower, covered from the fourteenth partial (2310 Hz.) to the seventeenth partial (2805 Hz.) at approximately 32 db. Band width in tone #3 covered from the fourteenth partial (2310 Hz.) to the nineteenth partial (3135 Hz.) at approximately 33 db. The energy of this formant was centered at 2640 Hz. in tone #1 and at 2475 Hz. in tones #2 and #3.

Vowel [i] at Pitch 256 Hz.

Phoneme Recognition by Auditors

Tone #1				Tone #2				Tone #3		
[i]	[ʌ]	[I]	other	[i]	[I]	[ʌ]	other	[i]	[I]	other
20	1	1	0	19	2	1	0	21	1	0

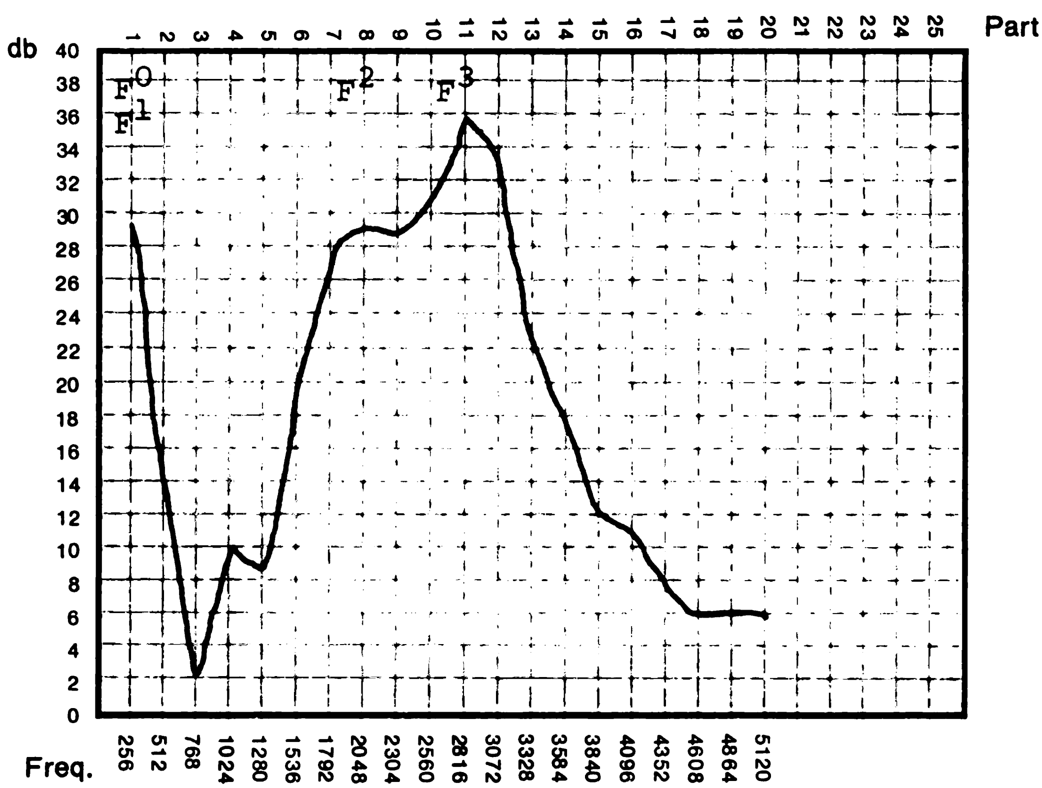
Consensus [i] Consensus [i] Consensus [i]

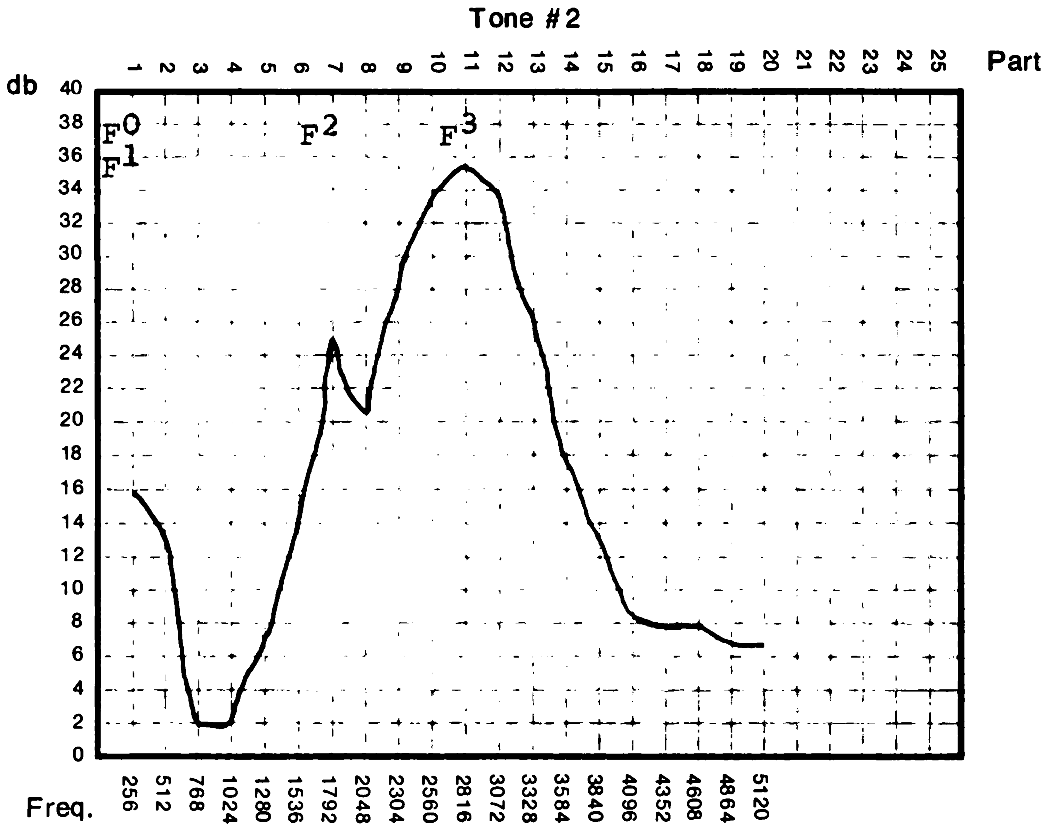
Auditor Judgment of Timbre

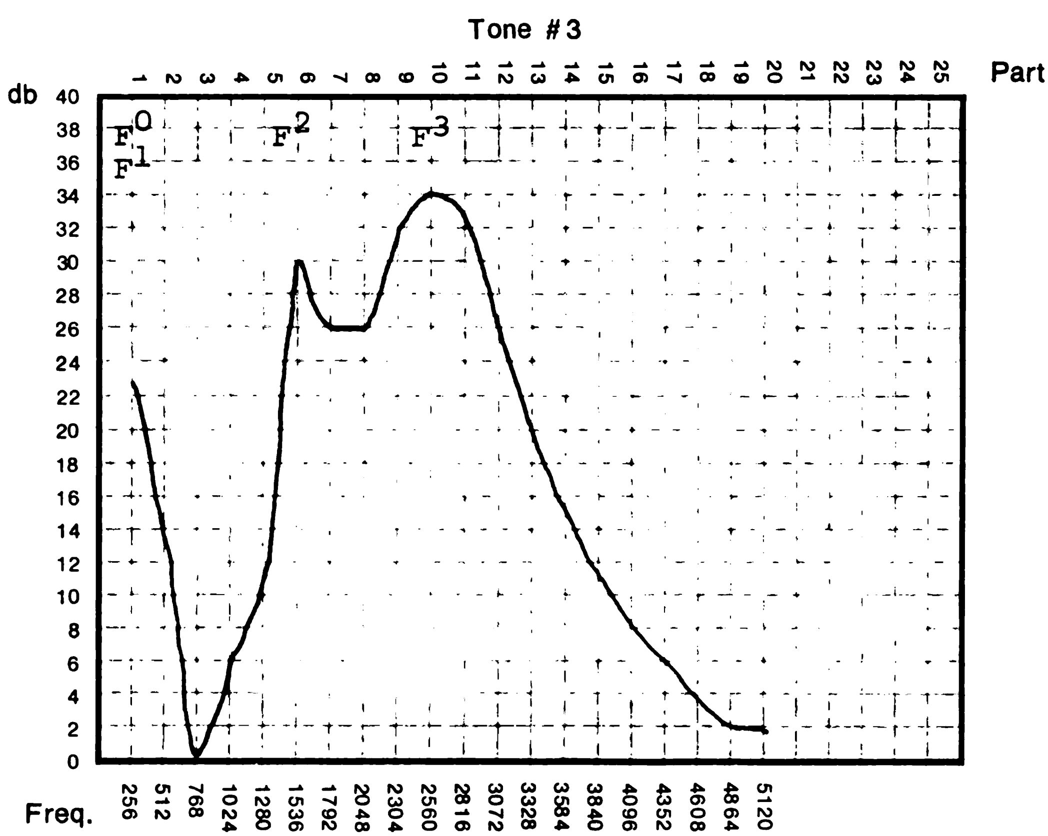
Tone #1	Tone #2	Tone #3
Mean 2.1 (Very good)	Mean 2.6 (Good)	Mean 2.7 (Good)

Comparison of Sound Spectra

Tone #1




Tone #2
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0
F1
F2
F3
Freq.
256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096 4352 4608 4864 5120


Tone #3
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0
F1
F2
F3
Freq.
256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096 4352 4608 4864 5120

Interpretation of Data for the Three Tones:
Vowel [i] at Pitch 256 Hz.

1. Auditor recognition of the [i] vowel as sung by all subjects was 91%.

2. Auditor mean ratings of timbre ranged from 2.09 to 2.72 (from very good to good).

3. Sound levels at the time of recording were 87.5 db, 94 db, and 96 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 16 to 29 db.

5. F1 appeared to be absorbed by the fundamental, first, because there were no other energy peaks present in the vicinity of F1, and second, because the intensity of the fundamental was noticeably increased in comparison with other samples.

6. F2 showed an energy peak on the eighth partial (2048 Hz.) in tone #1. The peak was on the seventh partial (1792 Hz.) in tone #2, and on the sixth partial (1536 Hz.) in tone #3. Decibel readings were 29, 25, and 30 db respectively.

7. F3 appeared as a broad band of high intensity in all tones. Partials covered in all tones were from the ninth (2304 Hz.) to the thirteenth (3328 Hz.). In tone #2 partial thirteen (3328 Hz.) was included also. The highest intensity in tones #1 and #2 was on partial eleven at 2815 Hz. In tone #3 the energy peak was on partial ten at 2640 Hz. The respective readings were 26 db, 35 db, and 34 db.

Vowel [i] at Pitch 330 Hz.

Phoneme Recognition by Auditors

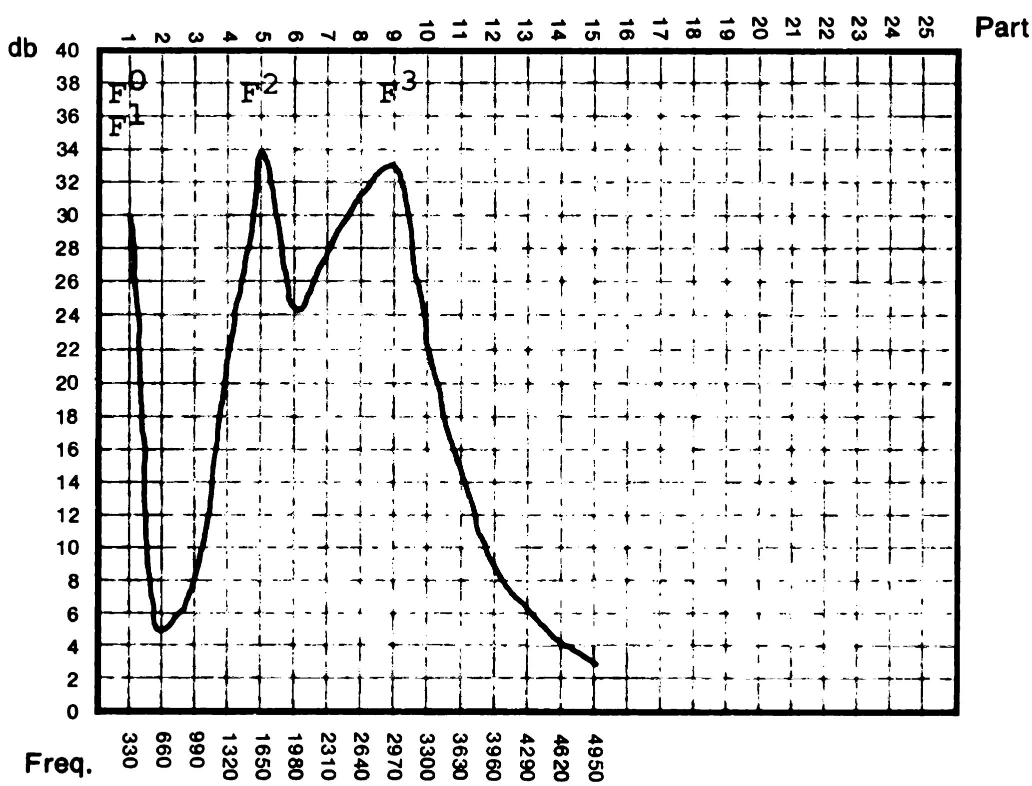
Tone #1				Tone #2				Tone #3			
[i]	[I]	[e]	other	[i]	[I]	[e]	other	[i]	[I]	[e]	other
17	4	1	0	15	6	1	0	16	5	1	0
Consensus [i]				Consensus [i]				Consensus [i]			

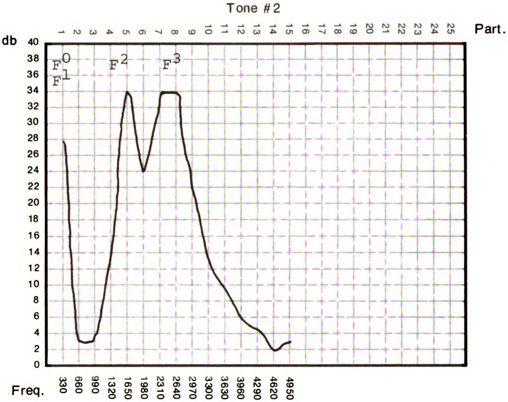
Auditor Judgment of Timbre

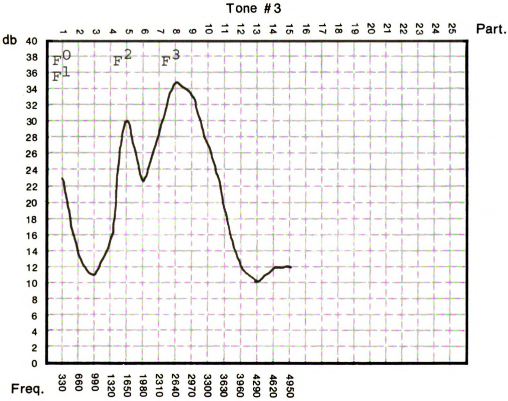
Tone #1	Tone #2	Tone #3
Mean 2.3 (Very good)	Mean 2.9 (Good)	Mean 3.4 (Good)

Comparison of Sound Spectra

Tone #1




Tone #2
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F^0
F^1
F^2
F^3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950


Tone #3
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F^0
F^1
F^2
F^3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950

Interpretation of Data for the Three Tones:
Vowel [i] at Pitch 330 Hz.

1. Auditor recognition of the [i] vowel as sung by all subjects was 72.7%.

2. Auditor mean ratings of timbre ranged from 2.27 to 3.36 (from very good to good).

3. Sound levels at the time of recording were 94.5 db, 101.5 db, and 97 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 23 to 30 db. F1 was included in this band.

5. F2 showed an energy peak on partial five (1650 Hz.) all tones. Decibel readings were 34, 34, and 30 respectively for tones #1, #2, and #3.

6. F3 appeared narrower than in preceding samples. Its width covered approximately 2 partials at the 30 db level. In tone #1 partials covered were the eighth (2640 Hz.) and ninth (2970 Hz.). Highest energy was 33 db on partial nine at a frequency of 2970 Hz. In tone #2 partials covered were the seventh (2310 Hz.) and eighth (2640 Hz.). Energy was at 34 db on both partials. In tone #3 partials covered were numbers seven (2310 Hz.) to nine (2970 Hz.). Decibel reading of partial eight (2640 Hz.) was 35.

Vowel [u] at Pitch 165 Hz.

Phoneme Recognition by Auditors

Tone #1

[u]	[o]	[U]	other
9	7	6	0

Consensus [u]

Tone #2

[u]	[U]	other
13	9	0

Consensus [u]

Tone #3

[u]	[U]	[o]	other
12	5	3	2

Consensus [u]

Auditor Judgment of Timbre

Tone #1

Mean 2.4
(Very good)

Tone #2

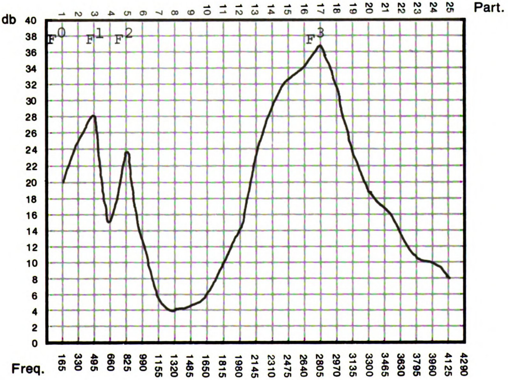
Mean 2.8
(Good)

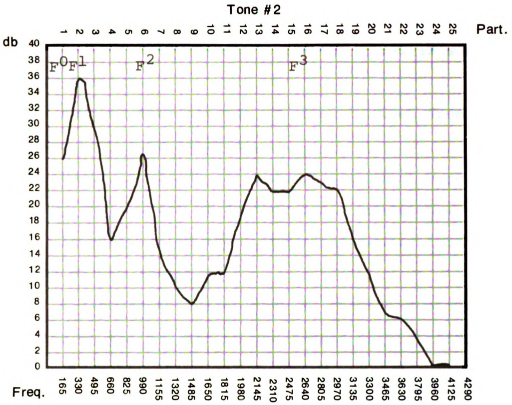
Tone #3

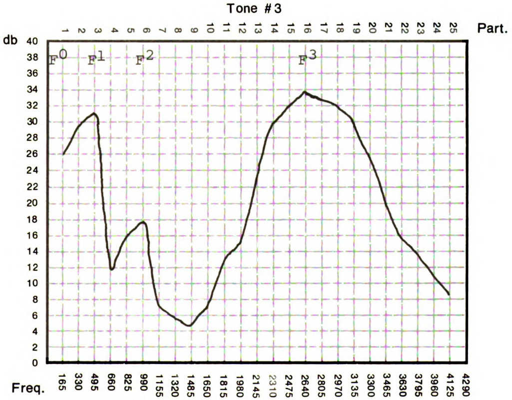
Mean 2.9
(Good)

Comparison of Sound Spectra

Tone #1




Tone #2
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0 F1 F2 F3
Freq.
165 330 495 660 825 990 1155 1320 1485 1650 1815 1980 2145 2310 2475 2640 2805 2970 3135 3300 3465 3630 3795 3960 4125 4290


Tone #3
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F0 F1 F2 F3
Freq.
165 330 495 660 825 990 1155 1320 1485 1650 1815 1980 2145 2310 2475 2640 2805 2970 3135 3300 3465 3630 3795 3960 4125 4290

Interpretation of Data for the Three Tones: Vowel [u] at Pitch 165 Hz.

1. Auditor recognition of the [u] vowel as sung by all subjects was 51%.

2. Auditor mean ratings of timbre ranged from 2.45 to 2.90 (from very good to good).

3. Sound levels at the time of recording were 91 db, 88 db, and 83 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 20 to 26 db. Tone #1 was lowest.

5. F1 showed an energy peak on the third partial (495 Hz.) in tones #1 and #3, and on the second partial (330 Hz.) in tone #2. Respective decibel readings were 28, 36, and 31 for tones #1, #2, and #3.

6. F2 showed an energy peak on the fifth partial (825 Hz.) in tone #1 and on the sixth partial (990 Hz.) in tones #2 and #3. Readings were 24 db, 27 db, and 18 db respectively.

7. F3 appeared as a broad band of high intensity in all tones, but in tone #2 it was much lower than in tones #1 and #3. Width of F3 in tone #1 at the 30 db level was from partial fourteen (2310 Hz.) to partial eighteen (2970 Hz.). Average intensity was 30 db. The peak was on partial seventeen (2805 Hz.) at 37 db. Width of F3 in tone #2 at the 22 db level was from partial thirteen (2145 Hz.) to partial eighteen (2970 Hz.) Average intensity was 23 db. The peak was on partial sixteen (2640 Hz.) at 24 db. Width of this formant in tone #3 at the 30 db level extended from partial

fourteen (2310 Hz.) to partial nineteen (3135 Hz.). Average intensity was 31 db. The peak was on partial sixteen (2640 Hz.) at 34 db.

Vowel [u] at Pitch 256 Hz.

Phoneme Recognition by Auditors

Tone #1

[u]	[U]	[o]	other
18	3	1	0

Consensus [u]

Tone #2

[u]	[U]	[o]	other
14	4	3	1

Consensus [u]

Tone #3

[u]	[U]	[o]	other
11	5	3	3

Consensus [u]

Auditor Judgment of Timbre

Tone #1

Mean 2.4
(Very good)

Tone #2

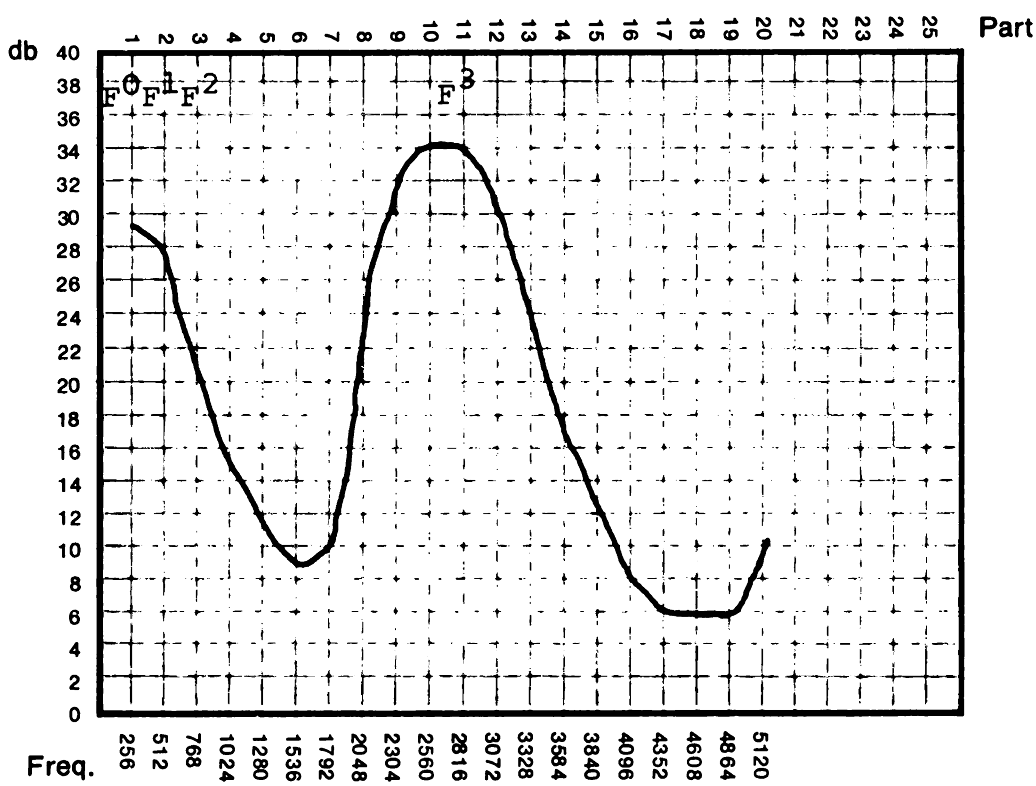
Mean 2.5
(Good)

Tone #3

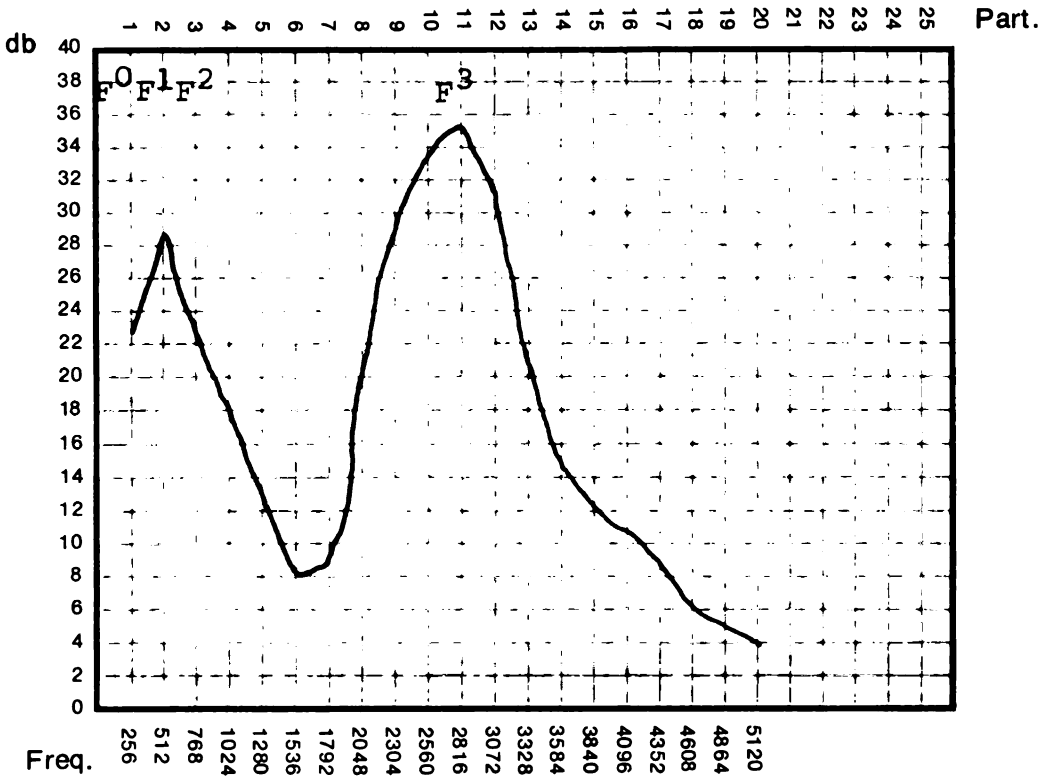
Mean 3.1
(Good)

Comparison of Sound Spectra

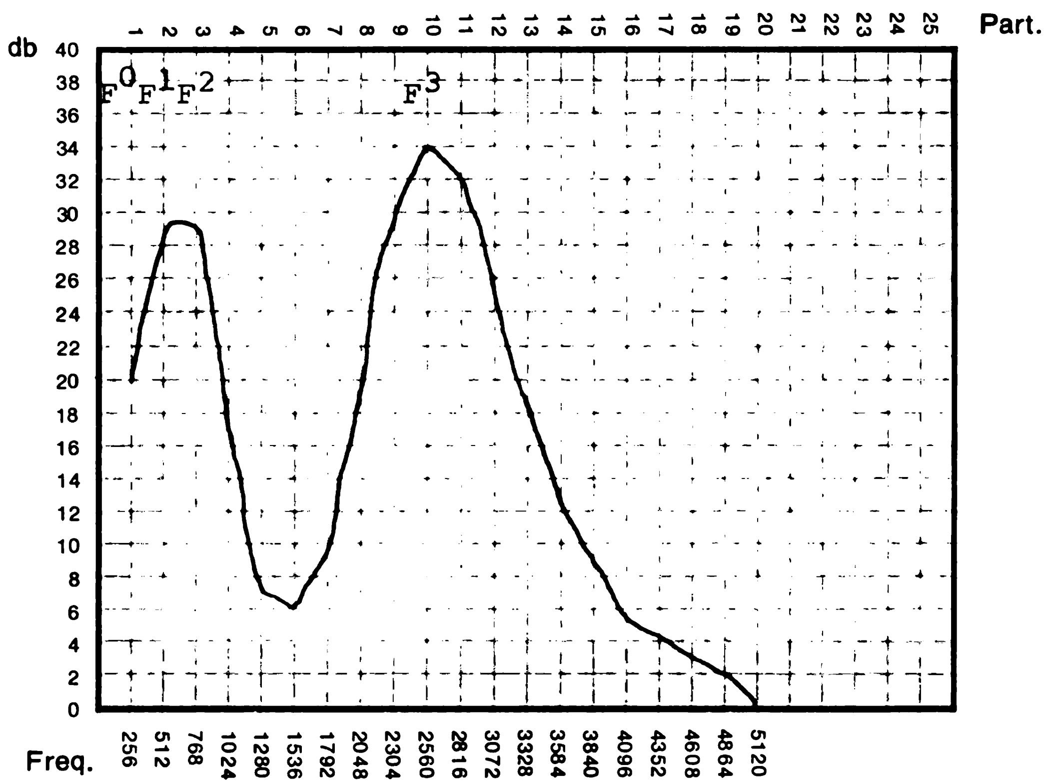
Tone #1



Tone #2


Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
$F^0 F^1 F^2$
F^3
Freq.
256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096 4352 4608 4864 5120

Tone #3


Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
$F^0 F^1 F^2$
F^3
Freq.
256 512 768 1024 1280 1536 1792 2048 2304 2560 2816 3072 3328 3584 3840 4096 4352 4608 4864 5120

Interpretation of Data for the Three Tones:
Vowel [u] at Pitch 256 Hz.

1. Auditor recognition of the [u] vowel as sung by all subjects was 65%.

2. Auditor mean ratings of timbre ranged from 2.4 to 3.55 (from very good to good).

3. Sound levels at the time of recording were 86 db, 89 db, and 97 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 20 to 30 db.

5. F1 showed an energy peak on the second partial (512 Hz.) for all tones. Decibel readings were 28, 29, and 29 respectively for tones #1, #2, and #3.

6. F2 appeared on the third (768 Hz.) and fourth (1024 Hz.) partials with the energy peak centered at partial three (768 Hz.). Respective decibel readings were 28, 23, and 29.

7. F3 was broadest in tone #1, covering partials nine (2304 Hz.) to twelve (3072 Hz.) at the 32 db level. The peak was on partial eleven (2816 Hz.) with a reading of 34 db. F3 in tone #2 covered partials nine (2304 Hz.) to twelve (3072 Hz.) at the 30 db level. The peak was on partial eleven (2816 Hz.) with a reading of 35 db. F3 in tone #3 covered partials nine (2304 Hz.) to eleven (2816 Hz.) at the 31 db level. The peak was on partial ten (2560 Hz.) with a reading of 34 db.

Vowel [u] at Pitch <u>330</u> Hz.

Phoneme Recognition by Auditors

Tone #1

[u]	[U]	other
19	3	0

Consensus [u]

Tone #2

[u]	[U]	other
21	1	0

Consensus [u]

Tone #3

[u]	[U]	[ʌ]	other
9	7	3	3

Consensus [u]

Auditor Judgment of Timbre

Tone #1

Mean <u>2.0</u>
(Very good)

Tone #2

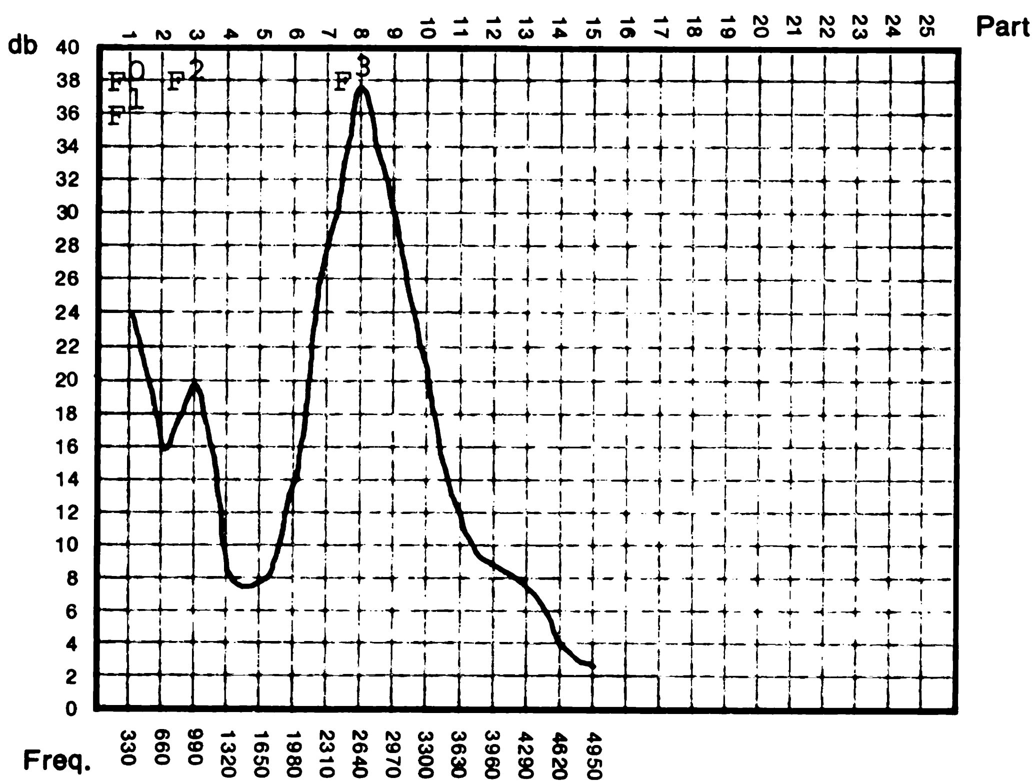
Mean <u>2.4</u>
(Very good)

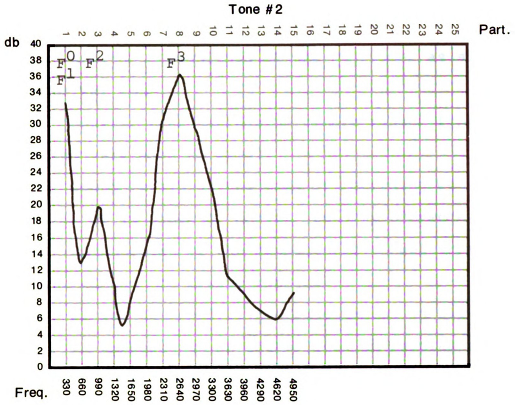
Tone #3

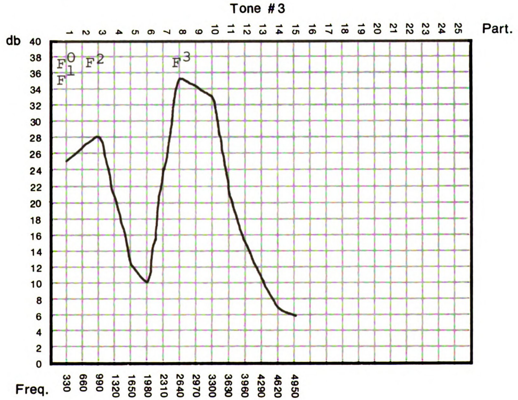
Mean <u>3.2</u>
(Good)

Comparison of Sound Spectra

Tone #1




Tone #2
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F^0
F^1
F^2
F^3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950


Tone #3
Part.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
db
40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
F^0
F^1
F^2
F^3
Freq.
330 660 990 1320 1650 1980 2310 2640 2970 3300 3630 3960 4290 4620 4950

Interpretation of Data for the Three Tones:
Vowel [u] at Pitch 330 Hz.

1. Auditor recognition of the [u] vowel as sung by all subjects was 74%.

2. Auditor mean ratings of timbre ranged from 2.0 to 3.18 (from very good to good).

3. Sound levels at the time of recording were 92 db, 93 db, and 97 db in order of auditor tonal preference.

4. Intensities of the fundamental ranged from 24 to 33 db. Tone #1 had the lowest reading.

5. F1 was absorbed by the fundamental in all tones.

6. F2 appeared as an energy peak on partial three (990 Hz.) for all tones. Respective readings were 20 db, 20 db, and 28 db.

7. F3 covered partials seven (2310 Hz.) to nine (2970 Hz.) in tones #1 and #2 at approximately 30 db. In tone #3 this formant covered partials eight (2640 Hz.) to ten (3300 Hz.) at approximately 33 db. All tones displayed peaks of energy on partial eight (2640 Hz.). Decibel readings of the peaks for tones #1, #2, and #3 were 38, 36, and 35 respectively.

TABLE 1

AUDITOR RATINGS OF TONES

Sample Number	Tone 1	Tone 2	Tone 3
1	2.1	2.7	2.8
2	1.8	2.3	2.4
3	2.4	2.6	3.0
4	2.3	2.8	3.0
5	2.1	2.6	2.7
6	2.3	2.9	3.4
7	2.4	2.8	2.9
8	2.4	2.5	3.1
9	2.0	2.4	3.2

Rating Scale: 1 - Excellent

2 - Very good

3 - Good

4 - Above average

5 - Average

TABLE 2

MEAN RATINGS OF TONES SHOWING VARIATIONS OF AUDITOR RATINGS FOR THE REPEATED TONES IN EACH SAMPLE

Sample Number	Tone 1	Tone 2	Tone 3	Tone 4	Tone 5	Tone 6	Variation.
1	3.18*	2.82	2.73	2.05	3.14	4.05*	.87
2	2.4	2.27*	3.41	3.45	1.82*	2.32	.45
3	3.0	2.4	3.27	4.41*	2.59	4.45*	.04
4	3.14	3.0*	2.27	2.86	3.0*	3.14	.0
5	2.64*	3.77	2.09	2.72	3.09	3.41*	.77
6	2.27*	3.36	4.18	2.95	2.36*	4.64	.09
7	2.82	2.90	2.86*	3.36	2.45*	4.59	.41
8	4.09	2.59*	3.05	2.55	3.36	2.44*	.15
9	2.0	3.63*	3.77	3.18*	4.32	2.36	.45

*Indicates repeated tone

The equation used to calculate the coefficient of reliability was:

$$r_{tt} = \frac{\sigma^2_{\infty}}{\sigma^2_{t}}$$

The true measure was considered to be the first rating given the repeated tone in each sample, and the error component represented the variation between the first and second ratings. The total measure was the sum of the true measure and the error component. By application of the formula given above, the coefficient of reliability was established as .956.

TABLE 3

SOUND LEVEL READINGS IN DECIBELS FOR SELECTED TONES

Sample Number	Tone 1	Tone 2	Tone 3
1	92.0	88.5	92.0
2	98.5	102.0	95.5
3	106.0	95.5	97.0
4	85.0	90.0	84.0
5	87.5	96.0	94.0
6	94.5	101.5	97.0
7	91.0	88.0	83.0
8	86.0	89.0	97.0
9	92.0	93.0	94.0

Data presented in this chapter have furnished information relating auditor judgment of sung vowel quality to tonal spectra. The experimental design given on page two of the study has been completed and information pertaining to each item has been provided. Tones have been recorded as specified; auditors have made quality judgments; spectrograms have been produced from selected tones; reliability of auditors' judgments has been established.

On the basis of the preceding data and subject to the delimitations of this study, the following chapter will be devoted to conclusions concerning formant characteristics of the selected tones.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE STUDIES

Summary

The problem of the study was to determine formant characteristics of certain sung vowels preferred by auditors. Patterns of formant behavior considered were the comparative strengths of formants, their proximity to partial frequencies, and their distribution within the spectrum.

A high factor of agreement was expected among auditors in relation to the excellence of the vowels under study. If auditors agreed concerning the quality of the sung vowels, similarities of tonal spectra were expected.

The study included the vowels [ɑ], [i], and [u]. Each of these vowels was sung on the pitches e 165 Hz., c 256 Hz., and e 330 Hz. by five singers with baritone voices judged to be of professional quality. Judges for the selection of subjects were members of the National Association of Teachers of Singing.

Tones were organized into samples each of which consisted of a specific vowel sung on a selected pitch. Tones in each sample were sung at similar intensity levels. This was accomplished by means of a sound level meter placed near the recording microphone. Subjects adjusted the meter for the proper ranges and modified the loudness of their tones to produce the required intensity readings. An acoustically treated studio was used for recording the samples.

The master tape of recorded tones was copied, edited, and spliced into the random sequence of samples and tones. Appropriate announcements and the time intervals for judging each tone were inserted in the specified order.

The twenty-two auditors chosen as evaluators of tones either met the requirements for membership in the National Association of Teachers of Singing or held the minimum of a masters' degree and taught vocal or choral music in high school or college. The tape was presented to evaluators individually by means of a tape player and earphones. Evaluation concerned quality of tones and phonetic recognition of vowels.

When auditors had accomplished the task requested of them, the results were tabulated. The three most highly preferred tones from each sample were removed from the audition tape and processed on the tone analyzer.

Spectrograms of tones were examined and reproduced on graphs indicating frequencies, intensities, widths, and locations of fundamentals and formants. Phonetic recognition and mean ratings of selected tones were tabulated and correlated with graphs for each sample.

Conclusions

Subject to the limitations of this study and on the basis of the experimental design, the results indicated the following conclusions:

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

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

a. For the vowel [ɑ] 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.

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

a. For the vowel [ɑ] 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 the 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 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.

4. The relationships between F1 and F2 were as follows:

a. For the vowel [ɑ] the intensity of F1 increased 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.

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

6. The intensity of F3 in all tones was high in relationship to the intensity of the fundamental and other formants.

7. F3 was broad on all pitches and vowels. The locations of peak energy were as follows:

a. For the vowel [ɑ] at pitch 165 Hz. the center of the band was 2805 Hz. on partial seventeen at 32.2 db.

b. For the vowel [ɑ] at pitch 256 Hz. the center of the band was 2560 Hz. on partial ten at 28.8 db.

c. For the vowel [ɑ] at pitch 330 Hz. the center of the band was 2640 Hz. on partial eight at 34.7 db.

d. For the vowel [I] at pitch 165 Hz. the center of the band was 2640 Hz. on partial sixteen at 32 db.

e. For the vowel [i] at pitch 256 Hz. the center of the band was 2816 Hz. on partial eleven at 31.7 db.

f. For the vowel [i] at pitch 330 Hz. the center of the band was 2970 Hz. on partial nine at 34 db.

g. For the vowel [u] at pitch 165 Hz. the center of the band was 2640 Hz. on partial sixteen at 31.7 db.

h. For the vowel [u] at pitch 256 Hz. the center of the band was 2815 Hz. on partial eleven at 34.3 db.

i. For the vowel [u] at pitch 330 Hz. the center of the band was 2640 Hz. on partial eight at 36.3 db.

8. Recognition of phonemes diminished as the pitch rose.

9. Formants were on partial frequencies for all tones analyzed.

Findings Related to Previous Research

Findings of the present study indicated that formants always showed peak energy on partial frequencies. Appelman stated, as quoted on pages nine and ten of the present study, that formant frequencies were not necessarily the same as partial frequencies. Further, he gave formants for the vowels included in this present study to be as follows without regard to the fundamental pitch: For the vowel [ɑ] F1 was 700 Hz., F2 was 1200 Hz., and F3 was 2600 Hz. For the vowel [i] F1 was 300 Hz., F2 was 1950 Hz., and F3 was 2750 Hz. For the vowel [u] F1 was 350 Hz., F2 was 640 Hz., and F3 was 2550 Hz. These fixed formant locations do not agree with findings in the present study which indicate characteristic relationships between fundamental pitch, partials, and formants. Sullivan spoke of a lack of relationship between fundamental and formant frequencies. In discussing the vowel [ɑ] he gave the frequency of F1 and F2 as 612 Hz. and 994 Hz. respectively above a fundamental frequency of 234 Hz. The formants are in the same vicinity as respective formants in the present study, but are not related exactly to partials. Therefore, the findings of the Sullivan study do not corroborate in detail the findings of the present investigation.

Findings of the present study indicated that the location of F3 varied according to vowel and pitch. This was in agreement with findings by Sullivan. Since pitches used were not the same in the two studies, exact comparisons of frequencies were not possible.

In the present study it was found that the strength of F3 was greater than that of the fundamental, and between one and two times as great as that of F1 in tones judged to be of good quality. Sullivan's findings were in agreement regarding formant relationships.

As stated above, the present study indicated that formants always showed peak energy on partial frequencies. Findings by Jones corroborate this. Further, though different conditions, subjects, and equipment were used, there was a duplication of formant findings for those vowels ([ɑ], [i], and [u]) sung at the pitch 330 Hz. These samples were the same in both studies. At the pitch 330 Hz. the formant locations were: For the vowel [ɑ] F1 was on partial two (660 Hz.). F2 was on partial three

(990 Hz.), and F3 was on partial eight (2640 Hz.). For the vowel [i] F1 was absorbed by F0, F2 was on partial five (1650 Hz.), and F3 was centered on partial eight (2640 Hz.). For the vowel [u] F1 was absorbed by F0, F2 was on partial three (990 Hz.), and F3 was centered on partial eight (2640 Hz.).

Recommendations for Future Studies

The present study was concerned with three different vowels sung on three pitches. Information gathered has indicated that statements concerning quality as related to tonal spectra should be limited to specific vowels sung on specific pitches. General statements describing overall quality characteristics are not valid. It is recommended that research be expanded to include all vowels sung at all singable pitch levels.

Baritone voices provided the samples analyzed in the present study. Research to include all voice classifications is needed to build a comprehensive body of knowledge identifying the spectral characteristics of tones judged to be excellent.

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.

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