EFFECTS OF AN AUDITOR'S PAST MUSICAL EXPERIENCE ON THE INTELLIGIBILITY OF VOWEL SOUNDS IN SINGING

DISSERTATION

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The purpose of this study was to determine the effects of an auditor's past musical training and experience on the intelligibility of selected vowel sounds at differential pitch levels. The specific problems of the study were to investigate the effects of extensive vocal music training, extensive non-vocal music training, and limited or no music training on an auditor's ability to discriminate accurately selected vowel sounds performed at various pitch levels. The effects of pitch and vowel sound on auditor recognition of vowel sounds in singing and the ability of each singer to be intelligible to auditors was also investigated.

An intelligibility test was prepared and administered to three experience groups of auditors, including ten college level voice teachers, ten college level instrument teachers, and ten college instructors from various non-music academic disciplines. The intelligibility test included the randomized sounds of twenty trained sopranos singing the five cardinal vowel sounds [i], [e], [a], [o], and [u] on each of the three pitches C4 (264 Hz.), C5 (523 Hz.), and C6 (1047 Hz.).

An analysis of variance with repeated measures and t-tests were employed to compare data. Results suggested that musical training in general and not vocal music training in particular had a significant effect on singing intelligibility.

All vowel sounds declined in auditor recognition as the pitch rose from C4 to C5 and then to C6, but each vowel sound had a differing rate of decline. For the most part all vowel sounds heard at C6, except [a], were intelligible to auditors at or less than the chance level. The [a] vowel sounds at C6 were generally recognized by at least half or more of the auditors.

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CHAPTER I

INTRODUCTION

Introduction and Purpose of the Study

Intelligibility of vowel sounds in singing has been the topic of numerous investigations over the past four decades. Linguists like Howie and Delattre (10), acousticians such as Bartholomew (3) and Benade (4), singing voice researchers including Appelman (1) and Vennard (18), and the singers Flechtner (8) and Triplett (17) have participated in research on singing intelligibility. These investigators and others have suggested that the formants which characterize vowel sounds make the vowel sounds distinguishable from one another. These researchers have proposed that the intelligibility of vowel sounds declines when the fundamental frequency (pitch) is appreciably higher than the first vowel formant frequency.

Formants are frequency regions of greater energy in relation to the other parts of the sound spectrum. These intensified frequencies are represented on sound spectrograms by relatively darker tracings. The spectral characteristics of any sound are merely a result of the partials collectively present in that sound. When a sound is produced, air molecules are set into motion at many different frequencies simultaneously. These frequencies are known as partials. In passing from the sound source through a resonator some partials in the sound spectrum are strengthened while others are weakened. Formants represent the frequency ranges where the strongest partials of a sound are present. A formant is identified by the center point of the frequency range composed of one or more partials. The number of formants and their relative strength is dependent largely upon what the sound source is and at what pitch the sound is being produced.

It is well established in voice research that vowel sounds are distinguished by modifying the vocal cord buzz with changes in the size and shape of the vocal tract which acts as a resonating tube. The resonant frequencies of the vocal tract (resonating tube) result in the vowel formants. It is generally accepted by voice researchers and acousticians that vowels are recognized by the position of the vowel formants. Unlike the formants which result from non-vocal sources, it is theorized that the vowel formant positions are relatively fixed (17).

A spoken vowel may have only two formants or as many as seven, but there is considerable evidence that the sung vowel has many more formants. Some researchers have reported as many as ten to fifteen prominent formants for sung vowels. It has been established in the research of Howie and Delattre (10), Nelson and Tiffany (14), Triplett (17), and many others that the first two vowel formants are the primary determinants of vowel quality. Using synthesizers to imitate speech, Delattre says, "all vowels can be synthesized with as few as two formants" (6, p. 5).

Formants vary slightly between people because of age, sex, anatomical differences, cultural influences, and because of vocal inconsistency from day to day. Taking into account these relatively small variations in the formants, many investigators believe that the formants are stationary for each vowel sound regardless of the spoken or sung pitch. In other words, when a certain set of vowel formant values exists in the sound spectrum, then a set vowel will be distinguished. This belief can be referred to as the "fixed-ratio theory."

Advocates of the fixed-ratio theory say that any time the vocal tract changes in shape or size to a significant degree, that a different vowel sound will result. The theory also states that intoning the vowel on various pitches or frequencies will not affect the position of the vowel formants. Supporters of the so-called "fixed-ratio theory" further speculate that it is theoretically impossible for a vowel sound to be intelligible (or understood) when the intoned fundamental frequency is higher than the first formant frequency band width. Appelman indicates his support of this theory when he states that

> The phonatory tract cannot become very much larger without distorting the vowel, because the acoustic formant table is permanently fixed. Formants are created when the tongue divides the phonatory tract

> into two cavities, the oral and the pharyngeal cavities, each having its own natural frequencies. When the frequency of the oral cavity is around 2000 Hz., and the frequency of the pharyngeal cavity is around 300 Hz., the resultant vowel has to be [i] if spoken or sung by a male voice (1, p. 12).

The fixed-ratio theory has had almost universal support from voice researchers for over three decades.

Recent studies in singing intelligibility have found evidence questioning the validity of some of the long-held tenets of the fixed-ratio theory, at least as it applies to singing. Investigators have suggested that there are singers who can skillfully manipulate the size and shape of the entire vocal tract in such a way that their formant frequencies can be raised and lowered to a point where vowels are recognizable even at extreme pitch levels. Morozov reports, as others have, "that great masters of the art of singing often succeed in preserving a high measure of intelligibility of their words even when vocalizing at the highest notes" (13, p. 283). This would not be possible if the formants remained stationary as the advocates of the fixed-ratio theory claim. Denes and Pinson have found that

> A wide range of formant frequencies is recognized as the same vowel, and the ranges appropriate for each vowel overlap. . . . They are also greatly influenced by the sounds that precede and follow them. It is impossible to say, therefore, that a particular vowel is invariably associated with a particular combination of formant frequencies (7, p. 187).

This statement contradicts the attributes of the fixed-ratio theory as stated by Appelman earlier.

The quote from Denes and Pinson points out an inherent weakness in nearly all intelligibility studies. Vowels are often recognized in the context in which they are placed. Furthermore, the consonants which precede and follow the vowels are important to the vowels' intelligibility. These are both factors that investigators have tended to ignore. Any intelligibility study must account for this lack of application to actual performance situations.

Several investigations of late have shown that there are significant differences in the physical acts of singing and speaking. Researchers like Sundberg (15) and Burton (5) have explained that the fixed-ratio theory which seems to fit the speaking voice so well, does not always apply to the singing voice, particularly when highly trained professional singers are involved. Many of the advocates of the fixed-ratio theory have not been acquainted with the trained singing voice and have assumed that what is true for the speaking voice must also be true of the singing voice.

There have been numerous investigations showing the many differences in the physical acts of singing and speaking and the resulting changes in the formant structures. Burton (5), Husson (11, pp. 12-15), Lindblom and Sundberg (12, pp. 1166-1179), Vennard and Irwin (19, pp. 18-23) and others have demonstrated that a singer's lip, tongue, and mandible movements are much larger than a speaker's. This has particularly been the case when professional singers have been examined during the physical act of singing. Singers have further demonstrated a marked lowering of the larynx and expansion of the pharyngeal cavity which has not been seen in speakers. These physical differences in the acts of singing and speaking have reportedly resulted in corresponding changes in the positions of the vowel formants in singing which are substantially removed from those positions found in speech. In addition to different vowel formant positions for speakers and singers, some researchers have claimed that trained singers have demonstrated the ability to be intelligible on vowel sounds performed at extreme pitch levels which is impossible according to the tenets of the fixed-ratio theory.

One of the major problems with intelligibility studies over the years has been the lack of control over potentially important variables such as auditor experience. It is also evident that many investigators were unaware of or chose to ignore the work of others. The variety of procedures employed by the numerous investigators testifies to this fact. No two researchers have investigated all of the same vowels, used auditors with similar backgrounds, or utilized singers with similar training and experience. Everything from Russian and Swedish vowels to various combinations of English vowels and consonants have been examined. Auditors' backgrounds have varied from graduate students in music, speech, or French language to linguistic experts, and amateurs in these fields and others. None of the investigations located by this researcher controlled the auditor's past experience.

It is certainly conceivable that one group of auditors could find vowel sounds to be intelligible that another auditor group would not be able to distinguish. Denes and Pinson present a rationale for this speculation.

> Knowledge of the right context can even make the difference between understanding and not understanding a particular sound wave sequence. You probably know at some airports you can pay a dime and listen in on the conversations between the pilots and the control tower. The chances are that many of these sentences would be incomprehensible to you because of noise and distortion. Yet this same speech wave would be clearly more intelligible to the pilots simply because they have more knowledge of the kind of message to expect . . . Speech recognition is based on the acoustic features of the speech wave, but it is also powerfully affected by our knowledge of the speaker, the rules of grammar and the subject being discussed (7, pp. 9, 168).

It is possible that voice teachers, because of their close relationship to the singing voice, may find vowel sounds to be intelligible, while musically and vocally unsophisticated auditors would find them unintelligible.

The information reported by past singing intelligibility investigators deserves further attention in light of the fact that variables were not controlled or even considered at times and no one based research on the findings of others. This researcher feels that the subject of singing intelligibility could benefit from a systematic series of studies which could provide better control of the variables that may influence an auditor's choice of intelligible sounds.

Purpose of the Study

The purpose of this study was to determine the effects of an auditor's past musical training and experience on the intelligibility of selected vowel sounds produced by trained singers at differential pitch levels.

Specific Problems of the Study

The specific problems of the study were

1. To investigate the effect of extensive vocal musical training and experience on an auditor's ability to discriminate accurately selected vowel sounds performed at various pitch levels.

2. To investigate the effect of extensive non-vocal musical training and experience on an auditor's ability to discriminate accurately selected vowel sounds performed at various pitch levels.

3. To investigate the effect of limited or no musical training or experience on an auditor's ability to

discriminate accurately selected vowel sounds performed at various pitch levels.

4. To compare results from the above inquiry and determine the relationship between specific musical training and the ability to identify accurately selected vowel sounds sung at various pitch levels.

Limitations

This study was subject to the following limitations:

1. Subjects were limited to sopranos ranging from amateurs with two or more years of college voice instruction and related vocal experience to semiprofessional graduate level voice students.

2. The vowels to be investigated are limited to the five cardinal vowels [i, e, a, o, u].*

3. The pitch levels represented are C4 (c. 264 Hz.) for the low or chest voice range, C5 (c. 523 Hz.) for the middle voice range, and C6 (c. 1047 Hz.) for the high or head voice range.

4. Generalizations eminating from the results of this study will be limited since the sample populations under investigation may not be representative of the total population.

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*Throughout this study vowel sounds are referred to by the appropriate symbols of the International Phonetic Alphabet (IPA).

Definition of Terms

The following definitions of terms were developed for the purpose of this study:

1. Extensively trained vocal musicians--College level voice teachers.

2. Extensively trained non-vocal musicians--College level keyboard or instrumental teachers who have had very limited, if any, formal vocal instruction.

3. Non-musicians--College level teachers with no formal musical instruction and no experience in organized musical performing organizations.

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CHAPTER II

REVIEW OF LITERATURE

The ability to sing with good intelligibility is a very important aspect of a singer's artistic achievement. While instrumental music is not normally concerned with conveying a verbal message, vocal music is closely related to the text. The words are usually an integral part of a vocal performance and the message those words carry should be understood. Because of the importance of being understood, there has been interest amongst singers, voice researchers, voice teachers, and others in discovering why singers in general and high pitched voices in particular, experience difficulty in maintaining intelligibility. The primary emphasis in intelligibility research has been centered on the problem of vowel intelligibility in singing. In addition to the research sponsored and instigated by the singing professionals, there has been a great deal of interest in singing intelligibility studies by professionals primarily concerned with the speaking voice.

Over several decades singing intelligibility research has been conducted by speech and singing voice researchers including Stumpf (1926), Bartholomew (1934), Joos (1948), Peterson and Barney (1951), Appelman (1953), Stevens and

House (1956), Rzhevkin (1956), Husson (1957), Fant (1960), Howie and Delattre (1962), Morozov (1965), Vennard and Irwin (1966), Lindblom and Sundberg (1967), Triplett (1967), Slawson (1968), Nelson and Tiffany (1968), Flechtner (1969), Webster (1970), Kirchener (1970), Sachs (1972), Large (1973), Ohala (1973), Gilbert (1973), Burton (1975), Ainsworth (1976), Seymour (1976), Sundberg (1977), and many others.

One idea which has emerged from this large body of research is a theory known as the fixed-ratio theory. The fixed-ratio theory could also be called the theory of stationary formants. The theory postulates that vowel sounds are recognized on the basis of a fixed set of vowel formant frequencies. In other words, each vowel has its own unique set of formant frequency values. Regardless of the pitch, these approximate formant frequency values will remain the same wherever the singer is intoning a vowel sound. Thus, the vowel formants are not affected by pitch. Advocates of the fixed-ratio theory have established that only the first two formants are necessary in the sound spectrum for a vowel to be understood.

Many researchers have measured the formants of numerous people and computed the average center frequencies for these formants, but the most frequently discussed values are the ones compiled by Peterson and Barney (19, p. 177). The following table is taken in part from the figures by Howie and Delattre (11, p. 2) which are based upon the

Peterson and Barney data. Supporters of the fixed-ratio theory say that the mean frequencies of the specific vowel formants will not significantly vary from the values reported in Table I.

TABLE I

NUMERICAL VALUES IN HERTZ (HZ.) FOR THE CENTER FREQUENCIES OF THE CARDINAL VOWEL FORMANTS

Vowels	[i]	[e]	[a]	[o]	[u]
Formant I	240	350	650	350	240
Formant II	2500	2200	1200	865	750

Another tenet of the fixed-ratio theory states that a vowel which is performed at a frequency or pitch which is above the first formant frequency will not be distinguishable to auditors. According to Howie and Delattre, vowels start losing intelligibility when the fundamental reaches the following frequencies for the cardinal vowels: [i, u] 350 Hz. (F4), [e, o] 450 Hz. (A5), and [a] 750 Hz. (G5). These values are all above the first formant figures presented in Table I.

While the fixed-ratio theory has enjoyed almost universal acceptance over the past four decades and a large body of research supports the theory, there have been those who have questioned some of the tenets of the fixed-ratio theory at least as it applies to the singing voice.

Studies which tend to support the fixed-ratio theory and studies which call into question some of the tenets of the theory will now be examined.

Advocates of the Fixed-Ratio Theory

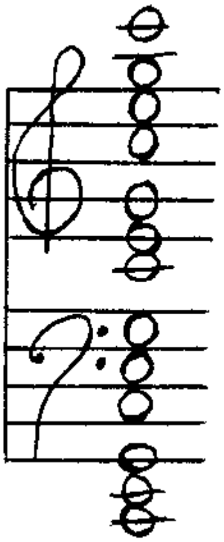
Two of the more prolific researchers in speaking and singing intelligibility have been Howie and Delattre. They are both teachers of French language and linguistics who have specialized in experimental phonetics. Howie and Delattre (11, pp. 6-9) tested the fixed-ratio theory in 1962 with a baritone and a soprano singer. Both singers were native American speakers with trained singing voices. The level of training of the singers, however, was not reported.

The singers were asked to sing the following nine French vowels which include the five cardinal vowel sounds: [a], [i], [e], [o], [u], [y], [ø], [ɔ̃], [ɛ̃]. The baritone sang each of the vowels on the pitches C3, E3, G3, C4, E4, and G4 while the soprano sang each vowel on the pitches C4, E4, G4, C5, E5, G5, and C6. These pitches are presented in Table II.

The resulting 117 sounds were recorded and then divided into four listening tests with two tests consisting of the initial one-half second of utterance and the other two tests with the middle one-half second of utterance. All four tests were presented in random order to fifteen auditors

TABLE II

PITCHES COVERING THE USABLE RANGE OF MOST SINGERS
IN THREE MODES OF NOTATION



C6--(c. 1047 Hz.)
G5--(c. 784 Hz.)
E5--(c. 659 Hz.)
C5--(c. 523 Hz.)
G4--(c. 392 Hz.)
E4--(c. 330 Hz.)
C4--(c. 262 Hz.)
G3--(c. 196 Hz.)
E3--(c. 165 Hz.)
C3--(c. 131 Hz.)
G2--(c. 98 Hz.)
E2--(c. 87 Hz.)
C2--(c. 65 Hz.)

(all graduate students in French language). The auditors were required to identify each vowel sound they heard.

Howie and Delattre found that all vowel sounds lost intelligibility as the fundamental frequency rose, and all vowels sung appreciably higher than the average center frequencies of the first formants in speech were found to be completely unintelligible. An important observation was that all vowels sung on C6 (1056 Hz.) were consistently identified as [a].

> A likely explanation for such consistent perception of [a] on C6 (1056 Hz.) is to be found in the assumption that the ear effectively averages two vowel formants which are close together, receiving from these two formants an impression which is highly similar to that which would be heard from one formant placed at a position somewhere intermediate between them . . . The fundamental tone of C6 (1056 Hz.) is thus considered to play the role of a single

> "average" formant for the vowel [a] since its frequency is nearly midway between the frequencies of [a]'s normal first formant (ca. 700 Hz.) and normal second formant (ca. 1200 Hz.). The result is that all utterances on high C are interpreted by listeners as [a], no matter what vowel the singer may attempt to produce (11, p. 8).

The vocal attack was found to contribute slightly to the intelligibility of all vowels and especially to the intelligibility of the closed, rounded vowels [u, y, o, ø]. The vocal attack was found to have the opposite effect on the intelligibility of the two nasal vowels [ɔ̃, ɛ̃] which were generally less intelligible in the initial segment than in the middle segment.

While the results of this study by Howie and Delattre support the tenets of the fixed-ratio theory, the research has some problems. First of all, the use of only two singers to represent the population of singers, especially when two different vocal classifications are involved, is questionable. Results obtained from such a small sample may not be generalizable to a normal population. Another point which deserves consideration is the fact that the vocal attack is present in all singing performances and any attempt to compare the results obtained from a study like this one with an actual performance situation would not be acceptable.

The auditors for this study by Howie and Delattre were forced to make a choice or guess when in actual fact some of the vowel sounds may have been completely unintelligible.

It would have been more appropriate to have added another response which would allow the auditors to choose "none of the above." Another question stems from the fact that the auditors for this study were all graduate students in French language who may or may not find vowel sounds in singing as intelligible as another group of auditors from a different background. Overall the study has presented some provocative speculations about singing intelligibility and has been an important contribution to the field of vocal research.

Another study of a similar nature which was also supportive of the fixed-ratio theory was conducted by Morozov in 1965. Morozov employed two basses, one baritone, three tenors, two mezzo sopranos, two sopranos, and seven high soprano children as subjects in his study. All of the singers with the exception of the children were students or graduates of the Leningrad Conservatory of Music. The children were sopranos from the children's choir of the M. I. Glinka Leningrad Academic Chorale with ages ranging from ten to fourteen years. All of the subjects were to sing twenty-five Russian vowels and consonants on pitches ranging two octaves for the adults and one and one-half octaves for the children. The only datum reported about the six auditors employed in this study was that they had normal hearing. The pitch range investigated covered all the diatonic notes from 98 Hz. to 1048 Hz.

Morozov discovered that the male vocalists produced sounds which had the widest range of intelligibility with one and one-half octaves while the women and children managed only an octave or less. Morozov related that,

> according to our data, optimum intelligibility in singing occurs at the middle notes of the voice range, becomes somewhat worse at the low notes, and declines considerably at the high notes. The last effect is particularly acute in female voices (17, p. 281).

Morozov's study was more comprehensive in the handling of the question of intelligibility with more vowels and even consonants being tested and his subjects were more numerous than the previously discussed study, thus better representing the population of singers and the variables. Morozov measured the entire pitch range note by note which is admirable, though probably not necessary. One weakness is the fact that Morozov apparently thought so little of the effect of the auditor that he did not bother to give any details about the rather small number of auditors employed. While he did test the effect of pitch on intelligibility, Morozov said nothing about the intelligibility of the individual vowels.

Another notable study in singing intelligibility of a somewhat different nature was conducted by Nelson and Tiffany (18, pp. 22-28, 33) in 1968. Nelson and Tiffany created a Sung Intelligibility Test (SIT) consisting of short sung phrases rather than isolated vowel sounds like the two previous studies used. Forty-four "aria-like" phrases were composed in such a manner that certain key words would fall on either C5 or G5. These phrases were sung by four experienced soprano solo artists and were judged for intelligibility by forty auditors, one-half of whom were musically sophisticated. One-half of the forty-four phrases were devised to test vowel discrimination at the two pitch levels while the other one-half were designed to test consonant discrimination on G5 only. The test words were arranged in such a way that several different vowels and consonants could be appropriate to the context, and grammatically permissible. For example, "I discovered I was lost," or "I discovered I was last" (17, p. 24).

The results of the study pointed out that vowels were identified correctly only at chance level on G5 while those at C5 were the most intelligible vowels. The study suggested again the strong effect that pitch has on intelligibility. The lack of intelligibility on G5 was most notable with the open vowels like [ɔ, ɛ]. Unlike the vowels, the consonants proved to be highly intelligible (90% and above) on G5. The high intelligibility of the consonants suggests that they may be somewhat resistant to the effects of pitch.

While Nelson and Tiffany's use of four sopranos is an improvement over the one or two to a part which has been used in other investigations, this is somewhat less impressive when the authors reveal that each of the sopranos sang different phrases and all of the impressive number of auditors did not hear the same stimulus. In addition, it must be noted that the opportunity to control the auditor's past experience (because of the use of forty auditors one-half of whom were musically sophisticated) was apparently allowed to pass. Nelson and Tiffany report nothing about the effect of the auditor's experience on intelligibility. A positive note to this study is the fact that this research comes closer than any others to an actual performance situation. Like the other studies discussed thus far, the Nelson and Tiffany research supports the fixed-ratio theory for vowel sounds.

One further study which falls in the realm of supporting evidence for the fixed-ratio theory, but brings into question some of the results of past investigations, is a study by Flechtner (9, pp. 23-26) in 1969. Flechtner assembled twelve sopranos varying in experience and training from freshman voice majors to mature singers with many years of training and professional experience. The sopranos were asked to sing six vowels [i, I, e, ɛ, æ, a] on each of five pitches (B4, F4, B5, F5, B6). Each vowel was sustained for six seconds. The recorded vowel sounds were edited so that the steady state of the tones (between the second and fourth seconds) could be fed into a Sonic Analyzer. Test patterns for four of the twelve singers were played for forty-two people, most of whom were graduate students in music and speech. No reason is given why only four of the twelve singers were used or how the four were selected. Furthermore, there is no indication of whether or not the vowel sounds were randomized for testing purposes. Flechtner's instructions to the auditors were:

> The listeners were told that they would hear vowel sounds only (no words) and they were asked to circle the vowel they heard or perceived or recognized on the answer sheet. It was found that intelligibility of the intended vowels declined with rise in fundamental pitch (9, p. 24).

This conclusion is in line for the most part with the previously discussed investigations supporting the fixed-ratio theory. Flechtner also found that the first formants of the sung vowels agreed with the average first formants for spoken vowels as presented by Peterson and Barney. A conclusion by Flechtner is "that the intelligibility of [a] is never as high as some of the other vowels, but also never declines as far as the others" (9, p. 24). In other words, the [a] vowel is not always the most intelligible vowel, but it is not effected as drastically by pitch as the other vowels.

Flechtner did not take advantage of many opportunities to make her study more plausible. For instance, she started with twelve sopranos and for some unreported reason had the auditors listen to only four of the singers. The large number of auditors is impressive, but no controls were placed upon selection of the auditors. Flechtner only played the middle two seconds of the six second sounds that she recorded for the auditors, thus eliminating not only the attack, but the release as well. This could have effected the intelligibility of the vowels performed and isolated this study from practical application to vocal performance where attacks and releases are always present. Finally, Flechtner does not give the reader of her research all the information that is necessary for a complete understanding of the research auditors. In addition, the auditors were given no opportunity to respond on the test that the sounds they were hearing were unintelligible. Thus, auditors probably had to guess at times.

In contrast to the studies discussed thus far which support the fixed-ratio theory, a study by Triplett (28, pp. 6-8, 50) in 1967

> demonstrated an important difference suggesting the possibility that seriously degraded intelligibility may not be an immutable concomitant of high pitched singing provided articulation is appropriate to the special demands of singing (18, p. 23).

Triplett (28, pp. 6-8, 50) recorded two student sopranos singing the five cardinal vowels [i, e, a, o, u] on the pitches C4, E4, G4, C5, E5, G5, and C6. Triplett served as the only auditor. One of the sopranos reportedly was able to make an [i] vowel sound intelligible on the highest pitch (C6-1056 Hz.). However, when the attack portion of the vowel was removed at the suggestion of Pierre Delattre, who felt the attack should not be considered, the vowel was identified as [a]. In attempting to explain why the soprano was at first intelligible, Triplett reasoned:

> At the start of the tone she was intent on producing the vowel color, and somehow managed to do this by emphasizing the partial that corresponds to the third formant of [i], making the sound intelligible to the listener. Very soon her desire for better voice quality became predominant, she allowed the intensity of the important partial to decrease and the sound became [a]. It is interesting to note that when the sound was heard in its entirety, the [i] seemed to carry throughout the tone in the mind of the listener (28, p. 8).

Triplett further reported that careful examination of the initial portion of the [i] vowel revealed that the third formant was stressed which may be a reason why the vowel was intelligible at least to one auditor. Triplett confirms the observation of Howie and Delattre and others that most vowels produced on high C6 are identified as [a].

While this study does present some interesting speculations, the weaknesses in the study make questionable some of the results. Only two sopranos were used as subjects which is not representative of the whole population of sopranos. Furthermore, the idea that the attack can not be considered as part of an intelligible vowel sound is not following practical application to performance. Probably the most disturbing weakness to this study is the fact that the researcher himself was the only auditor reported. Not only can an investigator be biased in the decisions made about his own study, but one auditor from any background can not be considered representative of a population of auditors. While the results of the study tend to confirm the tenets of the fixed-ratio theory with the exception of the [i] vowel sound on C6 being intelligible, any results must be looked upon as speculatory until more evidence is produced.

Evidence Against the Fixed-Ratio Theory

Although there seemed to be some weighty evidence in support of the fixed-ratio theory, early investigations were conducted for the most part by linguists, acousticians, and persons trained and concerned primarily with the speaking voice. Criticisms of some of the earlier studies included the use of small and often untrained groups of singers, no controls were exerted over the auditors, little if any use of variables used by others such as the same vowels or pitches, and the fact that assumptions were often made about the singing voice based upon knowledge of the speaking voice. The past decades have produced a new group of investigators, with an interest in singing intelligibility, who have been vocally trained and are principally concerned with the singing voice. Unfortunately, some of the same problems were evident in the new research that were present in the previously discussed research. Nevertheless, some of the latest research has raised important questions about the validity of the fixed-ratio theory, at least as it applied to the trained singing voice.

The first studies which began to question some of the long accepted tenets of the fixed-ratio theory, examined the differences between the physical acts of singing and speaking. Although the majority of these studies did not surface until the late sixties and the seventies, the roots of this research went back to the work of Raoul Husson. After six years of research from 1951 to 1957, the first results of Husson's work were published in a series of articles in The NATS Bulletin in 1957.

Husson (12, pp. 12-15) examined the vocal tracts and articulatory muscles of singers at the Paris Opera. This was accomplished by the use of tomography, x-rays, and photography. Husson found substantial differences in the physical acts of singing and speaking. Such factors as a lowering of the larynx, expansion of the pharyngeal wall, and larger mouth and jaw openings were observed as the subjects sang. These results were compared with observations made as the singers spoke.

Husson pointed out three areas where singing demanded more on the voice than speaking. During speech, men and women generally spoke around 100-300 Hz., sometimes reaching 500 Hz. with a high speaking female. This could be compared with the singing voice which must produce sounds from 400-1,100 Hz. and sometimes as high as 1,300 Hz. Another marked difference which Husson discussed was the greater intensity demands of singing as compared with speech. Intimate conversation rarely exceeded forty decibels while voices singing the operatic repertoire on stages advanced to as much as 125-130 decibels. Husson further pointed out that a speaker averaged a fifth of a second on the vowel sounds spoken, which if spoken at 150 Hz. would have required the recurrent nerve to send thirty successive influxes to the vocal cords, causing them to contract thirty times. This was compared to the tenor who held a high C5 (523 Hz.) for ten seconds and forced his recurrent nerve to conduct more than 5,000 successive influxes and his vocal cords to contract 5,000 times.

While Husson did not deal directly with the question of intelligibility in singing or with the fixed-ratio theory, his studies were the catalyst for numerous later investigations by Vennard and Irwin (29, pp. 18-23), Lindblom and Sundberg (16, pp. 1166-1179), Burton (6), and Benade (5) who have made an important contribution to the research on singing intelligibility.

One of the most active investigators in the area of singing intelligibility over the past decade has been Johan Sundberg. Sundberg, a singer and a voice researcher, has collaborated with speech expert and acoustician Gunner Fant to examine the singing voice. Much of their work has been concerned with comparing speech and song. Sundberg and Fant's investigations have shown, like Husson's research, that the physical acts of singing and speaking were considerably different. The following study is typical of the work published by Sundberg (26, pp. 28-47) in 1970.

Sundberg examined the formant frequencies and articulation movements of four trained bass singers as they spoke and sang nine Swedish vowels [u, o, a, æ, e, i, y, ʉ, ø] at a fundamental frequency of approximately 110 Hz. The recorded sounds were analyzed on a sonagram. Each singer was also photographed frontally while speaking and singing. In addition, three of the four singers were subjected to lateral x-rays as they phonated.

The photographs and the x-rays revealed that in singing as opposed to speaking the larynx was lowered, the jaw and lip openings were greater and the lips protruded on frontal vowels like the [i] and [e]. In addition, the velum was arched, the tongue tip was back, and the back of the tongue descended on the back vowels [u, o, a] as the larynx dropped. These articulatory movements corresponded with changes in the formant structure normally fixed in speech.

> Sung vowels as compared with the spoken vowels displayed the following four characteristics as regards the formant frequencies: 1. F2 is lowered in the non-back vowels; 2. F3 is raised in the back vowels and lowered in the other vowels; 3. F4 and F5 are lowered in all vowels; 4. The frequency distance between F3 and F4 is reduced in all vowels (26, p. 32).

This study by Sundberg (26, pp. 28-47) seems to indicate that the fixed-ratio theory may not completely apply to the singing voice. The movement of formants shown in this study is in opposition to the stationary formant tenet of the theory.

Basically, this is a good study, though it might have been improved with additional subjects and a wider range of pitch selections. The results of this research have been replicated by similar studies by Burton (6) in 1975 and an earlier investigation by Vennard and Irwin (29, pp. 18-23) in 1967.

In another study conducted in 1974, Sundberg (25, pp. 838-844) recorded a soprano, who was an experienced soloist, as she sang six vowels [u, o, a, e, i, y] on each of four pitches C4, G4, C5, and F5. As the soprano sang the vowels on each pitch, she was photographed frontally and her jaw movements were monitored by a special device which consisted of a helmet worn by the singer to which a bar was fastened. The bending of this bar by the movement of the singer's jaw was recorded on an oscillograph. Each of the twenty-four sounds were recorded three times so consistent readings could be made. Spectrographic analysis of the sung sounds allowed the first three formants to be measured.

Sundberg (25, p. 843) reported that the first formant frequency raised as the jaw increased its opening and the jaw opening was related to rising pitch. All vowels except

[a] were produced with a jaw and lip opening that increased as the pitch rose. It was also reported that the formant frequencies were similar to those found in normal speech as long as the fundamental frequency or pitch was lower in frequency than the average first formant normal in speech. However, when the fundamental frequency rose above the first formant normal in speech, the first formant would move to the proximity of the fundamental. In other words, the first formant moved to meet the fundamental frequency when that fundamental moved above the normal formant position. Simultaneous changes in the second formant frequency were also noted. Sundberg called this moving of the formants in conjunction with pitch a tuning of the formants. When considering the effects of these formant shifts on intelligibility of the vowel sounds, Sundberg's hypothesis was that "in the pitch range considered the soprano does not lose very much at all, and that indeed she would lose more of intelligibility if she retained her normal speech formants" (27, p. 29). This hypothesis was based upon empirical knowledge along with a systematic study of other sopranos.

Sundberg's study (25, pp. 838-844) is comprehensive except for having only one singer serve as a subject. It would have been more appropriate perhaps to use a number of subjects with soprano voices exploring a wider range.

References to intelligibility in singing were merely speculations since no auditors were employed to test the intelligibility of this one subject.

The reported moving of the vowel formants in conjunction with the pitch rising above the normal first formant in speech is evidence which tends to question the accuracy of the fixed-ratio theory as it applies to the singing voice. However, this study needs to be replicated with more subjects, a wider pitch range, and possibly the use of a controlled group of auditors to test intelligibility before the fixed-ratio theory as it applies to the singing voice can be dismissed.

Loren Jones, a voice teacher and choral director, speculated about how and why some trained singers may be able to change the formant positions normal in speech.

> By the time one is about a year old he has learned to produce most of the vowels with fairly good discrimination. In fact, we have learned the skill of manipulating the spaces of our vocal tract at such an early age that we do not recall ever having learned it. The disciplines of the singing voice, with a much wider range than speech and much more specific and more sustained pitches, demand a much greater degree of proficiency in controlling the spaces of the vocal tract and the resulting formants (13, p. 13).

Of course, research has not yet been sufficient to call for an acceptance of this view, though it may be shown to be correct at some future date.

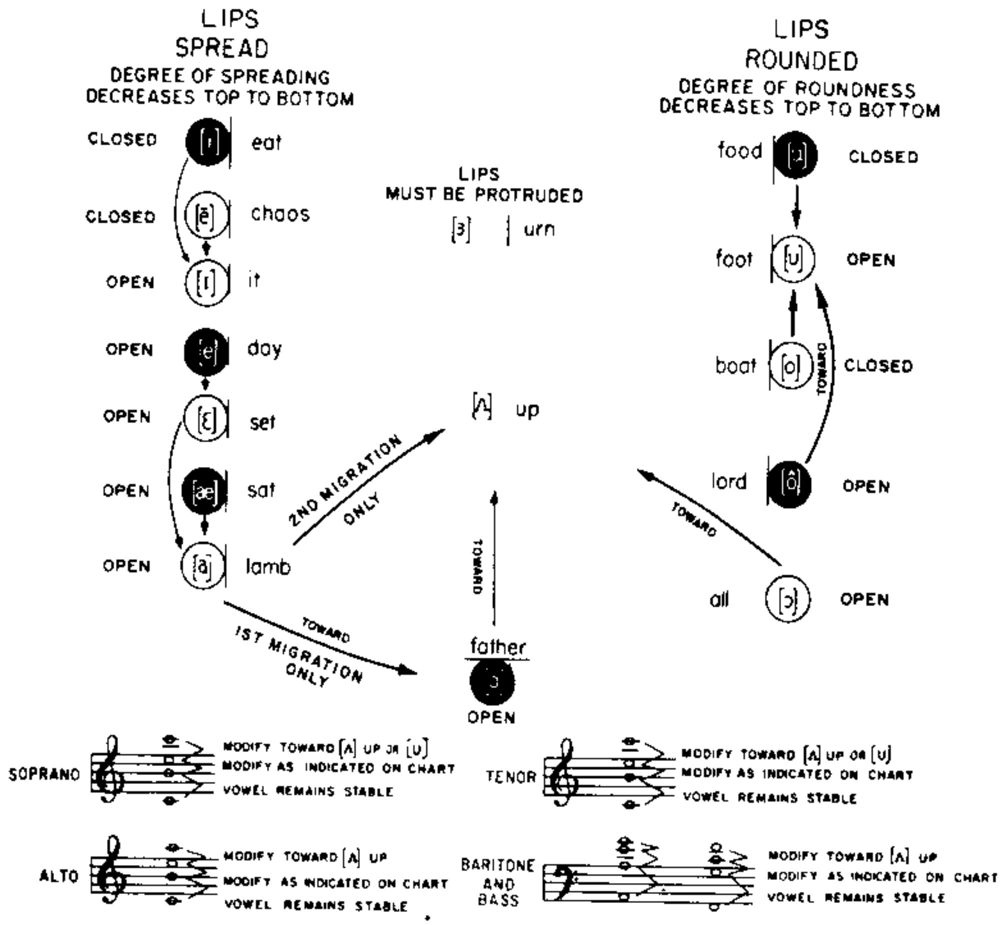
Vowel Migrations or Modifications

One technique many singers use in order to attempt an improvement in quality and intelligibility at high pitches is to introduce modifications in their ordinary vowel articulation when singing at extreme pitch levels. These vowel modifications can also make it easier for a singer to produce pitches in the high and in the low range. Appelman (3, p. 6) postulates that the proper vowel modifications or migrations can enable singers to maintain intelligibility of vowel sounds on high pitches. The fixed-ratio theory postulates it is impossible to maintain intelligibility of vowel sounds on high pitches, yet Appelman, in an apparent contradiction, supports the fixed-ratio theory as well as the vowel migration theory.

The chart found in Figure 1 outlines Appelman's system of vowel migration or modification. The following is an explanation of the logic of the chart.

> The migration chart is a conceptual aid that compels the singer to create the accurate phonetic domain of the twelve vowels through changes of frequency and intensity. The chart was designed to be a visual and aural device to preserve the integrity of the vowel by means of auditory feedback. The logic of the chart is based upon the acoustical fact that if the frequency to be sung changes so much as to go above the frequency of the lowest formant of the vowel, the resultant sound will be heard as some other vowel. This acoustic phenomenon I have called vowel migration (3, p. 7).

Appelman seems to be contradicting himself when he claims that the chart in Figure 1 shows how to preserve the



Vowels are stable within pianissimo (pp) and piano (p) intensities. As the vocal force is increased above mezzo forte (mf) the vowel migrates as indicated.
Basic vowels--shaded. Quality alternate vowels--unshaded.

Source: Appelman, "Interview," NATS Bulletin, XXXVIII, (November/December, 1981), p. 7.

Fig. 1--Migrations of vowels which enable singers to be intelligible as the pitch rises.

integrity of the vowel on higher pitches, while at the same time stating that the chart is based upon a tenet of the fixed-ratio theory which maintains that it is theoretically impossible for a singer to be intelligible on the highest pitches.

Figure 1 shows the standard modifications in articulation that many singers employ to enable them to maintain vowel intelligibility. While the singer is modifying the original vowel toward another vowel, the original vowel's integrity is kept in the ear of the auditor.

Loren Jones (13, pp. 13-17) is one of many voice teachers who, like Appelman, recommends the same modifications in vowel articulation as outlined in the chart in Figure 1. Jones adds one further point not expressed in the chart. He says that when a singer needs to discriminate between the [e] and [ɛ] vowel sounds in the high pitch range, a diphthong may be added to aid the listener in determining the difference between the two sounds.

When singers alter their articulation on high and low pitches, they do so by changing their lip openings, jaw excursions, larynx positions, and basically the shape of their entire vocal tracts. This may result, as discussed earlier, in a raising or lowering of the formant frequencies. The concept presented earlier by Sundberg (27, p. 29) concerning the tuning of the formants in high pitched singing in which the fundamental reportedly replaces the first formant, may well benefit a singer who must sing in the high pitch range. On the basis of empirical evidence reported by many singers and teachers of singing, Sundberg has stated that a skilled soprano can benefit in many ways by learning how to tune the formants.

> First, she produces strong sounds at the lowest possible price as regards vocal effort: her voice can be heard more easily when accompanied by an orchestra, and this appears to be a rather sensible criterion of a successful solo singer. Second she avoids substantial, pitch-dependent loudness variations, which otherwise would have to be compensated for by means of vocal effort. Thirdly, she does not seem to lose very much as regards vowel intelligibility as compared with a case where she uses the same formant frequencies for a given vowel regardless of pitch . . . Fourth, she may probably use the formant frequencies to reduce the timbre differences between vowels sung in chest and mid-registers (27, p. 34).

These speculations by Sundberg could, if verified by further research, challenge some ideas about the fixed-ratio theory's accuracy--at least as it applies to the singing voice. Further quality research needs to be conducted in this area of speculation which could either reinforce or refute the ideas in the preceding discussion.

The Singer's Formant

No discussion of singing intelligibility and the effect of formants would be complete without some mention of the singer's formant. Over many decades the phenomena of the singer's formant has been reported by numerous investigators including Bartholomew (1934), Rzhevkin (1956), Fant (1956), Vennard and Irwin (1967), Flechtner (1969), Sundberg (1974), and Seymour (1976).

Bartholomew (4, pp. 25-33) first reported in his study of 1934 the existence of extra added formants which were especially noticeable in good men's voices. Bartholomew collected over a thousand records of sounds produced by over forty male and female voices of all degrees of training and ability. The sounds were sung on various vowels at frequent points throughout the pitch range with different intensity levels. (None of the control measures were reported.) These sounds were examined with the aid of a Henrici analyzer in the Bureau of Standards at Washington. Judgments were made about the quality of the voices in question by unreported numbers of auditors with experienced musical taste and acquaintance with the voice. Bartholomew's results revealed

> Good male voices show a decided tendency toward strengthening of a low partial somewhere in the general range of 500 cycles or lower . . . An overwhelming majority of the total number of records taken show the presence of a high formant, usually lying for male voices between approximately 2400 and 3200 cycles. This formant is present in varying amounts in all male voices tested, though in some poorer ones the range runs higher . . . Speaking generally, the better the voice, or the louder the tone, the more prominent this formant becomes (4, p. 27).

Apparently women's voices were not found to have the characteristic singer's formants.

Bartholomew, working with the best equipment available during his day, reported some interesting results concerning these two singer's formant regions. The number of people tested was sufficient, but so many details important to a scientific investigation were not reported. In all likelihood, Bartholomew probably was one of the best researchers of his day, but he certainly should have reported more diligently his specific research variables.

A study by Rzhevkin (20, pp. 215-220) in 1956 confirmed the results of Bartholomew for the most part. Rzhevkin had two bass singers, one experienced and one inexperienced in singing, sing the five cardinal vowels on pitches corresponding to 94 Hz., 124 Hz., 169 Hz., 217 Hz., 259 Hz., and 288 Hz. A recording was made of the sounds which was analyzed with the aid of an epidiascope. This device magnified one cycle of the sound curve to an amplitude of eight to fifteen cm and then decomposed the segment into its harmonics by means of a mechanical analyzer which permitted analysis to be made up to the twenty-fifth partial. Not all sounds that were recorded were subjected to this analysis. One additional facet of the experiment which deserves mention is the fact that a middle segment of the recorded sound was used, thus eliminating the initial attack and the release from the performed sounds.

Rzhevkin's study (20, pp. 215-220) revealed an extra formant in the region between 400 and 600 Hz. and a higher formant in the interval between 2500 and 3000 Hz. on all sounds performed by the experienced singer regardless of pitch or vowel. These extra formants were not found to correspond at all to the formant regions of vowels in speech pronunciation. In addition, the singing formants did not have as wide a frequency band as the speech formant regions. The investigation of sounds which were performed softly did not show a substantial difference in terms of their spectrum from the sounds which were sung loudly. The inexperienced singer in this study was unable to produce these added formants though a general amplification of the partials was noted in the region from around 2500 to 3500 Hz.

Rzhevkin's study once again points to the differences in singing as compared with speech and confirms the data of Bartholomew. The principle weakness in this study is alluded to by Rzhevkin when he says, "the results we obtained here are based, for the time being, upon extremely tentative material" (20, p. 220). He went on to say that further research was needed to follow up on the hypothesis created by this study.

The future studies referred to by Rzhevkin were instigated by a new generation of researchers with more modern equipment and larger populations of singers being tested. The theory of two singers' formants gradually disappeared and was replaced with a theory emphasizing only one singer's formant, lying in the average range between 2800 to 3200 Hz. Sundberg (25, pp. 838-844), Vennard and Irwin (29, pp. 18-23), Seymour (22, pp. 253-257), and Benade (5) all have reported finding this upper singer's formant. Sundberg said of the formant:

> It appears to consist of a cluster of three formants. The lowest of these formants corresponds to the third formant in normal speech and the highest to the fourth. In between these formants an extra formant is found . . . The singing formant has been shown to add to the beauty of the tone. Also it has been found to be labeled "placement in the head" among singing teachers. An interesting circumstance is that the "singing formant" appears in a frequency region where the ear has its maximum amplitude sensitivity. Winckel has suggested that it may make the sung sounds easier to perceive (26, p. 4).

Furthermore, the singer's formant was found at a place in the sound spectrum where the large orchestras have a weak set of reinforced partials, thus enabling singers with a well-developed singer's formant to be heard over an orchestra.

Critical Observations

There has been considerable confusion in the area of singing intelligibility. While numerous investigations have been conducted over the past decades, progress has been slow because the majority of researchers have pursued isolated individual research projects that often resulted in contradictory findings. Some of the problems with the body of research on singing intelligibility included the use of small populations and the absence of a standard or controlled set of variables including pitch, vowels, singers, and auditors. The failure of many investigators to account for these potentially important variables or in some cases even to let the reader know what the variables are, has been a principle weakness in most of the studies reviewed. This researcher feels that the subject of singing intelligibility could benefit from a systematic series of research projects with controls placed on the variables mentioned above.

One variable apparently considered to be unimportant to previous researchers is the past experience or training of the auditor. No two studies have employed auditors with the same background and no control groups of auditors have been reported. Consideration has not been given to the possible effect an auditor's past experience and training might have on intelligibility of vowel sounds in singing. Phoneticians, linguists, pathologists, graduate students and teachers of foreign language, music, and speech, singers, and even the researchers themselves have participated in intelligibility studies as research auditors. Some investigators thought so little of the effect of the auditor, that they did not bother to report who the auditors were.

If an investigator proposes to do research and to discuss intelligibility in singing, then a determination needs to be made concerning what intelligibility is. As this writer pointed out in Chapter I, what is intelligible to one group of auditors may not be intelligible to another group. Nelson and Tiffany (18, pp. 22-28, 33) had an opportunity to test the effect auditors with divergent backgrounds might have on intelligibility. They had a special grouping, one-half of whom were musically sophisticated; however, no comparisions or effects were reported. While formulating a pilot study to anticipate problems in a future study on singing intelligibility, this researcher intended to give special consideration to the possible effects an auditor's background and training might have on singing intelligibility.

Pilot Study

This researcher developed a pilot study to examine several problem areas in the field of singing intelligibility, results of which follow in this chapter. The variables examined in the pilot study were borrowed, whenever possible, from some of the most reputable investigators of the past. Variables found to be of value in determining auditor effect on intelligibility of vowel sounds in singing were used in the main study.

Purpose of Pilot Study

The purpose of the pilot study was to produce a preliminary investigation of vowel intelligibility in singing by looking at several aspects of the subject which had been important to past researchers.

Research Problems of Pilot Study

The research problems of the pilot study were

1. To find which vowels were the most and which were the least intelligible at each pitch for each category of

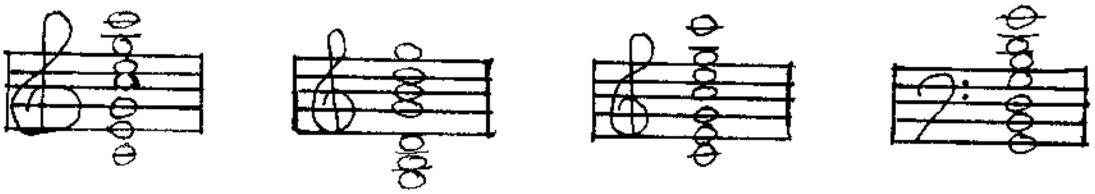
singer (bass, tenor, alto, soprano) for auditors with extensive vocal music backgrounds.

2. To find which vowels were the most and which were the least intelligible at each pitch for each category of singer (bass, tenor, alto, soprano) for auditors with limited or no musical experience.

3. To compare the results of the above inquiry to determine if any differences exist.

Methodology for Pilot Study

Eight vocally trained graduate students from North Texas State University were chosen as subjects. Included were two baritones, two tenors, two mezzo-sopranos, and two sopranos. Each singer was instructed to sing each of the five cardinal vowels [i, e, a, o, u] on seven pitches covering a two-octave range.



Sopranos Mezzos Tenors Baritones

There were thirty-five sounds for each singer making a total of 280 sounds. The singers were also asked to sing all sounds with their best quality, maintaining the maximum amount of intelligibility. After the sounds were recorded, they were labeled and randomly arranged by pulling corresponding numbers from a hat.

Auditors included five expert vocal musicians and five musical amateurs, all claiming to have normal hearing. The five expert auditors were voice teachers at North Texas State University while the amateurs were adults from various backgrounds who reported that they had no musical training or experience. All auditors were issued computer test forms with the five cardinal vowel sounds listed for each of the 280 numbers. Auditors were given instructions to match the vowel sounds on the computer forms with the vowel sounds each auditor perceived the singers to be attempting. All results were analyzed with an item analysis.

Results of Pilot Study

The intelligibility of all vowel sounds clearly declined on the highest pitches for both groups of auditors. The charts in Figures 2 and 3 show the average intelligibility of each vowel on the individual pitches by all auditors combined. Not only was a loss of intelligibility discovered at the highest pitches, but on the lowest pitches as well (as Morozov had reported in his research). This was particularly true of the tenors and mezzos, while little change was noticed in the soprano's intelligibility on the low notes. The baritones were actually more intelligible on the lowest pitches. An unexpected finding, not reported

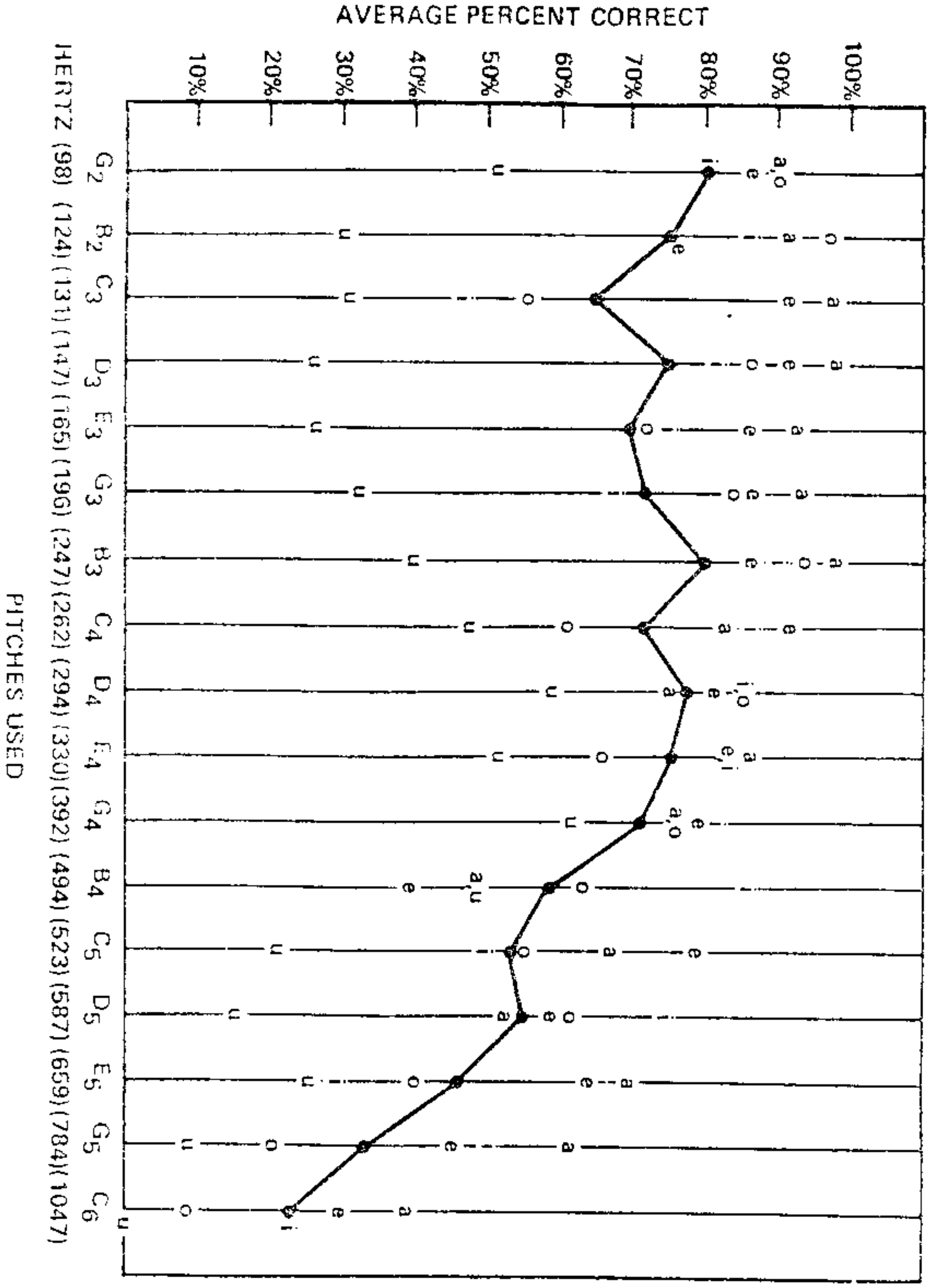


Fig. 2--Average overall intelligibility of each vowel on a given pitch and combined intelligibility indicated by a dark line.

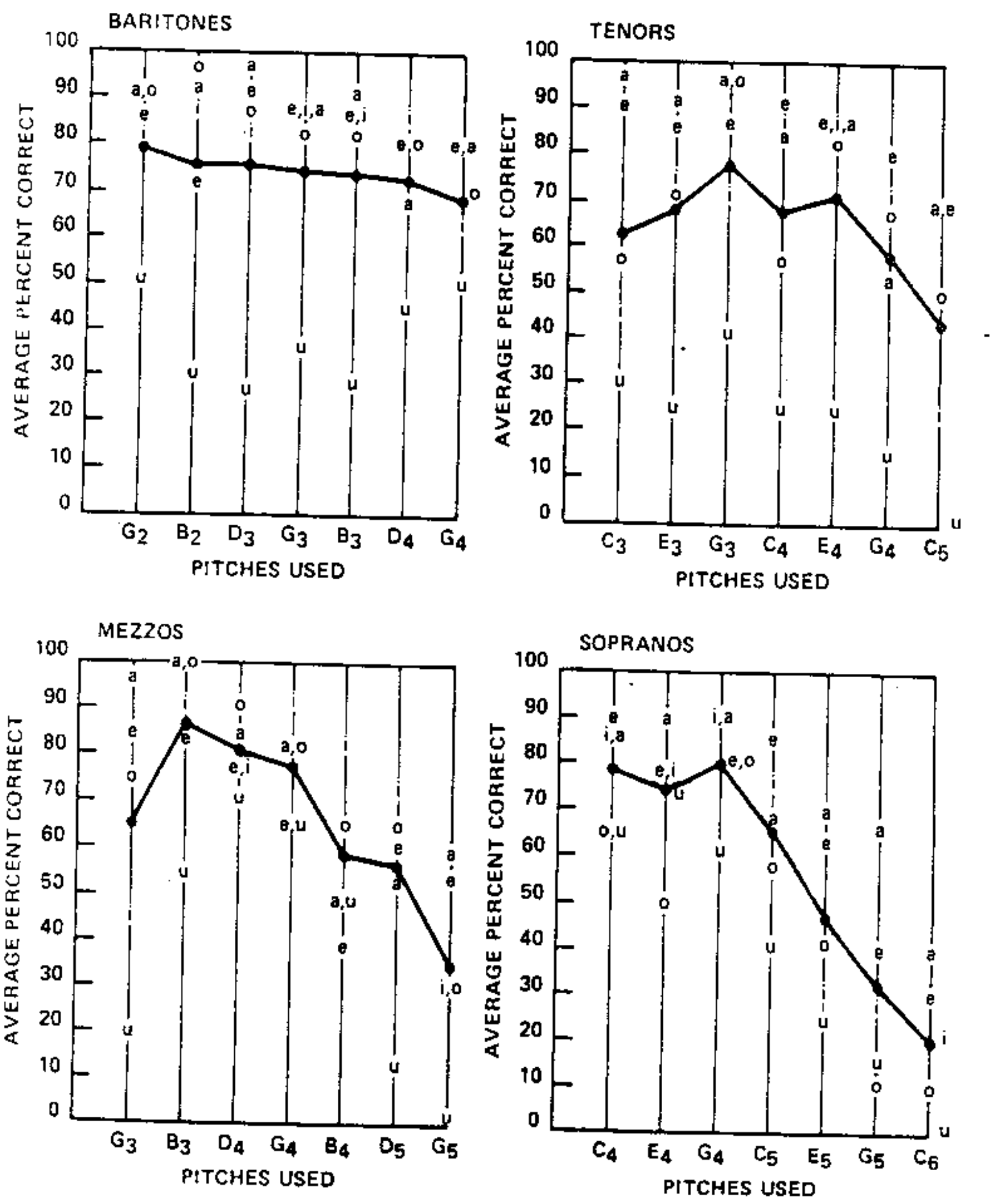


Fig. 3--Average overall intelligibility for all vowels combined for each group and individual intelligibility of each vowel for the four groups.

by past researchers, was the low level of intelligibility of the [u] vowel at all pitches and in all voices. The [u] vowel was always found below the average intelligibility as is clearly seen in Figure 2 and it was almost always the least intelligible vowel sound. Another unexpected finding was the fact that the [a, e, and i] vowels were very close in overall intelligibility even on the highest notes. Although the [a] vowel was the most intelligible vowel sound, as previously reported by Howie and Delattre and others, the [e and i] vowel sounds were only slightly less intelligible. This is contrary to the results of many investigations which have shown the [a] vowel sound to be considerably more intelligible than the other vowels, especially on the highest pitches.

The results varied substantially with the musical expertise of the auditor. The musically experienced (expert) auditors were able to identify accurately the vowels being attempted by the singers roughly 79 percent of the time while the non-musician (amateur) group managed the identification only 53 percent of the time. There was also much less variation in the percentages of accurate responses among individuals in the expert group with an 11 percent variation, while the amateurs had a 34 percent variation.

It is worthy of note that the experts unanimously agreed with each other and with the singer's intentions on the identity of 155 of the 280 sounds. In only eighteen cases could none of the expert auditors agree with the sounds intended by the singers. By way of contrast the amateur auditors unanimously agreed with each other and with the singer's intentions in only twenty-two of 280 sounds. In forty sounds of the 280 all of the amateurs failed to distinguish the vowel which was intended by the singers. Eleven of the eighteen sounds missed by all the experts and thirty of the forty sounds missed by all amateurs were attempts by the singers at producing the difficult [u] vowel.

The [u] vowel, when missed, was considered to be either [a or o] on the low and medium pitches, but the primary choice on the highest pitches was the [a] vowel.

Another surprising point was the fact that eight of the twelve sounds missed by all of the auditors in both groups were produced by only two of the eight singers suggesting that training or experience of the singer may have been an important factor.

As can be seen in Table III, in each voice classification (Soprano, Mezzo-soprano, Tenor, Baritone) at least one singer was intelligible on either the [i, e, or a] by at least half of the auditors. This is a clear contradiction of the results of many investigations discussed earlier which claim that there is no intelligibility on

TABLE III

INTELLIGIBILITY OF VOWELS SUNG ON HIGHEST PITCHES FOR EACH OF EIGHT SINGERS OUT OF A POSSIBLE TEN

Baritones-G4	Tenors-C5	Mezzo-Sopranos-G5	Sopranos-C6
#1 i-5	#1 i-4	#1 i-2	#1 i-2
#1 e-8	#1 e-8	#1 e-7	#1 e-5
#1 a-8	#1 a-9	#1 a-7	#1 a-4
#1 o-8	#1 o-5	#1 o-4	#1 o-0
#1 u-5	#1 u-0	#1 u-0	#1 u-0
#2 i-8	#2 i-1	#2 i-4	#2 i-2
#2 e-8	#2 e-6	#2 e-4	#2 e-1
#2 a-8	#2 a-5	#2 a-5	#2 a-4
#2 o-6	#2 o-5	#2 o-2	#2 o-2
#2 u-5	#2 u-0	#2 u-0	#2 u-0

these highest notes except for the [a] vowel sound. Thus, the fixed-ratio theory is supported by some results and not supported by other results of this study.

Conclusions and Speculations for the Pilot Study

This pilot study supported the conclusions of other investigators (both advocates of the fixed-ratio theory and those who had found evidence to refute the theory as it applies to the singing voice) who found that the intelligibility of vowel sounds suffers in the highest pitch range and to some extent at the lower range as previously reported by Morozov. Some vowel sounds other than [a] were, however, found to be intelligible on the highest pitches by at least a few auditors which would bring into question the theoretical assumption of the fixed-ratio theory which states that it is impossible to be intelligible on the highest pitches.

The fact that some of the singers were able to maintain a fairly high level of intelligibility even on the highest pitches, could be an indication that the singers mastered a skill not yet attained by the others. When one considers that only two of the singers produced most of the sounds which were identified incorrectly, the idea of a mastered skill gains even more credence. These skills could include such factors as a singer's ability to manipulate the spaces of the vocal tract in such a manner as to raise the first formant or to replace it with the fundamental frequency, the use of volume or intensity to heighten intelligibility, skillful use of vowel modification or migration, use of the extra reinforced areas in the sound spectrum known as the singer's formants or many others.

The low intelligibility of the [u] vowel raised important questions for future investigators into singing intelligibility. If the vowel formants in singing have the same relative values as those established in speech, then the fact that the [u] vowel sound had the lowest formant frequencies for both formants I and II might explain the vowel's low intelligibility. Another possible explanation could be simply that many singers experience difficulty singing the [u] vowel sound.

This pilot study presented evidence which suggested that the expertise of the auditor may be an important factor in intelligibility of vowel sounds in singing. The voice teachers who made up the expert group of auditors had many years of experience in singing and in teaching singing, which could make them more aware of what to expect of singers when they are singing in the difficult high pitch range. The amateur group, on the other hand, would not be familiar with the practices of singers when singing vowel sounds.

The pilot study, while not being a complete investigation, addressed the issue of intelligibility in singing. From this research project insights have been drawn which allowed more complete study to be conducted in the area of intelligibility in singing and into the possible effect that an auditor's experience may have on the results. It was evident from problems encountered with the pilot study, that some procedures and variables could be altered to avoid difficulties in the control and compilation of the data which would improve an expanded new investigation.

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CHAPTER III

METHODOLOGY

This study proposes to determine the effect of an auditor's past musical training and experience on the intelligibility of selected vowel sounds performed by trained singers at differential pitch levels. The pilot study discussed in Chapter II served as the initial step in this investigation, enabling this researcher to determine the feasibility and value of the variables experience, pitch, and vowel sound in ascertaining auditor effect on singing intelligibility. As a result of the pilot investigation and from the review of previous research, procedures and variables were altered to avoid difficulties in the preparation and administration of an intelligibility test for the main study. Thus, the pilot study became a model for the present investigation.

Research Variables

Four major research variables were considered: score on the intelligibility test, experience of the auditor, specific vowel sound, and pitch. Attempts were made to measure each variable accurately and to account for the effect that each of the variables had both collectively and individually on the intelligibility of vowel sounds in singing.

Selection of Auditors

Since the musical expertise of the auditor was the primary variable this study sought to examine, selection of the auditor groups was a crucial concern in developing this study. The pilot investigation suggested that different auditors would respond to vowel sounds on an intelligibility test with varying levels of comprehension. It was unclear, however, if vocal music experience in particular or just music experience in an auditor's background was responsible for the superior intelligibility test scores of the vocal musician auditors.

To examine further the effects of musical training on the intelligibility of vowel sounds in singing, two groups of musically trained auditors were selected. One group included only those persons with extensive vocal music training and experience, while the other musically experienced group of auditors consisted of persons with extensive non-vocal (instrumental or keyboard) musical training and experience.

It was decided further that the number of auditors employed in the pilot study would be increased in the present study so a more representative sample of auditors from the general population could be tested. Thus, the sample size was expanded in the present study to include ten auditors in each of the three experience groups.

In an attempt to control the educational backgrounds of the auditors in each experience group, the auditors chosen for the present study were all university level faculty members in good standing. Thus, for the main study the vocally experienced auditors consisted of ten university level faculty members who primarily taught applied voice (five males and five females); the instrumentally experienced auditors consisted of ten university level faculty members who primarily taught applied keyboard or other instruments (six males and four females); and the non-musician auditors were ten university level faculty members without musical training and experience from various academic disciplines (seven males and three females). All auditors were volunteers from various colleges and universities throughout the states of Kentucky and Tennessee.

Development of Tape

Vowel Sounds

The vowel sounds chosen for the main investigation were the same as those employed in the pilot study. These vowel sounds [i, e, a, o, and u] are known as the long, Latin, or cardinal vowel sounds and the symbols for these vowel sounds shown above were taken from the International

Phonetic Alphabet (IPA). These vowel sounds have been used by numerous past investigators who studied singing intelligibility including Delattre (3, pp. 4-7), Morozov (8, pp. 279-283), Triplett (11, pp. 6-8, 50), Flechtner (4, pp. 23-26), and Sundberg (10, pp. 23-35). Use of the five cardinal vowel sounds in the current study enabled important comparisons to be made with the results of past singing intelligibility investigations. While use of only the cardinal vowel sounds in this study does not approach the actual performance situation, the greater comparative aspects with other investigations into singing intelligibility which only used vowel sounds tends to justify the use of vowel sounds in this study.

Pitch

Each of the five vowel sounds was sung at three pitch levels. The three pitches employed in the main study were limited to C4 (264 Hz.), C5 (528 Hz.), and C6 (1047 Hz.). These pitches were within the soprano pitch range and were employed in the pilot study and in the investigations by Howie and Delattre (5, pp. 6-9), Triplett (11, pp. 6-8, 50), and by Morozov (8, pp. 279-283). It should be noted that the three pitches chosen for the main study were sufficient to represent in the soprano voice the lower or chest voice range with C4, the middle voice range with C5, and the high or head voice range with C6. Thus, the three pitches employed in the main study seemed to represent adequately the three major registers of the soprano voice. Care was taken to keep the test reasonably brief to avoid wearisome detail. If more pitches had been used in the present study, the intelligibility test would have been much longer and too cumbersome for the auditors.

Soprano Subjects

The pilot study employed two bass, two tenor, two mezzo, and two soprano singers as subjects. It was clear from the results of the pilot study that the major problems in singing intelligibility were with the soprano voice. This was not surprising in light of the corroborative evidence from several investigations, including those by Flechtner (4, pp. 23-26), Sundberg (10, pp. 25-35), and Triplett (11, pp. 6-8, 50). Thus, only soprano subjects were investigated in the main study.

Past investigators have at times used only one or two sopranos in their studies of singing intelligibility (11, pp. 6-8, 50; 10, pp. 25-35). Because of the small samples the results of these investigations were not generalizable to the whole soprano population which includes a variety of types of voices such as dramatic, lyric, spinto, and coloratura. It is possible that vocal type could influence auditor recognition of vowel sounds in singing. Thus, the number of soprano singers was increased to twenty vocally trained singers so that a more representative singing population could be examined.

Many past investigators employed untrained or minimally trained soprano subjects for their singing intelligibility investigations without considering that singer training might have a significant effect on the ability of the singer to produce sounds that auditors would find intelligible. The sopranos used in the present study were all trained singers who had studied applied voice at North Texas State University. The training ranged from singers with a minimum of two years of college level voice instruction to graduate level vocalists with over ten years of professional singing experiences. The subjects ranged in age from twenty to forty years.

Description of Recording Procedures

The twenty trained sopranos were recorded singing each of the five vowel sounds at the three pitch levels. The recording took place in a Wenger sound proof room. A TEAC A-33005-2T reel-to-reel stereo tape deck was used to record the singers. The recording tape was one-and-one-half mil, quarter inch, professional quality recording tape. All recordings were made at a tape speed of seven-and-one-half inches per second.

A Bruel and Kjaer Precision Sound Level Meter (type 2203) was placed alongside the recording microphone at a distance of eighteen inches from the singer's mouth. The sound level meter was used during the recording of the master tape in an attempt to minimize the sound pressure level (SPL) differences between singers at each pitch level. The sound level meter also enabled the researcher to measure SPL differences between singers on each vowel sound at each of the three pitches and between vowel sound pairs at the same pitch.

The efforts made to equalize the SPL readings at each pitch level for all the singers were in vain. It was evident very early that the wide variety of voice types employed in this study made equalization an almost impossible task. Thus, the SPL readings merely were recorded for each singer on each vowel sound produced so that comparisons could be instigated between SPL readings and the ability of each singer to be intelligible to auditors.

The subjects participating in the preparation of the intelligibility test tape were given specific instructions concerning their roles in the recording process. Each singer was instructed to sing the five cardinal vowel sounds, listed on an index card placed in front of them, on each of the three pitches. Sample words and IPA vowel sound symbols appearing on the index card were [i] as in "beet," [e] as in "ate," [a] as in "father," [o] as in "obey," and [u] as in "boot."

Singers were allowed to practice producing each of the vowel sounds at the three pitch levels prior to being recorded. However, once a vowel sound was recorded, the singers were not permitted to rerecord the sound. The subjects were told that each vowel sound was to be held for approximately two seconds. Singers were further instructed to be as intelligible as possible while still maintaining their best possible quality of sound. The researcher conducted the start and finish of all recorded sounds.

Because of problems experienced in the pilot study with the diphthongization of the [e] and [o] vowel sounds, singers were asked to sing only the [e] vowel sound instead of singing [ɛɪ] as in the word "day" and only the [o] vowel sound instead of the [ou] as in the word "no." Diphthongization of the [e] and [o] vowel sounds has traditionally been a problem which has plagued many singers. The problem, however, is generally not present in the production of the other cardinal vowel sounds used in this study [i], [a], and [u].

Test Order

After all of the vowel sounds were recorded, they were labeled and separated so the sounds could be arranged in a random order for presentation to the auditors. All sounds included the entire envelope from attack through release. There was a total of twenty items on each of the five vowel sounds at each pitch level. The random order was achieved using the method of drawing corresponding numbers from a hat and then splicing the sound segments together in the random order for the intelligibility test tape. In addition, another thirty of the original vowel sounds were randomly selected and duplicated. Then the duplicated items were added randomly to the original test tape to serve as a consistency check on the auditors. These thirty items were used only for consistency measurements and were not tabulated as a part of the intelligibility test score.

The reel-to-reel master tape, arranged in the random order, was then transferred to a high bias, low noise, TDK brand cassette tape for easier administration of the intelligibility test to the auditors. The cassette tape sound playback was judged by this researcher to be of equal quality to the reel-to-reel master tape.

Administration of the Intelligibility Test

The intelligibility test, consisting of the randomized sounds on the test tape, was administered to each of the thirty volunteer auditors individually. All tests were administered to each auditor at the location of the auditor's teaching studio. All auditors were given a test form with six possible choices listed for each of the sounds they were to hear. (See Appendix A for an example of the test form.) Five of the choices for the auditors were represented by the appropriate IPA symbols for the five cardinal vowel sounds with the sixth choice being a "none" response which was available for any sound other than the five cardinal vowel sounds or no perceivable vowel sound. The auditors were instructed that they would be hearing vowel sounds sung at various pitches and they were to match the vowel sound they thought the singer was attempting with the appropriate symbol for that sound found on the test form. If none of the vowel sounds on the test form could be distinguished, then the "none" response was to be chosen.

Some of the auditors were not familiar with the International Phonetic Alphabet (IPA) symbols at first. These auditors were trained to recognize the sounds associated with the IPA symbols. In order to enlighten those auditors who were not at first familiar with the IPA and to reinforce the knowledge of those who were already familiar with the IPA, the same sample words and symbols presented to the singers during the recording of the sounds were shown to the auditors.

In an attempt to acquaint the auditors with the test format and to give them examples of the test items they would be hearing, the auditors were allowed to hear ten test items taken from the middle section of the test tape. The sample sounds included each of the five cardinal vowel sounds and some vowel sounds sung at each of the three pitch levels. Auditors were also informed that during the course of the actual testing they could stop the tape at any time if they believed that the sounds they were hearing were progressing at too fast a pace. The auditors were informed that no test item could be heard more than one time.

LEBO TA-334 stereo headphones were used along with a Sharp RT-2000 stereo cassette deck for the administration of the intelligibility test. The headphones provided a full quality range of audible sounds and were portable, allowing easy transportation between the many testing locations. All tests were monitored by the researcher through an additional set of headphones. The researcher would stop the test tape upon request and also help the auditors know which item number on the test form they were to hear next. This enabled the auditors to concentrate fully on the task of taking the test.

In an attempt to minimize fatigue as a negative factor, the test was divided into two equal parts with a period of rest permitted between each part. Time for testing each part ranged from fifteen to twenty minutes.

Analysis of the Data

The intelligibility tests from the thirty auditors were evaluated and scored with the number of correct responses becoming the score. There were twenty possible correct responses on each of the five vowel sounds at each of the three pitch levels.

The thirty repeated sounds, which were randomly selected and mixed with the original vowel sounds, were, as noted above, not counted toward an auditor's intelligibility test score. These items merely served as a means of testing the consistency of the auditors. A 70.00 percent consistency rate was accepted as a minimum for an auditor to be considered a reliable judge. The consistency ranged from 70.00 percent to 93.33 percent with a median rate of 80.00 percent. Thus, all judges met or exceeded the criterion.

The data were examined and analyzed with statistical procedures capable of comparing the three independent variables (experience, vowel sound, and pitch) with the dependent variable (score on the intelligibility test). The three independent variables were treated as nominal level data because each variable formed a separate category. Scores on the test (the dependent variable) were treated as interval level data because they were discreet numbers.

Mean scores were calculated from the accurate responses by the auditors on each vowel sound at the three pitch levels. These mean scores were compared by using an analysis of variance with repeated measures to test the significance of interactions between the three levels of experience, the five vowel sounds, and the three pitch levels. If interactions were not present, the variables were also examined for significant main effects on the intelligibility test scores. The $p < .05$ level of significance was accepted for the results of this study.

The decibel readings of each singer on the five vowel sounds sung at the three pitch levels were compared with the ability of each of the twenty sopranos to be understood by the auditors. If a singer were to sing louder or softer than the other singers and at the same time proved to be understood by the auditors better or worse than the other singers, then a relationship between decibel level and singer intelligibility might have been established. The decibel levels on each of the vowel sounds were further examined to see if there was a relationship between intensity and one vowel sound being more or less intelligible to auditors than the others. A further comparison was made between overall auditor recognition of vowel sounds at each pitch level and the overall intensity of the singers at each pitch level. This last comparison tested the relationship between pitch and intensity.

Some of the statistical data were gathered with the aid of computer programs from the North Texas State University Statistical Library. The NTSU Computing Center assisted in processing the data.

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CHAPTER IV

RESULTS OF THE STUDY

A test was administered to thirty auditors to investigate the relationship between an auditor's past musical training and experience and the intelligibility of selected vowel sounds sung at differential pitch levels. The auditors were placed in three separate groups based upon their past musical experience. Group 1 (N = 10) were those persons who had extensive vocal music training. The auditors placed in Group 2 (N = 10) were persons who had extensive non-vocal musical training. Group 3 (N = 10) were persons with no musical training.

The test included the randomized presentation of the five cardinal vowel sounds [i, e, a, o, and u] as sung on the three pitches C4, C5, and C6 by twenty trained sopranos. The auditor's task was to identify if possible the vowel sounds attempted by the singers.

The intelligibility test was administered to each of the auditors individually with headphones on a cassette recorder. Auditors were each given a test form with six possible choices for each of the vowel sounds they would hear on the test tape. Five of the choices were the appropriate IPA symbols for the cardinal vowel sounds, while the sixth choice was a "none" response for use on sounds perceived other than one of the five cardinal vowel sounds.

Scores on the intelligibility test represented the number of correct responses for each vowel sound on the three pitch levels by each of the auditors. The maximum possible identification score was twenty for each sound since each of the vowel sounds at each of the three pitches were produced by twenty sopranos. The scores in Table IV represent the mean scores for each of the three auditor groups at the three pitch levels on each of the five vowel sounds. Group 1 in Table IV represents the scores for the auditors with extensive vocal music training and experience (vocalists). The auditors with extensive non-vocal music training and experience (instrumentalists) are represented as Group 2 while Group 3 is comprised of the non-musician auditors.

The mean scores for the vocalist auditors declined on each of the vowel sounds as the pitch ascended from C4 to C5 and then to C6. However, some vowel sounds seemed to suffer the effects of rising pitch more than other vowel sounds with differing rates of decline in auditor recognition. The [a] vowel sound for instance, declined with the vocalist auditors from a mean score of 19.9 at C4 to 17.0 on C5 and then down to 13.3 at C6 while the vocalist's scores on the [u] vowel sound declined from a mean score of 18.2 on C4 to 10.8 on C5 and then to 0.9 at C6. It was further clear that all vowel sounds at C6, with the possible exception of the [a] vowel sound were recognized only at chance level.

TABLE IV

MEANS FOR EACH AUDITOR GROUP FOR THE VARIABLES OF PITCH, VOWEL, AND EXPERIENCE OUT OF A POSSIBLE HIGH OF 20

		Vowels					
Pitch		i	e	a	o	u	Overall
Group 1 (N = 10)	C4	20.00	18.30	19.90	16.6	18.20	18.60
	C5	16.00	17.20	17.00	12.4	10.80	14.68
	C6	3.50	9.00	13.30	2.8	0.90	5.90
	Overall	13.17	14.83	16.73	10.6	9.97	13.06
Group 2 (N = 10)	C4	19.60	17.70	19.70	16.3	18.00	18.26
	C5	16.70	15.60	16.50	12.0	8.30	13.82
	C6	1.00	6.70	15.50	2.6	0.40	5.24
	Overall	12.43	13.33	17.23	10.3	8.90	12.44
Group 3 (N = 10)	C4	18.70	15.7	19.80	15.0	15.50	16.94
	C5	13.10	14.2	18.40	7.9	4.40	11.60
	C6	2.50	5.2	16.20	1.4	0.10	5.08
	Overall	11.43	11.7	18.13	8.1	6.67	11.21

Large differences were also seen in the vocalist's recognition of each individual vowel sound in comparisons with the other vowel sounds at the same pitch level. For example, the C5 [e] vowel sound was intelligible to the vocalist auditors with a mean score of 17.2 while the C5 [o] vowel sound was intelligible to the vocalist auditors with a mean score of only 12.4. This was not a unique example. Most of the vowel sound comparisons at each pitch level revealed similar differences in the scores of the vocalist auditors.

The mean scores for the instrumentalist auditors also declined on each of the vowel sounds as the pitch rose from C4 to C5 and then to C6. As with the vocalists, the scores of the instrumentalists auditors declined more on some vowel sounds than on others. For example, the instrumentalist auditors had a mean score of 19.7 on the [a] vowel sound at C4 which dropped to 16.5 at C5 and then down to 15.5 at C6. With the [u] vowel sound, however, the instrumentalists started with a mean score of 18.0 at C4 which descended to only 8.3 at C5 and then to 0.4 at C6. Once again, these differences were not isolated ones. The declines in the instrumentalist auditor's recognition with rising pitch effected each of the five cardinal vowel sounds differently. This was true even though all vowel sounds heard at C6 by the instrumentalists, except for the [a] vowel sound, were recognized only at chance level.

Comparisons between the mean scores of the instrumentalists on each of the individual vowel sounds at the same pitch levels revealed large differences in recognition. The [i] vowel sound at C5 was recognized with a mean score of 16.7 while the C5 [u] vowel sound had a mean score of only 8.3. The same trend can be seen in most of the vowel sound comparisons at each pitch level.

As with the other two auditor groups, the mean scores of the non-musicians declined on all vowel sounds as the pitch rose from C4 to C5 and then to C6 with some vowel sounds declining more than others in auditor recognition. The [i] vowel sound at C4, for instance, had a mean score of 18.7 declining to 13.1 at C5 and then to 2.5 at C6 while the [a] vowel sound only declined from 19.8 at C4 to 18.4 at C5 and then to 16.2 at C6. All vowel sounds declined in recognition by the non-musicians at different rates as the pitch rose. All vowel sounds heard at C6 with the exception of the [a] vowel sound were recognized only at chance level by the non-musicians as was true with the other auditors.

It was evident with the non-musicians as with the other auditors that there were large differences in the recognition of one vowel sound compared with the recognition of the other vowel sounds at the same pitch level. The non-musicians had a mean score of 14.2 on the C5 [e] vowel sound and only a 4.4 mean score on the C5 [u] vowel sound. This example was characteristic of the other vowel sound comparisons at the C4, C5, and C6 pitch levels.

Comparisons between the mean scores of the three auditor groups at each pitch level on each of the vowel sounds indicated that the vocally trained auditors usually had higher mean scores than the instrumentally trained auditors and the non-musician auditors. For most sounds the instrumentally trained auditors had higher mean scores than the non-musician auditors. There were a few instances where the mean scores of the non-musician auditors were higher than the scores of the vocalist and instrumentalist auditors. The non-musicians had better mean scores than the vocalists on the C5 and C6 [a] vowel sounds and the non-musicians had higher scores than the instrumentalists on the C4, C5, and C6 [a] vowel sounds and on the C6 [i] vowel sound. The instrumentalist auditors scored higher than the vocalists on the C5 [i] vowel sound and on the C6 [a] vowel sound.

The greatest difference observed between the mean scores of the three auditor groups was located between the vocally trained auditors and the non-musicians on the C5 [o] and [u] vowel sounds and the C6 [e] vowel sound. Differences between the mean scores of the instrumentally trained auditors and the non-musicians on the C5 [o] and [u] vowel sounds were also considerable.

To determine if the observed differences in mean scores were statistically significant, the data were subjected to an analysis of variance with repeated measures. The analysis of variance compared the means of the independent variables for main effects and for interactions. Table V presents the results of the analysis of variance.

TABLE V

ANALYSIS OF VARIANCE (SCORE BY EXPERIENCE/VOWEL/PITCH)

Sources of Variations	Sum of Squares	df	Mean Square	F	p
Main Effects:					
Experience	267.180	2	133.509	12.76	.000
Vowel Sound	4312.831	4	1078.208	79.82	.000
Pitch	12056.671	2	6028.336	1482.47	.000
2-Way Interactions:					
Experience/ Vowel Sound	237.916	8	29.739	2.20	.033
Experience/ Pitch	81.342	4	20.336	5.00	.002
Vowel Sound/ Pitch	2002.329	8	250.291	27.65	.000
3-Way Interactions:					
Experience/ Vowel Sound/ Pitch	154.524	16	9.658	1.07	.389

The results of the analysis of variance (seen in Table V) indicated that there was a significant two-way interaction between the variables experience and vowel sound ($p = .033$). Both variables, experience and vowel sound, were also found to have significant main effects on the intelligibility of vowel sounds in singing ($p = .000$). The vocally trained auditors scored better than the instrumentalist and non-musician auditors on most of the vowel sounds at the three pitch levels, but the instrumentally trained auditors and the non-musicians had higher mean scores on some of the [i] and [a] vowel sounds than the vocalists. These exceptions could help to explain the significant interaction between the variables experience and vowel sound.

A two-way interaction between the variables experience and pitch was also found to be significant (p = .002). While intelligibility of vowel sounds tended to be considerably different among the three auditor groups, pitch seemed to contribute to that difference by having a greater effect on one auditor group than on another. It was clear, when the mean scores in Table IV were examined, that the intelligibility scores of the non-musician auditors had a much higher rate of decline with rising pitch than the scores of the vocalists or instrumentalists, though all auditor groups declined in the recognition of vowel sounds as the pitch rose from C4 to C5 and then to C6.

A significant interaction was further found between the variables vowel sound and pitch (p = .000). Both variables had significant main effects on intelligibility (p = .000). While the mean scores in Table IV demonstrated that all vowel sounds were more difficult for the auditors to recognize as the pitch was raised from the pitch C4 to C5 and then to C6, it was also evident that the recognition of vowel sounds was effected in a different proportion as a result of the pitch changes. (See Appendix E.) The [a] vowel sound, for instance, declined in accurate auditor recognition by 23.66 percent from the C4 pitch level to the C6 pitch level, while the correct auditor recognition of the [u] vowel sound declined by 83.50 percent from C4 to C6. The largest decline in auditor recognition for any vowel sound from the pitches C4 to C6 was with the [i] vowel sound. The [i] vowel sound was recognized by auditors at C4 97.20 percent of the time, while at C6 the [i] vowel sound was understood by the auditors only 11.67 percent of the time which is below chance recognition. Although the overall effect of rising pitch on the vowel sound was to make the vowel sound less intelligible to auditors, there were a few isolated instances when the auditors reported that the [e] and [o] vowel sounds were more understandable at the C5 pitch level than at C4. (See Appendix G.) There were also two instances when the auditors reported that the [e] and [o] vowel sounds at C6 were more intelligible than they were at C5, but this could have been a chance occurrence.

While the analysis of variance confirmed that significant differences existed in interactions with the variables experience, pitch, and vowel sound, the specific location of those differences needed to be determined. T-tests were employed to examine the significance of the differences in auditor group recognition of the individual vowel sounds on each of the three pitch levels. The results of this series of t-tests are found in Table VI.

Significant differences were found between the mean scores of the vocalist and non-musician auditors on the C5 [o] vowel sound ($p = .008$), C5 [u] vowel sound ($p = .003$), and on the C6 [e] vowel sound ($p = .034$). A significant difference was located between the scores of the instrumentalist and non-musican auditors on the C5 [o] vowel sound ($p = .012$). No significant differences were discovered between the mean scores of the vocalist and instrumentalist auditors on individual vowel sounds. The significant differences mentioned above were in accord with the largest mean score differences examined earlier in Table IV.

Another series of t-tests were employed to compare the means for the overall intelligibility test scores of the three auditor groups. From a possible high score of 300 the overall mean score for the vocalists was 195.9. The instrumentalists had an overall mean of 186.6 and the non-musician auditors had an overall mean of 168.1. The mean scores were compared between the vocalists/instrumentalists, vocalists/non-musicians, and between the instrumentalists/non-musicians. The results of these comparisons are presented in Table VII.

The differences between the scores for the vocalist and non-musician auditors were significant ($p < .001$).

TABLE VI

T-TESTS FOR MEAN DIFFERENCES IN AUDITOR GROUP RESPONSES ON EACH VOWEL SOUND AND AT EACH PITCH LEVEL

Vowel Sounds	Group Comparisons*	Pitch					
		C4		C5		C6	
		t	p	t	p	t	p
i	Group 1-Group 2	1.31	.223	.45	.663	2.09	.060
	Group 1-Group 3	1.65	.134	1.18	.225	.73	.479
	Group 2-Group 3	1.06	.309	1.64	.128	1.69	.114
e	Group 1-Group 2	1.41	.175	1.46	.164	1.00	.335
	Group 1-Group 3	1.79	.105	1.70	.110	2.29	.034
	Group 2-Group 3	1.36	.203	.86	.408	.66	.521
a	Group 1-Group 2	.63	.540	.34	.738	1.12	.277
	Group 1-Group 3	.45	.662	1.61	.128	1.70	.111
	Group 2-Group 3	.28	.785	1.39	.191	.45	.658
o	Group 1-Group 2	.35	.731	.36	.722	.19	.854
	Group 1-Group 3	1.60	.128	3.07	.008	1.47	.163
	Group 2-Group 3	1.38	.187	2.85	.012	.97	.344
u	Group 1-Group 2	.23	.823	1.13	.272	.76	.463
	Group 1-Group 3	1.99	.064	3.43	.003	1.31	.223
	Group 2-Group 3	2.09	.059	1.88	.079	1.05	.314

*Group 1 represents extensively trained vocal musicians (vocalists), Group 2 represents extensively trained non-vocal musicians (instrumentalists), and Group 3 represents non-musician auditors.

TABLE VII

COMPARISONS OF THE OVERALL SCORES OF THE THREE AUDITOR GROUPS WITH T-TESTS

Group Comparisons	t	p
Vocalists/Instrumentalists	1.97	$p < .100$
Vocalists/Non-Musicians	4.56	$p < .001$
Instrumentalists/Non-Musicians	3.13	$p < .010$

Differences between the scores for the instrumentalist and non-musician auditors were also found to be significant ($p < .01$). However, no significant differences were found between the scores of the vocalist and instrumentalist auditors.

While the differences in overall scores may not be an important consideration because of the previously discussed interactions between the variables experience, vowel sound, and pitch, the results of both series of t-tests revealed that significant differences never occurred between the vocalist and instrumentalist auditors. Both series of t-tests found significant differences between the vocalist and non-musician auditors and between the instrumentalist and non-musician auditors. However, since auditor experience was also strongly affected by the variables vowel sound and pitch, the significant differences between auditor groups could also be attributable to chance.

Consistency of the auditors in the three experience groups was measured by repeating thirty of the original 300 vowel sounds and comparing responses of the auditor on the original sounds with the responses on the repeated ones. (See Appendix D for a chart of the consistency in responses on the intelligibility test between the original and the repeated sounds.)

The lowest consistency rating was found with one of the non-musician auditors who managed to match responses on the original sounds and the thirty repeated sounds only 70.0 percent of the time. The highest consistency rate of 93.33 percent was reached by one vocally trained auditor and by one of the instrumentally trained auditors. An 80.00 percent consistency rate proved to be the median rate. All auditors were accepted as reliable judges since they all met or exceeded the 70.00 percent consistency rate which was the criterion rate established by this researcher prior to the initiation of this research.

Vowel Sounds

The analysis of variance found that the variable "vowel sound" had a significant effect in both of the two-way interactions with the other two variables "experience" and "pitch" as well as a significant main effect. Examination of the mean scores in Table IV confirmed that large differences occurred in the recognition by the auditors of one vowel sound over another. The [a, e, and i] vowel sounds tended to be recognized better by the auditors than the [o] and [u] vowel sounds. While each of the three auditor groups tended to differ in their most to least intelligible vowel sounds at each pitch level, the overall ranking from the most to the least understandable vowel sounds was the same in all three auditor groups (see Appendix F). The [a] vowel sound was distinguished best by the auditors overall in this study with the percentage of correct responses by the auditors reaching 87.00 percent. Next in overall percentage of correct responses by the auditors was the [e] vowel sound with 66.50 percent. Not far behind the [e] vowel sound in auditor recognition was the [i] vowel sound with 61.23 percent auditor accuracy. The [o] vowel sound was fourth in auditor accuracy with 50.39 percent followed by the least intelligible vowel sound [u] with only 42.78 percent auditor accuracy. The line charts in Appendix H illustrate the percentages of auditor accuracy and the rate of decline for each of the five cardinal vowel sounds at the three pitches used in this study. (See also Appendix E.)

The [a] vowel sound was selected by all three auditor groups at each of the three pitch levels as the most accurate vowel sound. While at C4 the [a] vowel sound was just slightly more accurately identified than the [i] vowel sound (a = 99.00%, i = 97.20%), at C5 and C6 as well as overall, the [a] was considerably more intelligible to auditors than the other vowel sounds. Nineteen of the twenty [a] vowel sounds performed at C6 were judged to be intelligible by half or more of the thirty auditors. Five [e] vowel sounds were the only other sounds at C6 to be intelligible by half or more of the auditors.

While the results of the pilot study suggested that the [u] vowel sound was the least intelligible vowel sound at all pitch levels and for all auditors, the main study did not completely support that contention. In the present study the [o] vowel sound was found to be the least recognized of all vowel sounds at the C4 pitch. However, just as the pilot study had found earlier, the [u] vowel sound in the main study was the least intelligible vowel sound on the pitches C5 and C6 as well as the least recognized vowel sound overall. Sixteen of the vowel sounds on the intelligibility test were unintelligible to all thirty auditors. Eleven of the sixteen sounds, unrecognized by all auditors, were the [u] vowel sound.

A series of t-tests was employed in order to determine if there were significant differences in auditor recognition between the five cardinal vowel sounds on each of the three pitches. The results of the t-tests were found by comparing the mean scores of the auditors on each vowel sound in combinations with other vowel sounds at the same pitch level as illustrated in Table VIII. Table VIII

TABLE VIII

COMPARISONS OF AUDITOR RECOGNITION BETWEEN EACH VOWEL SOUND AT EACH PITCH USING T-TESTS

Comparisons	Pitches					
	C4		C5		C6	
	t	p	t	p	t	p
[i]-[e]	7.22	.000	.33	.745	4.50	.000
[i]-[a]	1.25	.222	1.84	.076	11.58	.000
[i]-[o]	6.66	.000	4.19	.000	.11	.914
[i]-[u]	3.89	.001	7.76	.000	5.00	.000
[e]-[a]	4.79	.000	2.08	.046	5.61	.000
[e]-[o]	1.88	.070	5.27	.000	6.31	.000
[e]-[u]	1.00	1.000	6.65	.000	7.22	.000
[a]-[o]	8.82	.000	6.41	.000	12.51	.000
[a]-[u]	5.17	.000	7.91	.000	16.95	.000
[o]-[u]	2.51	.018	3.08	.005	4.19	.000

reveals which of the thirty vowel sound combinations were significantly different. The chart of the significance of differences in auditor recognition between the vowel sound comparisons indicated that all but six of the thirty vowel sound combinations seen in Table VIII were significant in their differences. The large number of significant differences in auditor recognition between the vowel sounds suggested that the results of this study might have been varied substantially if a different group of vowel sounds had been chosen.

Decibel Readings

Decibel readings were recorded as each singer sang the five cardinal vowel sounds on the three pitches. The decibel values were collected and compared with other data to see if a singer's success or failure in making vowel sounds intelligible to auditors was linked with the decibel level where the sounds were intoned. No links were found between intensity and a singer's success or failure in becoming the least or most intelligible singer to auditors. The singer with the loudest decibel level was not the most or least intelligible singer nor was the singer with the softest decibel readings more or less intelligible to the auditors than the other singers.

Table IX was produced to show the decibel readings for each sound by each singer. Examination of Table IX revealed that the [a] and [o] vowel sounds were usually the loudest at all three pitch levels while the [i] and [u] vowel sounds were usually the softest, but the differences were insignificant, amounting to no more than five or six decibels difference.

As the pitch moved from C4 to C5 and then to C6, the decibel level rose as the pitch rose (around 10-20 decibels

TABLE IX

DECIBEL READINGS OF INDIVIDUAL SINGERS AS THEY SANG THE FIVE VOWEL SOUNDS ON THREE PITCHES

Singer Number	C4					C5					C6				
	i	e	a	o	u	i	e	a	o	u	i	e	a	o	u
1	60	70	70	70	60	82	82	88	86	80	100	102	110	108	100
2	68	70	70	70	78	88	86	94	94	94	86	86	86	86	94
3	62	62	74	74	60	84	84	90	88	84	102	100	108	106	100
4	62	62	68	66	62	84	82	90	88	82	94	94	96	94	92
5	70	70	76	74	70	84	80	92	90	88	104	104	110	108	106
6	60	60	72	72	64	78	78	88	84	78	106	104	108	104	104
7	70	70	74	72	66	86	86	90	90	88	102	102	106	104	102
8	72	72	72	72	66	88	90	90	90	86	94	92	96	96	94
9	66	68	74	68	66	88	86	92	92	88	102	102	104	98	98
10	68	68	72	72	66	84	82	86	90	90	96	96	98	96	88
11	78	76	81	81	74	92	92	98	96	92	104	104	104	104	102
12	66	72	76	74	66	88	88	94	94	92	104	103	104	103	102
13	62	66	70	68	62	82	84	88	88	88	100	102	104	103	100
14	68	72	74	70	68	88	88	88	84	88	104	102	103	104	104
15	72	74	76	74	68	88	86	88	88	88	98	102	104	102	98
16	62	68	70	72	62	86	84	82	86	86	96	96	96	96	96
17	66	70	70	70	64	88	88	85	90	84	94	94	94	94	94
18	70	70	76	76	68	90	88	88	96	92	99	98	99	100	99
19	70	74	76	76	72	92	90	96	98	92	100	102	104	102	100
20	72	74	76	76	72	92	92	90	92	92	96	96	98	96	96

per octave). This indicated that there may have been a relationship between overall intelligibility and decibel level possibly effecting all singers equally.

The results of this study indicate that many variables may have an important effect upon the intelligibility of vowel sounds in singing. Evidence has been presented which indicates that experience of the auditor, vowel sound, pitch, decibel level, and expertise of the singer may all be variables with profound effects upon what auditors find to be intelligible.

Summary of Results

1. The extensively trained vocal musicians (vocalists) usually had higher mean scores for each vowel sound at each pitch level than the instrumentalist and non-musician auditors. The vocally trained auditors declined in their ability to recognize each of the vowel sounds as the pitch rose from C4 to C5 and then to C6. The vocalists had more difficulty with the recognition of some vowel sounds than with others as the pitch rose which indicated that the adverse effects of pitch on the intelligibility of vowel sounds were different with each vowel sound. Large differences were often noted in the vocalists' recognition of one vowel sound as compared with the other vowel sounds at the same pitch level which seemed to indicate that the intelligibility of vowel sounds in singing is largely dependent upon which vowel sound is being attempted.

2. The extensively trained non-vocal musicians (instrumentalists) generally scored higher on the intelligibility test on each vowel sound at each pitch level than the non-musician auditors, but usually had lower mean scores than the vocalists. The instrumentalists did manage to score higher on the C5 [i] vowel sound and on the C6 [a] vowel sound than the vocalists. The instrumentally trained auditors experienced the same decline as the vocalists in their recognition of all vowel sounds as the pitch rose from C4 to C5 and then to C6. In like manner the instrumentalists tended to maintain more recognition of some vowel sounds than others as the pitch rose. Furthermore, the vowel sound comparisons at the same pitch level revealed that the instrumentalists also recognized some vowel sounds better than others at each pitch level.

3. The non-musician auditors generally had the lowest mean scores of the three auditor groups. The non-musicians, however, did have higher recognition of some sounds than the vocalist and instrumentalist auditors. The non-musicians had better mean scores than the vocalists on the C5 and C6 [a] vowel sounds and higher mean scores than the instrumentalists on the C4, C5, and C6 [a] vowel sounds and on the C6 [i] vowel sound. As with the other two auditor groups, the mean scores of the non-musicians declined on the recognition of all vowel sounds as the pitch rose from C4 to C5, and then to C6 with some vowel sounds declining in

auditor recognition more than others as the pitch rose. Vowel sound comparisons at the same pitch level revealed similar large differences in recognition for the non-musician auditors as with the vocalist and instrumentalist auditors.

4. An analysis of variance with repeated measures was employed to determine if observed differences in the mean scores were statistically significant. Significant two-way interactions were found between the variables experience/vowel sound ($p = .033$), experience/pitch ($p = .002$), and vowel sound/pitch ($p = .000$). Each of the three variables (experience, vowel sound, and pitch) was also found to have significant effects individually ($p = .000$) on the intelligibility test scores.

The t-tests employed to examine the significance of the differences in auditor group recognition of each individual vowel sound at the three pitch levels found four significant differences between auditor group responses from the forty-five mean score comparisons. Significant differences were found between the responses of the vocalist and non-musician auditors on the C5 [o] vowel sound ($p = .008$), C5 [u] vowel sound ($p = .003$), and on the C6 [e] vowel sound ($p = .034$). One significant difference was located between the mean scores of the instrumentalist and non-musician auditors on the C5 [o] vowel sound ($p = .012$).

A series of t-tests determined that both the vocalist and instrumentalist auditors scored significantly higher overall on the intelligibility test than the non-musician auditors. While the importance of this t-test was somewhat diminished in light of the aforementioned two-way interactions of the variables, it should be noted that the results of this t-test series revealed no significant differences between the scores of the vocalist and instrumentalist auditors as was the case with the first series of t-tests. Thus, the two series of t-tests were in accord with one another on this point.

A further series of t-tests was employed to determine if there were any significant differences in auditor recognition between each of the five cardinal vowel sounds at the same pitch level. Significant differences in auditor recognition were found with all but six of the possible thirty vowel sound comparisons over the three pitches which indicated that the accuracy of the auditor usually varied significantly depending on the vowel sound being attempted by the singer.

5. The auditors in all three experience groups were judged to be reliable judges by this researcher based upon the results of the measurement of consistency. Responses for the original sounds were consistent with responses on the thirty copied or repeated sounds an average of 81.67 percent with a median score of 80.00 percent and a range from 70.00 percent to 93.33 percent.

6. Decibel readings, when compared with overall intelligibility of the singers, had little or no influence upon whether any singer was more or less intelligible to auditors than another singer. The [a] and [o] vowel sounds were the loudest vowel sounds at all three pitch levels while the [i] and [u] vowel sounds were the softest. The decibel level rose from ten to twenty decibels as the pitch rose from C4 to C5 and then to C6.

7. It was found that overall singing intelligibility of vowel sounds was effected by many variables acting both independently and in combination with other variables.

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CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction and Purpose of the Study

An important part of most vocal music performances is the intelligibility of the text. The message that a singer is attempting to convey to the listener is largely contingent upon the singer's ability to make the text understandable. Because of this obvious need to be as intelligible as possible, singers and teachers of singing have demonstrated a strong interest in discovering why singers in general and high pitched singers in particular often experience difficulty articulating the words, so they are understandable to an audience. The majority of singing intelligibility research, conducted by interested singing voice investigators, has centered on the problem of vowel sound intelligibility in singing. Several persons primarily trained and concerned with the speaking voice have also been heavily involved with the investigation of vowel sound intelligibility in singing.

While the results of singing intelligibility investigations have sometimes been contradictory, it is generally accepted by singing and speaking voice researchers that vowel sounds in singing and in speech are recognized by the positions of the first two vowel formants. The large majority of studies investigating singing and speaking voice intelligibility give evidence which tends to support a theory known as the "fixed-ratio theory." This theory proposes that the positions of the vowel formants are relatively fixed regardless of the frequency a singer or speaker is intoning. Furthermore, advocates of the "fixed-ratio theory" propose that it is theoretically impossible for a vowel sound to be intelligible to auditors when the fundamental frequency (or pitch) is higher than the first formant frequency band width.

Although a large amount of research attests to the accuracy of the fixed-ratio theory, there have been investigators who have questioned some of the tenets of the fixed-ratio theory at least as it applies to the singing voice. Those who tend to challenge some aspects of the fixed-ratio theory begin by pointing to the many differences between the physical acts of speaking and singing and claim that while the theory may hold true for the speaking voice, the singing voice does not always follow the tenets of the theory. Some researchers such as Sundberg (18, p. 34), even claim that singers are able to make the formants move substantially from the positions normal in speech to positions where in high pitched singing, intelligibility can be maintained.

The numerous investigations of singing intelligibility have resulted in various conclusions concerning why some sounds are intelligible and some sounds are not. These conclusions have often been reached without giving adequate consideration to the auditor who ultimately determines which sounds are intelligible. Not one study, examined by this researcher, investigated the possibility that a sound which may be intelligible to one group of auditors, may not be intelligible to another group of auditors with different backgrounds.

The purpose of this study was to determine the effects of an auditor's past musical training and experience on the intelligibility of selected vowel sounds produced by trained singers at differential pitch levels.

Specific Problems of the Study

1. To investigate the effect of extensive vocal musical training and experience on an auditor's ability to discriminate accurately selected vowel sounds performed at various pitch levels.

2. To investigate the effect of extensive non-vocal musical training and experience on an auditor's ability to discriminate accurately selected vowel sounds performed at various pitch levels.

3. To investigate the effect of limited or no musical training or experience on an auditor's ability to discriminate

accurately selected vowel sounds performed at various pitch levels.

4. To compare results from the above inquiry and determine the relationship between specific musical training and the ability to identify accurately selected vowel sounds sung at various pitch levels.

Methodology

The methodology for the present study was suggested in part by the results of a pilot study conducted by this researcher. The pilot study enabled this researcher to determine the value of the variables experience, vowel sound, and pitch in ascertaining auditor effect on singing intelligibility. Procedures and variables were altered, as a result of the pilot investigation, to avoid difficulties in the preparation and administration of an intelligibility test for the main study. Thus, the pilot study was a model for the present investigation.

The specific problems of the main study were directed at trying to investigate the relationship between an auditor's past musical training and experience and the intelligibility of selected vowel sounds sung at differential pitch levels. These problems were addressed by the administration of a test to thirty auditors placed in three separate groups based upon their past musical experience. The three auditor groups included ten vocally trained university level faculty who primarily taught applied voice (five males and five females), ten instrumentally experienced university level faculty who primarily taught applied keyboard or other instruments (six males and four females), and ten non-musician university level faculty without musical training and experience from various academic disciplines (seven males and three females). All auditors were volunteers.

The intelligibility test was administered to each auditor individually and included the randomized presentation of the five cardinal vowel sounds [i, e, a, o, and u] as sung on the three pitches C4 (264 Hz.), C5 (528 Hz.), and C6 (1047 Hz.) by twenty trained sopranos. Also, thirty repeated sounds were randomly included as a test of auditor consistency. The auditor's task was to identify if possible the vowel sounds attempted by the singers.

For the test each auditor was given a test form with six possible choices for each of the vowel sounds they were to hear. Five of the choices were the appropriate IPA symbols for the five cardinal vowel sounds employed in this study, with the sixth choice being a "none" response for use on sounds perceived other than one of the cardinal vowel sounds. In an attempt to acquaint the auditors with the test format and method of presentation, the auditors were allowed to hear ten test items taken from the middle section of the test tape as presented over stereo headphones and a stereo cassette deck. Auditors were informed that during the actual testing, the test tape could be stopped at any time if it was felt that the sounds were progressing at too fast a pace.

The intelligibility tests were evaluated and scored with the number of correct responses becoming the score. The maximum possible identification score was twenty for each vowel sound at each of the three pitch levels. The thirty repeated items were not counted toward an auditor's intelligibility test score, but merely served to test the consistency of each auditor in responses on the original sounds and on the repeated sounds. A 70.00 percent consistency rate was accepted as a minimum for an auditor to be considered a reliable judge. All auditors met this criterion.

Mean scores were calculated from the accurate responses by the auditors on each vowel sound at the three pitch levels. These mean scores were compared with the assistance of an analysis of variance with repeated measures which tested the significance of interactions between the three levels of experience, five vowel sounds, and the three pitch levels, as well as examining the significance of each variable as a main effect. The $p < .05$ level of significance was accepted as sufficient for the results of this study.

Decibel readings for the singers were recorded and compared with the ability of each of the twenty sopranos to be understood by the auditors. Decibel readings were also compared with the auditor recognition of each vowel sound to determine if there was a relationship between intensity and one vowel sound being more or less intelligible to auditors than another vowel sound. A further comparison was made between intensity and the effect of pitch on the intelligibility of vowel sounds.

Results

The first three problem statements sought to investigate the effect that each of the three auditor groups had on the intelligibility of vowel sounds in singing. The same trends were evident with all three groups of auditors. Mean score comparisons within each of the three auditor groups revealed that as the pitch rose from C4 to C5 and then to C6, the accuracy of all auditors tended to decline dramatically. All auditors also seemed to have more difficulty with the recognition of some vowel sounds than with others as the pitch rose, indicating that the adverse effect of rising pitch on the intelligibility of vowel sounds varied depending upon which vowel sound was being sung.

Large differences were also noted in all three auditor groups with the recognition of one vowel sound as compared with the other vowel sounds at the same pitch level. The overall correct identification of the five cardinal vowel sounds found the [a] = 87.00 percent, [e] = 66.50 percent, [i] = 61.23 percent, [o] = 50.39 percent, and the [u] = 42.78 percent.

Comparisons between the mean scores of the three auditor groups at each pitch level and on each of the vowel sounds, indicated that the vocally trained auditors usually had higher mean scores than the instrumentally trained auditors and the non-musicians. For most sounds the instrumentally trained auditors had higher mean scores than the non-musician auditors. The few exceptions were on the C5 and C6 [a] vowel sound where the non-musicians had higher scores than the vocalists and on the C4, C5, and C6 [a] vowel sound as well as the C6 [i] vowel sound where the non-musicians had better scores than the instrumentally trained auditors. Additionally, the instrumentally trained auditors scored higher than the vocally trained auditors on the C5 [i] and on the C6 [a] vowel sounds.

While the auditors in all three auditor groups had lower scores on every vowel sound as the pitch rose, the non-musician auditors suffered a much greater rate of decline in their recognition of the vowel sounds, with rising pitch, than the vocalist or instrumentalist auditors on all vowel sounds except the [a]. This suggested that the pitch variable had an unequal effect on the auditor's ability to identify vowel sounds.

To determine if the observed differences between mean scores were statistically significant, the data were subjected to an analysis of variance with repeated measures.

Significant two-way interactions were found between the variables experience/vowel sound (p = .033), experience/pitch (p = .002), and vowel sound/pitch (p = .000). Each of the three variables was also found to have significant effects individually (p = .000) on the intelligibility test scores.

The t-tests employed to examine the significance of the differences in auditor group recognition of each individual vowel sound at the three pitch levels found four significant differences between auditor group responses from forty-five possible mean score comparisons. Differences between the vocalist and non-musician auditors on the C5 [o], C5 [u], and on the C6 [e] vowel sounds were found to be significant. One additional significant difference was located between the mean scores of the instrumentalist and non-musician auditors on the C5 [o] vowel sound. No significant differences were found between the mean scores of the vocally and instrumentally trained auditors.

Significant differences were also discovered between the vocalist and non-musician auditors and between the instrumentalist and non-musician auditors on overall intelligibility test scores. There were no significant differences, however, between the overall scores of the vocalists and instrumentalists.

Another series of t-tests found significant differences in the auditor recognition between all but six of the thirty vowel sound combinations where one vowel sound was compared to the other vowel sounds at the same pitch level. Thus, the accuracy of the auditor usually varied significantly depending on the vowel sound being attempted by the singer.

All auditors in each of the three experience groups were deemed to be reliable judges based upon their consistency in responses to the original and repeated items on the intelligibility test. The auditor consistency rate ranged from 70.00 percent to 93.33 percent with a median consistency rate of 80.00 percent.

Decibel readings had little or no influence upon the sopranos chosen by the auditors to be the most or least intelligible singers. The [a] and [o] vowel sounds were the loudest at all three pitch levels while the [i] and [u] vowel sounds were the softest. As the pitch rose from C4 to C5 and then to C6, the decibel readings had a corresponding rise from ten to twenty decibels indicating a possible relationship between intensity and loss of intelligibility with rising pitch.

Conclusions

The present study was primarily an attempt at determining if the musical expertise of the auditor had an effect on the intelligibility of vowel sounds in singing. More specifically, the main study sought to investigate the possible effects that auditors with extensive vocal music training, extensive non-vocal music training, and no music training had on the intelligibility of vowel sounds in singing.

The pilot study suggested that the vocally trained musicians used as auditors in the pilot study were able to recognize vowel sounds at differential pitch levels better than the non-musician auditors. In order to determine if vocal music experience or general music experience in an auditor's background contributed to the intelligibility of vowel sounds in singing, the non-vocal musicians (instrumentalists) were added to the present study. Since no significant differences were found between the vocalist and instrumentalist auditors and since both of the musically sophisticated auditors were found to be significantly better able to recognize vowel sounds sung at differential pitch levels than the non-musicians, it seems that musical experience in general and not vocal music in particular has an important effect on singing intelligibility.

While the pilot study and the present study are in accord concerning the significant effect of musical training in an auditor's background on the intelligibility of vowel sounds in singing, no other researcher has reported examining the auditor variable. Thus, any results or conclusions drawn from the present study, concerning the effect of the auditor, will have to be either supported or refuted by other research before more definitive conclusions can be reached. At least this study has indicated that the variable auditor experience may be an important variable for future consideration in relation to singing intelligibility research.

Intelligibility of vowel sounds in singing does not appear to be the result of merely one variable such as auditor experience, vowel sound, or pitch, but rather a complex interaction between these variables. Many investigators of the past such as Howie and Delattre (7, pp. 6-9), Morozov (12, pp. 279-283), and Triplett (19, pp. 6-8, 50) have only reported that pitch is the factor responsible for an auditor's recognition of a vowel sound. Other researchers including Flechtner (5, pp. 23-26) and Peterson and Barney (14, pp. 175-184) have indicated that the vowel sound performed can have an effect on singing intelligibility along with pitch. The analysis of variance in the present study has suggested that there was a significant series of two-way interactions between the variables (auditor experience, vowel sound, and pitch) which contributed to the intelligibility of vowel sounds in singing. Each of the three variables individually was found to have significant effects on the intelligibility scores, but the importance of each variable alone was not important in light of the two-way interactions discovered between the variables.

In the case of the significant two-way interaction between the variables experience and pitch, it seems that pitch influences the aforementioned significant effect of auditor experience on intelligibility in singing by having a stronger effect with some auditors than with others. The percentage rate of decline in auditor recognition of vowel sounds with rising pitch, which effects all auditors, is much greater with the non-musician auditors than with the vocalist or instrumentalist auditors. Many researchers including Flechtner (5, pp. 23-26), Howie and Delattre (7, pp. 6-9(, Morozov (12, pp. 279-283), Nelson and Tiffany (13, pp. 22-28, 33), Peterson and Barney (14, pp. 175-184), and Triplett (19, pp. 6-8, 50) have reported the adverse effect that rising pitch has on intelligibility in singing, but the two-way interaction between "pitch and experience" found in the present study, suggests that pitch alone does not account for decreasing intelligibility.

The significant two-way interaction between the variables experience and vowel sound is further evidence that more than one variable may be responsible for what auditors find to be intelligible. It was evident from examination of the mean scores that one group of auditors had better recognition of some of the vowel sounds than the other auditor groups. Different vowel sounds were more successfully recognized by the other groups of auditors. This data was confirmed by the t-tests.

A further significant two-way interaction was noted between the variables vowel sound and pitch. This interaction was anticipated by the obvious unequal effect of pitch upon the recognition of the individual vowel sounds. While all vowel sounds were less intelligible to auditors as the pitch rose, some vowel sounds declined in auditor perception more than others. The t-tests which compared the mean scores of each of the vowel sounds with one another at the same pitch levels, revealed significant differences in the auditor recognition of one vowel sound compared with the other vowel sounds at the same pitch. Since the present study only examined the five cardinal vowel sounds and since the recognition of these vowel sounds by all auditors varied significantly, a researcher examining vowel sounds other than the five cardinals might find results conflicting with the findings of this investigation.

Unlike the other two-way interactions discussed in this study, the two-way interaction between the variables vowel sound and pitch has been alluded to by past investigators. Flechtner (5, p. 24), for example, reported that vowel sounds differ in intelligibility to auditors at each pitch level and some vowel sounds decline more in auditor recognition than other vowel sounds as the pitch rises. Howie and Delattre (7, p. 9) explained that vowel sounds started losing auditor recognition at different pitches on the musical scale as the pitch rose above the first formant frequency. These aspects of the Flechtner research and the research of Howie and Delattre are in accord with the results of the present investigation.

Vowel Sounds

The significance of the variable "vowel sound" on the intelligibility of vowel sounds in singing was at least suggested by past singing intelligibility investigators including Howie and Delattre (7, pp. 6-9), Peterson and Barney (14, pp. 175-184), Flechtner (5, pp. 23-26), and Triplett (19, pp. 6-8, 50) when they reported that some vowel sounds are more intelligible to auditors than others. The present study found that the [a] vowel sound was the most intelligible vowel sound at all three pitch levels for all auditors. The pilot investigation also found the [a] vowel sound to be the most intelligible vowel sound at all pitch levels, but past investigators such as Howie and Delattre (7, p. 6) have reported the higher auditor recognition of the [a] vowel sound on the top pitches only (C6). Some of the auditors in the present study heard nothing but the [a] vowel sound at C6 regardless of the vowel sound being attempted by the soprano subjects. These auditors support the research of Howie and Delattre which suggests that all vowel sounds heard at C6, sound like the [a] vowel sound (7, p. 8). The assumption that all vowel sounds are heard as the [a] might explain why some auditors in the present study responded with the [a] vowel sound whenever a vowel sound was sung at C6. The assumption could also explain why nineteen of the twenty [a] vowel sounds sung at C6 were recognized by most auditors while the other vowel sounds sung at C6 were intelligible only by chance.

Howie and Delattre (7, p. 9) reveal their support of the fixed-ratio theory when they claim that it is theoretically impossible for any vowel sound other than the [a] to be intelligible on C6. While the present study supports that contention for the most part, the fact that five of the twenty [e] vowel sounds performed at C6 were recognized by half or more of the auditors, leads to the possibility that some singers may be able to be intelligible on vowel sounds other than [a] at C6. No corroborative evidence presently exists to support this assumption.

The low intelligibility of the [u] vowel sound in both the pilot and in the present study is a factor not mentioned by past investigators. Perhaps the contention of Peterson and Barney (14, p. 176) that the [u] vowel sound has the lowest frequencies of all the cardinal vowel sounds for both formants one and two is an explanation for this finding. Many singers experience difficulty in the production of the [u] vowel sound which could also account for the low intelligibility of this vowel sound. Further research is necessary before definitive conclusions can be reached about this vowel sound.

Pitch

Consistent with past singing intelligibility research, the pilot study for the present research, and the fixed-ratio theory, the present study found that the intelligibility of all vowel sounds suffered as a result of the pitch rising from C4 to C5 and then to C6 (with the aforementioned exceptions). Since all auditors declined in their recognition of each of the vowel sounds as the pitch rose, the results of the present study are in accord with the tenets of the fixed-ratio theory. Especially noteworthy is the tremendous decline in auditor recognition of vowel sounds at C6 where the intelligibility of all vowel sounds (with the exception of the [a]) was at less than chance level of recognition.

Generalizations and conclusions from this investigation ought, for the time being, to be limited to the present study since the sample populations may not be representative of the entire population. Some results and thus conclusions are in accord, however, with the evidence from other investigations and with the pilot study instigated by this researcher. Corroborative evidence of this nature will thus enhance the chances that the results and conclusions may be generalized to the entire population.

The results and conclusions of the present study were based upon the investigation of a fixed-set of variables in a limited context which tended to remove the study from practical performance. If the variables used in this study were changed significantly, the results and conclusions may be altered. Future investigations testing new variables as well as replications of the variables used here are invited.

The primary contribution of this study may not be in challenging or supporting popular theories or in creating new theories, but rather in exploring certain new variables which could have an important effect on the intelligibility of vowel sounds in singing. Thus, the present study in a sense is an initial effort in the investigation of variables not previously examined in relation to singing intelligibility. Future research into singing intelligibility including possible replications of this study could reveal if the variables found to be important contributors to singing intelligibility in the present study are significant variables.

Recommendations for Further Research

A number of areas in singing intelligibility research are suggested for future investigations as a result of this study. The expertise of the auditor, especially between groups of auditors like vocalists and instrumentalists, is an area with numerous possibilities for future research.

Replications of this study or research involving different auditor groups are just two examples of possible studies which could provide data to support or refute the importance of the experience variable.

The effect of vowel sounds upon intelligibility in singing is another potentially important area of research which still has unanswered questions. While many investigators have examined the effect of vowel sounds upon singing intelligibility, there has not been an accepted ranking of the vowel sounds from the most to the least intelligible vowel sounds except for the ranking of the five cardinal vowel sounds in the pilot and the main study. In the pilot study and in the present study the low level of recognition of the [u] vowel sound by all auditors at all pitch levels is another mystery that more research might be able to address.

A further area of investigation, which might reveal significant results, could examine the training, experience, and vocal techniques of singers in relation to their ability to be intelligible to auditors. The present study and the pilot study suggested that there were differences between the singers in the number of sounds they were able to make intelligible to auditors. Additionally, the study of singing intelligibility could benefit from some investigations of singing intelligibility in the actual performance situation. A better understanding of the variables of importance in singing intelligibility could lead to more intelligible singers.

Generalizations

Intelligibility in singing appears to be the result of a complex combination of variables including auditor experience, vowel sound, pitch, and perhaps singer training. Many investigations in the past have reported the strong effect of pitch on the intelligibility of vowel sounds in singing and some, as the present study, have even suggested that vowel sounds are recognized with varying degrees of accuracy by auditors, but the present investigation has shown that other variables may be important factors as well.

The present study and the pilot study found that musical training in an auditor's background was one of the important factors in determining what vowel sounds are intelligible. On nearly all vowel sounds at each pitch level, the vocalists were more accurate in their recognition of the vowel sounds than the instrumentalist auditors. Since college voice teachers work with singers regularly and are usually singers themselves, one might speculate that they should be able to recognize vowel sounds sung by trained singers better than instrumentalist auditors. However, this hypothesis was not supported by the results of this study and should be either verified or denied by further investigation.

Another important factor in singing intelligibility seems to be the expertise of the singer. Some singers in the present study were considerably more intelligible to auditors than others at all three pitch levels. (See Appendix C.) The pilot study also found considerable differences between auditor recognition of different singers. Exactly what skill these singers may have mastered, if any, is not clear. There is little doubt that acoustical phenomena have important effects on singing intelligibility. The strong effect of pitch on singing intelligibility, for instance, which was seen in the pilot study, the present investigation, and in many past research projects, is strong evidence in support of the impact of acoustical factors. Other important factors seen in the results of this study are the vowel sound being sung and the expertise of the auditor. If future investigations are able to find additional factors involved in singing intelligibility, then perhaps singers can learn to be more intelligible.

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APPENDIX A

TEST FORMS FOR AUDITORS

1. (i) (e) (a) (o) (u) (none)
2. (i) (e) (a) (o) (u) (none)
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159. (i) (e) (a) (o) (u) (none)
160. (i) (e) (a) (o) (u) (none)
161. (i) (e) (a) (o) (u) (none)
162. (i) (e) (a) (o) (u) (none)
163. (i) (e) (a) (o) (u) (none)
164. (i) (e) (a) (o) (u) (none)
165. (i) (e) (a) (o) (u) (none)

166. (i) (e) (a) (o) (u) (none)
167. (i) (e) (a) (o) (u) (none)
168. (i) (e) (a) (o) (u) (none)
169. (i) (e) (a) (o) (u) (none)
170. (i) (e) (a) (o) (u) (none)
171. (i) (e) (a) (o) (u) (none)
172. (i) (e) (a) (o) (u) (none)
173. (i) (e) (a) (o) (u) (none)
174. (i) (e) (a) (o) (u) (none)
175. (i) (e) (a) (o) (u) (none)
176. (i) (e) (a) (o) (u) (none)
177. (i) (e) (a) (o) (u) (none)
178. (i) (e) (a) (o) (u) (none)
179. (i) (e) (a) (o) (u) (none)
180. (i) (e) (a) (o) (u) (none)
181. (i) (e) (a) (o) (u) (none)
182. (i) (e) (a) (o) (u) (none)
183. (i) (e) (a) (o) (u) (none)
184. (i) (e) (a) (o) (u) (none)
185. (i) (e) (a) (o) (u) (none)
186. (i) (e) (a) (o) (u) (none)
187. (i) (e) (a) (o) (u) (none)
188. (i) (e) (a) (o) (u) (none)
189. (i) (e) (a) (o) (u) (none)
190. (i) (e) (a) (o) (u) (none)
191. (i) (e) (a) (o) (u) (none)
192. (i) (e) (a) (o) (u) (none)
193. (i) (e) (a) (o) (u) (none)
194. (i) (e) (a) (o) (u) (none)
195. (i) (e) (a) (o) (u) (none)
196. (i) (e) (a) (o) (u) (none)
197. (i) (e) (a) (o) (u) (none)
198. (i) (e) (a) (o) (u) (none)
199. (i) (e) (a) (o) (u) (none)
200. (i) (e) (a) (o) (u) (none)
201. (i) (e) (a) (o) (u) (none)
202. (i) (e) (a) (o) (u) (none)
203. (i) (e) (a) (o) (u) (none)
204. (i) (e) (a) (o) (u) (none)
205. (i) (e) (a) (o) (u) (none)
206. (i) (e) (a) (o) (u) (none)
207. (i) (e) (a) (o) (u) (none)
208. (i) (e) (a) (o) (u) (none)
209. (i) (e) (a) (o) (u) (none)
210. (i) (e) (a) (o) (u) (none)
211. (i) (e) (a) (o) (u) (none)
212. (i) (e) (a) (o) (u) (none)
213. (i) (e) (a) (o) (u) (none)
214. (i) (e) (a) (o) (u) (none)
215. (i) (e) (a) (o) (u) (none)
216. (i) (e) (a) (o) (u) (none)
217. (i) (e) (a) (o) (u) (none)
218. (i) (e) (a) (o) (u) (none)
219. (i) (e) (a) (o) (u) (none)
220. (i) (e) (a) (o) (u) (none)
221. (i) (e) (a) (o) (u) (none)
222. (i) (e) (a) (o) (u) (none)
223. (i) (e) (a) (o) (u) (none)
224. (i) (e) (a) (o) (u) (none)
225. (i) (e) (a) (o) (u) (none)
226. (i) (e) (a) (o) (u) (none)
227. (i) (e) (a) (o) (u) (none)
228. (i) (e) (a) (o) (u) (none)
229. (i) (e) (a) (o) (u) (none)
230. (i) (e) (a) (o) (u) (none)
231. (i) (e) (a) (o) (u) (none)
232. (i) (e) (a) (o) (u) (none)
233. (i) (e) (a) (o) (u) (none)
234. (i) (e) (a) (o) (u) (none)
235. (i) (e) (a) (o) (u) (none)
236. (i) (e) (a) (o) (u) (none)
237. (i) (e) (a) (o) (u) (none)
238. (i) (e) (a) (o) (u) (none)
239. (i) (e) (a) (o) (u) (none)
240. (i) (e) (a) (o) (u) (none)
241. (i) (e) (a) (o) (u) (none)
242. (i) (e) (a) (o) (u) (none)
243. (i) (e) (a) (o) (u) (none)
244. (i) (e) (a) (o) (u) (none)
245. (i) (e) (a) (o) (u) (none)
246. (i) (e) (a) (o) (u) (none)
247. (i) (e) (a) (o) (u) (none)
248. (i) (e) (a) (o) (u) (none)
249. (i) (e) (a) (o) (u) (none)
250. (i) (e) (a) (o) (u) (none)
251. (i) (e) (a) (o) (u) (none)
252. (i) (e) (a) (o) (u) (none)
253. (i) (e) (a) (o) (u) (none)
254. (i) (e) (a) (o) (u) (none)
255. (i) (e) (a) (o) (u) (none)
256. (i) (e) (a) (o) (u) (none)
257. (i) (e) (a) (o) (u) (none)
258. (i) (e) (a) (o) (u) (none)
259. (i) (e) (a) (o) (u) (none)
260. (i) (e) (a) (o) (u) (none)
261. (i) (e) (a) (o) (u) (none)
262. (i) (e) (a) (o) (u) (none)
263. (i) (e) (a) (o) (u) (none)
264. (i) (e) (a) (o) (u) (none)
265. (i) (e) (a) (o) (u) (none)
266. (i) (e) (a) (o) (u) (none)
267. (i) (e) (a) (o) (u) (none)

268. (i) (e) (a) (o) (u) (none)
269. (i) (e) (a) (o) (u) (none)
270. (i) (e) (a) (o) (u) (none)
271. (i) (e) (a) (o) (u) (none)
272. (i) (e) (a) (o) (u) (none)
273. (i) (e) (a) (o) (u) (none)
274. (i) (e) (a) (o) (u) (none)
275. (l) (e) (a) (o) (u) (none)
276. (i) (e) (a) (o) (u) (none)
277. (i) (e) (a) (o) (u) (none)
278. (i) (e) (a) (o) (u) (none)
279. (i) (e) (a) (o) (u) (none)
280. (i) (e) (a) (o) (u) (none)
281. (i) (e) (a) (o) (u) (none)
282. (i) (e) (a) (o) (u) (none)
283. (i) (e) (a) (o) (u) (none)
284. (i) (e) (a) (o) (u) (none)
285. (i) (e) (a) (o) (u) (none)
286. (i) (e) (a) (o) (u) (none)
287. (i) (e) (a) (o) (u) (none)
288. (i) (e) (a) (o) (u) (none)
289. (i) (e) (a) (o) (u) (none)
290. (i) (e) (a) (o) (u) (none)
291. (i) (e) (a) (o) (u) (none)
292. (i) (e) (a) (o) (u) (none)
293. (i) (e) (a) (o) (u) (none)
294. (i) (e) (a) (o) (u) (none)
295. (i) (e) (a) (o) (u) (none)
296. (i) (e) (a) (o) (u) (none)
297. (i) (e) (a) (o) (u) (none)
298. (i) (e) (a) (o) (u) (none)
299. (i) (e) (a) (o) (u) (none)
300. (i) (e) (a) (o) (u) (none)
301. (i) (e) (a) (o) (u) (none)
302. (i) (e) (a) (o) (u) (none)
303. (i) (e) (a) (o) (u) (none)
304. (i) (e) (a) (o) (u) (none)
305. (i) (e) (a) (o) (u) (none)
306. (i) (e) (a) (o) (u) (none)
307. (i) (e) (a) (o) (u) (none)
308. (i) (e) (a) (o) (u) (none)
309. (i) (e) (a) (o) (u) (none)
310. (i) (e) (a) (o) (u) (none)
311. (i) (e) (a) (o) (u) (none)
312. (i) (e) (a) (o) (u) (none)
313. (i) (e) (a) (o) (u) (none)
314. (i) (e) (a) (o) (u) (none)
315. (i) (e) (a) (o) (u) (none)
316. (i) (e) (a) (o) (u) (none)
317. (i) (e) (a) (o) (u) (none)
318. (i) (e) (a) (o) (u) (none)
319. (i) (e) (a) (o) (u) (none)
320. (i) (e) (a) (o) (u) (none)
321. (i) (e) (a) (o) (u) (none)
322. (i) (e) (a) (o) (u) (none)
323. (i) (e) (a) (o) (u) (none)
324. (i) (e) (a) (o) (u) (none)
325. (i) (e) (a) (o) (u) (none)
326. (i) (e) (a) (o) (u) (none)
327. (i) (e) (a) (o) (u) (none)
328. (i) (e) (a) (o) (u) (none)
329. (i) (e) (a) (o) (u) (none)
330. (i) (e) (a) (o) (u) (none)

APPENDIX B

RAW SCORES OF AUDITORS FOR EACH VOWEL AT THE THREE PITCHES

TABLE X

RAW SCORES OF AUDITORS FOR EACH VOWEL
AT THE PITCH C4*

	Auditor Number	i	e	a	o	u
Experience I						
Vocalists	1	20	17	20	15	19
	2	20	20	20	15	17
	3	30	19	20	19	19
	4	20	18	20	19	20
	5	20	18	20	17	19
	6	20	18	20	18	17
	7	20	18	20	14	12
	8	20	18	20	14	20
	9	20	19	19	19	20
	10	20	18	20	16	19
Experience II						
Musical Instrumentalists	11	20	18	20	19	19
	12	20	19	20	17	20
	13	20	17	20	15	18
	14	20	18	20	16	16
	15	20	19	20	13	19
	16	19	18	20	18	19
	17	17	16	17	18	17
	18	20	18	20	16	18
	19	20	18	20	15	18
	20	20	16	20	16	16
Experience III						
Non-Musicians	21	20	17	20	16	19
	22	20	18	20	17	20
	23	19	18	20	16	12
	24	20	17	20	15	18
	25	18	10	20	15	18
	26	20	18	20	13	15
	27	12	5	20	17	18
	28	18	17	20	16	10
	29	20	19	20	9	13
	30	20	18	18	16	12

*Number of correct responses for each vowel by each auditor out of 20.

TABLE XI

RAW SCORES OF AUDITORS FOR EACH VOWEL
AT THE PITCH C5*

	Auditor Number	i	e	a	o	u
<u>Experience I</u>						
Vocalists	1	20	14	18	13	16
	2	17	18	18	11	11
	3	17	19	18	13	10
	4	11	20	19	10	10
	5	19	17	18	9	16
	6	19	18	17	16	10
	7	20	11	12	17	6
	8	9	19	17	11	9
	9	18	16	14	13	17
	10	10	20	19	11	3
<u>Experience II</u>						
Musical Instrumentalists	11	18	14	15	12	15
	12	14	20	16	12	6
	13	19	16	20	9	12
	14	20	14	18	15	3
	15	18	17	18	8	2
	16	14	15	13	13	16
	17	15	15	7	16	7
	18	17	16	20	12	10
	19	13	16	19	12	1
	20	19	13	19	11	11
<u>Experience III</u>						
Non-Musicians	21	19	12	15	12	13
	22	17	12	17	8	5
	23	16	19	18	6	1
	24	7	17	19	7	1
	25	20	13	19	3	5
	26	18	13	18	2	3
	27	7	4	20	12	4
	28	4	19	18	14	4
	29	5	20	20	7	0
	30	18	13	20	8	8

*Number of correct responses for each vowel by each auditor out of 20.

TABLE XII

RAW SCORES OF AUDITORS FOR EACH VOWEL
AT THE PITCH C6*

	Auditor Number	i	e	a	o	u
Experience I						
Vocalists	1	2	12	19	2	0
	2	12	9	5	7	6
	3	1	10	16	2	0
	4	0	10	13	2	0
	5	6	11	9	3	1
	6	3	13	10	3	0
	7	3	13	12	2	0
	8	3	2	18	1	0
	9	5	6	12	3	2
	10	0	4	19	3	0
Experience II						
Musical Instrumentalists	11	3	12	13	3	2
	12	0	14	11	10	0
	13	1	0	19	0	0
	14	3	0	20	3	0
	15	0	0	20	0	0
	16	0	0	19	1	2
	17	2	13	11	3	0
	18	1	11	10	4	0
	19	0	5	18	1	0
	20	0	12	14	1	0
Experience III						
Non-Musicians	21	1	10	17	8	0
	22	5	5	12	2	0
	23	1	9	17	0	0
	24	1	8	17	0	0
	25	4	4	19	0	0
	26	3	2	12	0	0
	27	8	1	14	0	1
	28	1	4	17	1	0
	29	0	0	20	0	0
	30	1	9	17	3	0

*Number of correct responses for each vowel by each auditor out of 20.

APPENDIX C

OVERALL INTELLIGIBILITY OF THE THREE AUDITOR GROUPS DIVIDED BY GENDER

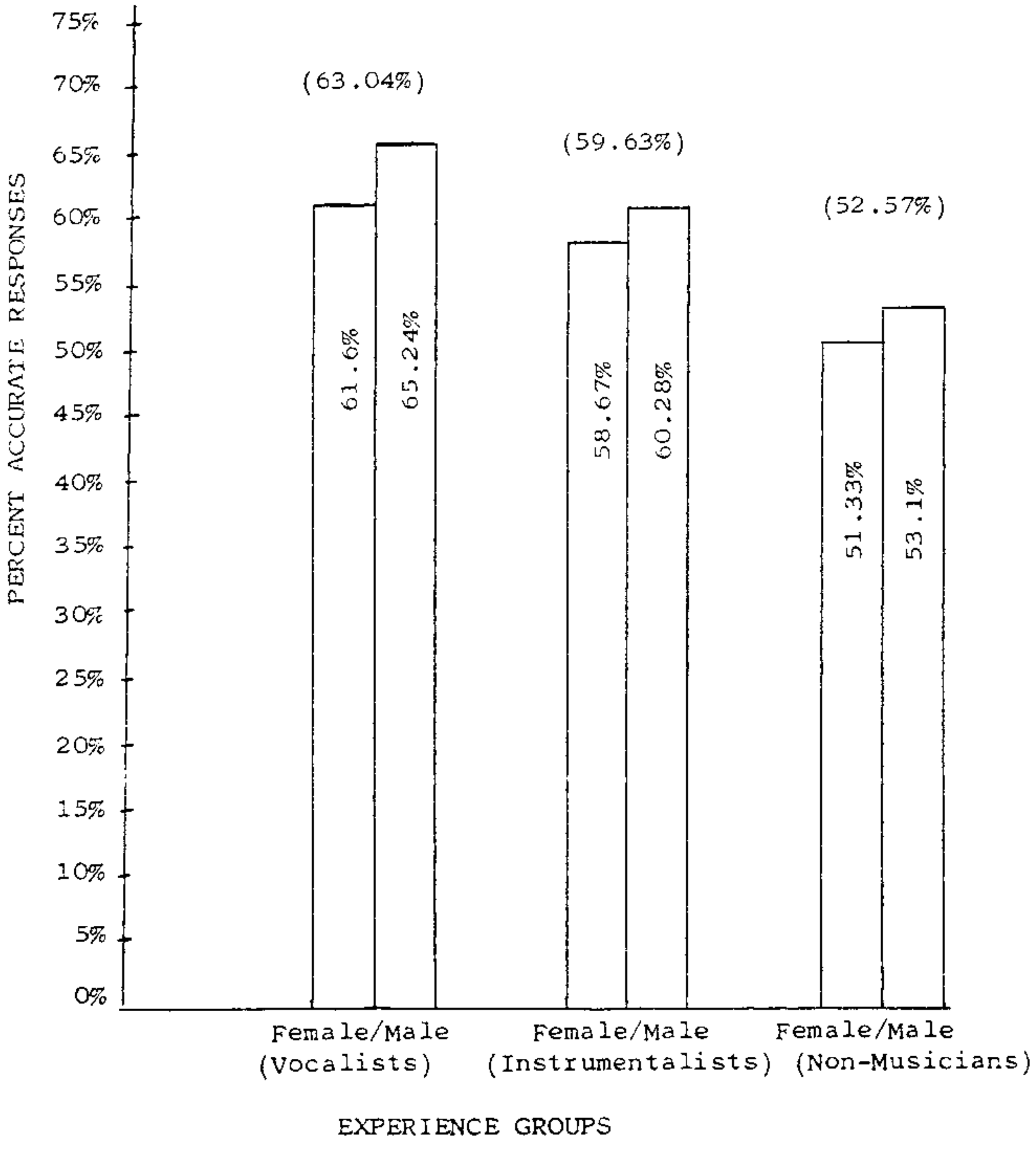

Fig. 4--Overall intelligibility of the three auditor groups divided by gender.

APPENDIX D

RELIABILITY OF AUDITORS AS MEASURED BY MATCHING REPEATED SOUNDS

TABLE XIII

RELIABILITY OF AUDITORS AS MEASURED BY MATCHING REPEATED SOUNDS*

Auditors	Sound Numbers												
	53	54	76	88	81	48	10	85	55	30	78	31	45
1 M	+-	-+	++	++	++	++	-+	-+	++	--	++	++	--
2 M	++	++	++	--	++	++	+-	--	++	++	++	++	--
3 M	++	++	++	-+	--	++	--	--	++	--	++	++	--
4 M	++	++	++	+-	+-	++	--	--	++	--	++	++	--
5 F	++	--	++	++	-+	++	++	+-	++	--	++	++	--
6 F	+-	++	++	+-	-+	++	-+	--	-+	-+	++	++	--
7 F	+-	++	++	+-	++	++	--	--	--	--	++	++	--
8 F	+-	+-	++	++	--	++	--	--	+-	--	++	++	++
9 F	+-	--	++	++	+-	+-	++	+-	++	+-	++	++	--
10 F	+-	+-	++	++	--	++	--	+-	+-	--	++	++	--
11 M	+-	+-	++	+-	++	++	++	+-	++	+-	++	++	--
12 M	+-	++	++	++	+-	++	--	--	++	--	++	++	--
13 F	++	+-	++	++	++	++	--	+-	--	--	++	++	--
14 F	++	++	++	++	++	++	--	--	++	--	++	++	--
15 F	++	++	++	++	++	++	--	--	++	--	++	++	--
16 F	--	++	+-	++	-+	++	++	+-	++	-+	++	++	--
17 M	+-	++	++	++	--	++	--	+-	--	--	++	++	--
18 M	++	+-	++	++	++	++	+-	+-	++	--	++	++	--
19 M	++	+-	++	++	--	++	--	--	-+	--	++	++	--
20 M	++	+-	++	++	-+	++	--	+-	++	--	++	++	--
21 F	+-	+-	++	++	++	++	+-	+-	++	--	++	++	--
22 M	+-	++	++	+-	+-	++	--	--	++	--	++	++	--
23 M	++	++	++	-+	++	++	--	--	--	--	++	++	--
24 M	++	++	++	++	--	++	--	--	--	--	++	++	--
25 M	++	+-	-+	++	++	++	--	--	++	--	++	++	--
26 M	++	+-	++	++	++	++	+-	--	--	--	++	++	--
27 F	++	++	++	++	--	++	-+	--	+-	--	++	+-	--
28 M	++	++	++	++	--	++	--	--	--	--	++	++	--
29 F	++	++	++	++	--	++	--	--	--	--	++	++	--
30 M	++	++	++	++	-+	++	--	+-	+-	--	++	++	--
Pitch	C5	C5	C4	C6	C5	C4	C5	C5	C5	C6	C4	C4	C6
Vowel	a	o	i	a	i	a	u	u	u	u	a	i	u

*(+) symbolizes a correct response, (-) symbolizes an incorrect response; auditors 1-10 = vocalists, 11-20 = instrumentalists, 21-30 = non-musicians.

TABLE XIII--Continued

Sound Numbers																	Percent Consistent
43	38	51	69	70	79	68	67	20	82	65	34	52	47	64	40	61	
--	++	++	++	++	++	++	++	++	++	++	-+	--	--	++	++	++	83.3
--	-+	++	++	++	++	++	++	++	++	++	--	-+	++	++	+-	++	86.67
++	++	++	++	++	++	++	++	-+	++	++	++	++	++	++	++	++	93.33
-+	++	++	+-	-+	++	++	++	++	++	++	++	++	++	++	-+	++	80.0
--	++	++	++	+-	++	++	++	++	++	++	--	++	++	++	++	++	90.0
-+	--	++	++	-+	++	++	++	++	++	++	--	++	++	++	--	++	73.33
--	--	++	++	-+	++	++	++	+-	++	++	-+	--	++	++	+-	++	80.0
++	++	+-	++	--	++	++	++	++	-+	++	-+	++	++	++	-+	++	76.67
+-	--	++	++	++	++	++	++	++	++	++	++	--	++	++	++	++	80.0
+-	++	+-	++	++	++	++	++	++	++	++	++	++	++	++	-+	++	76.67
+-	--	++	++	++	++	++	++	++	++	++	++	--	++	++	-+	++	76.67
-+	++	++	++	+-	++	++	++	++	++	++	++	++	++	++	++	++	86.67
++	++	++	++	++	++	++	++	++	++	++	--	++	+-	++	++	++	90.0
++	+-	++	++	-+	++	++	++	++	++	++	--	--	++	++	--	++	93.33
++	+-	++	+-	--	--	++	++	++	++	++	--	-+	++	++	--	++	90.0
++	++	++	++	++	++	+-	++	++	++	++	++	+-	++	++	++	++	80.0
--	-+	++	++	+-	++	-+	++	++	++	++	-+	--	-+	++	-+	++	73.33
--	-+	++	++	++	++	-+	++	++	+-	+-	+-	+-	++	++	+-	++	76.67
++	++	++	+-	--	++	++	++	++	++	++	--	+-	++	++	+-	++	83.3
+-	--	++	++	+-	++	-+	++	+-	++	++	++	--	++	++	-+	++	73.33
+-	++	++	++	+-	++	+-	++	++	++	++	+-	-+	++	++	++	++	70.0
+-	++	++	++	--	++	+-	++	++	++	++	-+	++	++	++	++	++	80.0
++	-+	++	--	--	+-	++	++	--	++	++	--	++	++	++	--	++	90.0
+-	++	-+	++	--	++	++	--	++	+-	++	--	-+	++	++	--	++	86.67
++	++	++	-+	--	+-	++	--	++	+-	++	--	--	--	++	-+	++	80.0
--	++	++	--	+-	+-	+-	++	++	++	+-	--	--	++	++	--	++	80.0
--	++	--	-+	--	++	++	--	++	--	++	-+	--	--	++	--	++	83.3
++	+-	-+	++	++	++	++	++	+-	++	++	+-	++	-+	++	+-	++	80.0
++	++	+-	--	--	-+	++	++	+-	++	++		++	++	++	--	++	90.0
+-	++	++	--	++	+-	++	+-	++	++	++	+-	+-	++	++	--	++	73.33
C6 a	C5 a	C5 i	C5 o	C5 u	C4 o	C5 a	C5 e	C4 u	C5 e	C4 u	C4 o	C5 e	C4 e	C4 o	C5 u	C4 i	

APPENDIX E

VOWEL RECOGNITION BY THE AUDITORS AT THE THREE PITCH LEVELS BY PITCH AND OVERALL

TABLE XIV

VOWEL RECOGNITION BY THE AUDITORS AT THE THREE PITCH LEVELS BY PITCH AND OVERALL (In Percentages)

Vowels	Pitch			
	C4	C5	C6	Overall
i	97.20	74.84	11.67	61.23
e	86.17	78.50	34.84	66.50
a	99.00	86.67	75.34	87.00
o	80.00	54.34	16.84	50.39
u	86.17	39.50	2.67	42.78
Overall	89.70	66.77	28.27	61.58

APPENDIX F

NUMBER OF CORRECT RESPONSES FOR EACH VOWEL SOUND BY THE THREE AUDITOR GROUPS AT THE THREE PITCHES OUT OF A POSSIBLE 200

TABLE XV

NUMBER OF CORRECT RESPONSES FOR EACH VOWEL SOUND BY THE THREE AUDITOR GROUPS AT THE THREE PITCHES OUT OF A POSSIBLE 200*

	Vowel Sounds				
	i	e	a	o	u
C4					
Experience 1	200	183	199	166	182
Experience 2	196	177	197	163	180
Experience 3	187	157	198	150	155
C5					
Experience 1	160	172	170	124	108
Experience 2	167	156	165	120	83
Experience 3	131	142	184	79	44
C6					
Experience 1	35	90	133	28	9
Experience 2	10	67	155	26	4
Experience 3	25	52	162	14	1
Overall*					
Experience 1	395	445	502	318	299
Experience 2	373	400	517	309	267
Experience 3	343	351	544	243	200

*Scores are out of a possible 600.

APPENDIX G

RAW SCORES FOR EACH INDIVIDUAL SINGER ON EACH VOWEL AT THE THREE PITCH LEVELS

TABLE XVI

RAW SCORES FOR EACH INDIVIDUAL SINGER ON EACH VOWEL AT THE THREE PITCH LEVELS

Singer Number	C4					C5					C6				
	i	e	a	o	u	i	e	a	o	u	i	e	a	o	u
1	30	29	30	30	18	28	26	30	3	6	1	0	27	3	3
2	29	8	30	29	26	20	11	24	26	6	3	7	18	5	3
3	29	27	29	12	23	17	27	23	3	16	2	15	13	0	0
4	28	24	29	29	29	27	18	20	27	19	4	9	26	4	1
5	30	27	30	30	27	25	26	26	21	14	6	12	27	1	0
6	30	26	30	28	22	17	29	29	13	0	1	13	24	10	0
7	28	28	30	18	25	25	26	28	14	17	4	8	25	3	0
8	29	29	30	28	30	24	27	29	25	20	12	15	28	3	0
9	30	29	30	27	29	17	27	30	11	11	6	12	24	9	1
10	28	29	30	23	30	24	27	28	22	10	5	19	19	0	1
11	30	28	28	30	26	28	10	27	20	18	5	13	26	4	1
12	28	28	30	29	20	25	23	29	20	8	0	1	23	2	0
13	29	30	30	23	17	25	28	14	26	7	3	8	20	1	0
14	29	28	30	14	28	23	18	20	17	5	6	14	21	4	0
15	29	30	30	30	28	25	30	27	9	12	1	1	28	5	1
16	28	1	30	11	30	20	10	30	20	5	4	16	25	6	1
17	30	30	30	15	25	27	29	29	9	22	2	12	22	1	1
18	29	29	29	20	28	28	22	24	15	16	1	10	20	0	0
19	30	29	30	26	30	15	30	27	12	19	3	15	18	6	0
20	30	28	29	28	26	9	27	26	13	6	1	9	18	2	3

APPENDIX H

LINE CHARTS REPRESENTING AVERAGE ACCURATE RESPONSES OF ALL AUDITORS FOR EACH VOWEL SOUND AT THE THREE PITCH LEVELS

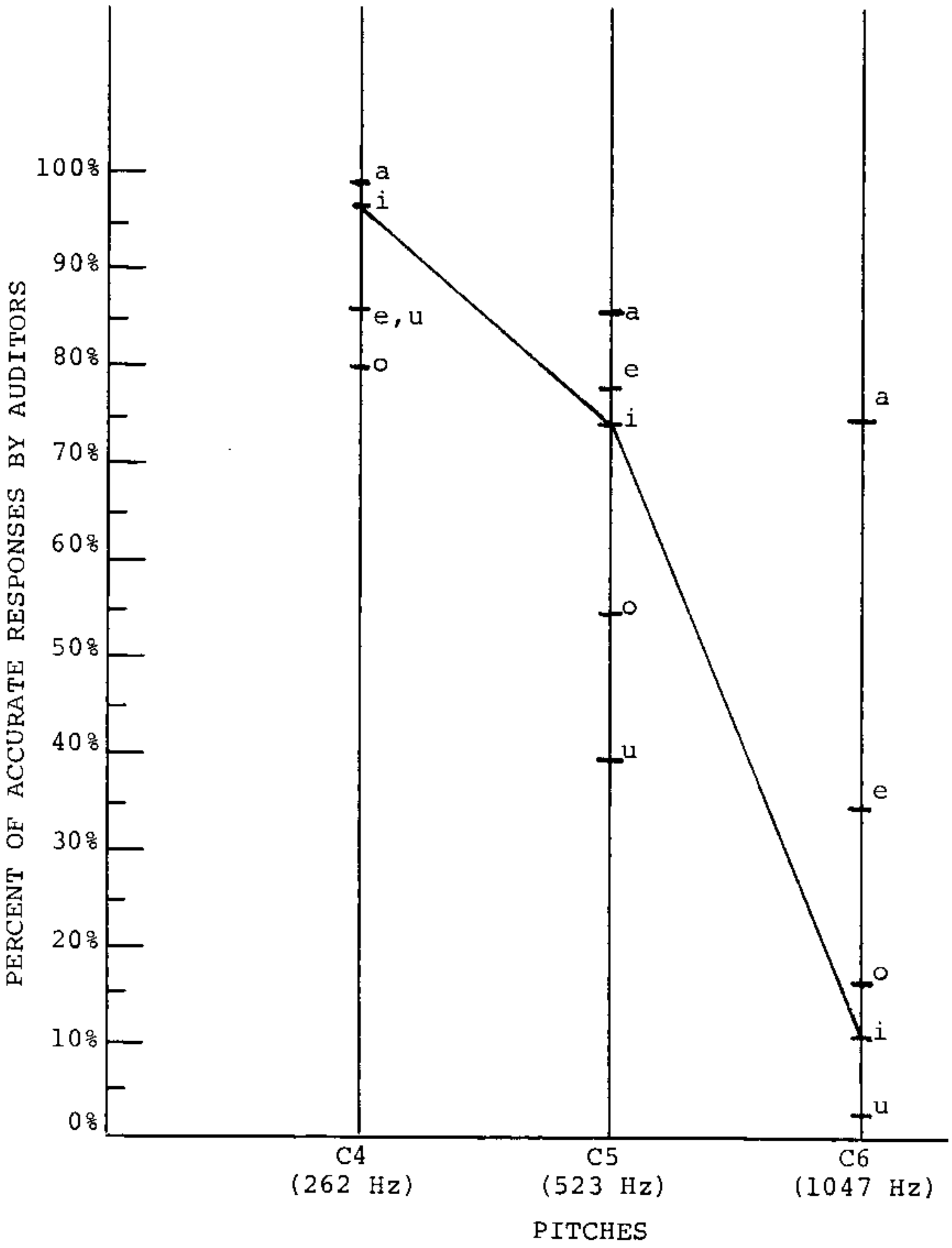

Fig. 5--Line chart representing the average accurate responses of all auditors for each vowel sound at the three pitch levels. The dark line between the [i] vowel sound symbols demonstrates the decline in auditor accuracy.

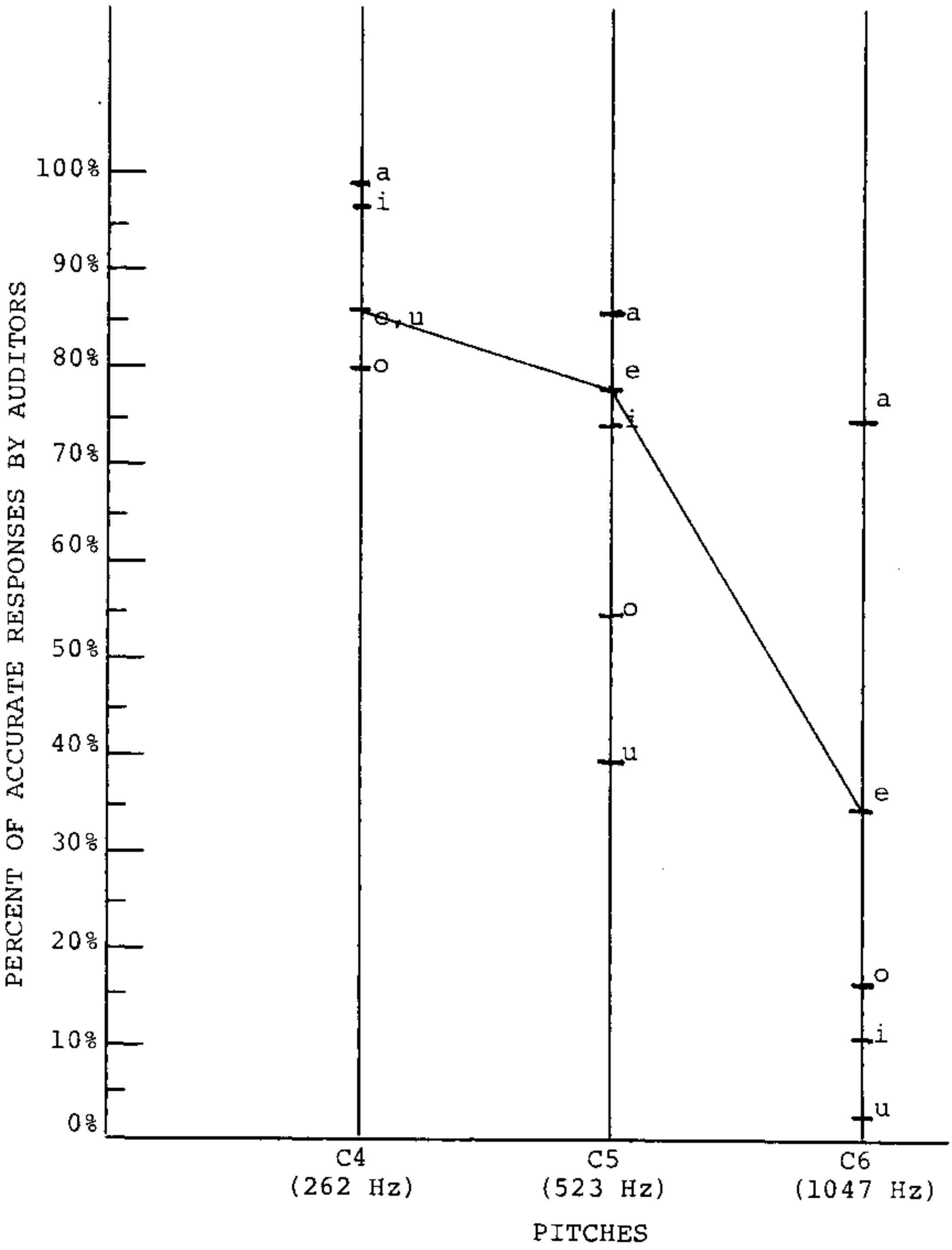

Fig. 6--Line chart representing the average accurate responses of all auditors for each vowel sound at the three pitch levels. The dark line between the [e] vowel sound symbols demonstrates the decline in auditor accuracy.

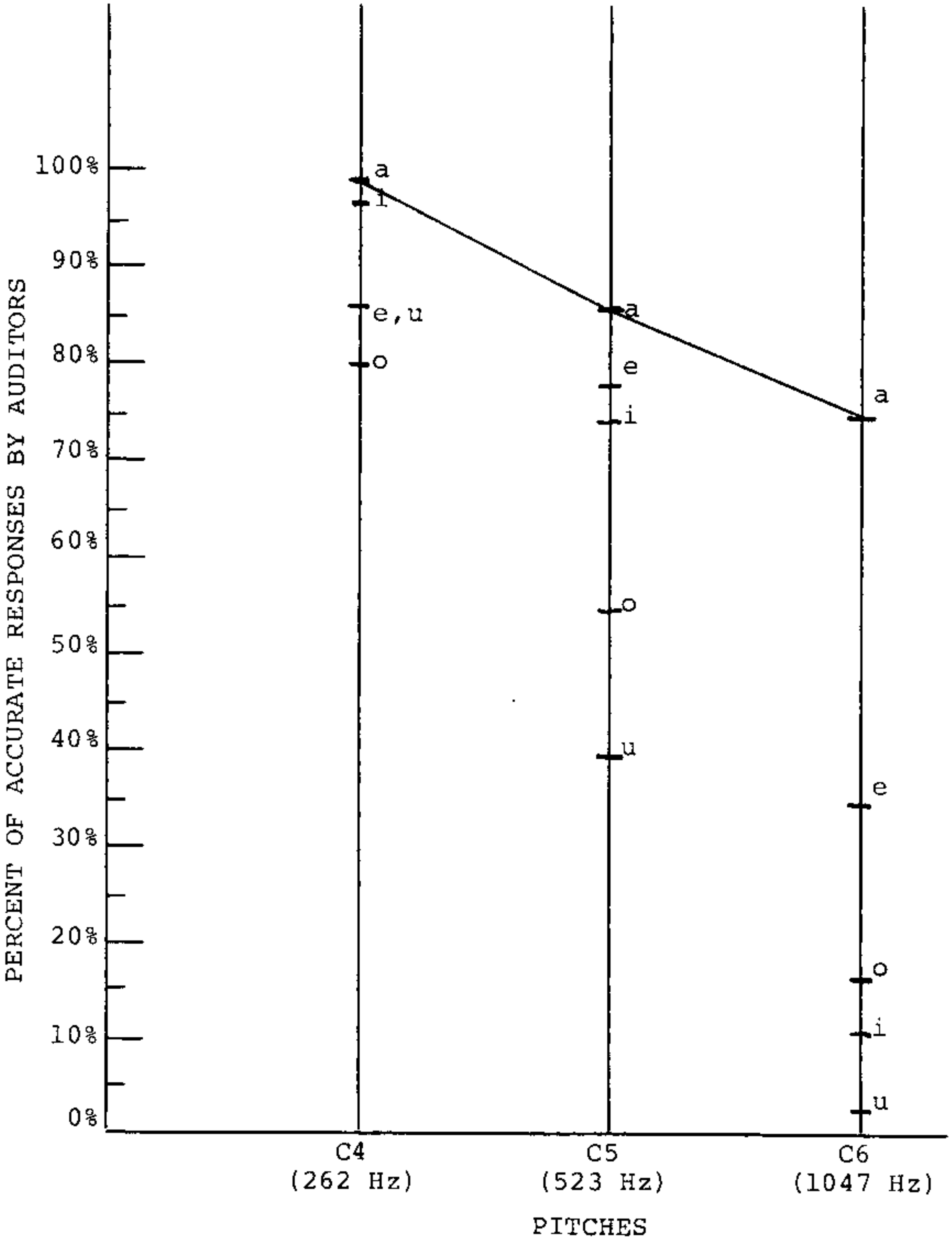

Fig. 7--Line chart representing the average accurate responses of all auditors for each vowel sound at the three pitch levels. The dark line between the [a] vowel sound symbols demonstrates the decline in auditor accuracy.

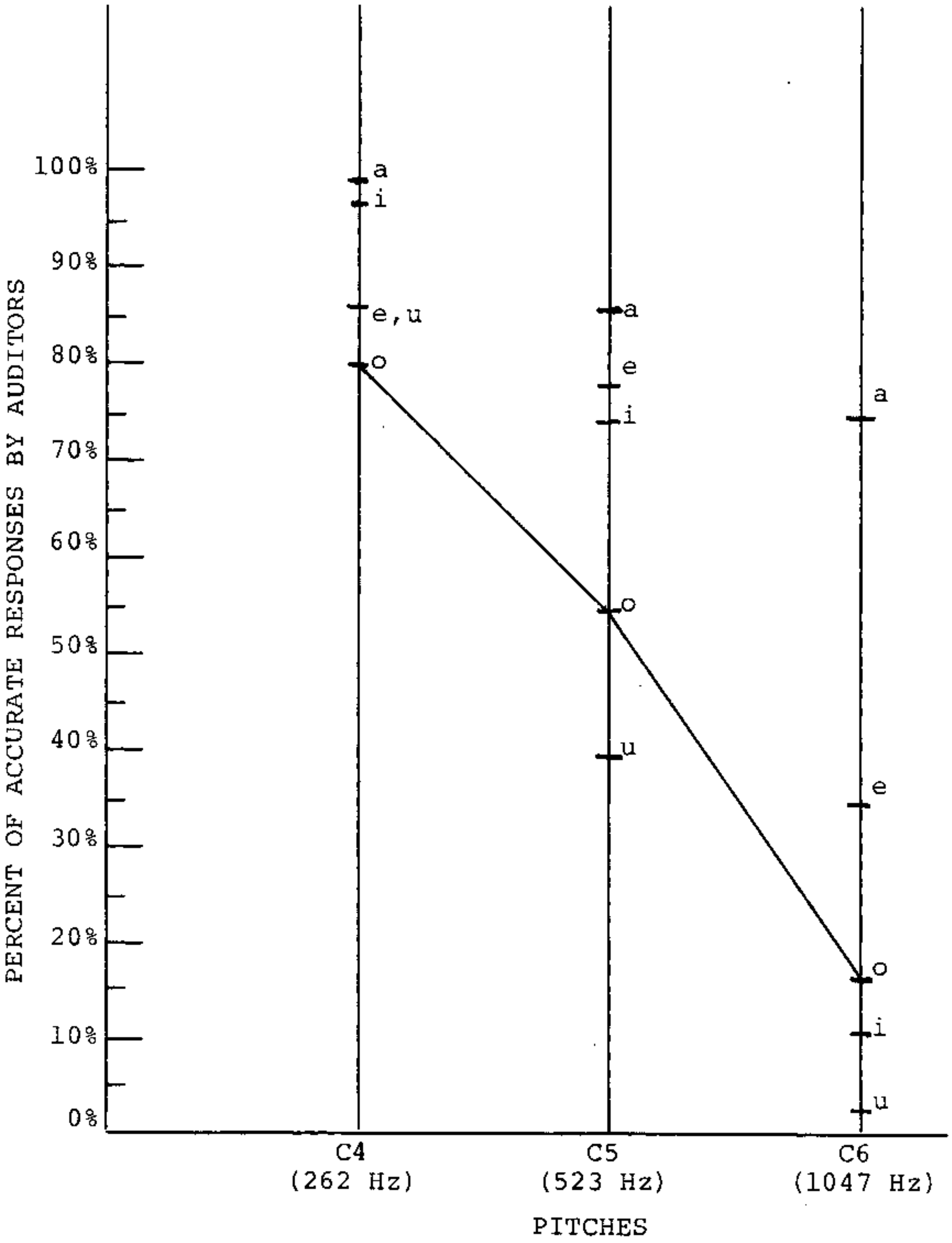

Fig. 8--Line chart representing the average accurate responses of all auditors for each vowel sound at the three pitch levels. The dark line between the [o] vowel sound symbols demonstrates the decline in auditor accuracy.

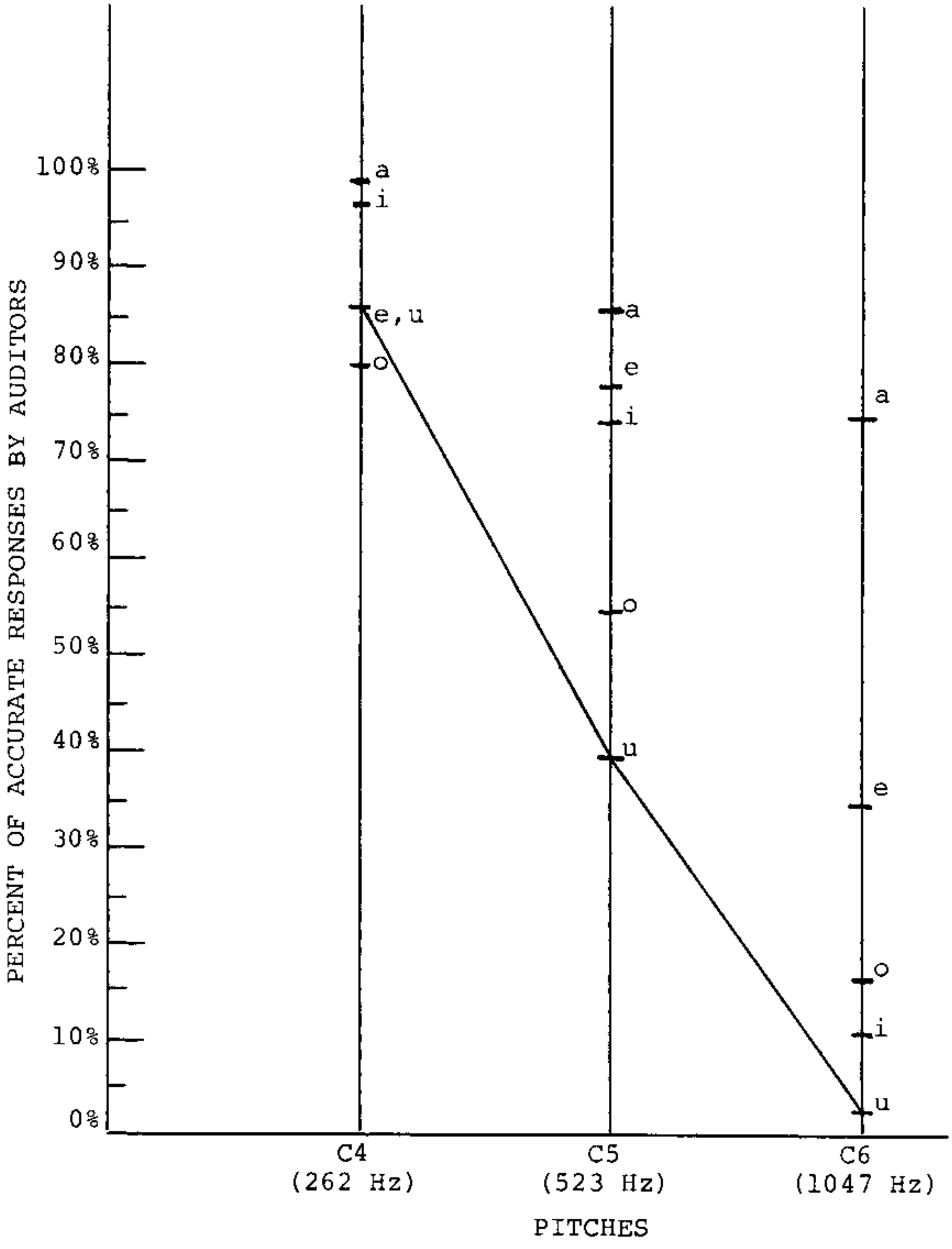

Fig. 9--Line chart representing the average accurate responses of all auditors for each vowel sound at the three pitch levels. The dark line between the [u] vowel sound symbols demonstrates the decline in auditor accuracy.

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