SPECTROGRAPHIC ANALYSIS OF THE ACOUSTICAL PROPERTIES OF

SELECTED VOWELS IN CHORAL SOUND

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SPECTROGRAPHIC ANALYSIS OF THE ACOUSTICAL PROPERTIES OF SELECTED VOWELS IN CHORAL SOUND

DISSERTATION

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By

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CHAPTER I

INTRODUCTION

Vocal blend is a primary concern for teachers of choral music at all educational levels. Much has been theorized about good choral blend and how it may best be obtained. These theories have been largely subjective, depending for effectiveness upon the aural perception of the individual. Vocal blend can be described as the sound produced by the mixing of the various characteristics of voices. An aurally pleasing sound is said to have good blend, an unpleasant sound to have poor blend. Little empirical evidence has been utilized in support of any of the various theories of choral blend.

There is a need for the gathering and codifying of empirical data which can be used as a scientific basis for the formulation and evaluation of theories and techniques of achieving good choral blend. Such information, by separating the factual from the supposed, can help disperse the mysticism which has existed among teachers of singing and lead to more thorough understanding and clearly defined processes for the teaching of choral singing.

Statement of the Problem

The problem of this study was a spectrographic analysis of the acoustical properties of selected vowels in choral sound.

Purposes of the Study

The purposes of this study were (1) to categorize examples of vowel sounds by means of subjective evaluation, (2) to ascertain by spectrographic analysis the distinguishing characteristics of the acoustical properties of the examples in the categories, (3) to determine the similarities and dissimilarities which exist within and between the categories, and (4) to analyze the implications of the findings for the teaching of choral singing.

Background and Significance of the Study

"The problem of blend is the mixing of all types of voices, colors, and intensities into one common tone quality that is the best possible for that particular group" (4, p. 147). The sound of the voice when used in singing has duration, intonation, loudness, vibrato, quality of tone or timbre, and vowel sound. When voices are combined into a choral group the resulting quality of sound depends upon how well the characteristics of the voices blend and/or unify.

In choral singing, unity should be sought in duration, intonation, and loudness. The vibrato should be used for expression and should be governed by intensity, vocal timbre, and musical style. Vocal timbre should be regarded as an individual property and should not be modified for the sake of achieving choral blend. The vowel sound, which is common to all voices, is variable and can be used as the vehicle for the mixing of individual timbres into a blended sound. "There is almost unanimous agreement that one of the most important factors, if not the most important factor in the achievement of choral blend is unity of vowel" (22, p. 40).

Research studies using the sound spectrograph to analyze individual voices have indicated that vowel sounds are measurable concentrations of energy at certain frequency levels within a tonal spectrum. The strongest of these concentrations, the formants, determine the vowel sound which is perceived.

Howie and Delattre explain the formant theory in the following manner:

> Briefly, the theory of formants is as follows: The cavities of the vocal tract possess natural notes of resonance which "pass" or reinforce certain harmonics of the vocal chord tone. These emphasized harmonics form concentrations of acoustic energy at frequency regions on the spectrum corresponding to the natural notes of resonance of the cavities. The term formant refers to the selective resonance in a particular frequency which characterize the timbre, or color, of vowels, while the higher formants contribute mostly to the timbre, or quality, of the individual voice (6, p. 6).

The pitch of the formants can be calibrated in cycles-per-second, or Hertz, on the sound spectrogram. The intensity of the formants can be measured in decibel units by making an amplitude section on the spectrogram. This is illustrated in a study by Taff:

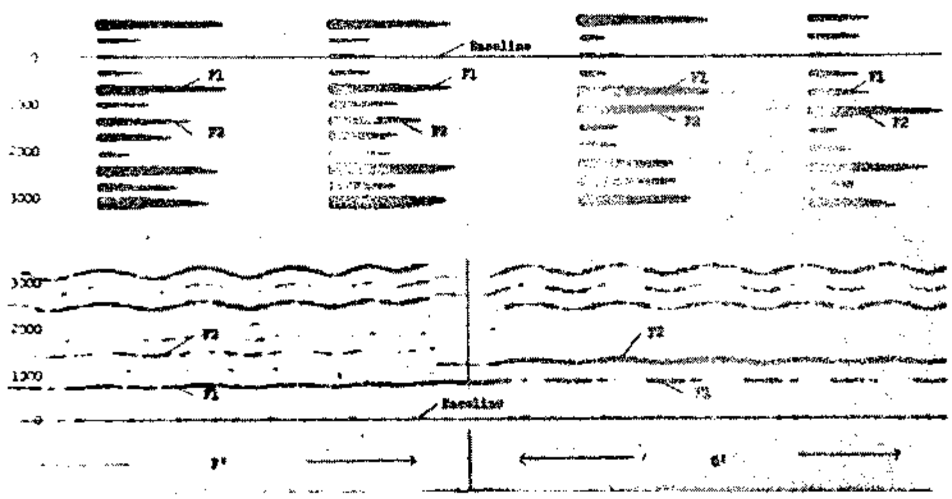

Fig. 1--A spectrogram of the vowel (a) sung on the pitches f' and g', with sections made from the low and high points of the vibrato wave. The baseline and the first two formants are indicated (19, p. 8).

Each vowel is characterized by two well-defined formants. When a specific vowel is spoken or sung, these two formants should be in a specific relationship. These relationships are shown in the following chart made from the finding of a study by Peterson and Barney (11, p. 182).

The symbols identifying the vowel sounds in the chart are from the International Phonetic Alphabet. These symbols, along with English equivalent sounds, were used for the identification of vowels in this study.

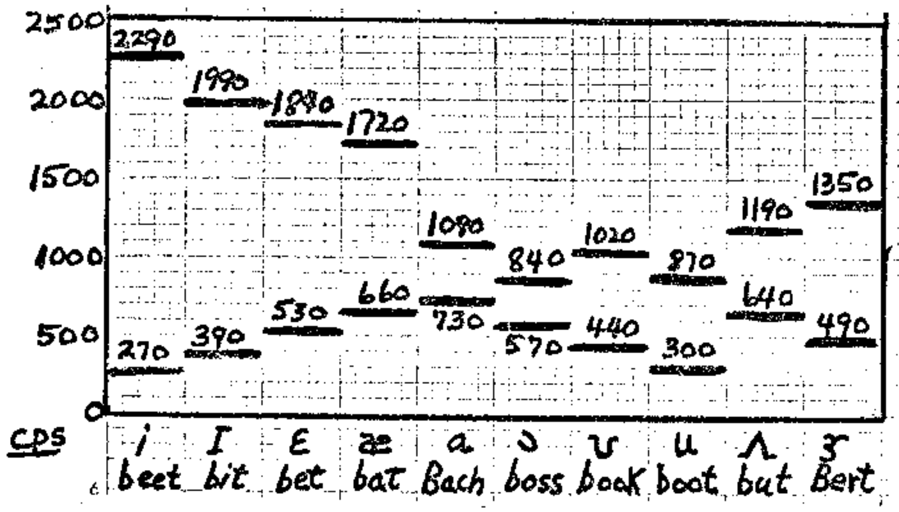

Fig. 2--A chart of average frequencies of vowel formants

When there is a modification of the vowel, the formant frequencies should also modify, or deviate, in a predictable direction. Examination of numerous sound spectrograms (13) indicates that this modification is smooth and continuous and independent of the pitch being sung by the voice. The following information is from a study by Delattre.

> Obviously formant frequency is independent from the fundamental frequency, subjectively called voice pitch and whose variations make "intonation" in speaking and "melody" in singing. For example, if the utterance of an "a" vowel is sustained while the pitch is made to fall, the spectrum will show that all the formants of the "a" keep constant frequencies:

Fig. 3--A spectrogram of a showing that voice pitch can be independent of vowel color: The voice melody frequency falls by about one octave (about 240 cps to 120 cps), but the formant frequencies of a (about 700, 1200, and 2400 cps) remain unchanged throughout.

Conversely, if the pitch is sustained while vowel color is changed--let us say, from "a" to "eh"--the first formant falls by some 200 cps and the second rises by some 600 cps while all the harmonics keep a constant frequency.

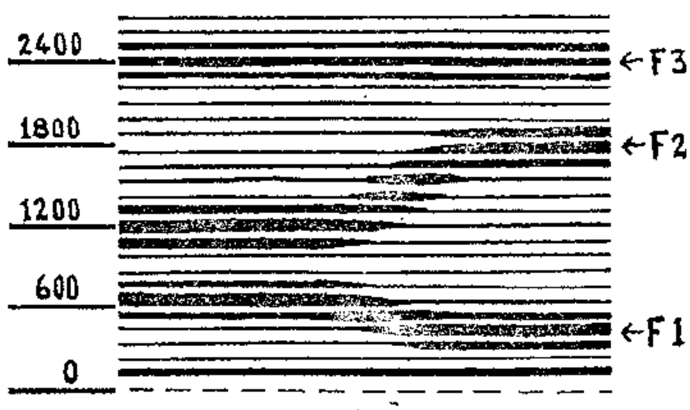

Fig. 4--A spectrogram of a-eh showing that vowel color can be independent of voice pitch: The frequencies of formants one and two change from about 700 cps and 1200 cps for a to 500 cps and 1800 cps for eh but the voice melody frequently remains unchanged at about 110 cps throughout.

> Changes in formant frequency are due only to changes in the shape of the vocal tract cavity or cavities; changes in pitch frequency to stretching of the vocal chords. If the two physiological events are independent, so are the acoustic results of each event--formant frequency changes and overtone frequency changes (3, pp. 4-5).

These studies have been concerned with the recording and analyzing of the sound of a single voice. The concern of this study was to determine in part what happens to vowel formants when a number of voices are combined as in a choral group. This study attempted to analyze and define the distinguishing characteristics of the acoustical properties of the vowel formants in choral sound, and to determine the effect of the combined deviations of the formants upon the blend of choral sound. In utilizing the empirical evidence of the spectrogram and the subjective judgment of a jury of experts, this study came to bear upon the theory that "the most important factor in the achievement of choral blend is unity of vowel" (22, p. 40).

Limitations

This study was limited to the analysis and evaluation of 216 tape-recorded examples of choral sound. An equal number of examples, seventy-two each, were obtained from junior high school choirs, senior high school choirs, and college choirs, There is no reason to suppose that the analysis of blend of choral sound would have differed in significant ways should a larger number of examples have been used.

Basic Assumptions

It was assumed that the members of the choral groups used as examples sang during the recording session in a manner not different from the manner in which they would sing in rehearsal or performance. It was also assumed that the members of the jury were competent and that they responded honestly in the evaluation of the examples. It was further assumed that the sound spectrograph used in the study was an adequate instrument for analyzing choral sound.

Instruments

The sound spectrograph is a device developed at the Bell Telephone Laboratories for use in teaching the deaf to speak with normal sound (8, 9, 12, 13, 14, 17). This device produces a graphic record of vocal sound. The visual comparison of spectrograms has been used to teach the deaf to speak with specific speech patterns. The machine has been used frequently to analyze the solo singing voice and has been accepted as an adequate instrument for use in comparing visual analysis with aural evaluation of sound (1, 2, 5, 7, 10, 15, 16, 18, 19, 20, 21).

As the study progressed, a limitation of the instrument was discovered. For the purpose of musical analysis, the scale of the spectrogram is extremely distorted. In the present spectrogram, all musical intervals from the low threshold of hearing to approximately the C above Middle C are compressed into the lowest calibration band. (See Figure 5.) In musical notation this distance is approximately

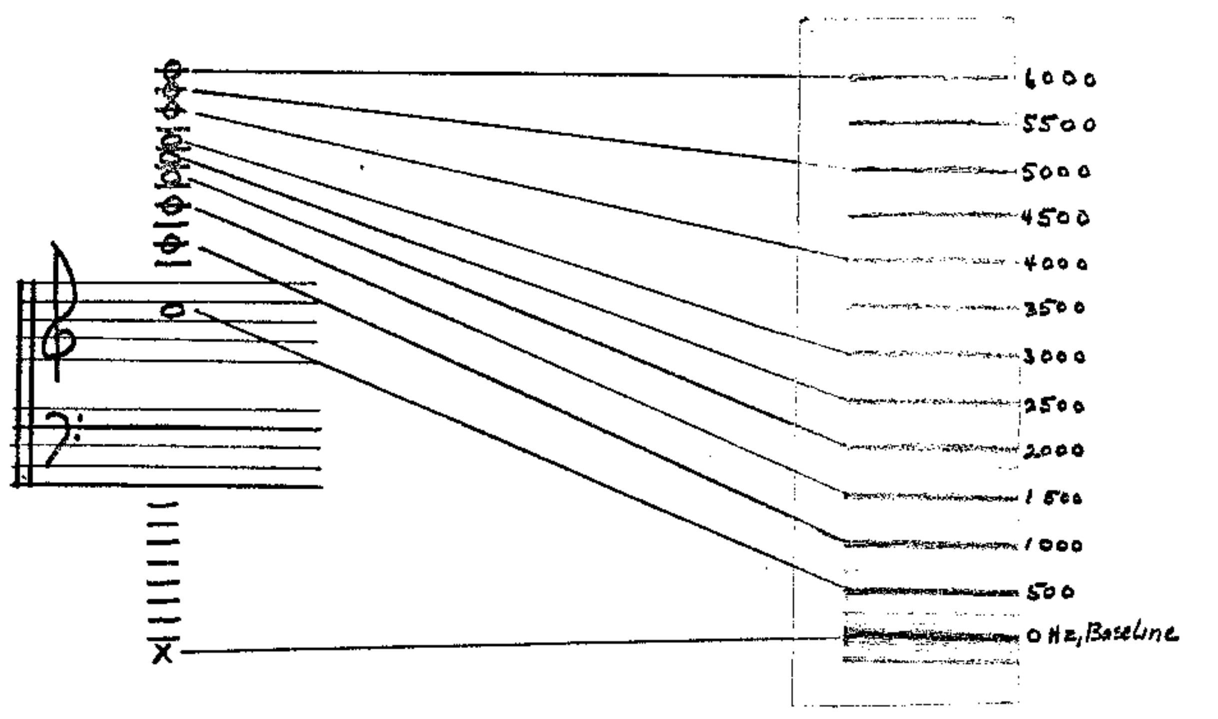

Fig. 5--An illustration comparing the notation of musical intervals with the calibration scale of the sound spectrogram.

five octaves. The second calibration band encompasses approximately one octave. The third calibration band encompasses an interval of a fifth, the fourth band encompasses an interval of a fourth, the fifth band a major third, the sixth band a minor third, etc., continuing in the same diminishing proportions as the natural harmonic series. For purpose of analysis of musical sound, it would seem more appropriate if the scale were calibrated to be more closely aligned with the acoustical intervals of music.

The instrument the jury used is included in Appendix A. The instrument instructs the jury to evaluate the examples on a three-point scale: I, Good; II, Acceptable; III, Poor. The jury was also asked to indicate the particular vowel sound which was perceived.

Procedures for Collecting Data

Choral groups used as sources for examples were selected with the approval of the dissertation advisory committee from successful school programs. Examples were obtained from junior high schools for examples of voices in the changing stage, from senior high school for examples of voices in the formative stage, and from college for examples of voices in the mature state. Each of the choral groups was between forty and fifty members in size.

To obtain the examples of sound, each of the choral groups sang, unaccompanied, the C major scale. The scale was sung on each of the following vowel sounds: $\overline{\text{ee}}$ (i), as in beet; eh (ε), as in bet; and ah (a), as in Bach. The scale was sung in the following combinations: (1) male voices alone, (2) female voices alone, and (3) male and female voices together. Each of the choral groups sang eight examples of each vowel in three combinations, giving a total of 216 examples to be analyzed and evaluated. There were seventy-two examples of each vowel sound.

The tape-recorded examples selected were cut into fifteen-inch lengths and attached to sixty-inch timing-tapes. The examples were identified, numbered and cataloged. To eliminate the bias of identification in the sequence of analysis and evaluation, a table of random numbers was utilized to determine the order in which the examples were presented. The examples were presented in one continuous tape.

The examples were subjected to evaluation by a jury of seven experts on the variables of quality of blend and intelligibility. Each judge was asked to rate the quality of the choral blend and to identify the vowel sound which he heard.

The jury consisted of seven choral directors selected with the advice of a faculty committee from the School of Music at North Texas State University. The jury was assembled in the Recital Hall in the School of Music at North Texas State University to perform the evaluation. Each member of the jury made his evaluation independently and without consultation. According to his own criteria, each member of the jury rated each example either "Good," "Acceptable," or "Poor." To check the reliability of the evaluation the entire sample was played and evaluated twice and the percentage of agreement was calculated.

Sound spectrograms for the analysis were made on the Kay Electric Sound Spectrograph. The examples were transferred from the tape play-back equipment to the sound spectrograph by direct wire connection. Spectrograms and amplitude sections were made of each of the examples.

Procedures for Analyzing Data

The data obtained from the jury of experts were entered into tables. The tables indicate the number, and percentage, of ratings in each category for each judge; ther percentage of accuracy in identifying the vowel sound intended; and the percentage with which the judge agreed with himself in the two evaluations. The tables also indicate the ratings of examples from each of the instructional levels and the percentage of accuracy between the vowel sound intended and the vowel sound perceived.

The spectrograms were placed into categories according to the data obtained from the jury of experts. The spectrograms were examined in detail to determine the distinguishing characteristics of the acoustical properties of each example. The distinguishing characteristics were described and defined to determine what similarities and dissimilarities existed within and between the categories.

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CHAPTER II

SURVEY OF RELATED RESEARCH

The sound spectrograph, which was developed initially for speech analysis, has been increasingly used in the field of vocal music. Discoveries about speech sound have had a great influence upon the study and teaching of singing. The sound spectrograph can show in an objective way the acoustical properties of the voice as it is used in singing. Previously, teachers of singing have had to depend entirely upon subjective evaluation to determine the quality of sound.

In essence a sound spectrograph is a machine which graphically represents a complex sound wave in its component parts. These component parts can be measured in terms of duration, pitch, and intensity. Several steps are involved in the making of a sound spectrogram.

The first step in the process is to record on the internal turntable the sound which is to be analyzed. The recorded sound is then replayed continuously until the graphic representation is complete. The second step involves the playing back of this sound through a variable filter. The current from this filter activates a stylus which records on paper the intensity and duration of frequency. The paper is on a drum which reveolves at the same speed as the tape loop.

The filter is set first at a low frequency, e.g., 50 cps, or Hz, and is then progressively raised until all frequencies present in the complex wave are represented on the graph. This procedure is accomplished automatically on the current models of the machine. A narrow band filter, 50 Hz, gives more detail on the graph, while a wide band filter, 300 Hz, tends to give more concentration and definition to the resonance bars on the graph. The turntable has a duration of 2.4 seconds and the time required for making a sound spectrograph is about three minutes.

Each sound, vowel or consonant, has a distinctive conformation on the spectrogram. Vowels are distinguished by horizontal bars of varying height and intensity. Of the bars, or formants, the second is the most variable in the case of vowel sounds. In studies by Potter, Kopp, and Kopp (13) the second formant is referred to as the hub and is considered the most significant part of the vowel change. The first formant remains at a fairly constant frequency range while the second formant, the hub, has a fairly wide frequency range. The second formant can be as high as 2290 Hz for the ee (i) vowel and as low as 840 Hz for the awh (ɔ) vowel (11, p. 182).

Consonants are also recognizable on the spectrogram. Un-voiced consonants appear as "white noise"; voiced consonants have some of the properties of vowels; and other consonants are combinations of white noise and vowel characteristics.

In the Journal of the Acoustical Society of America in 1946, a group of articles appeared: "Introduction to Technical Discussions of Sound Portrayal," Ralph K. Potter (14); "Portrayal of Visible Speech," J. C. Steinberg and N. R. French (16); "Sound Spectrograph," W. Koenig, H. K. Dunn, and L. H. Lacy (8); "Visible Speech Cathode-Ray Translator," R. R. Riez and L. Scott (10); "Visible Speech Translators with External Phosphors," Homer Dudley and Otto O. Gruenz, Jr. (4); and "Basic Phonetic Principles of Visible Speech," G. A. Kopp and H. C. Green (9). These articles were the result of experiments which had been conducted in association with the Bell Telephone Laboratories, Incorporated.

These experiments, begun in 1941, were instigated for the purpose of helping persons with hearing and speech problems. A language of "visible sound" was formulated from the experiments. Persons who are unable to hear can learn to speak with specific speech patterns by comparing their own "visible sound" with a model.

The information in these articles and other related information went into the making of a book, Visible Speech, by Potter, Kopp, and Green (13). The authors present a very complete analysis of all vocal sound as it appears on the spectrogram. A complete alphabet of sound is given in standard English and in regional dialects. The book presents the sounds combined into words and short sentences. A perusal of this book indicates that it could be of great value to singing teachers to give a better understanding of vocal sound.

A good discussion of methods for conducting an experiment in the evaluation of vowel sounds is "Control Methods Used in a Study of Vowels" by Gordon E. Peterson and Harold E. Barney (11). This article gives a detailed description of the steps and procedures of a study utilizing spectrographic analysis and subjective judgment. A total of seventy-six speakers recorded a randomized list of the following words: heed, hid, head, had, hod, hawed, hood, who'd, hurd, and heard. Each speaker recorded two lists, resulting in a total of 1,520 recorded words. These words were randomized and a group of seventy listeners, some of whom were also speakers, were asked to indicate on paper each word they heard as the edited tapes were played back.

Comparisons were drawn between what the speaker intended to say, what the listener thought the speaker said, and what the spectrograms indicated that the speaker had said. This was a carefully constructed experiment which produced valid results.

A number of articles on the use of the sound spectrograph in the analysis of the voice have also been published in the Bulletin of the National Association of Teachers of Singing. In an article on the subject of vowel color and voice quality, Pierre Delattre (3) demonstrates with the aid of the spectrogram that voice pitch and vowel formants are independent of each other. When a particular vowel is maintained while the voice changes pitch, the vowel formants remain constant. Conversely, when the voice pitch is held constant while changing the vowel sound, the formants change but the overtones of the voice remain unchanged. Delattre states that "the color of the vowels--what causes one vowel to be perceived as linguistically the same or different from another--is mainly characterized by formant frequency" (3, p. 5). Delattre goes on to make a distinction between formants which distinguish vowel color and those which distinguish voice quality. It is reported in this article that the first two formants determine the vowel color and the "voice quality in singing is mainly characterized by the two or three formants whose frequencies are just above the vowel formants" (3, p. 5).

Also presented in this article were X-rays which were previously published in a study by Raoul Husson. These X-rays show different mouth formations used in speaking and singing the same sounds. The X-rays indicate that resonance factors in the vocal cavity are more efficient in singing than in speaking.

An article concerning research on vocal efficiency by Perkins, Sawyer, and Harrison (10) was a report of a study conducted by speech therapists in an attempt to objectively define "good quality" in the vocal sound.

In this study, thirty-two males with low-pitched voices were selected as subjects. They were to sing three test vowels, ($\overline{ee}$, ah, $\overline{oo}$), in both an efficient and an inefficient manner. X-ray photographs and tape-recordings were made simultaneously of each sound. The tapes were judged by a panel and rated as efficient or inefficient sounds. The X-rays were measured to determine physical differences made between the two types of sounds. The tapes were also analyzed on the sound spectrogram and line spectrum to determine the acoustical differences between the two types of sound. The line spectrum produces a picture of the sound at a given instant and shows amplitude in a linear graph. The spectrogram shows amplitude in dark or light lines. The two types of graphs indicate that efficient sounds are rich in harmonics and inefficient sounds are almost devoid of harmonics.

"Toward an Objective Vocabulary for Voice Pedagogy" by van den Berg and Vennard (20) was a study conducted to objectively measure with X-ray and spectrogram various vocal faults which have been subjectively described by singing teachers. Common vocal problems in breathing, attack, registration, resonance, and articulation were examined. The faults were divided as Hypofunction (under-doing) and Hyperfunction (over-doing). Subjective vocabulary connected with these faults was given: breathiness, yelling tone, shallow tone, white tone, throaty tone, etc.

Each of the vocal faults was demonstrated for the X-ray and spectrogram. The study describes the physical and acoustical characteristics of each of the subjectively described vocal problems. The authors state that the study was an attempt to formulate a tentative vocabulary with objective definitions. The authors suggest that other studies could eventually refine the vocabulary to a point of usefulness to the profession.

In 1962, Howie and Delattre collaborated on a study of the effect of pitch on the intelligibility of sounds (6). This study was an attempt to discover why intelligibility varies in certain ways with changes of pitch. The study was based on the measurement of the formants in spectrographic analysis. It has been established that the first two formants determine the vowel color and that the upper formants have to do with voice color. Formants for certain vowels have a relatively fixed frequency resonance (11, p. 183). It has been established that the change of formant range changes the vowel. It was determined in the Howie and Delattre study that if the pitch sung by a subject is higher than the first formant of the vowel, the color of the vowel is changed. The fundamental frequency of the pitch which is sung would, in such a case, become the first formant. The second formant of the vowel would thus be closer to the fundamental, and the vowel color would be altered.

The vowel sound which lost intelligibility most quickly as the voice pitch was raised was the vowel $\overline{ee}$ (i). The vowel which retained intelligibility at the highest pitches was the vowel ah (a). As pitch rises higher all vowels come to resemble ah (a), and from high C (1,050 Hz) up all vowels were identified as ah (a), regardless of the vowel that was intended by the singer.

The conclusions of the study were that vowels generally lose intelligibility as pitch rises, and that recognizable vowels cannot be produced when the fundamental frequency of the pitch sung is appreciably higher than the first formant of the particular vowel.

A follow-up of the Howie-Delattre study (6) was an investigation concerning vowel sounds on high pitches conducted by Triplett (19).

In this study, two female singers recorded five vowels on C_4 (middle C), E_4, G_4, C_5, E_5, G_5, and C_6 (high C). Spectrograms and amplitude sections were made of all vowels sung on C_6 (High C). The recordings and spectrograms were taken to Delattre for examination. Listening observations were made with the following results: when the observer heard the initial attack of the sound he could identify the intended vowel; when the recording was begun just after the attack, the observer identified all sounds as ah (a). The spectrograms showed the following changes: the initial attack showed formants resembling the intended vowel but quickly changed to formants resembling the vowel ah (a).

The conclusions of the study were that for more intelligible sounds on high pitches the singer should make the attack of the tone be as nearly as possible the intended vowel, after which the singer may relax into the ah (a) sound without losing intelligibility.

Merle E. Taff conducted a study of the acoustics of vowel modification and register transition in the male voice (18). In this study five baritones and five tenors sang ascending octave scales in two chromatically adjacent keys. This gave sound examples of every semitone of the octave range. The tapes were played for observers who were asked to judge where the register transition took place. The tapes were arranged in random order and each one was played twice in succession. The tapes were analyzed by spectrograph and the decisions of the observers were tabulated and compared to the findings of the spectrographic analysis.

The results indicate that all singers in the study made significant changes in the formant frequencies when singing from the lower to the higher register. The formant frequency changes varied with the vowel and with the person. This study used charts and scattergrams to illustrate the types and locations of the changes in vowels that were made. The average transition point for tenors was approximately a minor third higher than for baritones. Closed vowels ($\overline{ee}$

and $\overline{oo}$) are modified at lower pitches than open vowels (eh, ah, and oh).

A study by Vennard and Irwin was concerned with speech and song as compared in sound spectrograms. In this study one phrase of words was both spoken and sung in rhythm. The recordings of the phrase were transferred to the spectrogram. The spectrograms were measured in several ways to determine the relationships of the two examples. The authors also quoted considerable material concerned with the use of the spectrogram and vowel formant study. The following is their summary:

> To summarize: Song is at least 10 decibels louder than normal speech in this case. It prolongs both vowels and consonants but especially vowels far beyond the duration of speech. Its sound energy is concentrated in fewer and more powerful formants. . . . The slogan, "Sing as you speak," or at least "Sing as you should speak" holds good in most vowels and almost all consonants (21, p. 23).

A doctoral dissertation by Appleman was entitled "A Study by Means of Planigraph, Radiograph and Spectrograph of the Physical Changes Which Occur During the Transition from the Middle to the Upper Register in Vocal Tones" (1). The purpose of this study was to determine what physical changes occur when a singer makes a transition from an open to a closed, or covered, vocal tone. X-ray and radiograms were made simultaneously with tape-recordings of six subjects. The subjects sang predetermined vocal patterns on each of three vowels. The tape-recordings were analyzed by sound spectrograph.

The oral cavities, as shown in the X-rays and radiograms, were measured and a comparison was made between the open and closed positions. The findings were that the oral cavity is expanded during the physical adjustment called "covering."

A dissertation study by Wooldridge (23) was concerned with the nasal resonance factor in the sustained vowel tone in the singing voice. This study was an investigation of resonation in the nasal cavities and the relative effect on the oral vowel in singing.

A sample of singers was recorded singing the five primary vowel sounds. Each vowel was sung once with the nasal passages open and once with the nasal passages closed. The recorded examples were analyzed by sound spectrograph to determine differences. It was concluded that there was no significant difference between the pairs of vowels and that the term "nasal resonance" is without validity in describing voice quality in the singing voice.

In 1956, a doctoral dissertation study was conducted by Sullivan (17) on the subject of the relationships between physical characteristics and subjective evaluation of male voice quality in singing. In this study eighteen subjects sang three vowels: ah (a), $\overline{\text{ee}}$ (i), and $\overline{\text{oo}}$ (u), on A# (234 Hz) and F (347 Hz). Recordings were made and analyzed by sound spectrograph on twenty-two variables of pitch, intensity, and location of partials and formants. The recordings were played for a jury which made subjective evaluations of the voice qualities. The data were correlated using the Pearson product-moment. The results indicate that the strongest formant above the second vowel formant had the greatest effect on voice quality. In general, as the intensity of this formant increased, the tone was ranked higher in quality.

"A Study of the Relationship Between Vowel Modification and Changes in Pitch in the Male Singing Voice: A Spectrographic Analysis, Reinforced by the Judgements of Phonetics Experts" was a dissertation study by Robert W. Hohn (5). This study was concerned with finding out what changes might occur in formant patterns at different pitch levels as singers intend to produce the same vowel. Excerpts were taken from available LP recordings and analyzed by sound spectrograph. A jury of trained phoneticians were asked to judge what vowel was sung in each example. The findings of the study were that all singers showed significant changes in formant frequencies on all vowels at the three pitch levels studied. Formant frequencies for the lowest pitches were nearest to the frequencies of the spoken vowel. The jury showed greater agreement on low pitches than on high pitches.

David W. Scott conducted a dissertation study of the effect of changes in vocal intensity upon the harmonic structure of selected singing tones produced by female singers. This study was an effort to determine the effect of intensity in the production of the tone upon the acoustical characteristics of the tone as shown on the sound spectrogram. Ten subjects sang three vowel sounds: $\overline{ee}$ (i), ah (a), and $\overline{oo}$ (u), at three intensity levels: +13 db, +5 db, and -3 db, on the pitch C (523 Hz). The recorded sounds were analyzed by sound spectrograph. The findings were that as the tone became less intense, all the partials except the first decreased in strength, with the higher partials disappearing first. The first partial remained constant at all intensity levels.

A dissertation study by Arment (2) utilized the sound spectrograph to investigate the brightness and darkness qualities of vowel tones in women's voices. Five subjects, sopranos, recorded 240 tones of six vowels. Each vowel was sung "as bright as possible," "as dark as possible," and without distortion. The recordings were played for a jury and were judged as "very bright," "very dark," or "neither bright nor dark." The findings indicated that brightness, or lack of brightness, can be shown on the spectrogram and can be detected by the ear. Brightness depends upon the presence of strong high harmonics and symmetrical distribution of narrow formant bands. Darkness of tone shows a general lack of high harmonics and relatively broad formant bands.

James R. Whitworth conducted the following study: "A Cinefluorographic Investigation of the Supralaryngeal Adjustments in the Male Voice Accompanying the Singing of Low Tones and High Tones" (22). This study involved the making of X-ray moving pictures of ten subjects as they caused their voices to glide from low to high pitches on each of three vowel sounds: ah (a), oh (o), and ee (i). The X-ray films were analyzed and measured to determine what changes took place within the oral cavity as the pitch changes took place.

"An Investigation of the Effect of Training in the Articulation of Vowels by the Speaking Voice Upon the Articulation of Vowels by the Singing Voice" was a dissertation study conducted by Johnson (7). This study was conducted as an experiment, using two groups from a university choir. The groups were assigned by a random method and equated by voice-type, aural acuity, pitch discrimination, and vowel perception. The experiment was concerned with the pedagogical concept "sing as you speak." The experimental group was given six weeks of training in the spoken articulation of the cardinal vowels. Recordings were made of each of the subjects, both before and after the period of experiment.

Sound spectrograms were made of the recorded examples and were analyzed to determine the improvement made by the subjects. The result showed that the experimental groups improved in spoken articulation but showed little improvement in singing articulation.

A comprehensive study of the aspects of choral blend is a master's thesis by Wyatt (24). This study was based upon a review of literature of the acoustics of music, a review of writings relating to the achievement of blend in choral sound, and a report of the results of a questionnaire which was sent to choral music authorities throughout the nation.

The value of this study was in the extensive compilation of the opinions and experiences of many of the contemporary choral music authorities. Wyatt presents in a clear manner what choral authorities consider desirable and important in choral blend, and the authorities' recommendations concerning the achievement of blend in choral sound.

The aspects of choral blend which were discussed were rhythmic unity, vowels, quality of tone, vibrato, intonation, selection and classification of voices, seating and standing arrangements, balance, and room acoustics. The information, which was collected from books, articles, unpublished theses, and the questionnaire, was primarily subjective in nature.

In view of the studies discussed above, it is apparently a logical step to determine what application the sound spectrograph has to the analysis of choral sound. The aim of this study is to use the sound spectrograph to analyze selected vowels in choral sound in order to determine acoustical differences between "Good" and "Poor" choral blend.

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CHAPTER III

PROCEDURES

The Sample

The choral groups which were used as sources of examples were selected with the approval of the dissertation advisory committee from successful school programs. Tape recordings were made of several public school and college choral groups. Each of the groups had a minimum of forty and a maximum of fifty members performing for the recording. The tape recordings were monaural and at a tape-speed of 7.5 inches-per-second.

For the recording, the choral groups were assembled on standing choir risers. The girls stood on the front two rows and the boys on the back two rows. The members of the choral groups were instructed that they were participating as subjects in an experiment having to do with the blend of choral sound as related to particular vowel sounds. They were asked to sing the vowel sounds as their own director had instructed them. They were asked to achieve a good ensemble effect in attack, duration, intonation, loudness, and vowel sound. Each group was conducted by its own director.

Each of the choral groups sang without instrumental accompaniment the notes of the C major scale. The scale was repeated using each of the following vowel sounds: $\overline{\text{ee}}$ (i), as in beet; eh (ε), as in bet; and ah (a), as in Bach. The scale, on each of the vowels, was sung by the male voices alone, the female voices alone, and by the male and female voices together. The male voices sang the scale as illustrated:

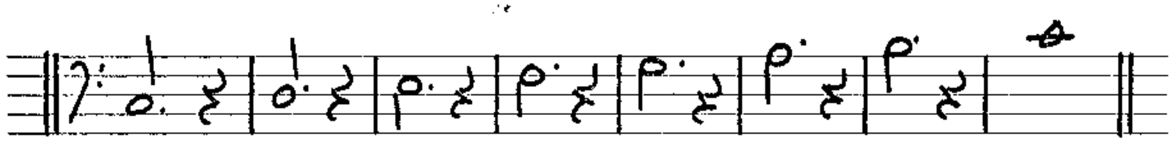

Fig. 6--An example of the C major scale as sung by the male voices alone.

the female voices sang the scale in the same manner:

Fig. 7--An example of the C major scale as sung by the female voices alone.

and the male and female voices sang together as follows:

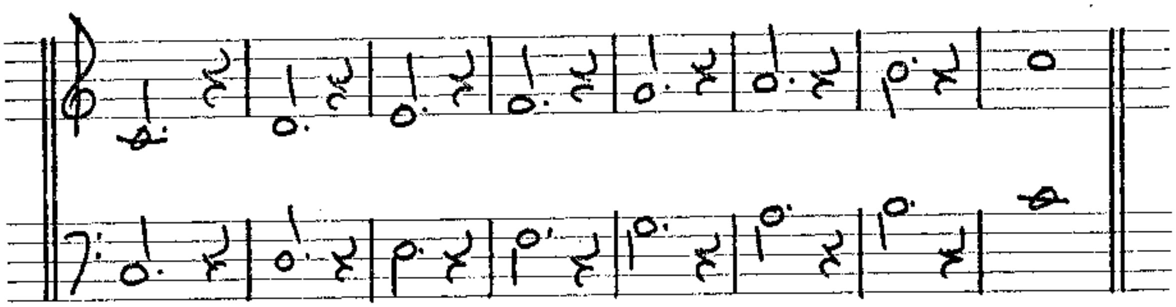

Fig. 8--An example of the C major scale as sung by the male and female voices combined.

The pitch for the scale was given from a piano prior to the singing of each scale. Each note was sung approximately three seconds in duration, at a moderate intensity. A breath was taken before the attack of each note of the scale. The choral groups were encouraged to perform at their best. No attempt was made to structure any of the recording sessions to obtain either "good" or "poor" sounds for the sample.

For the purpose of controlling acoustical quality, tape recordings having extraneous sounds or other quality deterrents were rejected. Those recordings which were a true representation of the choral group were retained for the study. It was determined that the sample would be comprised of examples from one junior high school group, two senior high school groups, and two college groups.

From each of the educational levels there were to be eight examples of each of the three vowels, sung in the three combinations of voices. For the purpose of selecting the correct number of examples from the two senior high school groups and the two college groups, a method of distribution was devised. The method was devised to avoid, insofar as possible, any structuring or pre-judging of the examples of choral sound.

The college group which was recorded first was designated C1, and the other college was designated C2. In the same manner, the senior high school groups were designated S1 and S2. The designations "1-head," "1-tail," "2-head," and "2-tail" were written on individual slips of paper and placed in a bowl. For each scale, one slip was drawn and a coin was tossed to determine which group would begin on the first note of the scale. The succeeding notes of the scale alternated between the two groups in a systematic manner as illustrated:

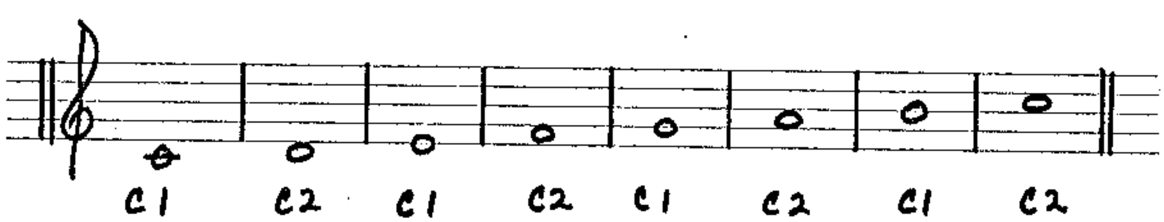

Fig. 9--An illustration of the method of alternating the notes of the scale between two groups of the same educational level.

This procedure was carried out for each of the scales in the college and senior high school sample. Since the one junior high school sample furnished the correct number of examples for the study, all the examples from the group were included in the study. A listing of the distribution of all the examples is included in Appendix B.

The sounds which were used as examples were isolated and extracted from the original tape. After each example was identified, the tape was cut just before the attack of the sound and the leading end of the example was attached to a sixty-inch length of timing-tape. Each example was coded and cataloged and rolled onto a storage reel. This process was continued until all examples were individually coded, cataloged, and placed on a storage reel.

To eliminate the bias of identification in the sequence of evaluation, the examples were assembled in a random sequence. To determine the random sequence the catalog numbers which had been assigned to the examples were listed in numerical order. Included with the catalog number was the coded identification of each example. A table of random numbers (1, pp. 179-180) was utilized. It was decided to begin with column nine, row five, to utilize three columns and read downward. This procedure was continued until all the catalog numbers had been assigned a random sequence number. A list of the numbers which were assigned is included in Appendix B. The examples were removed from the storage reels, arranged in the random sequence and replaced on the storage reels.

So that the examples would have a uniform duration which would accommodate the capacity of the spectrograph, it was necessary to cut the example tapes in uniform lengths. Since the time duration of the sound spectrogram is 2.4 seconds, and since space was needed for the insertion of a calibration scale, it was decided that the optimum duration for the example would be 2 seconds. With the tape-speed of 7.5 inches-per-second, a fifteen-inch length gave the correct duration.

Each example in the random sequence was measured and cut fifteen inches from the leading end of the example. The trailing end of each example was spliced onto the leading end of the timing-tape leader of the following example. The result was one continuous tape, presenting the 216 examples in the random sequence, each example two seconds in duration, separated by eight seconds of silence.

The Evaluation

The sample was subjected to evaluation by a jury of experts, on the variables of quality of blend and intelligibility of vowel sound. The members of the jury were asked to rate the quality of the vocal blend and to identify the vowel sound which he perceived.

The jury consisted of seven choral directors selected with the advice of a committee of faculty members from the School of Music of North Texas State University. The members of the jury as selected included four faculty members and three doctoral candidates. The jury was assembled in the Recital Hall of the School of Music for the purpose of evaluating the recorded examples.

Prepared instructions explaining the procedures of the evaluation were furnished each member of the jury. The instructions were read aloud and points of clarification were made. The members of the jury were seated separately and did not consult on the ratings.

According to his own individual criteria for choral blend, each member of the jury rated the examples by circling a symbol representing the vowel sound in the appropriate column. The judge could circle one of three vowel symbols: "$\overline{ee}$," "eh," or "ah" in one of three columns; "Good," "Acceptable," or "Poor" for each example in the sequence. A copy of the prepared instructions and an example of the rating sheet are included in Appendix A.

The tape, which was thirty-six minutes in duration, was played straight through, with a rest stop at the half-way point. To afford a check on the reliability of the evaluation, the entire sample was played and evaluated twice in the same manner. Each example was heard only once during each evaluation sequence.

The Analysis

For the purpose of acoustical analysis, sound spectrograms were made of all examples on a Kay Electric Sound Spectrograph. The examples were transferred from the tape play-back equipment to the internal recording turntable of the spectrograph by direct wire connection. A standard setting for play-back and record loudness levels was maintained insofar as was feasible. Adjustments were made when necessary to obtain the best quality spectrograms.

For the purpose of isolating machine noise from the recorded sound, spectrograms were made of the machine characteristics alone. Machine characteristic examples were made with the play-back and record loudness levels at the maximum setting, the minimum setting, and at the standard or average setting that was used with the examples. A sample spectrogram was also made of the spectrograph alone with no input connected.

Two types of spectrographic display were made of each example The type 1 display shows time duration horizontally, pitch frequency vertically, and intensity as shading between gray and black. A white area indicates no sound, a gray area indicates a low intensity sound, and a black area indicates a high intensity sound. The type 2 display is a cross-section showing intensity horizontally and frequency vertically. The time spot of the cross-section can be selected at various intervals along the time axis of the spectrogram. To ascertain if there were acoustical differences in the examples between the sound at the moment of attack and after the attack, cross-sections were made at the attack and approximately 1 to 1.2 seconds after the attack. Each spectrogram contains both the Type 1 and the Type 2 displays.

A frequency calibration scale, in bands of 500 Hz, was included on each spectrogram. After each example had been recorded on the internal turntable, the calibration tone was recorded during the .4 second interval between the end of the examples and the repetition of the attack. The spectrograph paper was placed on the drum in such a way that the calibration scale appears at the beginning of each spectrogram.

As each spectrogram was completed, it was identified with the sequence number, catalog number, identification code and the tabulated evaluation of the judges. When all spectrograms had been made they were rearranged in the sequence of the catalog numbers.

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CHAPTER IV

ANALYSIS OF THE DATA

The problem of this study was a spectrographic analysis of the acoustical properties of selected vowels in choral sound. Examples of the vowels $\overline{\text{ee}}$ (i), eh (ɛ), and ah (a), were obtained from choral groups from junior high school, senior high school, and college. The purposes of this study were to categorize the examples of vowel sounds by means of subjective evaluation, to ascertain by means of spectrographic analysis the distinguishing characteristics of the acoustical properties of the examples in the categories, and to determine the similarities and dissimilarities which exist within and between the categories.

The Evaluation

In the process of evaluating the recorded examples, the taped sequence was played and evaluated twice. Explicitly, each member of the jury heard and evaluated each of the 216 examples twice. Consequently, each judge gave a total of 432 ratings, two for each example. The ratings were tabulated to determine how many ratings each judge gave in each category. Table I contains these tabulations.

It is apparent from the tabulations that a diversity of criteria were utilized in the evaluation of the examples.

TABLE I

JUDGES' RATINGS OF VOWEL EXAMPLES, GIVING THE NUMBER AND PERCENTAGE IN EACH CATEGORY

	I "Good"		II "Acceptable"		III "Poor"	
Judge	Number	Percent	Number	Percent	Number	Percent
A	95	22.0	215	49.8	122	28.2
B	165	38.2	146	33.8	121	28.0
C	146	33.8	162	37.5	124	28.7
D	54	12.5	293	67.8	85	19.7
E	177	41.0	48	11.1	207	47.9
F	10	2.3	176	40.7	246	56.9
G	123	28.5	177	41.0	132	30.6
Total	770	25.5	1,217	40.2	1,037	34.2

A large difference can be noted between Judge E and Judge F in the ratings placed in the "Good" column. Judge E rated 41.0 percent of the examples as "Good," which Judge F, in hearing the examples, rated only 2.3 percent as "Good."

Judges A, B, C, and G were fairly similar in the evaluation. Of this group, Judge A gave the lowest number of "Good" ratings, and the highest number of "Acceptable" ratings. Judge D was unusual in that he rated a high percentage in the "Acceptable" category and a low percentage in the "Good" and "Poor" categories. On the other hand, Judge E was inclined to rate most of the examples as either "Good" or "Poor" and rated only a small percentage in the "Acceptable" category. The tabulations indicate that

Judges D and E exhibited opposing inclinations in rating the examples.

Judge F placed the lowest percentage of ratings in the "Good" category and the highest percentage in the "Poor" category. This seems to indicate that Judge F utilized a more severe set of criteria than the other judges.

The above tabulations were an indication of how the judges agreed with each other in the evaluation of the examples. The ratings were also computed to determine how each judge agreed with himself.

As previously stated, the entire sample was played in the random sequence and evaluated twice, each judge rating each example twice. The ratings were tabulated to determine if each judge gave the same rating to the same example both times, or if he gave different ratings to the same example. Table II gives the percentage of accuracy between the two sequences. The figures indicate whether the judge gave the same rating both times, whether he deviated by one rating, e.g., I to II, or II to III; or whether he deviated by two ratings, e.g., I to III, between the two sequences. To determine a reliability coefficient, Pearson's Product-Moment was computed. Score values were assigned to ratings in each category: a score of three for a "Good" rating, a score of two for an "Acceptable" rating, and a score of one for a "Poor" rating. The correlation for the panel of judges is reported in Table II.

TABLE II

JUDGES' RATINGS OF VOWEL EXAMPLES, GIVING THE PERCENTAGE OF ACCURACY AND THE CORRELATION BETWEEN THE TWO EVALUATION SEQUENCES

	Agreement		Deviation of 1 Rating		Deviation of 2 Ratings		Reliability Coefficient
Judge	Number	%	Number	%	Number	%	Pearson's <u>r</u>
A	128	59.3	87	40.3	1	0.4	
B	137	63.4	70	32.4	9	4.2	
C	109	50.5	98	45.4	9	4.2	
D	149	69.0	67	31.0	0	0.0	
E	143	66.2	38	17.6	35	16.2	
F	144	66.7	72	33.3	0	0.0	
G	147	68.1	66	30.6	3	1.3	
Panel	957	63.3	498	32.9	57	3.8	.56

It is apparent from the tabulations that the judges were fairly high in accuracy. It should be noted that Judge D, who rated the highest percentage of examples in the "Acceptable" category, and the lowest percentages in the "Good" and "Poor" categories had the highest percentage of agreement. It should also be noted that Judge E, who rated the lowest percentage of examples in the "Acceptable" category and the highest percentages in the "Good" and "Poor" categories, had the highest number of split ratings. However, Judge E did maintain a high percentage of agreement.

Judge F, who rated only 2.3 percent of the examples as "Good" and 56.9 percent as "Poor," apparently maintained the same criteria throughout both evaluation sequences. He gave the same rating two out of three times for the two sequences, and did not deviate by more than one rating.

As indicated in Table I, 25.5 percent of the ratings given for the sample were "Good," 40.2 percent were "Acceptable," and 34.2 percent of the ratings given were "Poor." Table II indicates that the percentage of agreement for all the judges was 63.3 percent. All the judges deviated by one rating an average of 32.9 percent of the time, and deviated by two ratings only 3.8 percent of the time. The reliability coefficient for the panel was .56.

Table III indicates the accuracy with which the judges correctly identified the vowel sound. The figures in this

TABLE III

NUMBER AND PERCENTAGE OF ERROR IN JUDGES' IDENTIFICATION OF VOWEL SOUNDS

Judge	Number	Percent	Judge	Number	Percent
A	1	0.4	E	5	2.3
B	1	0.4	F	2	0.9
C	2	0.9	G	1	0.4
D	2	0.9			

table indicate how many errors were made by each judge in the identification of the vowel sound. The percentage figure given is for the entire sample which was heard twice. Judges A, B, and G marked a vowel sound incorrectly once each, and Judges C, D, and F marked vowels incorrectly twice each. Judge E, who had the largest number of split ratings marked five vowel sounds incorrectly for the highest percentage of error of 2.3 percent.

In tabulating the ratings according to educational level, the figures in Table IV indicate that the distribution

TABLE IV

SUMMARY OF JUDGES' RATINGS OF VOWEL EXAMPLES BY CATEGORY AND EDUCATIONAL LEVEL

	I "Good"		II "Acceptable"		III "Poor"	
Level	Number	Percent	Number	Percent	Number	Percent
Junior High	263	34.2	379	31.1	366	35.3
Senior High	269	34.9	422	34.7	317	30.6
College	238	30.9	416	34.2	354	34.1
Totals	770	100.0	1,217	100.0	1,037	100.0

of "Good," "Acceptable," and "Poor" ratings was fairly even. Of the ratings given in each category, roughly a third of the number was from each of the three educational levels.

This would seem to indicate that all three educational levels were equally represented in the sample. It further seems to indicate that the examples, which were presented in a random sequence, were evaluated with the same criteria and without bias.

To consider the distribution of the sample in detail, the ratings were tabulated by instructional level, voice combination, and vowel sound. These tabulations are presented in Tables V through IX.

At the junior high school level, Table V, the figures indicate that the female voices furnished the highest percentage of examples in the "Good" category. The ah (a) vowel was rated the highest, the ee (i) vowel next highest, and the eh (ε) the lowest. The male voices were significantly lower in the number of "Good" ratings with only 15 percent rated in that category. For the male voices in this portion of the sample, nearly half of the examples were rated as "Poor."

For the male and female voice combination, the ratings inclined toward the low ratings of the male voices. These examples were not rated nearly as high as were the female voices alone. This seems to indicate that, in this case, the "Poor" vocal blend of the male voices had more effect upon the vocal blend of the combined voices than the "Good" vocal blend of the female voices.

The incorrectly marked vowels were also tabulated by educational level. In Table VI, it is reported that the largest number of incorrect markings were for vowel sounds sung by the female voices alone. None of the vowel sounds which were sung by the male and female voices together were

TABLE V

JUDGES' RATINGS OF VOWEL EXAMPLES, GIVING THE NUMBER AND PERCENTAGE FOR EACH VOWEL AND VOICE COMBINATION IN THE JUNIOR HIGH SCHOOL SAMPLE

Vowel	"Good"		"Acceptable"		"Poor"	
	Number	Percent	Number	Percent	Number	Percent
			Female Voices			
ee	62	55.4	32	28.5	18	16.1
eh	52	46.4	33	29.5	27	24.1
ah	69	61.6	38	33.9	5	4.5
Sub-Totals	183	54.5	103	30.7	50	14.9
			Male Voices			
ee	7	6.3	50	44.6	55	49.1
eh	15	13.4	44	39.3	53	47.3
ah	9	8.0	48	42.9	55	49.1
Sub-Totals	31	9.2	142	42.3	163	48.5
			Male and Female Voices			
ee	19	17.0	49	43.8	44	39.3
eh	13	11.6	48	42.9	51	45.5
ah	17	15.2	37	33.0	58	51.8
Sub-Totals	49	14.6	134	39.9	153	45.5
Totals	263	26.1	379	37.6	366	36.3

marked incorrectly, and only one vowel sound was marked incorrectly for the male voices alone.

At the senior high school instructional level the female voices again produced the highest percentage of

TABLE VI

NUMBER AND PERCENTAGE OF VOWEL SOUNDS INCORRECTLY IDENTIFIED IN THE JUNIOR HIGH SCHOOL SAMPLE

Vowel	Number	Percent
Female Voices		
ee	4	3.6
eh	2	1.8
Male Voices		
ah	1	0.9

examples in the "Good" category. (See Table VII.) In this case the $\overline{ee}$ (i) vowel was rated the highest, the ah (a) vowel next, and the eh (ε) vowel was again rated the lowest.

In contrast to the junior high school sample, the examples sung by the male voices alone, and the female voices alone, were rated higher than were the examples sung by the male and female voices together. In each voice combination in the high school portion of the sample, the $\overline{ee}$ (i) vowel and the ah (a) vowel were rated fairly evenly. The eh (ε) vowel in each case was rated lower than the others.

The incidents of vowel sounds being marked incorrectly in the senior high school portion of the sample were isolated and fairly evenly distributed between the different voice combinations. As in the junior high school sample,

TABLE VII

JUDGES' RATINGS OF VOWEL EXAMPLES, GIVING THE NUMBER AND PERCENTAGE FOR EACH VOWEL AND VOICE COMBINATION IN THE SENIOR HIGH SCHOOL SAMPLE

Vowel	"Good"		"Acceptable"		"Poor"	
	Number	Percent	Number	Percent	Number	Percent
Female Voices						
ee	49	43.8	51	45.5	12	10.7
eh	39	34.8	40	35.7	33	29.5
ah	44	39.3	53	47.3	15	13.4
Sub-Totals	132	39.3	144	42.8	60	17.9
Male Voices						
ee	31	27.7	50	44.6	31	27.7
eh	20	17.9	46	41.1	46	41.1
ah	32	28.5	30	26.8	50	44.6
Sub-Totals	83	24.7	126	37.5	127	37.8
Male and Female Voices						
ee	22	19.6	53	47.3	37	33.0
eh	10	8.9	50	44.6	52	46.4
ah	22	19.6	49	43.8	41	36.6
Sub-Totals	54	16.1	152	45.2	130	38.7
Totals	269	26.7	422	41.8	317	31.5

more vowel sounds were marked incorrectly for the female voices than for the other voice combinations (see Table VIII).

The examples from the college level choral groups were rated in much the same proportions as those from the senior

TABLE VIII

NUMBER AND PERCENTAGE OF VOWEL SOUNDS INCORRECTLY IDENTIFIED IN THE SENIOR HIGH SCHOOL SAMPLE

Vowel	Number	Percent
Female Voices		
eh	2	1.8
ah	1	0.9
Male Voices		
ah	1	0.9
Male and Female Voices		
ee	1	0.9

high school choral groups. These ratings are presented in Table IX.

As in the senior high school sample, the female voice combination received the highest number of "Good" ratings in vocal blend. The male voices were rated the next highest. The male and female voice combination was again rated the lowest.

It was apparently significant that the eh (ε) vowel was consistently rated the lowest in vocal blend. The one exception was in the junior high school portion of the sample where the eh (ε) vowel was rated slightly higher than the other vowels sung by the male voices alone.

In the evaluation of the sample, each judge was asked to rate, according to his own criteria, the quality of the

TABLE IX

JUDGES' RATINGS OF VOWEL EXAMPLES, GIVING THE NUMBER AND PERCENTAGES FOR EACH VOWEL AND VOICE COMBINATION IN THE COLLEGE SAMPLE

Vowel	"Good" Number	"Good" Percent	"Acceptable" Number	"Acceptable" Percent	"Poor" Number	"Poor" Percent
Female Voices						
ee	48	42.9	40	35.7	24	21.4
eh	29	25.9	55	49.1	28	25.0
ah	40	35.7	55	49.1	17	15.2
Sub-Totals	117	34.8	150	44.6	69	20.5
Male Voices						
ee	25	22.3	36	32.1	51	45.5
eh	18	16.1	45	40.2	49	43.8
ah	30	26.8	41	36.6	41	36.6
Sub-Totals	73	21.7	122	36.3	141	42.0
Male and Female Voices						
ee	17	15.2	51	45.5	44	39.3
eh	11	9.8	44	39.3	57	50.9
ah	20	17.9	49	43.8	43	38.4
Sub-Totals	48	14.3	144	42.8	144	42.8
Totals	238	23.6	416	41.3	354	35.1

vocal blend of each of the sounds presented. The jury performed this task with an overall percentage of accuracy of 63.3 percent. The examples from each of the educational levels, when presented in random sequence, received approximately the same kinds of ratings. This would seem to indicate that the adjudication was valid and that the sample was well distributed among the three educational levels.

The examples were arranged in rank order in the following manner. The examples with the greatest number of "Good" ratings and the least number of "Poor" ratings were ranked the highest. The examples with the smallest number of "Good" ratings and the greatest number of "Poor" ratings were ranked the lowest. The examples were ranked progressively from the greatest number of "Good" ratings downward to the greatest number of "Poor" ratings. The ratings and the ranking of each example are listed in Appendix B.

It was determined, by the number of "Good" ratings, that the first twenty-seven samples in the rank order were rated high enough to be considered as the "Good" examples for the spectrographic analysis. A similar number of examples, twenty-eight, in the lowest rank order were considered as the "Poor" examples for the spectrographic analysis. All of the remaining samples were considered in the "Acceptable" category.

The Spectrographic Analysis

In the spectrographic analysis of the individual examples, terminology referring to the natural harmonic series, vowel formant frequencies, and the spectrographic display will be utilized. In order to clarify the meaning and application of the terminology, the following explanation is offered.

The natural harmonic series, or overtone series, consists of a fundamental frequency and the subsequent overtones. The overtones will be multiples of the fundamental frequency in the order of 1, 2, 3, 4, 5, 6, 7, 8, etc. With a fundamental frequency of 110 Hz, the natural harmonic series would be 110 Hz, 220 Hz, 330 Hz, 440 Hz, 550 Hz, 660 Hz, 770 Hz, 880 Hz, etc. These frequencies converted into musical notation would be

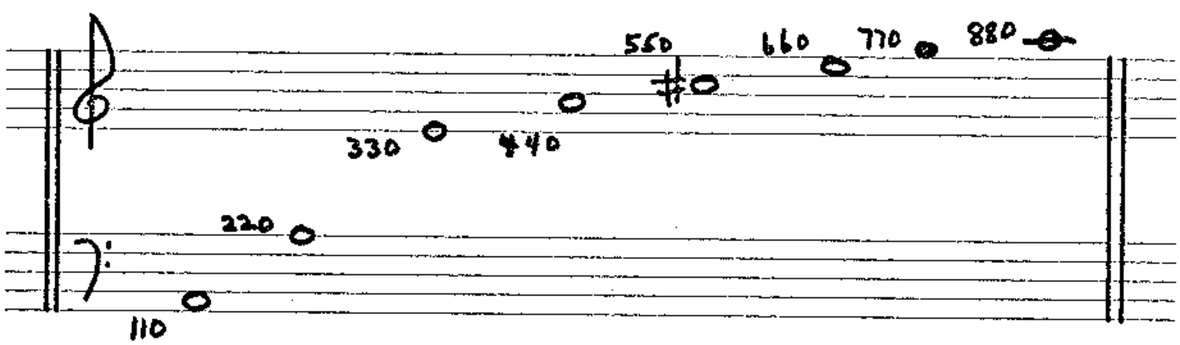


Fig. 10--An example of the natural harmonic series beginning on the pitch A, 110 Hz.

The natural harmonic series will continue in these same proportions to as high a frequency as the tone generator will produce.

Of the tones illustrated above, the seventh tone is out-of-tune with modern musical instruments. As the harmonic series continues into higher multiples, several overtones will be out-of-tune. The natural harmonic series is present in all musical sound, excluding electronically produced "pure" tone. The intensity of each of the harmonics will vary with different instruments and voices.

Vowel formants have been discussed in previous chapters. In Chapter I, average frequency ratings were reported for the first and second formants of several vowels. The average frequencies for each of the vowels when converted into musical notation would be as follows:

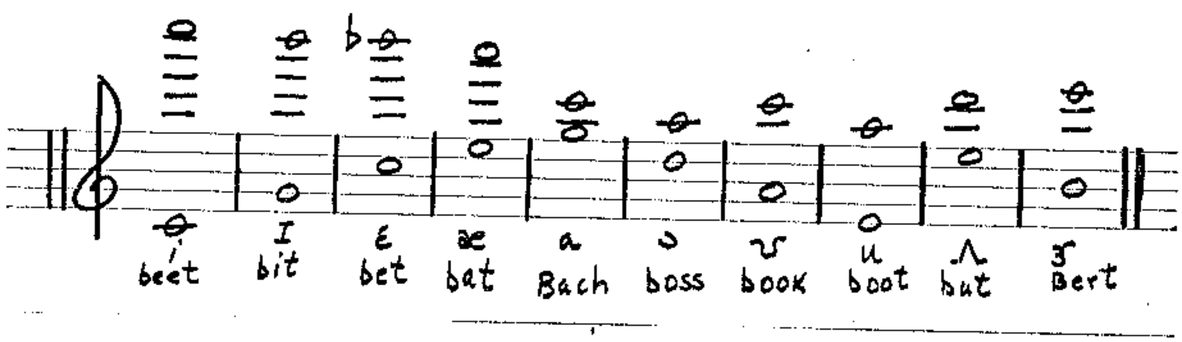


Fig. 11--Average frequencies of vowel formants illustrated in musical notation.

It is understood that the average frequencies illustrated above are from a specific sample, and that the notation used is approximate to the average frequency. Variations of these frequencies would be expected within any specific sample.

Two types of spectrographic display were utilized in the analysis of the examples. The Type 1 display shows frequency vertically, time duration horizontally, and intensity as shading between gray and black. The Type 2 display is a cross-section showing frequency vertically, in an inverted scale, and intensity horizontally.

In the Type 1 display the frequency calibration scale is in units of 500 Hz. (See Figure 12.) The lowest band on

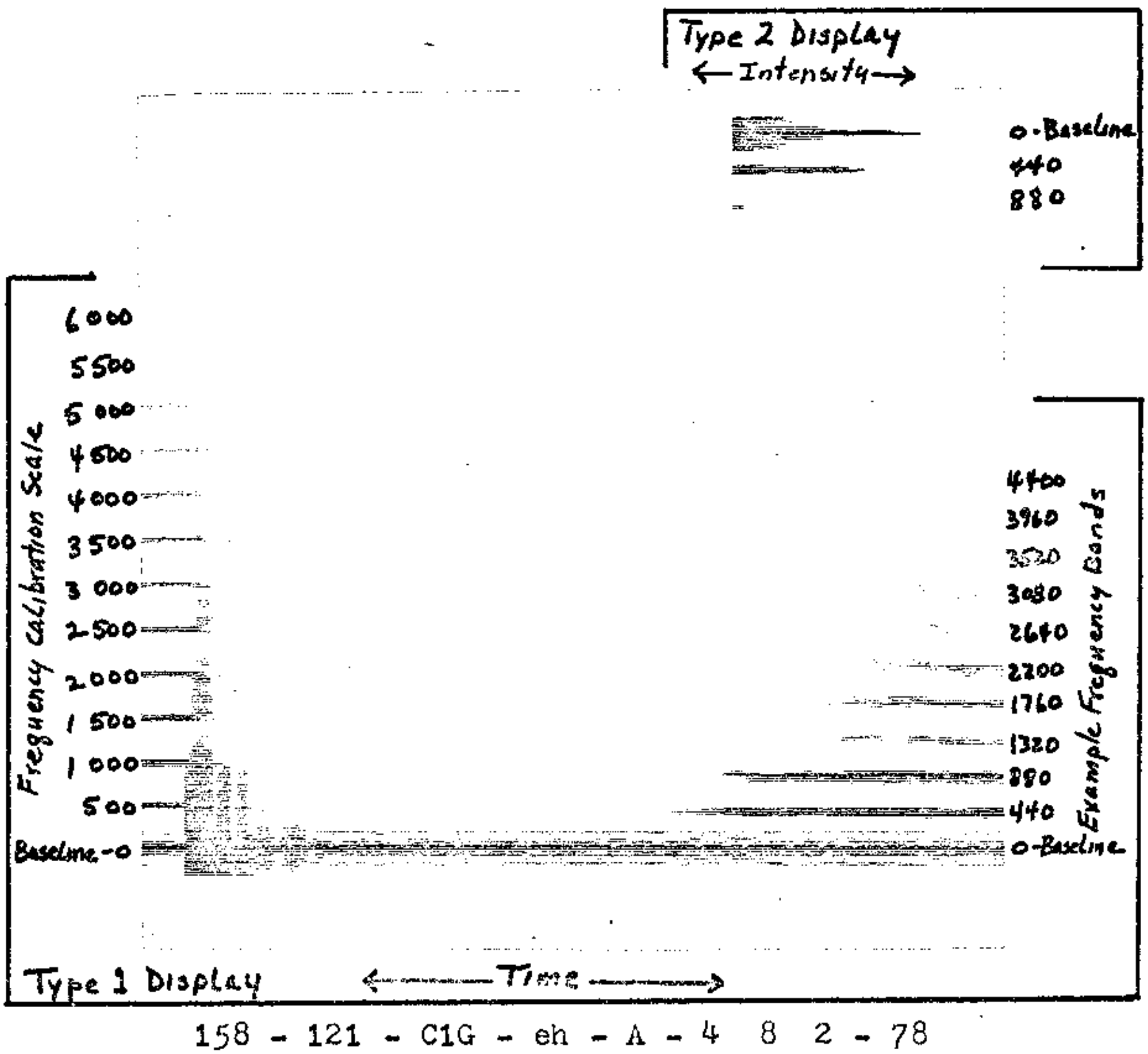


Fig. 12--A spectrogram of the vowel eh (ε) sung by college female voices on the pitch A (approximately 440 Hz).

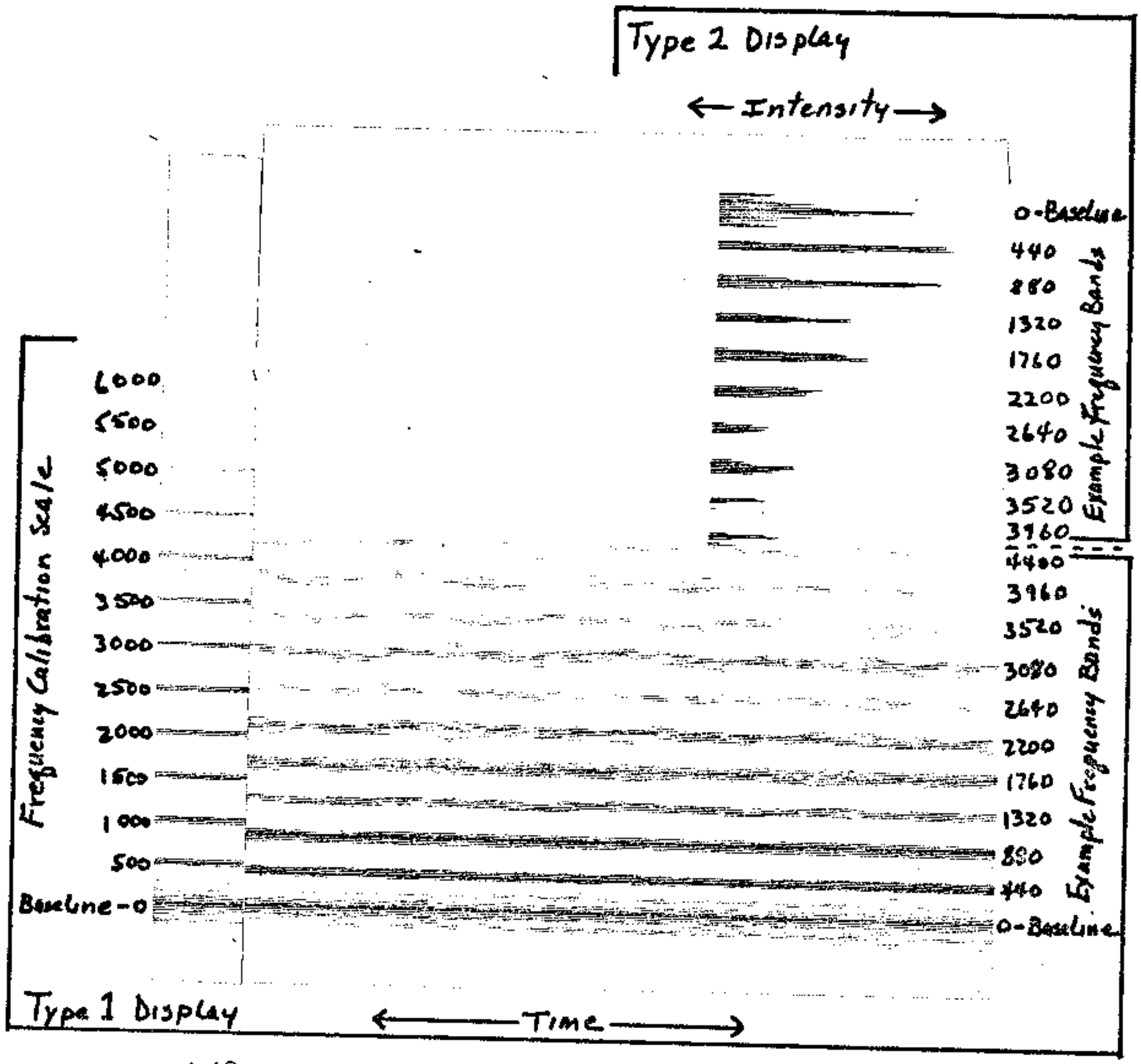
the spectrogram is the baseline. The baseline is machine noise and is not a part of the recorded sound. In this example, the fundamental voice pitch is approximately 440 Hz.

The first bank above the baseline is the fundamental pitch. Each of the frequency bands is a multiple of the fundamental frequency.

The intensity of each frequency band is indicated by the darkness of the line on the spectrogram. A black area indicates a high intensity sound, a gray area indicates a low intensity sound, and a white area indicates that there was no sound. Figure 13 indicates that the first and second frequency bands, the dark black color, were high in intensity. The third frequency band is of a gray color, indicating a lower intensity sound. The white areas between frequency bands indicates that no sound was present at those frequencies. Time duration is indicated on the horizontal axis from left to right. On the spectrogram, five-eighths of an inch is equal to one-tenth of a second, and six and one-half inches is equal to one second.

In Figure 13 the wavy lines in the higher frequencies indicates that individuals within the choral group were singing with noticeable vibrato. Because the frequency scale used on the spectrogram compresses the musical intervals in the low frequencies and spreads the musical intervals in the high frequencies, the vibrato is visible on the spectrogram only in the high frequencies.

The Type 2 display is a cross-section of the sound, which in this case corresponds exactly in time with the Type 1 display. In the Type 2 display, the frequency scale



158 - 121 - C1G - eh - A - 4 8 2 - 78

Fig. 13--A spectrogram of the vowel eh (ε) sung by college female voices on the pitch A (approximately 440 Hz).

is inverted, with the baseline at the top and the high frequencies at the bottom. (See Figure 13.) The intensity of each frequency band is indicated by the length of the line from left to right. In Figure 13 the first and second frequency bands are high in intensity and the shorter lines are lower in intensity. The white areas between the frequency bands indicates that no sound was present at those frequencies.

The sound spectrograms of the twenty-seven "Good" examples were examined to determine the most logical sequence of presentation for this discussion. It was determined that the examples would be grouped first by voice combination, then by pitch, vowel sound, and educational level, respectively. Listed with each example as it is discussed is (1) the catalog number, (2) the random sequence number, (3) the code for the educational level and voice combination, (4) the vowel sound (with incorrect vowels in parentheses), (5) the code for the pitch, (6) the ratings of the judges (with ratings for the incorrect vowels in parentheses), (7) the rank of the example, and (8) the page number of the example in the Appendix. Spectrograms of the examples categorized as "Good" are included in Appendix C in rank order.

Female voices on the pitch c.--The first group of examples from the "Good" category to be considered is of female voices alone. The examples of the pitch coded as c, approximately 523 Hz, present each vowel sound, and represent each of the educational levesl.

All of the examples in this group are characterized by narrow, well defined frequency bands. These frequency, or resonance, bands are steady dark lines with white area between. There is no diffusion of the resonance bands which would be indicated by gray area around and between the bands. In each case in this group, the resonance bands are evenly spaced and clearly defined.

The resonance bands begin at approximately 523 Hz which is the fundamental pitch intended by the singers. The first resonance band above the base line on the spectrogram is the fundamental pitch. There are as many as seven or eight bands above the base line in some, but not all, of the examples. Each of the frequency bands are equidistant from the adjacent band or bands. The distance between the resonance bands is equal to the frequency of the fundamental pitch, in this case 523 Hz. For this first group of examples, the fundamental pitch is the first resonance band at approximately 523 Hz. The second resonance band is at approximately 1,046 Hz, the third band is at 1,569 Hz, the fourth at 2,092 Hz, the fifth at 2,615 Hz, the sixth at 3,138 Hz, and the highest visible resonance band lies at approximately 3,662 Hz. This sequence of frequency bands follows exactly the natural harmonic series for the given fundamental frequency. This general discussion applies to the following examples in this group and will not be restated with each example.

While the frequency, spacing, and clarity of the resonance bands are uniform for the examples in this group, the intensity of the bands varies from one example to the next. To best illustrate this variation, each of the examples are discussed individually.

The explanation of the identification code below is as follows. The example below is catalog number 8, it was 197th in the random sequence, and was recorded by the female voices of the first junior high school group. The vowel sound $\overline{\text{ee}}$ (i), which was identified as eh (ε) by one of the judges, was sung on the note C above middle C. The ratings from the two evaluation sequences were 9 "Good," 3 "Acceptable," and 2 "Poor." One of the "Poor" ratings was given to the vowel sound which was incorrectly identified. This example ranked 18th in the sample. The spectrogram of this example is included on page in Appendix C.

8 - 197 - J1G - ee(eh) - c - 9 3 1(1) - 18 (p. 137).

In this example the resonance band of the fundamental is the most intense. The second band is approximately one-half the intensity, and the third is no more than one-fourth the intensity of the first band. A fourth resonance band is lightly visible. None of the higher resonance bands appear on this spectrogram. The first resonance band, 523 Hz, is the first formant for the vowel, and the fourth resonance band at approximately 2,092 Hz is the second formant.

The average frequencies for the distinguishing formants for the $\overline{\text{ee}}$ (i) vowel fall at approximately 270 Hz and 2,290 Hz, a difference of 2,020 Hz. In the case of this example, the difference between the highest and lowest resonance bands was approximately 1,560 Hz. It is possible that this variation would make the vowel more difficult to distinguish. Note that one of the judges incorrectly identified the vowel.

80 - 84 - S2G - ee - c - 10 3 1 - 7 (p. 126).

For this example there are five resonance bands visible above the baseline of the spectrogram. The fundamental band serves as Formant 1 and the fourth band serves as Formant 2 for the vowel. These two resonance bands are more intense than the other bands.

152 - 118 - C2G - ee(eh) - c - 7(1) 6 0 - 23 (p. 141).

In this example there are six resonance bands clearly visible. The fundamental is the strongest in intensity. The succeeding bands reduce proportionately in intensity. Vibrato wave, indicated by the curving line, is visible in the higher frequencies. The vibrato wave is characterized by an increase and decrease of intensity as the vibrato pitch crosses the resonance band. The vibrato wave is visible on the spectrogram only as the frequency of the wave matches the frequency of the resonance band. Here, as in example 8 above, the vowel sound was incorrectly identified by one of the judges.

16 - 145 - J1G - eh - c - 10 3 1 - 7 (p. 125).

In this example, the first and second resonance bands are the more intense. The third band shows a steady intensity. The fourth and sixth bands are less intense than the other bands. There is not a band visible in the area where the fifth band should be. For the vowel, the fundamental, 523 Hz, is the first formant, and the third resonance band, 1,569 Hz, is the second formant.

24 - 124 - J1G - ah - c - 12 2 0 - 2 (p. 120).

This example is characterized by the prominence of the first two resonance bands. The third band is fairly well defined. The higher bands are visible only in short traces. The fundamental and the first overtone are equal in intensity and serve as the first and second formants for the vowel.

96 - 53 - S2G - ah - c - 12 2 0 - 2 (p. 121).

This example is also characterized by the prominence of the first two resonance bands. The third and sixth bands are barely visible on the spectrogram. There are no other resonance bands visible. The first two resonance bands, which are equal in intensity, serve as the distinguishing formants for the vowel. The frequencies are 523 Hz for Formant 1 and 1,046 Hz for Formant 2.

168 - 119 - C2G - ah - c - 9 5 0 - 11 (p. 130).

This example has very strong first and second resonance bands. The second resonance band is slightly more intense than the first. The third and sixth bands are clearly defined and relatively strong. The other frequency bands appear only in traces. There is vibrato wave in the higher frequencies which appears as intensity reinforcement for the resonance band. The first two resonance bands are the distinguishing formants for the ah (a) vowel.

Female voices on the pitch B.--The next group of examples to be considered is of female voices alone, on the pitch B. As in the above group, the resonance bands are well defined and clearly spaced with no gray areas between the bands. The resonance bands are all multiples of the fundamental frequency, 494 Hz.

7 - 95 - J1G - ee(eh) - B - 6(3) 3 2 - 18 (p. 136).

The only prominent resonance band is the fundamental tone. The second band is readily visible, but it is of low intensity. The third and fourth frequency bands appear in traces. The higher frequency bands are not visible on the spectrogram. Only one, the lower, of the two distinguishing formants for the vowel ee (i) is present. Apparently the vowel sound was difficult to identify. Three of the judges indicated that the vowel heard was eh (ε).

159 - 21 - C2G - eh - B - 8 5 1 - 26 (p. 144).

This is a complex spectrogram, with a total of eight resonance bands visible. The frequency of the highest band is approximately 4,000 Hz. Resonance bands one, two, three, four, and six are the stronger bands. The fundamental, 494 Hz, is the first formant for the vowel. The fourth resonance band is Formant 2. The fourth band is wider than the other bands and has a slight division. Apparently part of the band is strengthened by the pitch harmonic and part is strengthened by the vowel formant resonance. The frequency of the fourth band is approximately 1,900 Hz.

23 - 104 - J1G - ah - B - 9 5 0 - 11 (p. 129).

This example of the ah (a) vowel has two prominent resonance bands. The fundamental tone at approximately 494 Hz and the second band at approximately 988 Hz are the strongest. These two bands serve as the distinguishing formants for the vowel. A third band, at 1,482 Hz is also fairly well defined.

Female voices on the pitch A.--The following group of examples of female voices singing the pitch A, possesses the same general characteristics attributed to the groups discussed above. The resonance bands are clearly defined and equally spaced. The fundamental frequency for this group of examples is 440 Hz.

6 - 66 - J1G - ee - A - 10 3 1 - 7 (p. 124).

The fundamental tone is the only prominent resonance band on this spectrogram. The second band is approximately one-third the intensity of the fundamental. The other bands appear only as traces. The fundamental tone serves as Formant 1. There is no frequency band which can serve as Formant 2 for the vowel $\overline{\text{ee}}$ (i).

150 - 26 - C2G - ee - A - 8 6 0 - 23 (p. 140).

In this example there are seven visible frequency bands. The strongest bands are the fundamental, 440 Hz, which is Formant 1; the second band is the first overtone at 880 Hz; and the fifth band at 2,200 Hz is Formant 2.

22 - 182 - J1G - ah - A - 9 5 0 - 11 (p. 128).

This example of the ah (a) vowel has three prominent resonance bands. Bands one and two are equally strong; band three is approximately two-thirds as intense. Other higher bands are visible, but are not consistent. It is not clear which bands are the distinguishing formants for the vowel. Bands two and three appear to be closest to the average frequencies for the distinguishing formants for the ah (a) vowel.

94 - 156 - S2G - ah - A - 10 4 0 - 4.5 (p. 122).

This is a fairly complex spectrogram, with ten resonance bands visible. The highest of the resonance bands is above 4,000 Hz. The first two bands are equal in intensity, the third is approximately two-thirds as strong. Bands four, five, and six are barely visible. Bands seven, eight, and nine are approximately one-fourth the intensity of the fundamental. The second band at 880 Hz, and the third band at 1,760 Hz serve as Formant 1 and Formant 2, respectively.

Female voices on the pitch G.--Two examples of female voices of the pitch G, 392 Hz, were categorized as "Good." Both examples display clearly defined, evenly spaced resonance bands.

5 - 33 - J1G - ee - G - 9 3 2 - 18 (p. 135).

This example from the junior high school sample is characterized by a strong fundamental tone and two weak overtones. The fundamental serves as Formant 1 for the vowel, but there is no frequency band to serve as Formant 2.

149 - 192 - C1G - ee - G - 8 3 3 - 27 (p. 145).

This spectrogram is characterized by several strong, high resonance bands. There are eleven resonance bands in all, the highest is above 4,000 Hz in frequency. A considerable amount of vibrato wave is visible in the higher frequencies. The vibrato wave appears to broaden and diffuse the resonance bands. The fundamental tone stands out as the strongest resonance band. Above the fundamental, the second, fifth, sixth, seventh, and eighth bands are equal in intensity at about half the strength of the fundamental. The third and fourth bands are visible in traces. The fundamental is Formant 1, and the sixth resonance band, 2,352 Hz, serves as Formant 2.

Female voices on the pitch F.--For female voices alone, four examples of the pitch F were categorized as "Good." The general acoustical characteristics are the same as those mentioned for the groups discussed above.

4 - 58 - J1G - ee - F - 9 3 2 - 18 (p. 134).

This example displays a strong fundamental frequency band at approximately 349 Hz. The second resonance band, at approximately 698 Hz, is only about one-third the intensity of the fundamental. The higher resonance bands are weak and intermittent. In order to have a clearly formulated ee (i) vowel, there should be a fairly strong resonance band at 2,000 to 2,200 Hz. In this example there is a weak, but traceable, resonance band at approximately 2,094 Hz.

76 - 39 - S2G - ee - F - 9 4 1 - 14.5 (p. 133).

This spectrogram displays twelve resonance bands. However, only the fundamental is steady and strong. The upper resonance bands are visible as light gray traces. The strongest of the higher resonance bands is less than one-fourth as strong as the fundamental frequency band. This resonance band is at approximately 2,094 Hz and serves a Formant 2.

20 - 158 - J1G - ah - F - 12 2.0 - 2 (p. 119).

This example displays three equally strong resonance bands at frequencies of 349 Hz, 698 Hz, and 1,047 Hz. These resonance bands are the fundamental pitch and the first two overtones in the natural harmonic series. The first overtone, 698 Hz, is Formant 1, and the second overtone, 1,047 Hz, is Formant 2 for the vowel ah (a). The higher resonance bands diminish quickly in intensity. There is an isolated resonance band at approximately 3,031 Hz. This band does not appear on the spectrogram until about one-third of the time duration has elapsed.

92 - 10 - S2G - ah - F - 8 6 0 - 23 (p. 139).

As in the example immediately above, there are three equally strong resonance bands at 349 Hz, 698 Hz, and 1,047 Hz. These resonance bands serve as the fundamental pitch, Formant 1, and Formant 2, respectively. A fourth resonance band, 1,396 Hz, is also fairly strong. This band serves as a harmonic reinforcement for the fundamental tone. The ninth band is also steady and fairly strong at approximately 3,041 Hz. A strong band at this approximate frequency is characteristic of a resonant vocal sound.

Female voices on the pitch E.--Only one example for female voices alone on the pitch E was categorized as "Good." The approximate frequency of the pitch E is 330 Hz.

19 - 41 - J1G - ah - E - 9 5 0 - 11 (p. 127).

In this example there are two equally strong resonance bands at 330 Hz and 660 Hz. There is another band which is only slightly less in intensity at approximately 990 Hz. Two weaker resonance bands are visible, one at 1,320 Hz, and one at approximately 2,970 Hz. The second resonance band serves as Formant 1, the third band serves as Formant 2 for the vowel sound ah (a).

Female voices on the pitch D.--Two examples which were sung on the pitch D, approximately 294 Hz, were categorized as "Good." Both are examples of the ee (i) vowel.

74 - 18 - S2G - ee - D - 9 4 1 - 14.5 (p. 132).

This spectrogram displays a strong fundamental tone and little else in the way of resonance. There are intermittent resonance bands at approximately 588 Hz and 882 Hz. These bands seem to alternate in occurrence. Only twice, and for a very short duration, do these two bands occur at the same time. The fundamental tone serves as Formant 1 for the vowel. There is no visible Formant 2 for the vowel $\overline{ee}$ (i).

146 - 5 - C2G - ee - D - 10 4 0 - 4.5 (p. 123).

This spectrogram displays several well defined resonance bands in a pattern which seems to be indicative of the $\overline{ee}$ (i) vowel. The fundamental tone is a strong resonance band at approximately 294 Hz. The second resonance band at 588 Hz is a little more than one-half the strength of the fundamental. The third band is approximately one-fourth the strength of the fundamental. The fourth, fifth, and sixth bands are only visible in very light traces. The seventh, eighth, and ninth resonance bands are approximately one-fourth the strength of the fundamental. As many as thirteen resonance bands are discernable, the highest band is at approximately 3,822 Hz. The fundamental tone, at 294 Hz, is Formant 1, and the eighth resonance band, at 2,352 Hz, is Formant 2 for the $\overline{ee}$ (i) vowel.

<u>Male and female voices on the pitch c</u>.--Only one example of male and female voices combined was categorized as "Good." This example has the well defined, evenly spaced resonance bands which were characteristic of the examples of female voices alone. The resonance bands are more closely spaced due to the lower fundamental pitch sung by the male voices. There are two natural harmonic series present simultaneously.

One series is in multiples of the fundamental frequency, approximately 261.5 Hz, sung by the male voices. The other series is in multiples of the fundamental frequency, approximately 523 Hz, sung by the female voices. Beginning with the second resonance band in the harmonic series for the male voices, every second resonance band will coincide with a band in the harmonic series for the female voices.

216 - 130 - C1M - ah - c - 8 6 0 - 23 (p. 143).

Above the baseline of the spectrogram, the first resonance band, at approximately 261.5 Hz, is the fundamental frequency sung by the male voices. The second resonance band, at approximately 523 Hz, is (1) the fundamental frequency sung by the female voices, (2) the first harmonic overtone of the frequency sung by the male voices, and (3) the first formant for the vowel sound sung by the female voices. The second band is also the strongest in intensity. The third resonance band at approximately 784.5 Hz is the second harmonic overtone for the frequency sung by the male voices. This band is almost twice as strong as the fundamental sung by the male voices. Since this band is not reinforced by a pitch overtone of the frequency sung by the female voices, it possibly is reinforced by a vowel formant frequency. The third resonance band is possibly Formant 1 for the vowel sound sung by the male voices.

The fourth resonance band at approximately 1,046 Hz is very slightly less in intensity than the strongest band.

This band is (1) the first harmonic overtone for the frequency sung by the female voices, (2) the third harmonic overtone for the frequency sung by the male voices, and (3) Formant 2 for the vowel sound sung by both the male and female voices.

In all, there are sixteen resonance bands visible on the spectrogram. The highest visible band is above 3,500 Hz. The frequency ratings of all the bands are multiples of the fundamental frequency sung by the male voices. The even numbered bands, 2, 4, 6, *etc.*, have frequency ratings which are multiples of the fundamental frequency which was sung by the female voices. The stronger resonance bands are those which were reinforced by both the natural harmonic series of both the male and female voices.

Male voices on the pitches c, A, and D.--Three examples sung by male voices alone were categorized as "Good." The acoustical characteristics of these examples are similar to those of the examples of the female voices alone. Due to the difference in frequency ratings of the fundamental tones, the spacing of the resonance bands is much closer with the male voice examples than it was with the female voice examples. For proportionately resonant sounds, twice as many resonance bands can be visible in the same frequency range.

176 - 97 - C2B - ee - c - 9 5 0 - 11 (p. 131).

The first seven resonance bands are fairly well defined. The strongest bands are the first, second, and seventh. The resonance bands above the seventh, approximately 1,931 Hz, become diffuse and not well defined on the Type 1 display. However, the cross-section Type 2 display indicates strong resonance peaks at regularly spaced intervals. The resonance bands are clearly visible up to approximately 3,500 Hz. This indicates that the sound was fairly complex and rich in overtones. The fundamental frequency, 261.5 Hz, serves as Formant 1, and the seventh resonance band at approximately 1,841 Hz serves as Formant 2 for the vowel $\overline{ee}$ (i).

190 - 100 - C2B - ah - A - 8 6 0 - 23 (p. 142).

In this example there are five strong resonance bands in the lower frequency range. The first band is the fundamental frequency at approximately 220 Hz. The second band is the first harmonic overtone at 440 Hz. The strongest of the bands is the third band at approximately 660 Hz. This resonance band is the second harmonic overtone and is Formant 1 for the vowel ah (a). The fourth resonance band is a harmonic overtone at 880 Hz. The fifth band, at approximately 1,100 Hz, is Formant 2 for the vowel as well as a harmonic overtone. A strong resonance band also occurs at approximately 2,640 Hz. This resonance band, which is approximately one-half the intensity of the fundamental, is characteristic of a resonant vocal sound.

114 - 150 - S2B - ah - D - 9 3 2 - 18 (p. 138).

This example is characterized by closely grouped, strong resonance bands in the lower frequency range. The fundamental frequency is approximately 147 Hz. The succeeding frequency bands are multiples of the fundamental frequency. The strongest of the bands are the fundamental and the first harmonic overtone. The fourth resonance band, at approximately 588 Hz, serves as Formant 1 for the vowel. The seventh band, at approximately 1,029 Hz, serves as Formant 2. The area on the spectrogram between 1,029 Hz and 2,500 Hz is devoid of resonances. There are traces of resonance in the area around 2,500 Hz.

All the examples discussed above were categorized as "Good" by a majority of ratings by the jury of experts. There were twenty-seven examples categorized as "Good." The ranks of the examples were from 2 to 27. The examples to be discussed below were categorized as "Poor" by a majority of ratings of the jury of experts. A total of twenty-eight examples with ranks from 191 to 215.5 are considered in this category. Spectrograms of the examples categorized as "Poor" are included in Appendix D, arranged in rank order.

The examples categorized as "Good" were characterized by clearly defined resonance bands which were evenly spaced and separated by white area. The resonance bands for the examples categorized as "Poor" in vocal blend are not as clearly defined. Generally, in this category the spectrograms display little clearly defined white area within the frequency range of the resonance bands. The resonance bands of the natural harmonic series stand out as the strongest frequency bands, but the areas between them are filled in with lower intensity frequency bands. The result is that much of the information on the spectrogram is attributable not to natural harmonics or vowel formants, but to other undefined sources.

Several of the spectrograms indicate that sound was produced at every definable frequency level from the fundamental tone to as high as 3,000 Hz. In most cases, the Type 1 display presents a confusing mass of black and gray. White area occurs only in areas which are devoid of resonance bands. The Type 2 display indicates, in most cases, that there are strong peaks of resonance at the frequency levels of the overtones of the natural harmonic series, but that these resonance bands are obscured at the base by resonances of lower intensity. The result is a continuous band of resonances from the lowest to the high frequency.

Male and female voices combined.--The examples to be considered in the "Poor" category are grouped by voice combination, pitch, vowel sound, and educational level. The first group to be discussed is of male and female voices combined.

70 - 27 - J1M - ah - A - 1 0 13 - 211 (p. 169).

In this example there are six prominent resonance bands. The lower bands are strong, the higher bands decrease quickly in intensity. The resonance bands are at frequencies which are multiples of the fundamental frequency of 220 Hz which was sung by the male voices. These resonance bands are well defined at the peaks, but the bases are connected by lower intensity frequencies. The area between the resonance peaks is gray with little area which could be described as white. Traces of resonance bands are visible up to 3,000 Hz. However, after the sixth band, at approximately 1,320 Hz, the intensity level is very low. Formant 1 and Formant 2 apparently coincide with the second and fourth resonance bands.

142 - 9 - S1M - ah - A - 0 5 9 - 191 (p. 149).

This example is also characterized by six prominent resonance bands. These bands are fairly well separated by white area, but the Type 2 display indicates that the bands are of irregular configuration. The irregular shape apparently indicates a lack of alignment of pitch frequencies and vowel formant frequencies. In this example there is a sharp drop in intensity in the resonances above 1,320 Hz. There are traces of resonance bands as high as 4,000 Hz. In this example the third resonance band at 660 Hz, and the fourth resonance band at 880 Hz are the strongest in intensity. It is not clear which bands serve as formants for the vowel.

204 - 17I - C2M - eh - F - 0 1 13 - 213 (p. 172).

This example is characteristic of the elements attributed to the "Poor" category. The frequency bands are almost continuous from the fundamental pitch of approximately 174 Hz to above 3,500 Hz. The resonances decrease in intensity as the rate of the frequency increases. One small band of white area occurs at approximately 1,900 Hz. This is the only white area within the range of the frequency bands. The third resonance band at approximately 524 Hz is the strongest in intensity. It is not apparent which of the resonance bands are the vowel formants.

203 - 4 - C1M - eh - E - 0 3 11 - 204 (p. 164).

This spectrogram displays continuous frequency bands from approximately 165 Hz to above 4,000 Hz. There are no white areas apparent within the frequency range. The third band at approximately 495 Hz and the fourth band at approximately 660 Hz are the strongest of the resonance peaks. The Type 2 display indicates that the resonance bands are irregular in shape and intensity. The intensity of the resonance peaks decreases and the rate of the frequency increases.

211 - 92 - C2M - ah - E - 1 3 10 - 195.5 (p. 154).

This spectrogram indicates continuous frequency bands from approximately 165 Hz to about 1,320 Hz. There is a white area from 1,320 Hz to about 2,310 Hz. A lightly shaded gray area extends from approximately 2,310 Hz to about 3,500 Hz. There are resonance peaks at 495 Hz, 660 Hz, and 825 Hz which are equally strong in intensity. These resonance peaks are not separated by white area on the spectrogram. The vowel formants are not discernable.

58 - 112 - JlM - eh - D - 0 3 11 - 204 (p. 162).

In this spectrogram the first four resonance peaks are equal in intensity. The bases of the resonance bands are heavily connected by bands of lower intensity frequencies. Above the fourth band there is a sharp drop in intensity at all frequencies. There is a fairly strong band at approximately 1,470 Hz which is apparently the second formant for the vowel. The location of Formant 1 is not apparent.

194 - 50 - ClM - ee - D - 0 5 9 - 191 (p. 151).

This spectrogram displays four strong resonance bands which are connected by lower intensity frequency bands. In the cross-section Type 2 display, the frequency bands which lie between the resonance peaks appear to be approximately one-half the strength of the strongest peak. From the base of the cross-section to the half-way point in intensity, the spectrogram shows continuous frequency bands. In the area between 588 Hz and 1,500 Hz, almost no resonances are indicated. From 1,500 Hz to a point above 4,000 Hz the spectrogram shows a lightly shaded gray area without definitive resonance bands. The lack of resonances between the frequencies of 588 Hz and 1,500 Hz is indicative of the $\overline{ee}$ (i) vowel. However, it is not apparent which of the resonance bands serve as the distinguishing formants for the vowel.

49 - 60 - J1M - ee - C - 0 2 12 - 209 (p. 166).

This example presents a cluster of resonances in the lower frequency range, from approximately 131 Hz to 524 Hz. Above that point very little is visible on the spectrogram. There are light gray areas at about 1,800 Hz and about 2,200 Hz. The resonance band at approximately 2,200 Hz should serve as Formant 2 for the vowel sound.

57 - 80 - J1M - eh - C - 2 2 10 - 194 (p. 152).

The strongest resonances are in the lower frequency range. The strength of the frequency bands decreases sharply after 500 Hz. The area above 500 Hz is lightly shaded in gray on the spectrogram, with few definable resonance bands. A fairly strong frequency band at approximately 1,300 Hz is apparently indicative of the vowel sound.

201 - 36 - C1M - eh - C - 1 3 10 - 195.5 (p. 153).

In this spectrogram the beginning of the frequencies presents a cluster of resonances ranging from approximately 131 Hz to 800 Hz. As the time duration continues, additional resonances appear in the higher frequency range. After approximately one second has elapsed, the spectrogram shows a continuous band of frequencies ranging from the fundamental to above 3,500 Hz. The least intense of the lower frequencies appears at approximately 1,000 Hz. The strongest of the higher frequencies appears at approximately 1,824 Hz. This resonance band should serve as Formant 2 for the vowel eh (ε).

209 - 183 - C2M - ah - C - 0 2 12 - 209 (p. 168).

This example presents a mass of resonance bands with no separation from approximately 131 Hz to 786 Hz. From approximately 786 Hz to about 2,000 Hz there is no evidence of frequency bands. Above 2,000 Hz there is a light gray area indicating low intensity frequencies in a range up to about 3,500 Hz. The vowel formants are concealed in the mass of resonances in the lower frequency range.

Male voices alone.--The next group of examples to be considered in the "Poor" category is of male voices alone. These examples display in general the same acoustical confusion that was apparent in the above examples of male and female voices together.

31 - 154 - J1B - ee - B - 0 4 10 - 198.5 (p. 155).

In this example the resonance bands are fairly well defined and separated more or less clearly. However, only the fundamental and the first overtone are steady in intensity. The higher overtones are strong, but intermittent. There is considerable gray area between the first two resonance bands. This indicates that there were lower intensity frequency bands which would interfere with the stability of the pitch. The fundamental tone serves as Formant 1, and a fairly steady band at approximately 1,976 Hz could serve as Formant 2 for the vowel.

39 - 106 - J1B - eh - B - 0 3 11 - 204 (p. 161).

This example is very much like the one described just above. The first six frequency bands are fairly well defined in pitch, but are unstable in intensity. The strongest of the bands are the fundamental tone at approximately 247 Hz, and the first harmonic overtone at approximately 494 Hz. Isolated well above the lower resonance bands is a fairly strong band at approximately 2,470 Hz. The second resonance band at 494 Hz serves as Formant 1, and the sixth band at approximately 1,482 Hz serves as Formant 2 for the vowel.

47 - 176 - J1B - ah - B - 0 4 10 - 198.5 (p. 157).

This spectrogram displays five strong resonance bands in the lower frequencies. The peaks of the resonance bands are strong, but there are lower intensity frequency bands between the stronger bands. These five bands range in frequency from approximately 247 Hz to 1,235 Hz. The area above 1,235 Hz is devoid of frequency bands up to approximately 2,717 Hz. At this point, and above, five more resonance bands are faintly visible. Apparently, the second resonance band at 494 Hz and the fourth band at 988 Hz serve as the distinguishing formants for the vowel.

119 - 162 - S1B - ah - B - 0 5 9 - 191 (p. 148).

This example is much like the one immediately above. The resonance bands appear to be stronger in intensity. The frequencies of the resonance bands are the same, the same area is devoid of frequency bands. The intensity of the resonance bands decreases and the frequency increases. It is not clear which of the resonance bands serves as the distinguishing formants for the vowel.

37 - 56 - J1B - eh - G - 0 3 11 - 204 (p. 160).

This spectrogram presents a cluster of resonances with no separation in the lower frequencies. The resonance peaks of the first three bands are strong and steady. The next three bands appear weaker and more unstable. The seventh band is fairly strong and apparently serves as Formant 2 for the vowel. The third resonance band at approximately 588 Hz apparently serves as Formant 1 for the vowel eh (ε).

99 - 52 - S1B - ee - E - 0 1 13 - 213 (p. 170).

In this spectrogram there is a cluster of frequency bands near the baseline. Three resonance bands are discernable, at frequencies of 165 Hz, 330 Hz, and 495 Hz. Above this point, the next resonance bands of significant strength occur at approximately 1,900 Hz. The band at 1,900 Hz and the ones above, appear only in traces. The second resonance band at 330 Hz and the thirteenth band at approximately 2,145 Hz appear to be the distinguishing formant bands for the vowel.

171 - 138 - C1B - ee - E - 0 0 14 — 215.5 (p. 174).

This spectrogram displays a continuous band of sound from the fundamental, approximately 165 Hz, through the fifth resonance band at approximately 825 Hz. Another continuous band begins at approximately 1,485 Hz and runs up to approximately 3,600 Hz. The intensities of the resonances in the higher frequencies are very strong compared to other examples in the sample. There is a strong resonance band at approximately 1,815 Hz, which is apparently the second formant for the vowel. The second resonance band at approximately 330 Hz would serve as the first formant for the vowel.

115 - 125 - S1B - ah - E - 0 2 12 - 209 (p. 167).

A mass of seven closely connected resonance bands form the lower part of this spectrogram. These bands range in frequency from approximately 165 Hz to 1,155 Hz. A higher group of resonance bands of lower intensity range from approximately 2,500 Hz to about 3,800 Hz. The area between the two groups of resonances is mostly white, with traces of gray. It is not apparent which of the resonance bands are the distinguishing formants for the vowel.

187 - 216 - C1B - ah(?) - E - 0 1 11(2) - 213 (p. 171).

This spectrogram in most respects is similar to the one immediately above. In addition to the characteristics already described, there is in this spectrogram evidence of extraneous noises. It is apparent from listening to this example that the tape recording itself became damaged in the process of handling in the experiment. Note that the example was the last example in the random sequence. Note also that one of the judges failed to give any identification of the vowel sound in either evaluation sequence.

170 - 114 - C2B - ee - D - 0 5 9 - 191 (p. 150).

A cluster of resonances, ranging from 147 Hz to 588 Hz, forms the lower part of this spectrogram. A second smaller cluster lies between 1,764 Hz and 2,058 Hz. A third cluster of resonances begins at approximately 2,352 Hz and continues to above 3,500 Hz. The second formant for the vowel would be in the second cluster of resonances at approximately 1,911 Hz. The first formant would be in the first cluster of resonances at a frequency of approximately 294 Hz.

106 - 205 - S1B - eh - D - 0 3 11 - 204 (p. 163).

The resonance formants in this spectrogram are diffuse and difficult to distinguish. The lower frequencies are grouped together in resonance bands extending from approximately 147 Hz to 588 Hz. Two other areas of strong resonance occur at approximately 1,617 Hz and 2,940 Hz. The first formant of the vowel would be in the lowest group of resonances at a frequency of approximately 441 Hz. The second vowel formant would be in the resonance area at a frequency of approximately 1,617 Hz.

178 - 208 - C1B - eh - D - 0 4 10 - 198.5 (p. 158).

This spectrogram exhibits an unbroken string of frequency bands from approximately 147 Hz to well above 3,500 Hz. This indicates that all the frequencies in the spectrum between 147 Hz and 3,500 Hz were audible. This configuration would closely fit the definition of "noise," as opposed to musical sound. There is a resonance peak at approximately

441 Hz which is stronger than the surrounding resonance peaks. This frequency apparently serves as Formant 1 for the vowel. Another strong resonance peak at approximately 1,617 Hz is apparently the second formant for the vowel.

25 - 184 - J1B - ee - C - 0 5 9 - 191 (p. 147).

Four strong resonance bands are closely clustered between 131 Hz and 524 Hz on this spectrogram. Another group of low intensity frequency bands begins at approximately 1,562 Hz and continues to above 3,000 Hz. The lower resonance bands are high in intensity, but are not separated by white area. The higher resonance bands are separated by white area, but are of low intensity. The third resonance peak, at approximately 393 Hz, is apparently the first formant of the vowel. Formant 2 is apparently at a frequency of approximately 1,824 Hz.

169 - 155 - C1B - ee - C - 0 0 14 - 215.5 (p. 173).

This spectrogram exhibits a strong black band of resonances from the fundamental frequency of approximately 131 Hz to 524 Hz. Another cluster of lower intensity resonance bands begins at approximately 1,690 Hz and extends to well above 3,500 Hz. The area devoid of frequency bands between 524 Hz and 1,690 Hz is characteristic of the $\overline{\text{ee}}$ (i) vowel. Although this example was not aurally pleasing to the panel of experts, the vowel sound apparently was distinguishable.

41 - 131 - J1B - ah - C - 0 4 1 - 198.5 (p. 156).

A mass of frequency bands extends from the fundamental, at approximately 131 Hz, to approximately 1,049 Hz. The area from this point to approximately 2,600 Hz is devoid of resonance. Beginning at approximately 2,600 Hz, there are traces of frequency bands up to approximately 3,000 Hz. The strongest of the resonance peaks in the lower frequencies comes at approximately 524 Hz. Another resonance peak comes at approximately 1,048 Hz. These two resonance peaks apparently serve as the distinguishing formants for the vowel ah (a).

185 - 146 - C1B - ah - C - 1 2 11 - 201 (p. 159).

In this spectrogram there is also a mass of frequency bands in the lower range. In the Type 1 display, none of the frequency bands are distinguishable as resonance peaks. The Type 2 display indicates that certain frequency levels are more intense than others. The range of the mass is from approximately 131 Hz to approximately 1,431 Hz. From this point to approximately 2,348 Hz the spectrogram is devoid of frequency bands. Light gray traces begin at 2,348 Hz and extend to above 3,000 Hz. It is not possible to determine which of the resonance peaks in the lower frequency mass serve as the distinguishing formants for the vowel sound.

Female voices alone.--The last example to be discussed in the "Poor" category is one of female voices alone. This is the only example of female voices alone which was rated as "Poor" by the jury of experts.

145 - 16 - C1G - ee - C - 1 1 12 - 207 (p. 165).

This spectrogram exhibits two strong resonance bands. The first resonance band is the fundamental frequency of approximately 261.5 Hz. The second strong resonance band is at approximately 523 Hz. A resonance band at approximately 784.5 Hz appears intermittently. The area between 784.5 Hz and 2,092 Hz is devoid of resonance bands. An area of weak tracings of resonance bands begins at approximately 2,092 Hz and continues to above 4,000 Hz. The fundamental frequency of 261.5 Hz serves as the first formant for the vowel $\overline{ee}$ (i). A relatively strong resonance band at approximately 2,353 Hz apparently serves as Formant 2 for the vowel. Although this example was categorized as "Poor" by the panel of experts, the spectrographic display is not significantly different from examples in the "Good" and "Acceptable" categories.

The distinguishing characteristics of the acoustical properties of the examples categorized as "Good" are consistent within the category. The resonance bands of frequencies are clearly and cleanly aligned. No traces of lower intensity frequency bands occur between the resonance bands. The resonance bands follow in each case the pattern of the natural harmonic series. The frequencies of the resonance bands were sequential multiples of the fundamental frequency in the order 1, 2, 3, 4, 5, etc. The vowel formant frequencies in each case coincided with the frequency of a resonance band in the natural harmonic series.

The distinguishing characteristics of the acoustical properties of the examples in the "Poor" category were also consistent within the category. The resonance bands were obscured and diffused by lower intensity frequency bands which were not a part of the natural harmonic series. In practically all instances conflicting frequency bands were present. These conflicting frequency bands were usually as much as one-half the intensity of the resonance bands which were aligned with the natural harmonic series. Despite the fact that prominent resonance peaks were visible, it was often not possible to determine which ones coincided with the distinguishing formants of the vowel.

The category which was termed "Acceptable" could have been more appropriately termed "neither Good nor Poor." The acoustical characteristics of these examples are in some instances similar to those of the examples categorized as "Good." In other instances the characteristics of these examples are similar to those examples categorized as "Poor." There are apparently no distinguishing acoustical characteristics for the examples categorized as "Acceptable." It is apparent that the definitive acoustical differences occur between the examples categorized as "Good" and the examples categorized as "Poor."

Common to all examples was the change which took place in the higher frequencies following the attack of the tone. In each example there were fewer acoustical factors present at the instant of the attack than there were in the time duration which followed. The fundamental frequency and the first harmonic overtone were present at the attack. After the attack of the tone, the other acoustical factors--voice pitch overtones, vowel formants, resonance formants, *etc.*--occur in a sequence from low frequency to high frequency.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to analyze the acoustical properties of choral sound. Several studies, which are mentioned in previous chapters, have dealt with the acoustical analysis of the solo singing voice. The subjects of these studies were concerned with vowel formants theories, vowel modification, "brightness" and "darkness" qualities of tone, voice quality, etc. Heretofore, no study has been concerned with the spectrographic analysis of choral singing.

Because of its utilization in previous studies involving the acoustical analysis of sound, the sound spectrograph was selected for use in this study as the analyzing instrument. This study sought to determine the potential use of the sound spectrograph in the analysis of choral sound. In research of the solo voice, the sound spectrograph, as an analyzing instrument, has led to greater understanding of the singing voice. The information gained from this research has been of considerable benefit to those who teach singing. The information gained from the spectrographic analysis of choral sound should be of further benefit to those who teach singing, both solo and choral.

The blending of voices in a choral group is of particular concern to both the choral director and the voice teacher: to the choral director because vocal blend is a necessity to good choral sound, to the voice teacher because of his concern with the vocal development of the individual student. Information which can shed light on the problem of blending voices should be of benefit to the teaching profession.

It is thought by many choral authorities that the vowel sound is one of the most important factors in the achievement of good choral blend. This study concentrated on three vowel sounds: $\overline{\text{ee}}$ (i), eh (ɛ), and ah (a). These vowels are common to all modern Western languages, and are three of the five primary vowels most often used in the teaching of singing.

In order to explore the problem of blending of voices at different developmental stages, three educational settings were utilized. At the junior high school level the voices are in various stages of change in range and vocal timbre. At this level few, if any, of the choral students are receiving instruction in solo singing. At the senior high school level, the voices are beginning to develop toward maturity. In high school many of the choral students begin to receive instruction in solo singing. At the college level most of the voices are physically mature and most of the choral students are receiving private instruction in solo singing. These three educational levels were given equal attention in this study.

To simplify the tonal aspects of the analysis, no harmonies were included in the experiment. The examples which were gathered for the sample were structured to be either of unison or octave sounds.

The evaluation portion of the experiment was performed by a panel of choral authorities. Although it is apparent that a diversity of criteria were utilized in the evaluation, the application of the criteria was consistent. Different trends were apparent in the ratings of the examples. One member of the panel rated very few of the examples as either "Good" or "Poor." He instead rated most of the examples as "Acceptable." On the other hand, another member of the panel tended to rate all of the examples as either "Good" or "Poor," and rated only a few as "Acceptable." A third member of the panel rated very few of the examples as "Good." This judge rated over one-half of the examples as "Poor," and only 2.3 percent as "Good." However, in the two evaluation sessions, the members of the panel gave the same rating to the same example approximately two out of three times.

The results of the evaluation indicate that the ratings were equally distributed among the three instructional levels in the sample. In each of the categories--"Good," "Acceptable," and "Poor"--each of the educational levels received approximately one-third of the total number of ratings in the category.

At all three educational levels the examples sung by the female voices were rated the highest. These examples were consistently rated higher than those sung by the male voices alone, or those sung by the male and female voices together. At all educational levels the eh (ε) vowel was rated lower than the other vowels.

In the factor of the identification of the intended vowel sound, the accuracy of the judges was quite high. It should be pointed out however, that the experiment was not designed to be particularly sensitive in this factor. Since the three vowel sounds used in the study are relatively dissimilar in sound, there should have been little difficulty in the correct identification of the intended vowel. It is worthy of mention therefore, that some of the vowel sounds were not correctly identified. The highest percentage of vowel examples which were not correctly identified were sung by the female voices.

Findings

In the spectrographic analysis, certain aspects appear to have significance. The most prominent aspect seems to be one of tonal clarity. The major findings of this study were

1. Of the examples of choral sound categorized as "Good," the analysis indicated that all the sound which was

present was concentrated into frequency bands which were exactly aligned with the natural harmonic series. All of the known acoustical factors--vowel formants, resonance formants, the fundamental voice pitch and its overtones--were all tuned to the same tonal pattern. The spectrograms show this tonal pattern to be clear and distinct, without deviation in frequency. The resonance bands appear in multiples of the fundamental frequency in the order of 1, 2, 3, 4, 5, 6, etc. The intensity of the frequency bands gradually decreases as the frequency increases.

2. Of the examples of choral sound categorized as "Poor," the analysis indicated that there were sounds present which were not aligned with the natural harmonic series. The analysis indicated that the components of the natural harmonic series were discernible as peaks of resonance which were of greater intensity than the other frequency bands. However, the lower intensity frequency bands combined with the higher intensity frequency bands gives an impression of acoustical confusion. The frequency bands of the natural harmonic series were present with considerable intensity, but were not clear and distinct, or free of frequency deviation. The cross-section, or Type 2, display indicated that the higher frequencies maintained a high level of intensity. This intensity level is significantly higher than that which was indicated for the examples categorized as "Good."

3. Of the examples of choral sound categorized as "Acceptable," the analysis indicated that characteristics of both the "Good" and the "Poor" categories were evident in variable degrees.

4. Common to all examples was the basic acoustical alignment of the natural overtone series. In the examples of good vocal blend, the alignment was clear and precise, with all acoustical factors tuned to the same frequencies. In the examples of poor vocal blend, the alignment was unclear and obscured. Acoustical factors which were not tuned to the fundamental frequency were present in considerable intensity.

5. Of the twenty-seven examples of choral sound which were considered in the "Good" category for the spectrographic analysis

(a) By voice combination, the largest number were of female voices alone. Of the twenty-seven examples, twenty-three were of female voices alone, three were of male voices alone, and only one example was of male and female voices combined.

(b) By educational level, the junior high school level had a slightly larger number. Of the twenty-seven examples, eleven were of the junior high school level, nine were of the college level, and seven were of the senior high school level.

(c) By vowel sound, the smallest number of examples were of the eh (ɛ) vowel. Of the twenty-seven examples, thirteen were of the $\overline{ee}$ (i) vowel, twelve were of the ah (a) vowel, and only two were of the eh (ε) vowel.

6. In the tabulation of the total number of "Good" ratings given by the judges

(a) By voice combination, the largest number of "Good" ratings were for female voices alone. Of the total of 770 "Good" ratings which were given, 432 were for examples of female voices alone, 187 were for male voices alone, and 151 were for male and female voices combined.

(b) By educational level, the ratings were evenly distributed. Of the total of 770 "Good" ratings given, 263 were for the junior high school level, 269 were for the senior high school level, and 238 were for the college level.

(c) By vowel sound, the smallest number of "Good" ratings were for the eh (ε) vowel. Of the 770 "Good" ratings which were given, 283 were for the ah (a) vowel, 280 were for the $\overline{ee}$ (i) vowel, and 207 were for the eh (ε) vowel.

7. Of the twenty-eight examples of choral sound which were considered in the "Poor" category for the spectrographic analysis

(a) By voice combination, the largest number were of male voices alone. Of the twenty-eight examples, sixteen were of male voices alone, eleven were of male and female voices combined, and only one example was of female voices alone.

(b) By educational level, the largest number of examples were of college level. Of the twenty-eight examples, thirteen were of the college level, ten were of the junior high school level, and five were of the senior high school level.

(c) By vowel sound, the number was evenly distributed. Of the twenty-eight examples, ten were of the ah (a) vowel, nine were of the $\overline{ee}$ (i) vowel, and nine were of the eh (ε) vowel.

8. In the tabulation of the total number of "Poor" ratings given by the judges

(a) By voice combination, the smallest number of "Poor" ratings were for female voices alone. Of the total of 1,037 "Poor" ratings which were given, 431 were for male voices alone, 427 were for male and female voices combined, and only 179 were for female voice alone.

(b) By educational leve, the ratings were fairly evenly distributed. Of the total of 1,037 "Poor" ratings, 366 were for the junior high school level, 354 were for the college level, and 317 were for the senior high school level.

(c) By vowel sound, the largest number of "Poor" ratings were for the eh (ε) vowel. Of the 1,037 "Poor" ratings which were given, 396 were for the eh (ε) vowel, 325 were for the ah (a) vowel, and 316 were for the $\overline{ee}$ (i) vowel.

9. In the adjudication of the sample, it was apparent from the tabulation of the ratings that a diversity of criteria were utilized in the evaluation of the examples. However, in the two evaluation sessions, the members of the panel gave the same rating to the same example 63.3 percent of the time. The reliability coefficient for the panel, computed by the Pearson's Product-Moment method, was $\underline{r}$ = .56. According to Borg, this correlation is statistically significant beyond the 1 percent level (1, p. 283).

Conclusions

The conclusions derived from the findings of this study indicate the following:

1. The concept of unity of vowel sound is essential in the achievement of good vocal blend in choral sound.

2. The problem of vowel unity in choral sound is a problem of intonation of vowel formant frequencies.

3. In order to achieve good vocal blend in choral sound, all of the acoustical factors in the choral sound must be aligned with a common natural harmonic series.

It has been borne out by acoustical research that the sound of a vowel consists of two distinct frequency resonances, referred to as the distinguishing formants. The vowel sound is distinguished by the relationship of the frequency levels of the two formants.

In Chapter I, average frequency ratings were reported for the distinguishing formants of several vowel sounds. Research indicates that when the frequencies of the distinguishing formants occur at 270 Hz and 2,290 Hz, the vowel sound would be aurally perceived as $\overline{ee}$ (i). If the lower formant increases in frequency to 390 Hz and the upper formant decreases in frequency to 1,990 Hz, the vowel sound would be aurally perceived as ih (I). Further, if the lower formant were to move up to 530 Hz and the upper formants were to move down to 1,840 Hz, the vowel sound would be perceived as eh (ε).

From the evidence it would appear that the influential factors involved are (1) the rate of frequency of each vowel formant, and (2) the distance, in terms of Hz, between the two formants. If the frequency rate of one formant increases as the other decreases, or vice versa, the distance between the formants changes. In this case aural perception would indicate that the vowel sound had changed from one identifiable vowel to another. As an example, from $\overline{ee}$ (i), 270 Hz and 2,290 Hz, to eh (ε), 530 Hz and 1,840 Hz. If the frequency rate of both formants increased, or decreased, at the same rate, the distance between the formants would remain the same. In this case, the aural perception would indicate that the vowel sound remained the same vowel, but changed in what is subjectively called "color." For example, an $\overline{ee}$ (i) vowel of 330 Hz and 2,350 Hz would be "brighter" than average. An ee (i) vowel of 210 Hz and 2,230 Hz would be "darker" than average. However, because the relative positions of the formants are the same, both sounds would most likely be perceived as ee (i).

Acoustical research also indicates that voice pitch frequencies and vowel formant frequencies are independent. In Chapter I it is pointed out that changes in formant frequencies are due to changes in the resonating cavities of the vocal tract, and that voice pitch changes are due to changes in the positions of the vocal chords. Voice pitch frequencies can be changed without affecting vowel formant frequencies. Vowel formant frequencies can be changed without affecting voice pitch frequencies. In a choral group, each individual produces a voice pitch with the resultant overtones, and a vowel sound with the distinguishing formants. The problem of vocal blend is one of achieving the best combination of these acoustical factors.

In order to achieve good vocal blend within a choral group, all the acoustical factors in the choral sound must be aligned with a common harmonic series. In order to produce a common harmonic series for voice pitch, each individual in the choral group must sing a pitch which is correctly in tune with the desired frequency. The overtones produced with the voice pitch must be of like frequencies, and should be similar in number and in intensity. The factors of the voice pitch and its overtones should be effectively controlled by striving for unity of duration, pitch intonation, and loudness.

In order to effectively align the distinguishing formants of the vowel, it is necessary that each individual in the choral group sing a vowel sound which will result in distinguishing formants of like frequencies. An $\overline{ee}$ (i) vowel which is "brighter" than average and an $\overline{ee}$ (i) vowel which is "darker" than average will most likely not result in distinguishing formants of like frequencies. Only by producing all vowel formants of the same frequencies can the exact alignment of the formants take place. Only if the individuals in a choral group sing a like vowel sound can all of the vowel formants be of the same frequency. Unity of vowel, then, would be achieved within a choral group by all the individuals singing a vowel sound which would result in distinguishing formants of the same frequencies.

The problem of the alignment of the distinguishing formants of the vowel in choral sound is further complicated if the formants of the vowel must be aligned with the natural harmonic series of the voice pitch. The spectrographic analysis in this study indicated that in the examples of good vocal blend, the vowel formants were aligned with the natural harmonic series of the fundamental pitch. This would seem to indicate that in those examples the individuals in the choral group sang a vowel sound which resulted in vowel formant frequencies which coincided with voice pitch frequencies in a common harmonic series. The spectrographic analysis indicated that in the examples of poor vocal blend many acoustical factors were not aligned with the natural harmonic series of the fundamental pitch. This would seem to indicate that in those examples the individuals in the choral group sang vowel sounds which resulted in vowel formant frequencies which did not coincide with voice pitch frequencies.

In order to achieve good vocal blend, the individuals within a choral group should sing vowel sounds which will result in correct intonation of the distinguishing vowel formants. In order to achieve correct intonation of the distinguishing vowel formants and voice pitch frequencies, the vowel sounds should be modified in "color" to achieve alignment with the natural harmonic series of the voice pitch.

Recommendations

Based upon the findings and conclusions of this study, it is recommended that teachers of choral singing be equally concerned with intonation of voice pitch factors and vowel formant factors. Acoustical research indicates that vowel formants are audible frequencies which can be adjusted in pitch by modification of the vowel sound. As audible frequencies, the vowel formants can be tuned to a desired frequency in much the same way as the voice pitch.

Vowel unity should be presented as a basic concept in the teaching of choral singing. The concept of vowel unity is not one of matching a model vowel, or of matching a model tone sound. The concept of vowel unity is one of intonation.

It is recommended that further research into aspects of choral singing utilize the potential of the sound spectrograph. Based upon the findings and conclusions of this study, the following questions are proposed:

1. Are certain frequencies of voice pitch more adaptable to certain vowels than others in the achievement of choral blend?

2. If the concept of vowel unity is one of intonation, how can it be best taught as a basic concept in choral singing?

3. Are acoustical factors of overtones and difference tones a problem of vocal blend when male and female voices are combined in a choral group?

4. What effect does the singing of harmony, as opposed to unison or octaves, have upon the intonation of vowel formants and the blend of choral sound?

5. What are the acoustical characteristics of brightness and darkness qualities in choral sound?

6. What is the effect of brightness and darkness qualities upon the intelligibility of vowels in choral sound?

7. Can good vocal blend be achieved more readily with female voices than with male voices? What are the contributing acoustical factors? What are the contributing subjective factors?

8. Can good vocal blend be achieved more readily on voice pitches in the mid-range than on more extreme high or low pitches? What are the contributing acoustical factors? What are the contributing subjective factors?

9. Can good vocal blend be achieved more readily on certain vowels than on others? What are the contributing acoustical factors?

CHAPTER BIBLIOGRAPHY

1. Borg, Walter R., *Educational Research, An Introduction*, New York, David McKay Company, Inc., 1963.

APPENDIX A

EXPLANATION:

This study is being conducted to determine, by means of spectrographic analysis, the distinguishing characteristics of the acoustical properties of choral sound in relationship to subjective evaluation of vocal blend. This jury has been assembled to make, individually, a subjective judgment as to the quality of the vocal blend of each example presented.

The examples are pre-recorded from choirs of five different school settings, including junior high school, senior high school, and college. The vowel sounds, ee, eh, ah, were sung in unison on notes of the middle range C major scale; in combinations of female voices alone, male voices alone, and male and female voices together. The examples are completely randomized as to pitch, vowel sound, voice combination, and school level.

INSTRUCTIONS:

Each example will be two seconds in duration, followed by an eight-second pause. Please evaluate, according to your own criteria, the quality of the vocal blend of each sound presented. Indicate your rating on the adjudication sheet by circling the appropriate vowel symbol in the appropriate column.

The entire sample is thirty-six minutes in duration. To establish reliability the sample will be evaluated twice. A short rest period will be taken at the mid-point of the sample and between the two hearings. If at any point more time is needed for scoring, the tape can be stopped momentarily.

Judge __________ Hearing ___________

BLEND: I - Good; II - Acceptable; III - Poor

_____	I	II	III	_____	I	II	III
	ee	ee	ee		ee	ee	ee
	eh	eh	eh		eh	eh	eh
	ah	ah	ah		ah	ah	ah
_____	I	II	III	_____	I	II	III
	ee	ee	ee		ee	ee	ee
	eh	eh	eh		eh	eh	eh
	ah	ah	ah		ah	ah	ah
_____	I	II	III	_____	I	II	III
	ee	ee	ee		ee	ee	ee
	eh	eh	eh		eh	eh	eh
	ah	ah	ah		ah	ah	ah
_____	I	II	III	_____	I	II	III
	ee	ee	ee		ee	ee	ee
	eh	eh	eh		eh	eh	eh
	ah	ah	ah		ah	ah	ah
_____	I	II	III	_____	I	II	III
	ee	ee	ee		ee	ee	ee
	eh	eh	eh		eh	eh	eh
	ah	ah	ah		ah	ah	ah
_____	I	II	III	_____	I	II	III
	ee	ee	ee		ee	ee	ee
	eh	eh	eh		eh	eh	eh
	ah	ah	ah		ah	ah	ah

APPENDIX B

THE SAMPLE

The catalog numbers were assigned by a systematic method in the following priorities: female voices, male voices, and male and female voices together; junior high school, senior high school, and college. The sequence number was assigned by a random method. The code symbols for the school groups are J for junior high school, S for senior high school, C for college; 1 for the first group recorded, 2 for the second group recorded; G for female voices, B for male voices, and M for male and female voices together.

The symbols ee, eh, and ah, represent the intended vowel. When a vowel other than the intended vowel was marked by a judge, the vowel symbol and the rating which was marked are shown in parentheses. The pitch names represent the notes of an ascending C major scale. The figures in the rating columns are a summation of the ratings of all the judges in both evaluation sessions. The last column gives rank of each example in the sample. The ranks were determined by the number of "Good," "Acceptable," and "Poor" ratings of the judges.

Catalog Number	Sequence Number	School Group	Vowel Sound	Pitch Name	Ratings of Judges I	II	III	Rank
1	93	J1G	ee	C	5	7	2	67.5
2	200	J1G	ee	D	6	6	2	41
3	7	J1G	ee	E	5	4	5	50
4	58	J1G	ee	F	9	3	2	18
5	33	J1G	ee	G	9	3	2	18
6	66	J1G	ee	A	10	3	1	7
7	95	J1G	ee (eh)	B	6 (3)	3	2	18
8	197	J1G	ee (eh)	c	9	3	1 (1)	18
9	166	J1G	eh	C	5	3	6	137.5
10	47	J1G	eh (ee)	D	6 (1)	3	4	35.5
11	86	J1G	eh (ah)	E	4	9	0 (1)	89
12	127	J1G	eh	F	7	4	3	35.5
13	79	J1G	eh	G	6	6	2	41
14	78	J1G	eh	A	6	3	5	48
15	142	J1G	eh	B	7	2	5	38
16	145	J1G	eh	c	10	3	1	7
17	75	J1G	ah	C	5	7	2	67.5
18	108	J1G	ah	D	6	5	3	44.5
19	41	J1G	ah	E	9	5	0	11
20	158	J1G	ah	F	12	2	0	2
21	77	J1G	ah	G	7	7	0	29.5
22	182	J1G	ah	A	9	5	0	11
23	104	J1G	ah	B	9	5	0	11
24	124	J1G	ah	c	12	2	0	2
25	184	J1B	ee	C	0	5	9	191
26	105	J1B	ee	D	0	6	8	179
27	12	J1B	ee	E	2	6	6	148.5
28	202	J1B	ee	F	1	7	5	127
29	37	J1B	ee	G	1	6	7	159.5
30	22	J1B	ee	A	0	6	8	179
31	154	J1B	ee	B	0	4	10	198.5
32	59	J1B	ee	c	2	10	2	96
33	11	J1B	eh	C	3	7	4	121
34	68	J1B	eh	D	6	7	1	63.5
35	128	J1B	eh	E	1	8	5	114.5
36	212	J1B	eh	F	2	5	7	155.5

Catalog Number	Sequence Number	School Group	Vowel Sound	Pitch Name	Ratings of Judges I	II	III	Rank
37	56	J1B	eh	G	0	3	11	204
38	102	J1B	eh	A	1	4	9	185.5
39	106	J1B	eh	B	0	3	11	204
40	40	J1B	eh	c	2	7	5	127
41	131	J1B	ah	C	0	4	10	198.5
42	167	J1B	ah	D	1	9	4	102.5
43	159	J1B	ah	E	2	8	4	109
44	85	J1B	ah (eh)	F	2 (1)	4	7	152.5
45	123	J1B	ah	G	1	6	6	148.5
46	157	J1B	ah	A	0	7	7	163.5
47	176	J1B	ah	B	0	4	10	198.5
48	88	J1B	ah	c	1	6	7	159.5
49	60	J1M	ee	C	0	2	12	209
50	31	J1M	ee	D	1	9	4	102.5
51	191	J1M	ee	E	2	8	4	109
52	170	J1M	ee	F	2	8	4	109
53	136	J1M	ee	G	5	3	6	137.5
54	147	J1M	ee	A	3	7	4	121
55	175	J1M	ee	B	2	6	6	148.5
56	178	J1M	ee	c	4	6	4	60
57	80	J1M	eh	C	2	2	10	194
58	112	J1M	eh	D	0	3	11	204
59	164	J1M	eh	E	2	10	2	96
60	3	J1M	eh	F	3	9	2	92.5
61	196	J1M	eh	G	2	4	8	168.5
62	46	J1M	eh	A	0	6	8	179
63	211	J1M	eh	B	3	8	3	81
64	181	J1M	eh	c	1	6	7	159.5
65	63	J1M	ah	C	3	3	8	166
66	213	J1M	ah	D	2	4	8	168.5
67	179	J1M	ah	E	3	7	4	121
68	140	J1M	ah	F	4	6	4	60
69	82	J1M	ah	G	1	9	4	102.5
70	27	J1M	ah	A	1	0	13	211
71	115	J1M	ah	B	1	4	9	185.5
72	28	J1M	ah	c	2	4	8	168.5

Catalog Number	Sequence Number	School Group	Vowel Sound	Pitch Name	Ratings of Judges			Rank
					I	II	III	
73	72	S1G	ee	C	5	7	2	67.5
74	18	S2G	ee	D	9	4	1	14.5
75	99	S1G	ee	E	1	12	0	98
76	39	S2G	ee	F	9	4	1	14.5
77	168	S1G	ee	G	3	7	4	121
78	163	S2G	ee	A	6	6	2	41
79	44	S1G	ee	B	5	8	2	75.5
80	84	S1G	ee	c	10	3	1	7
81	204	S2G	eh (ee)	C	5	5	3 (1)	51.5
82	24	S1G	eh	D	3	5	6	144
83	103	S2G	eh	E	7	5	2	33
84	107	S1G	eh	F	5	6	3	55
85	193	S2G	eh	G	6	2	6	49
86	187	S1G	eh	A	5	6	3	55
87	169	S2G	eh	B	7	2 (1)	4	35.5
88	129	S1G	eh	c	1	8	5	114.5
89	90	S1G	ah	C	0	7	7	163.5
90	148	S2G	ah	D	6	5	3	44.5
91	30	S1G	ah	E	4	9	1	89
92	10	S2G	ah	F	8	6	0	23
93	87	S1G	ah (eh)	G	4	8 (1)	1	89
94	156	S2G	ah	A	10	4	0	4.5
95	96	S1G	ah	B	0	11	3	99
96	53	S2G	ah	c	12	2	0	2
97	43	S1B	ee	C	2	8	4	109
98	152	S2B	ee	D	5	7	2	67.5
99	52	S1B	ee	E	0	1	13	212
100	71	S2B	ee	F	6	8	0	73.5
101	109	S1B	ee	G	1	5	8	173
102	126	S2B	ee	A	7	7	0	29.5
103	122	S1B	ee	B	4	6	4	60
104	14	S2B	ee	c	6	8	0	73.5
105	83	S2B	eh	C	4	4	6	140
106	295	S1B	eh	D	0	3	11	204
107	23	S2B	eh	E	4	7	3	71.5
108	153	S1B	eh	F	3	8	3	81

Catalog Number	Sequence Number	School Group	Vowel Sound	Pitch Name	Ratings of Judges I	II	III	Rank
109	174	S2B	eh	G	3	5	6	144
110	38	S1B	eh	A	1	7	6	130.5
111	62	S2B	eh	B	5	6	3	55
112	25	S1B	eh	c	0	6	8	179
113	210	S1B	ah	C	3	4	7	152.5
114	150	S2B	ah	D	9	3	2	18
115	125	S1B	ah	E	0	2	12	209
116	69	S2B	ah	F	6	3(1)	4	46.5
117	6	S1B	ah	G	1	4	9	185.5
118	190	S2B	ah	A	7	4	3	35.5
119	162	S1B	ah	B	0	5	9	191
120	91	S2B	ah	c	6	4	4	46.5
121	73	S2M	ee	C	2	5	7	155.5
122	134	S1M	ee	D	1	8	5	114.5
123	116	S2M	ee	E	2	7	5	127
124	42	S1M	ee	F	1	9	4	102.5
125	120	S2M	ee	G	4	5	5	136
126	172	S1M	ee(eh)	A	3(1)	4	6	140
127	141	S2M	ee	B	5	5	4	51.5
128	1	S1M	ee	c	3	10	1	94
129	81	S1M	eh	C	1	5	8	173
130	132	S2M	eh	D	2	7	5	127
131	203	S1M	eh	E	0	6	8	179
132	198	S2M	eh	F	1	9	4	102.5
133	51	S1M	eh	G	1	6	7	159.5
134	2	S2M	eh	A	2	5	7	155.5
135	206	S1M	eh	B	1	4	9	185.5
136	29	S2M	eh	c	2	8	4	109
137	160	S2M	ah	C	5	7	2	67.5
138	34	S1M	ah	D	0	6	8	179
139	55	S2M	ah	E	3	5	6	144
140	70	S1M	ah	F	1	5	8	173
141	13	S2M	ah	G	5	8	1	75.5
142	9	S1M	ah	A	0	5	9	191
143	19	S2M	ah	B	4	7	3	71.5
144	94	S1M	ah	c	4	6	4	60

Catalog Number	Sequence Number	School Group	Vowel Sound	Pitch Name	Ratings of Judges I	II	III	Rank
145	16	C1G	ee	C	1	1	12	207
146	5	C2G	ee	D	10	4	0	4.5
147	161	C1G	ee	E	4	8	2	78
148	61	C2G	ee	F	6	6	2	41
149	192	C1G	ee	G	8	3	3	27
150	26	C2G	ee	A	8	6	0	23
151	165	C1G	ee	B	3	6	5	133.5
152	118	C2G	ee (eh)	c	7 (1)	6	0	23
153	133	C2G	eh	C	2	10	2	96
154	135	C1G	eh	D	1	4	9	185.5
155	180	C2G	eh	E	5	9	0	84.5
156	209	C1G	eh	F	3	6	5	133.5
157	143	C2G	eh	G	3	6	5	133.5
158	121	C1G	eh	A	4	8	2	78
159	21	C2G	eh	B	8	5	1	26
160	57	C1G	eh	c	3	7	4	121
161	139	C1G	ah	C	2	6	6	148.5
162	48	C2G	ah	D	5	9	0	84.5
163	151	C1G	ah	E	1	5	8	173
164	98	C2G	ah	F	6	7	1	63.5
165	17	C1G	ah	G	5	9	0	84.5
166	35	C2G	ah	A	7	7	0	29.5
167	113	C1G	ah	B	5	7	2	67.5
168	119	C2G	ah	c	9	5	0	11
169	155	C1B	ee	C	0	0	14	215.5
170	114	C2B	ee	D	0	5	9	191
171	138	C1B	ee	E	0	0	14	215.5
172	215	C2B	ee	F	4	6	4	60
173	32	C1B	ee	G	3	5	6	144
174	177	C2B	ee	A	5	6	3	55
175	76	C1B	ee	B	4	9	1	89
176	97	C2B	ee	c	9	5	0	11
177	194	C2B	eh	C	2	5	7	155.5
178	208	C1B	eh	D	0	4	10	198.5
179	188	C2B	eh	E	1	8	5	114.5
180	101	C1B	eh	F	0	7	7	163.5

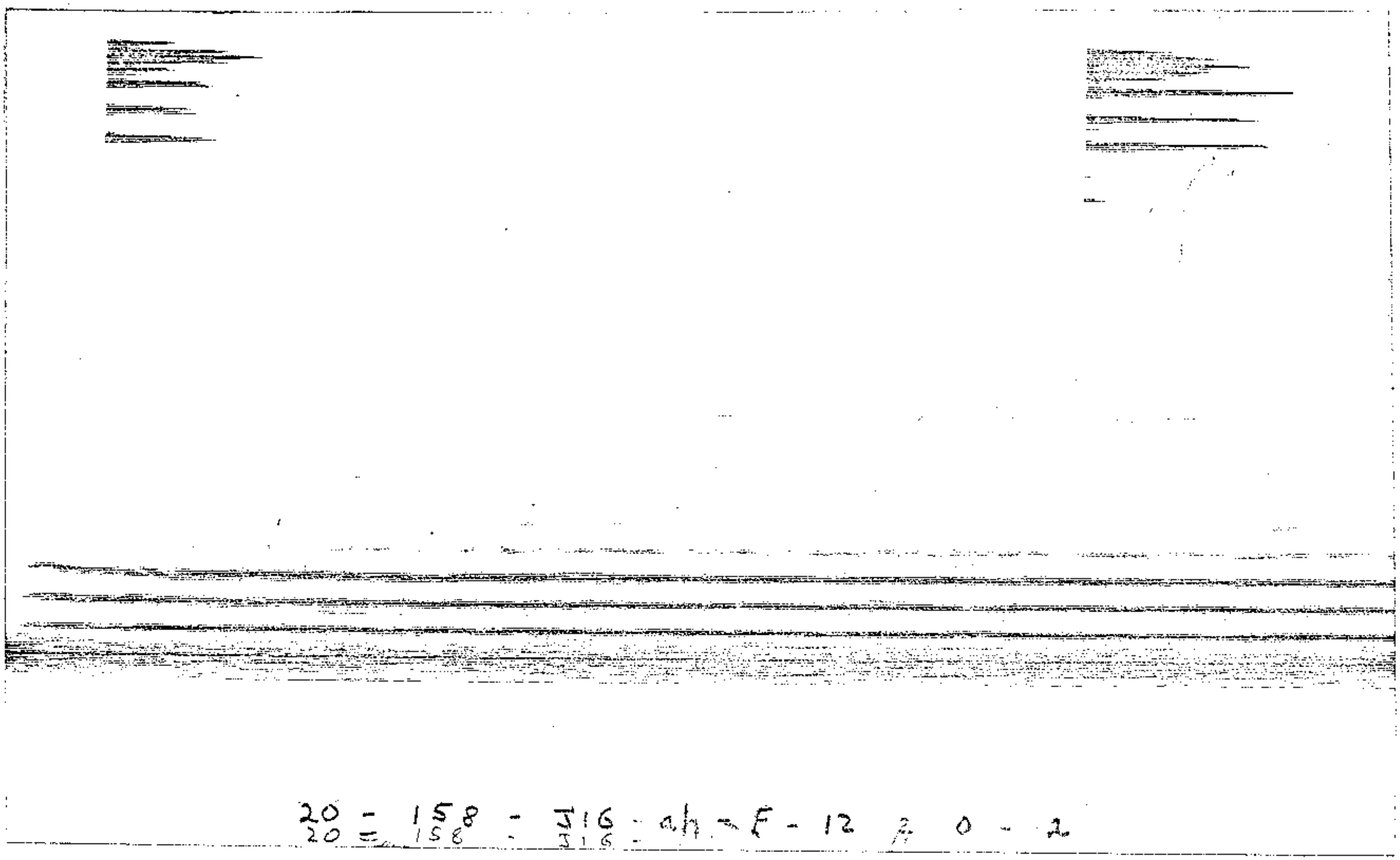
Catalog Number	Sequence Number	School Group	Vowel Sound	Pitch Name	Ratings of Judges I	II	III	Rank
181	110	C2B	eh(ee)	G	2	4	7(1)	168.5
182	185	C1B	eh	A	7	6	1	32
183	64	C2B	eh	B	2	7	5	127
184	74	C1B	eh	c	4	4	6	140
185	146	C1B	ah	C	1	2	11	201
186	149	C2B	ah	D	3	8	3	81
187	216	C1B	ah(?)	E	0	1	11(2)	213
188	207	C2B	ah	F	4	3	7	151
189	144	C1B	ah	G	3	5	6	144
190	100	C2B	ah	A	8	6	0	23
191	199	C1B	ah	B	4	9	1	89
192	8	C2B	ah	c	7	7	0	29.5
193	189	C2M	ee	C	0	7	7	163.5
194	50	C1M	ee	D	0	5	9	191
195	214	C2M	ee	E	3	7	4	121
196	54	C1M	ee	F	1	5	8	173
197	20	C2M	ee	G	1	7	6	130.5
198	65	C1M	ee	A	1	8	5	114.5
199	15	C2M	ee	B	6	6	2	41
200	201	C1M	ee	c	5	6	3	55
201	36	C1M	eh	C	1	3	10	195.5
202	89	C2M	eh	D	1	8	5	114.5
203	4	C1M	eh	E	0	3	11	204
204	171	C2M	eh	F	0	1	13	213
205	186	C1M	eh	G	0	9	5	106
206	67	C2M	eh	A	1	4	9	185.5
207	45	C1M	eh	B	5	9	0	84.5
208	49	C2M	eh	c	3	7	4	121
209	183	C2M	ah	C	0	2	12	207
210	137	C1M	ah	D	0	6	8	179
211	92	C2M	ah	E	1	3	10	195.5
212	173	C1M	ah	F	3	6	5	133.5
213	111	C2M	ah	G	1	9	4	102.5
214	117	C1M	ah	A	3	9	2	92.5
215	195	C2M	ah	B	4	8	2	78
216	130	C1M	ah	c	8	6	0	23

APPENDIX C

This appendix contains sound spectrograms of the examples categorized as "Good" by the panel of experts. The spectrograms are arranged in rank order according to the ratings of the panel. Of the 216 examples in the sample, 27 were considered in the "Good" category, with ranks from 2 to 27.

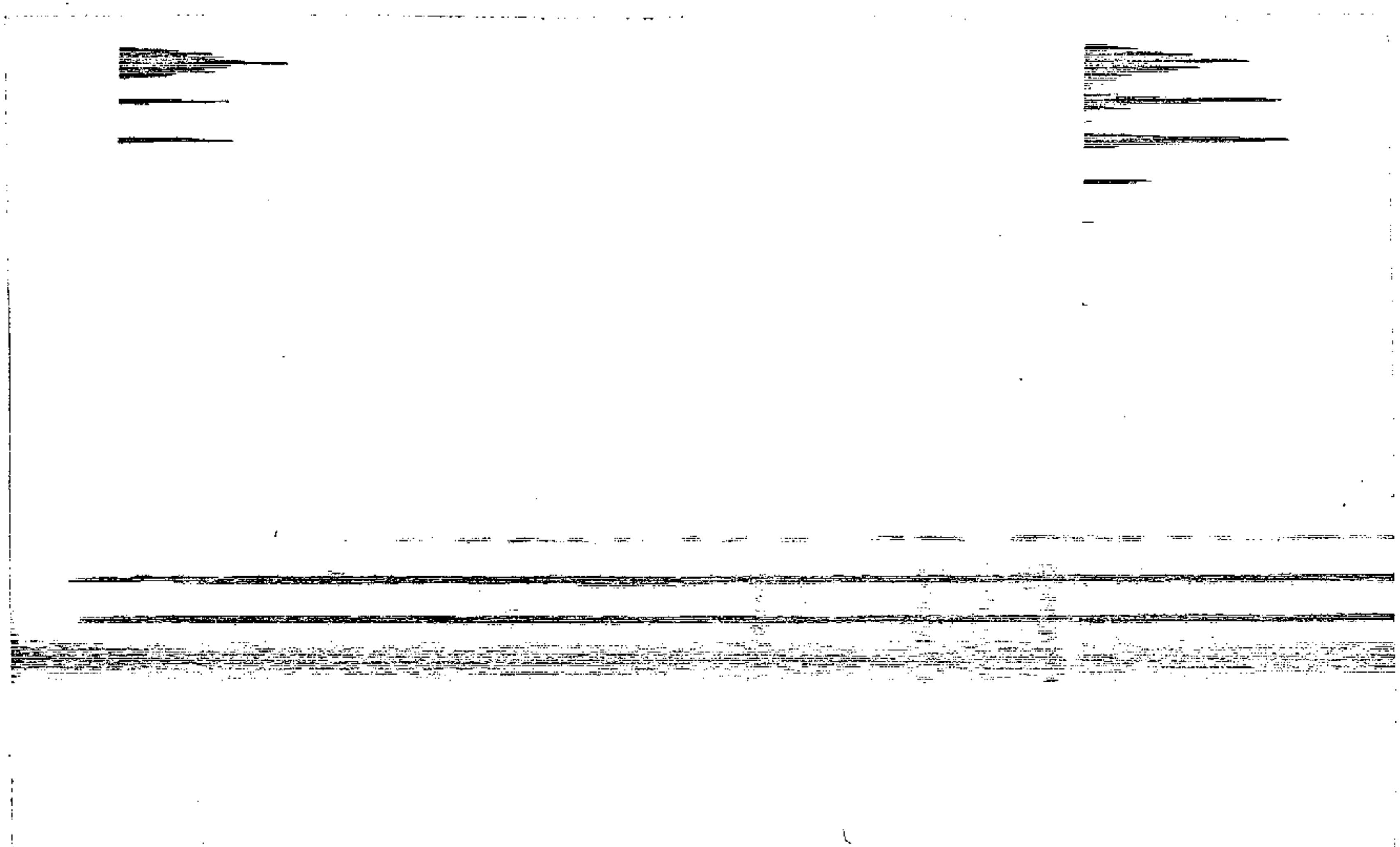
Each spectrogram exhibits two types of spectrographic display. The Type 1 display shows pitch frequency vertically, time duration horizontally, and intensity as shading between gray and black. The Type 2 display is a cross-section showing frequency vertically and intensity horizontally. The frequency scale of the cross-section is inverted on the spectrogram. The cross-sections were made approximately at the attack and 1.2 seconds later. The cross-section is shown on the spectrogram at the exact time spot which coincides with the Type 1 display.

Each spectrogram is identified by vowel sound, educational level, voice combination, pitch frequency, and rank.



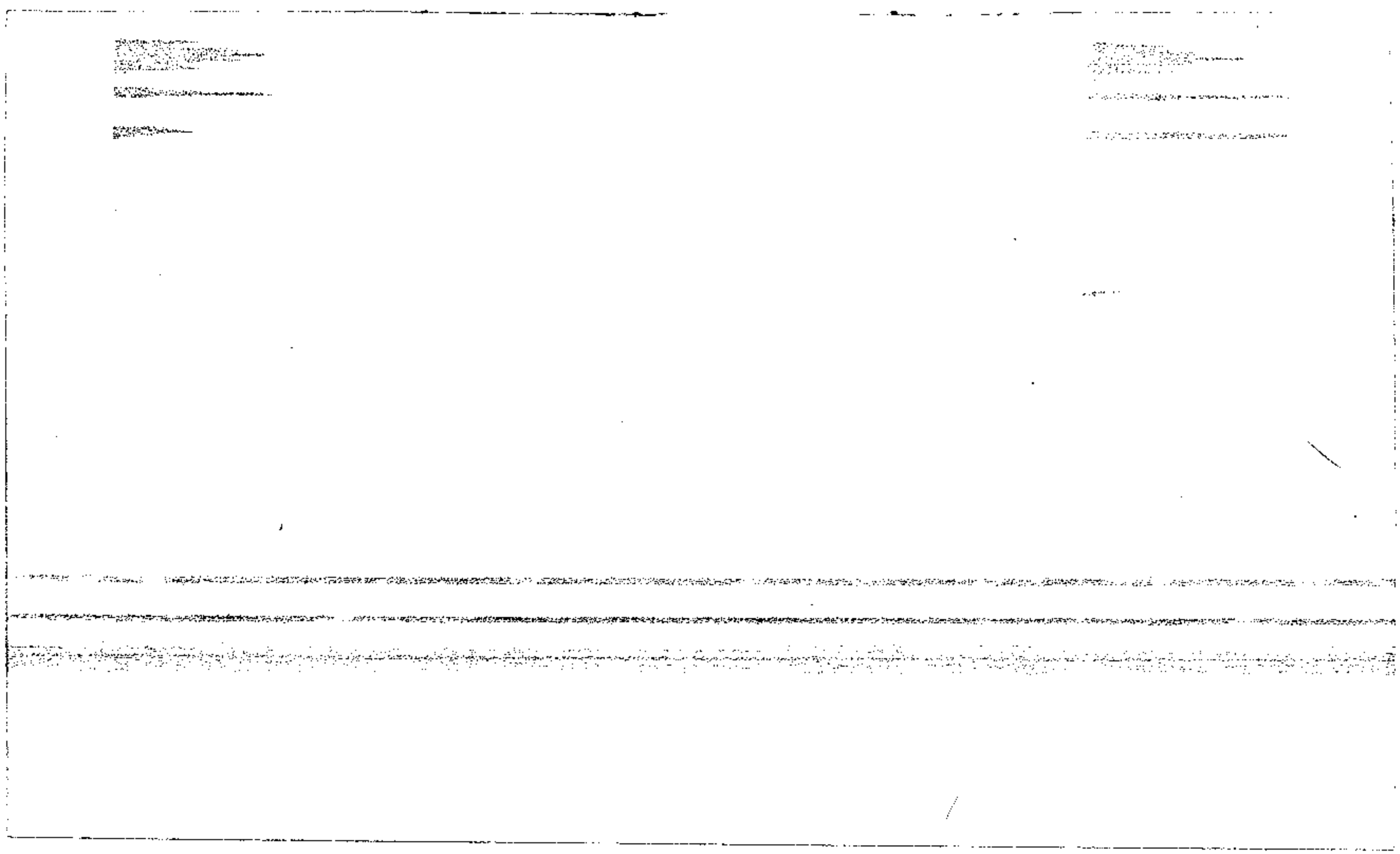
20 - 158 - J1G - ah - F - 12 2 0 - 2

Fig. 14--A spectrogram of the vowel ah (a) sung by junior high school female voices on the pitch F (approximately 349 Hz). Rank of 2.



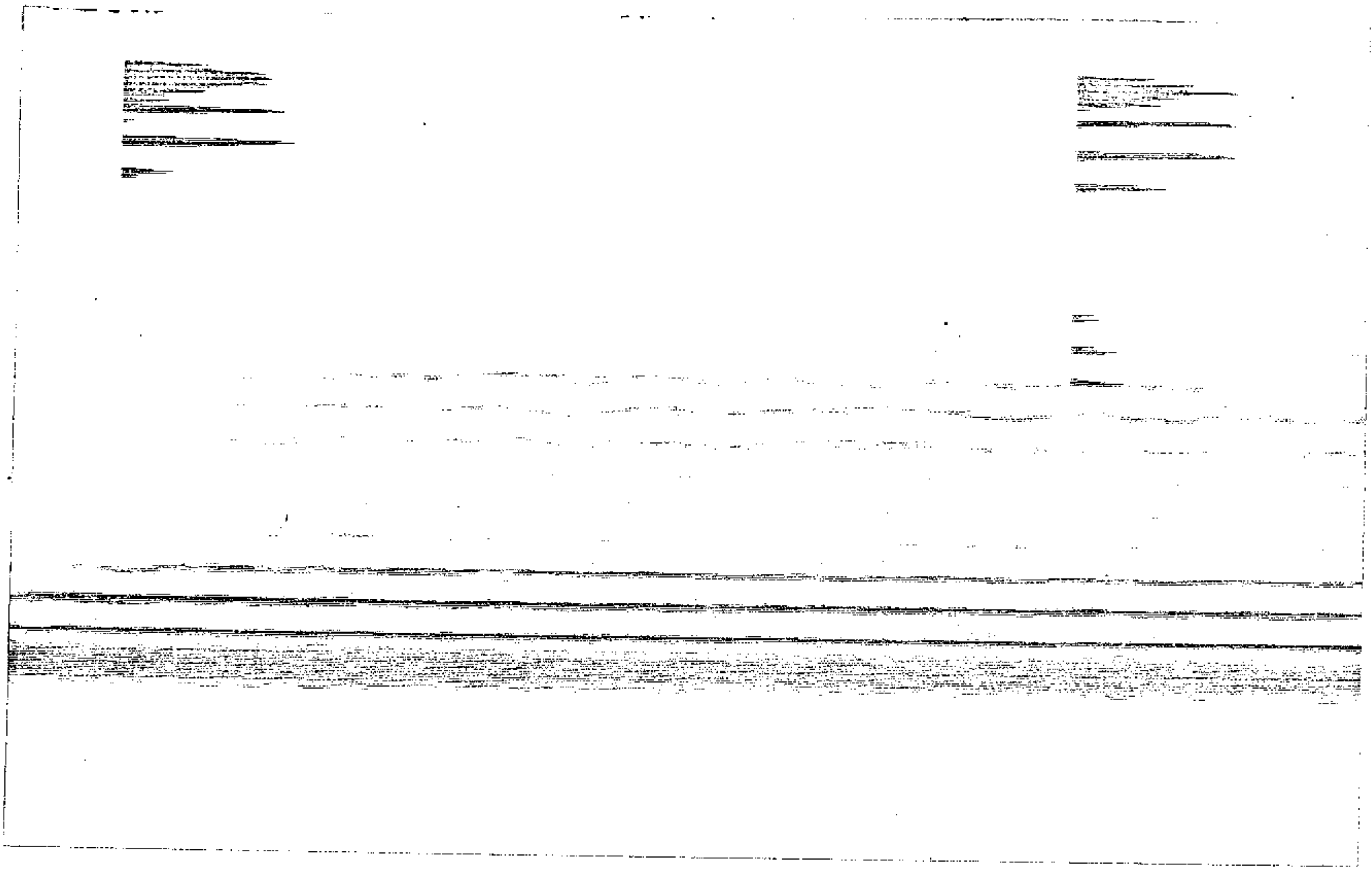
24 - 124 - J1G - ah - c - 12 2 0 - 2

Fig. 15--A spectrogram of the vowel ah (a) sung by junior high school female voices on the pitch c (approximately 523 Hz). Rank of 2.



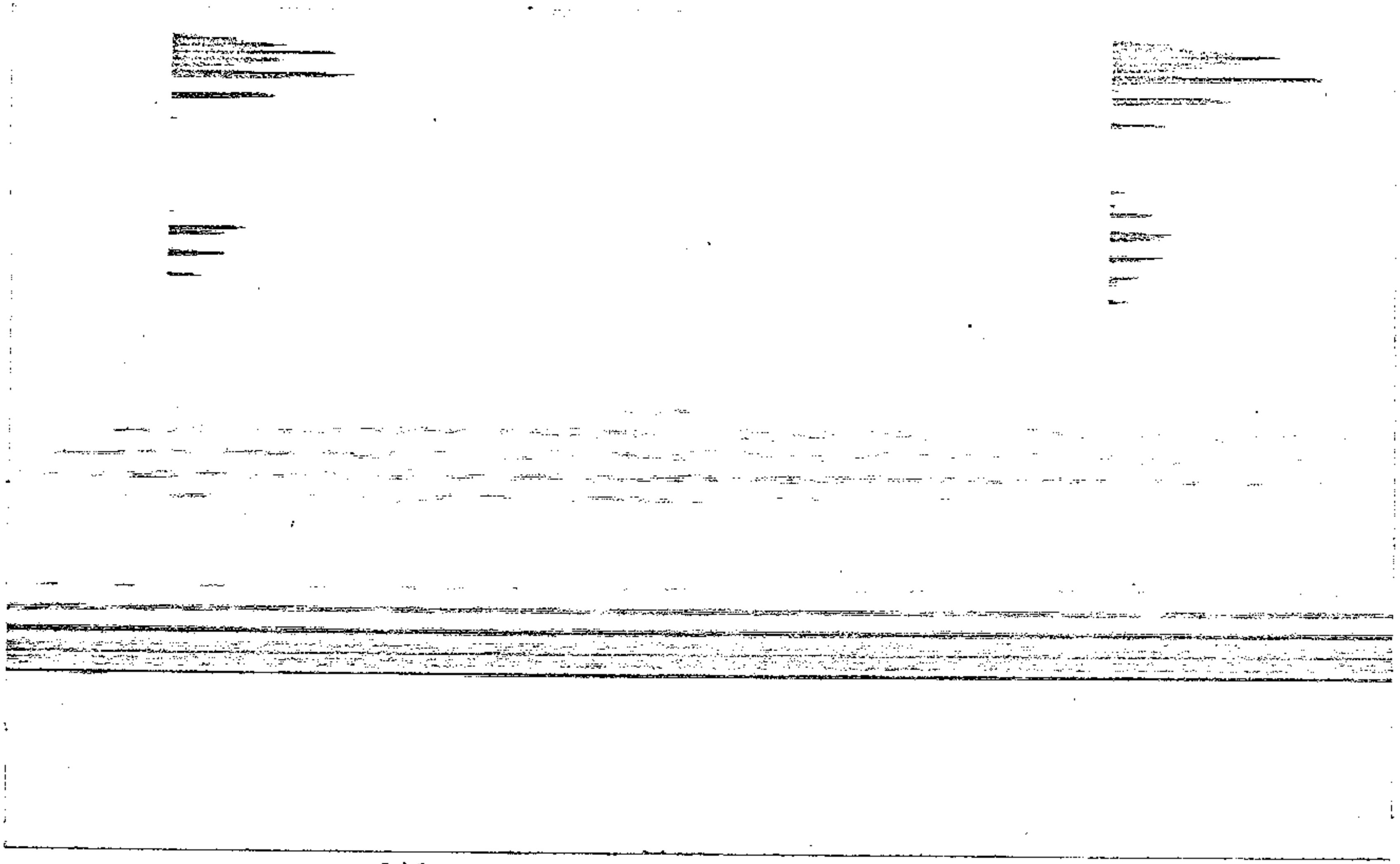
96 - 53 - S2G - ah - c - 12 2 0 - 2

Fig. 16--A spectrogram of the vowel ah (a) sung by senior high school female voices on the pitch c (approximately 523 Hz). Rank of 2.



94 - 156 - S2G - ah - A - 10 4 0 - 4.5

Fig. 17--A spectrogram of the vowel ah (a) sung by senior high school female voices on the pitch A (approximately 440 Hz). Rank of 4.5.



146 - 5 - C2G - ee - D - 10 4 0 - 4.5

Fig. 18--A spectrogram of the vowel $\overline{\text{ee}}$ (i) sung by college female voices on the pitch D (approximately 294 Hz). Rank of 4.5.

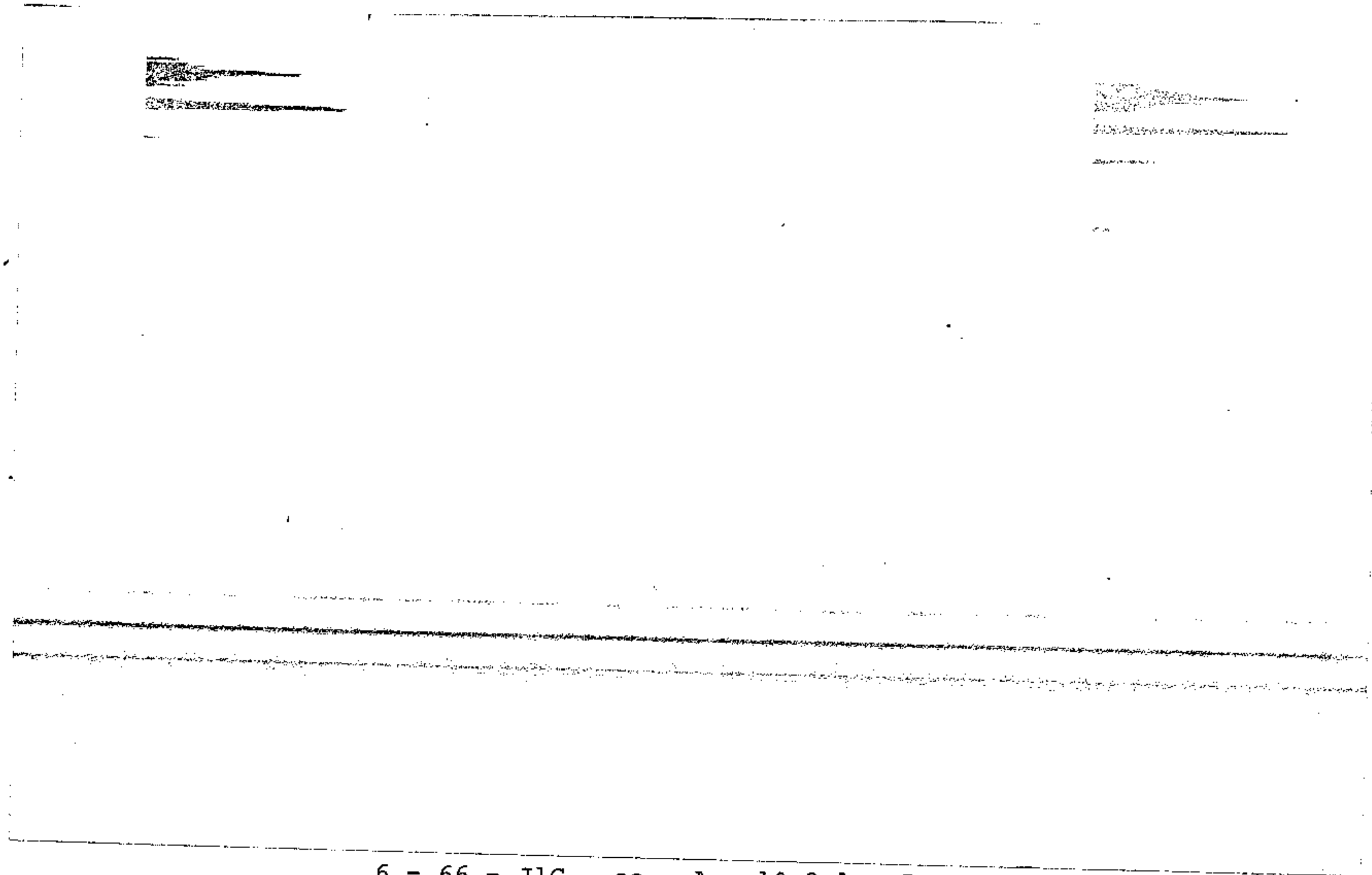
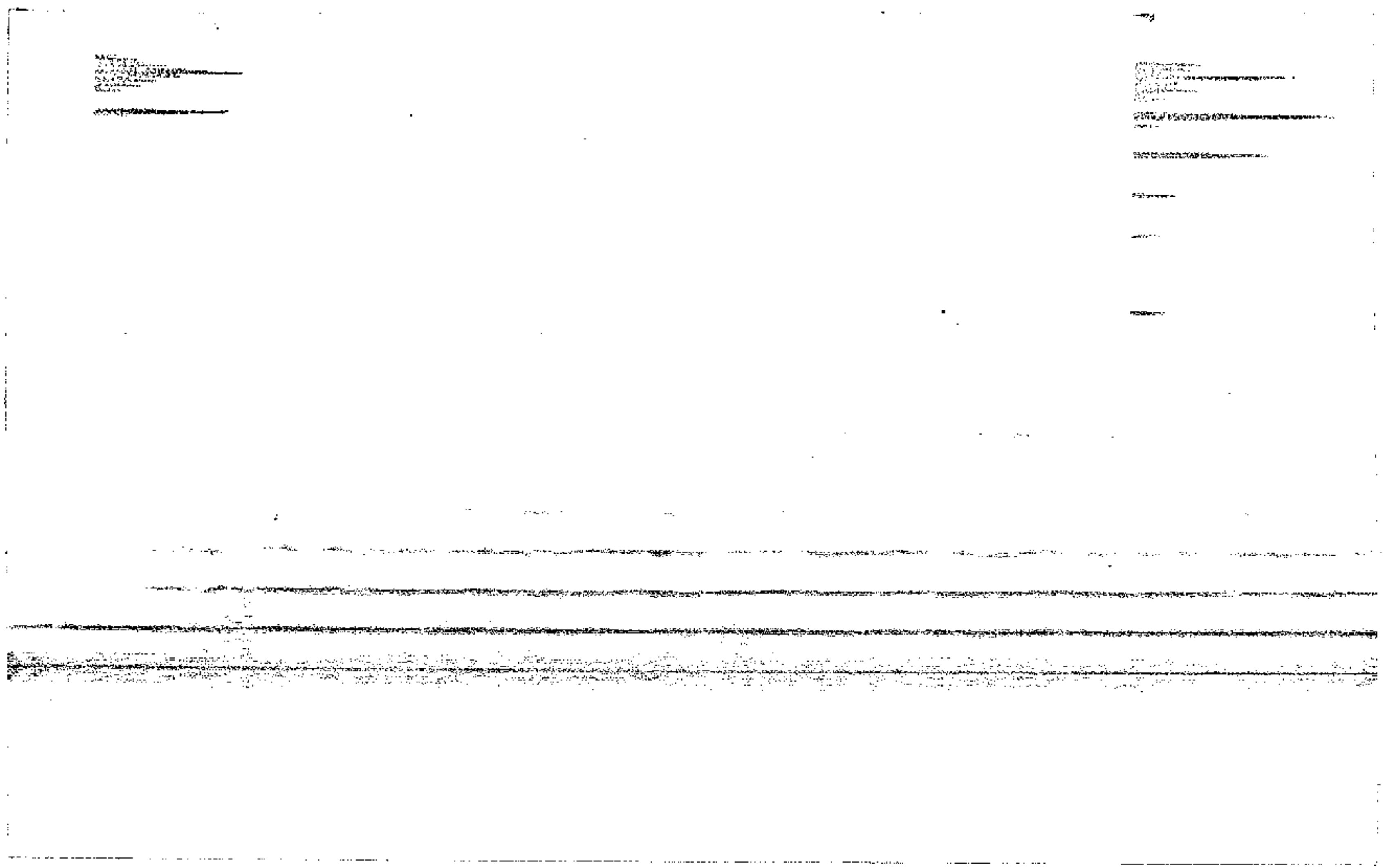
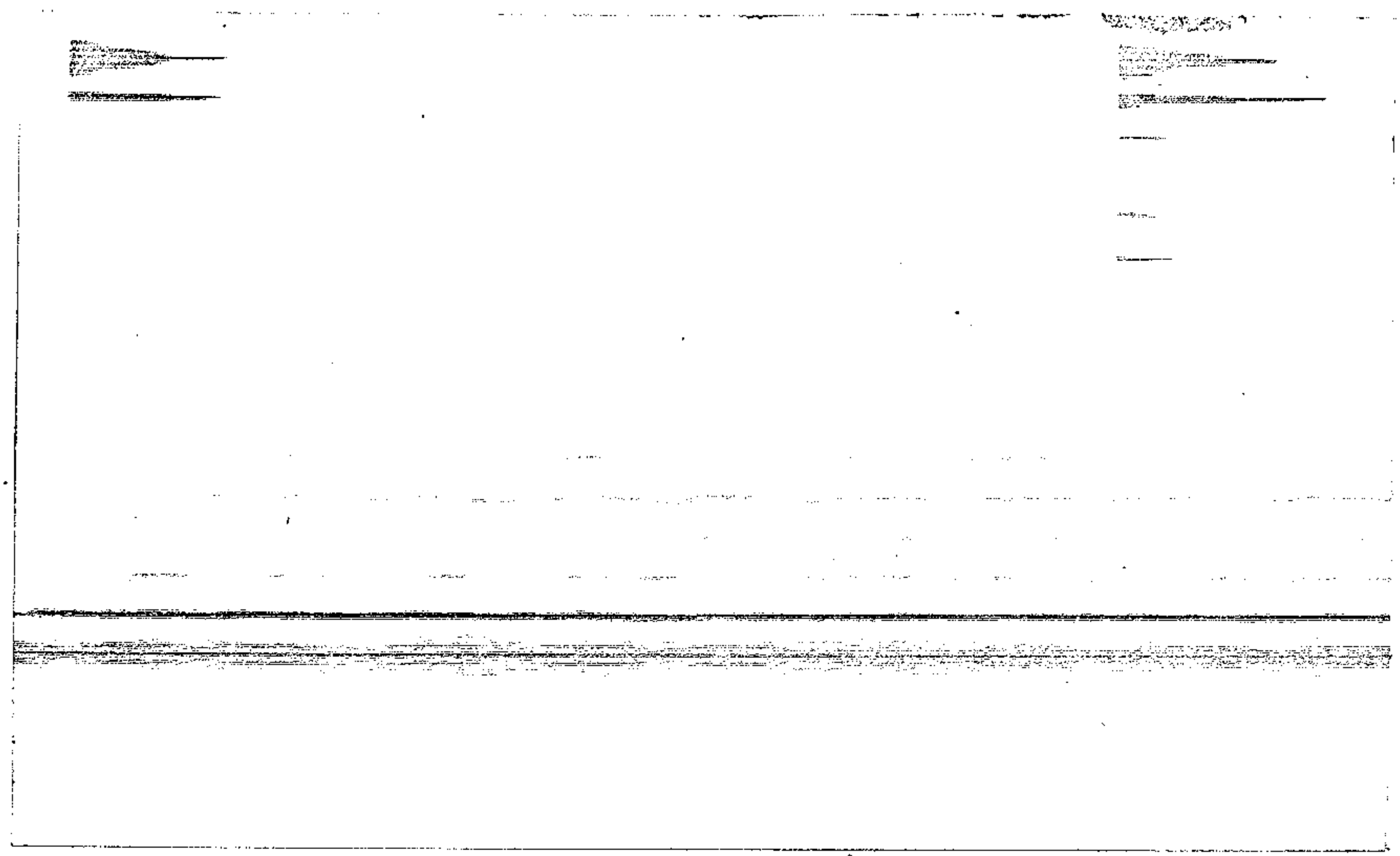


Fig. 19--A spectrogram of the vowel $\overline{ee}$ (i) sung by junior high school female voices on the pitch A (approximately 440 Hz). Rank of 7.



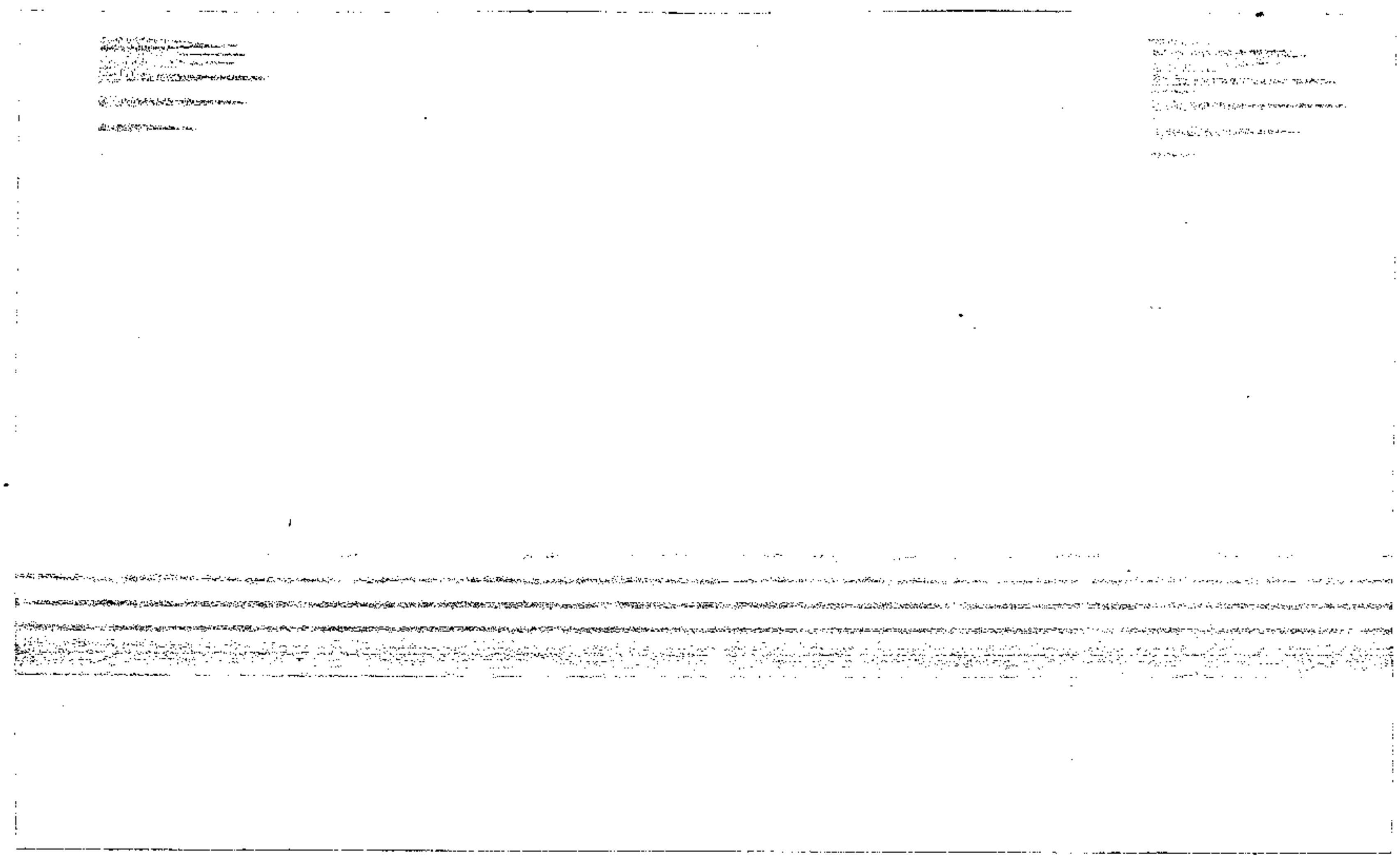
16 - 145 - J1G - eh - c - 10 3 1 - 7

Fig. 20--A spectrogram of the vowel eh (ε) sung by junior high school female voices on the pitch c (approximately 523 Hz). Rank of 7.



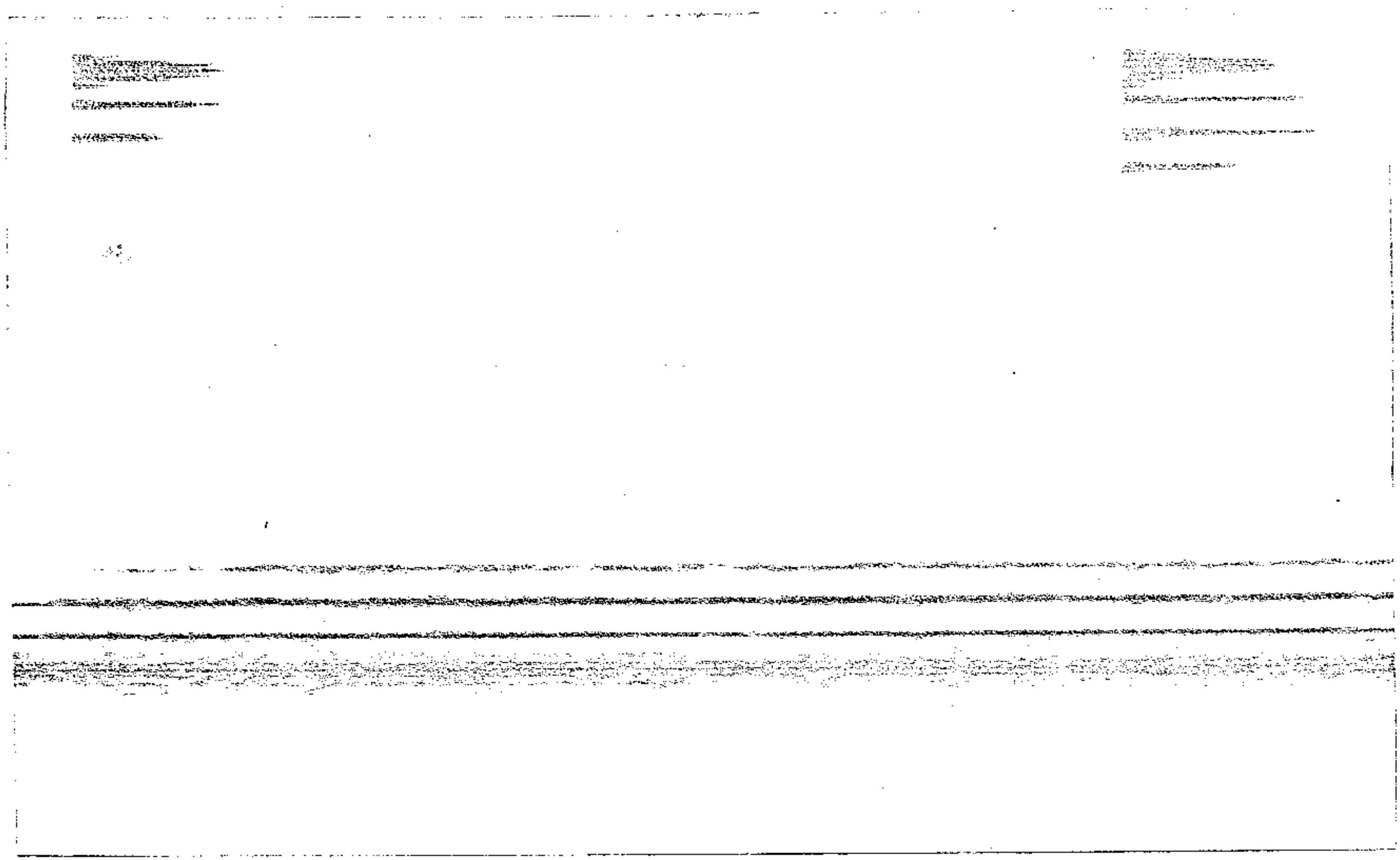
80 - 84 - S1G - ee - c - 10 3 1 - 7

Fig. 21--A spectrogram of the vowel $\overline{ee}$ (i) sung by senior high school female voices on the pitch c (approximately 523 Hz). Rank of 7.



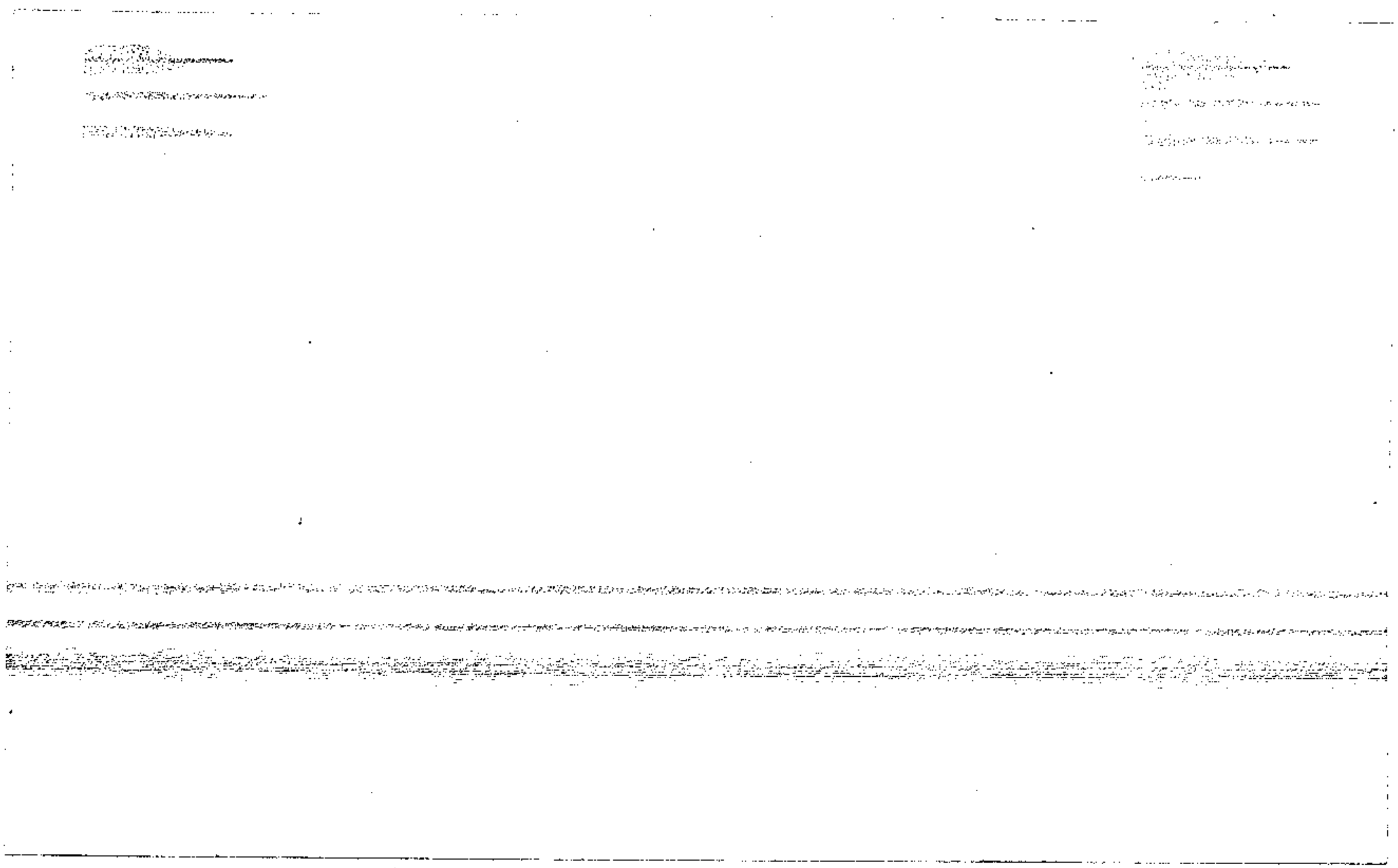
19 - 41 - J1G - ah - E - 9 5 0 - 11

Fig. 22--A spectrogram of the vowel ah (a) sung by junior high school female voices on the pitch E (approximately 330 Hz). Rank of 11.



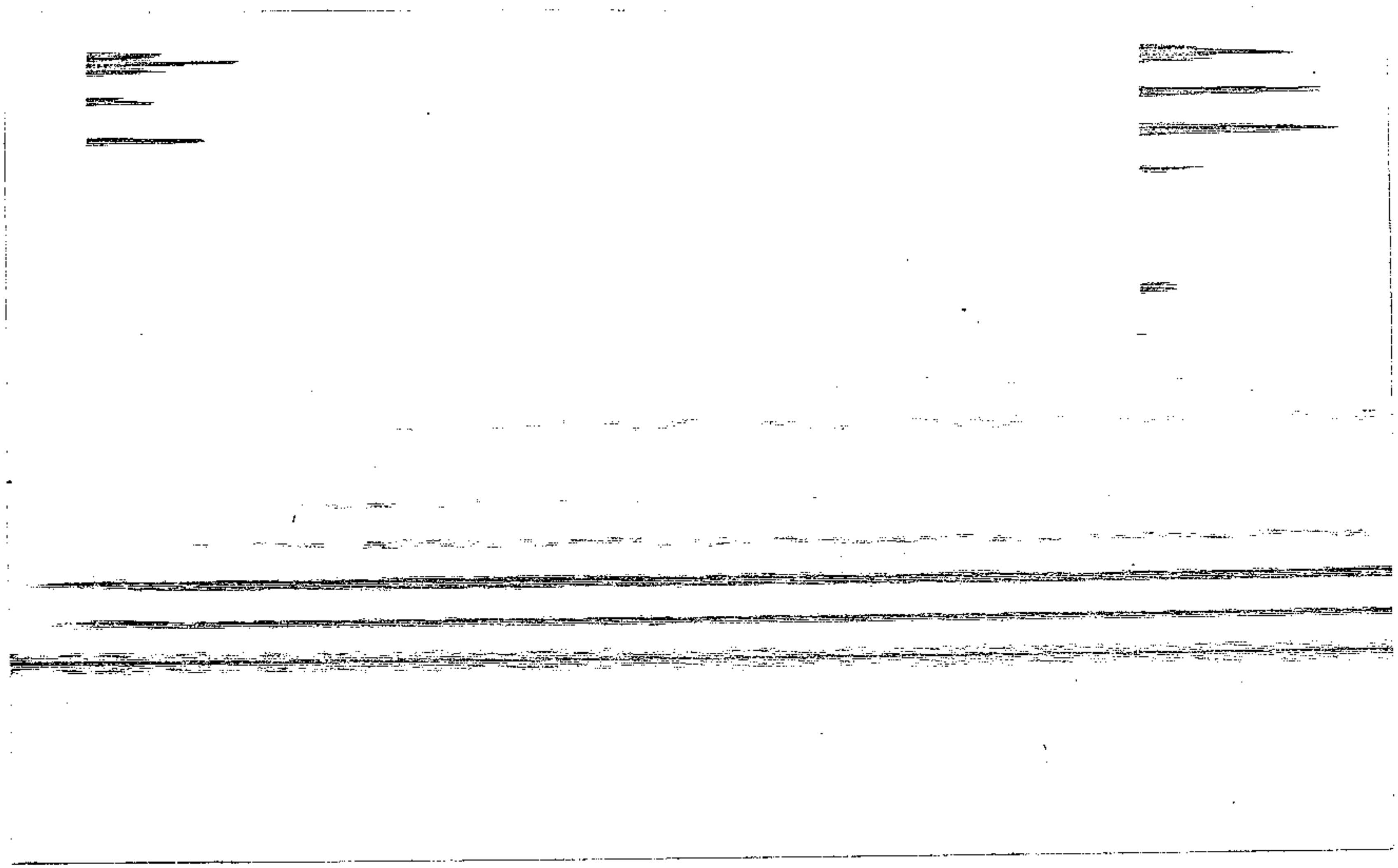
22 - 182 - J1G - ah - A - 9 5 0 - 11

Fig. 23--A spectrogram of the vowel ah (a) sung by junior high school female voices on the pitch A (approximately 440 Hz). Rank of 11.



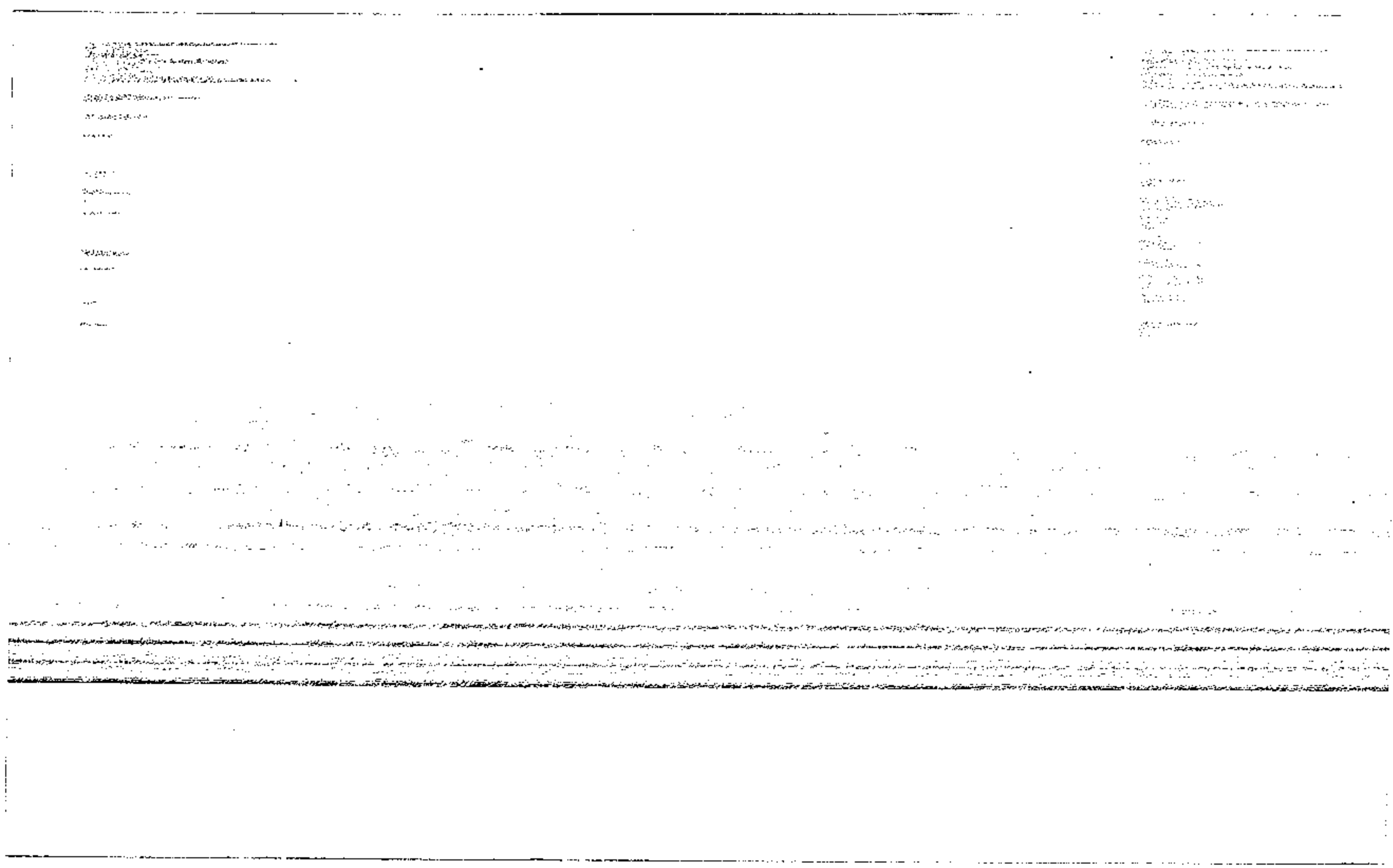
23 - 104 - J1G - ah - B - 9 5 0 - 11

Fig. 24--A spectrogram of the vowel ah (a) sung by junior high school female voices on the pitch B (approximately 494 Hz). Rank of 11.



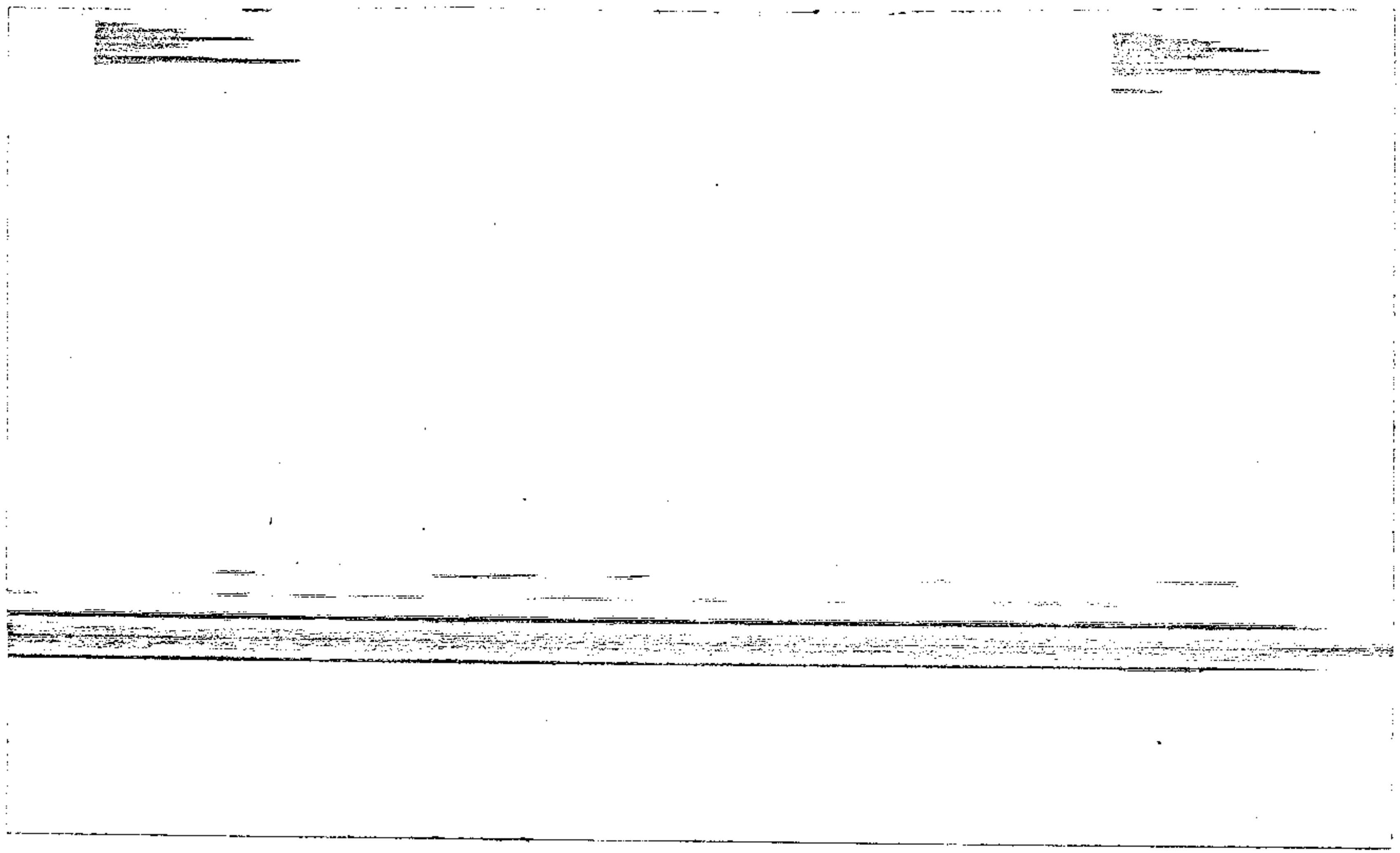
168 - 119 - C2G - ah - c - 9 5 0 - 11

Fig. 25--A spectrogram of the vowel ah (a) sung by college female voices on the pitch c (approximately 523 Hz). Rank of 11.



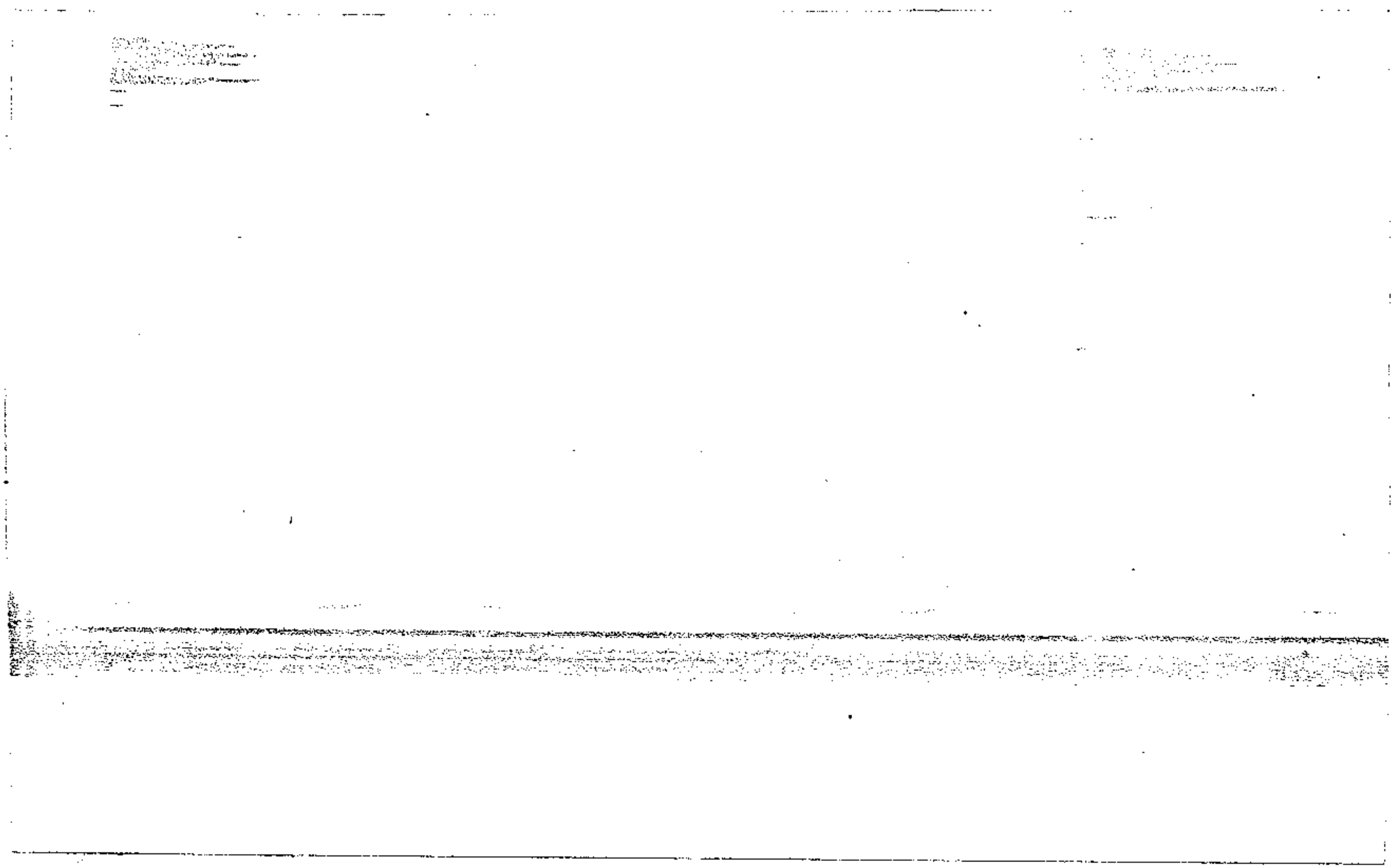
176 - 97 - C2B - ee - c - 9 5 0 - 11

Fig. 26--A spectrogram of the vowel $\overline{\text{ee}}$ (i) sung by college male voices on the pitch c (approximately 261.5 Hz). Rank of 11.



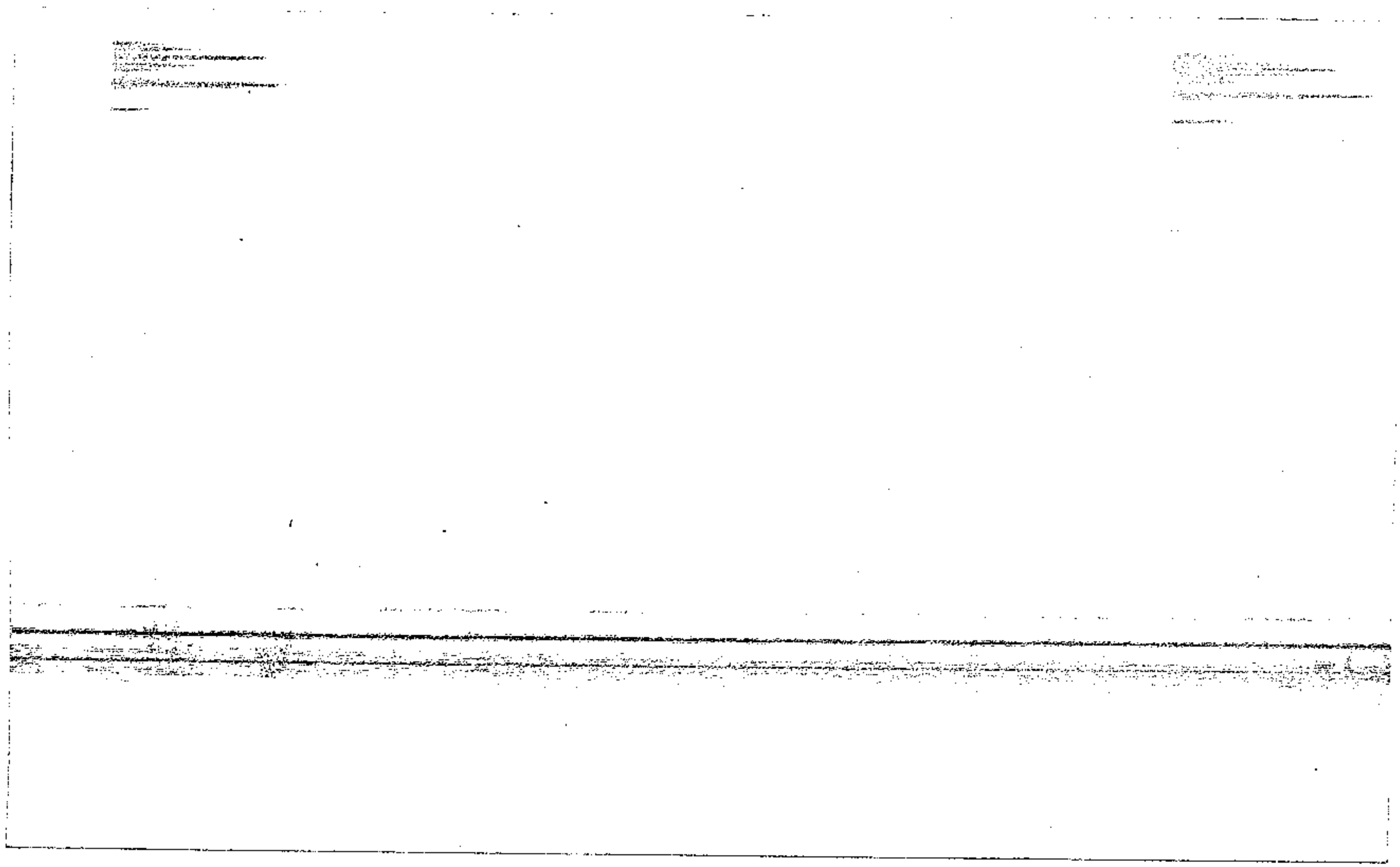
74 - 18 - S2G - ee - D - 9 4 1 - 14.5

Fig. 27--A spectrogram of the vowel $\overline{ee}$ (i) sung by senior high school female voices on the pitch D (approximately 294 Hz). Rank of 14.5.



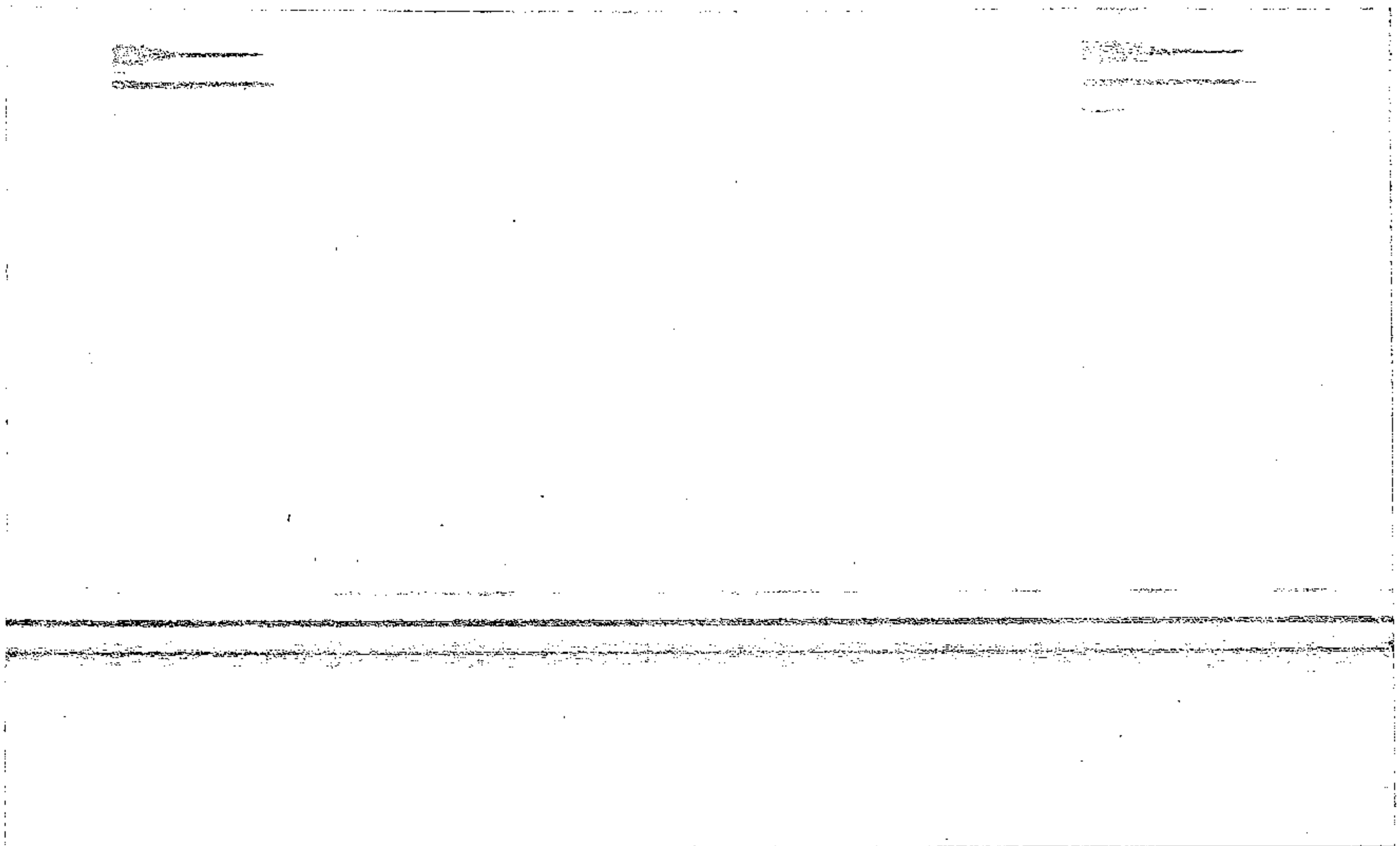
76 - 39 - S2G - ee - F - 9 4 1 - 14.5

Fig. 28--A spectrogram of the vowel $\overline{ee}$ (i) sung by senior high school female voices on the pitch F (approximately 349 Hz). Rank of 14.5.



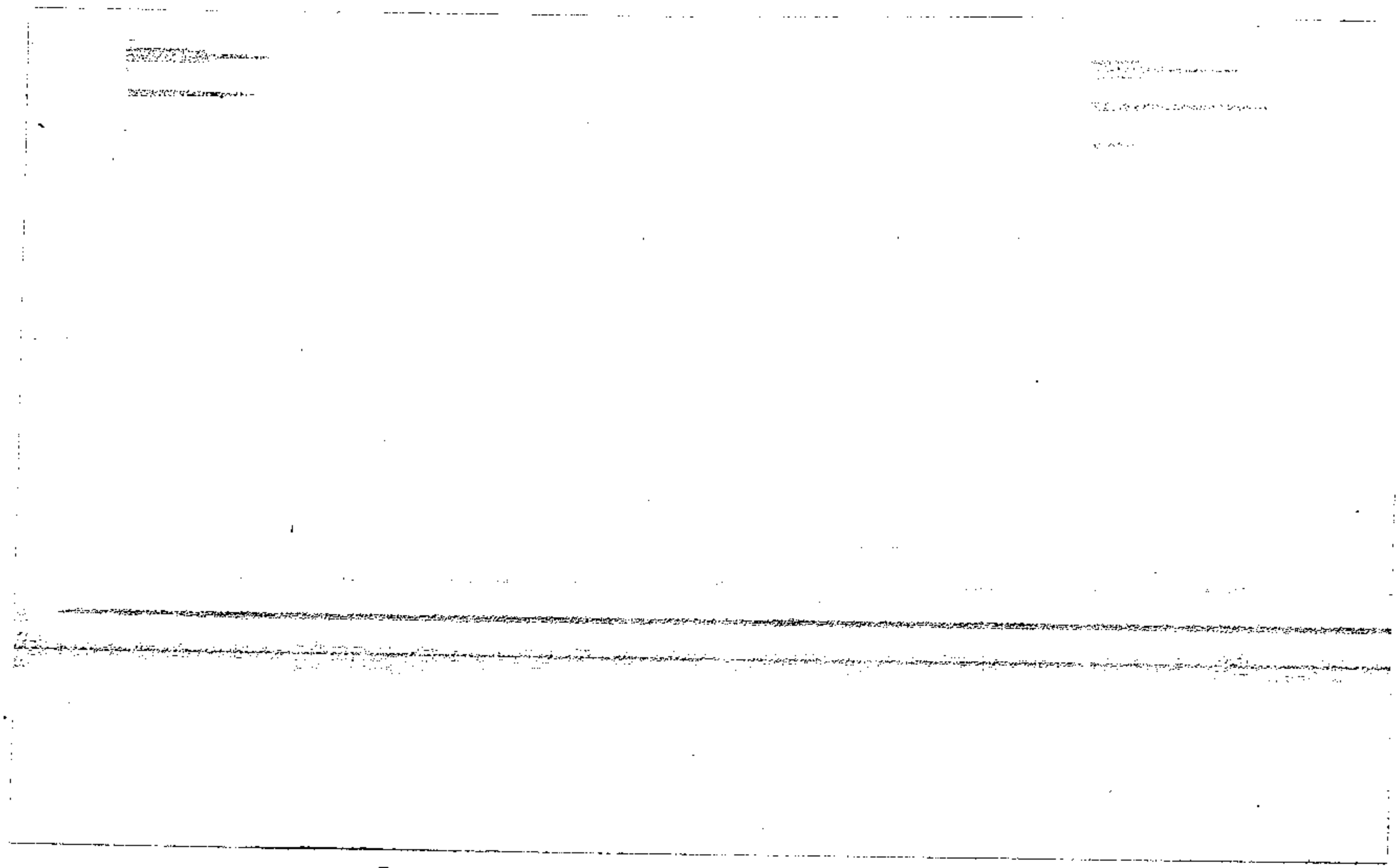
4 - 58 - J1G - ee - F - 9 3 2 - 18

Fig. 29--A spectrogram of the vowel $\overline{ee}$ (i) sung by junior high school female voices on the pitch F (approximately 349 Hz). Rank of 18.



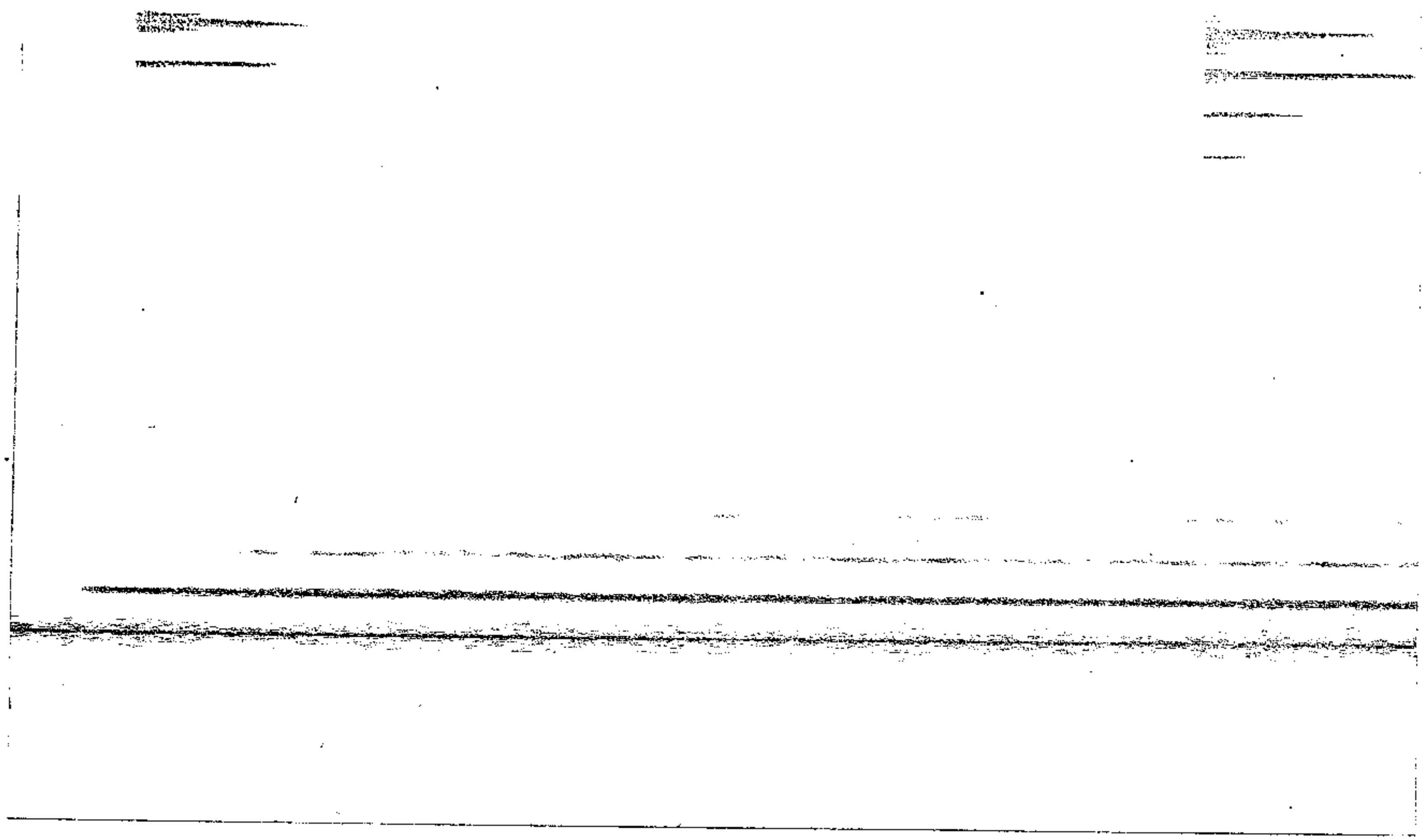
5 - 33 - J1G - ee - G - 9 3 2 - 18

Fig. 30--A spectrogram of the vowel $\overline{ee}$ (i) sung by junior high school female voices on the pitch G (approximately 392 Hz). Rank of 18.



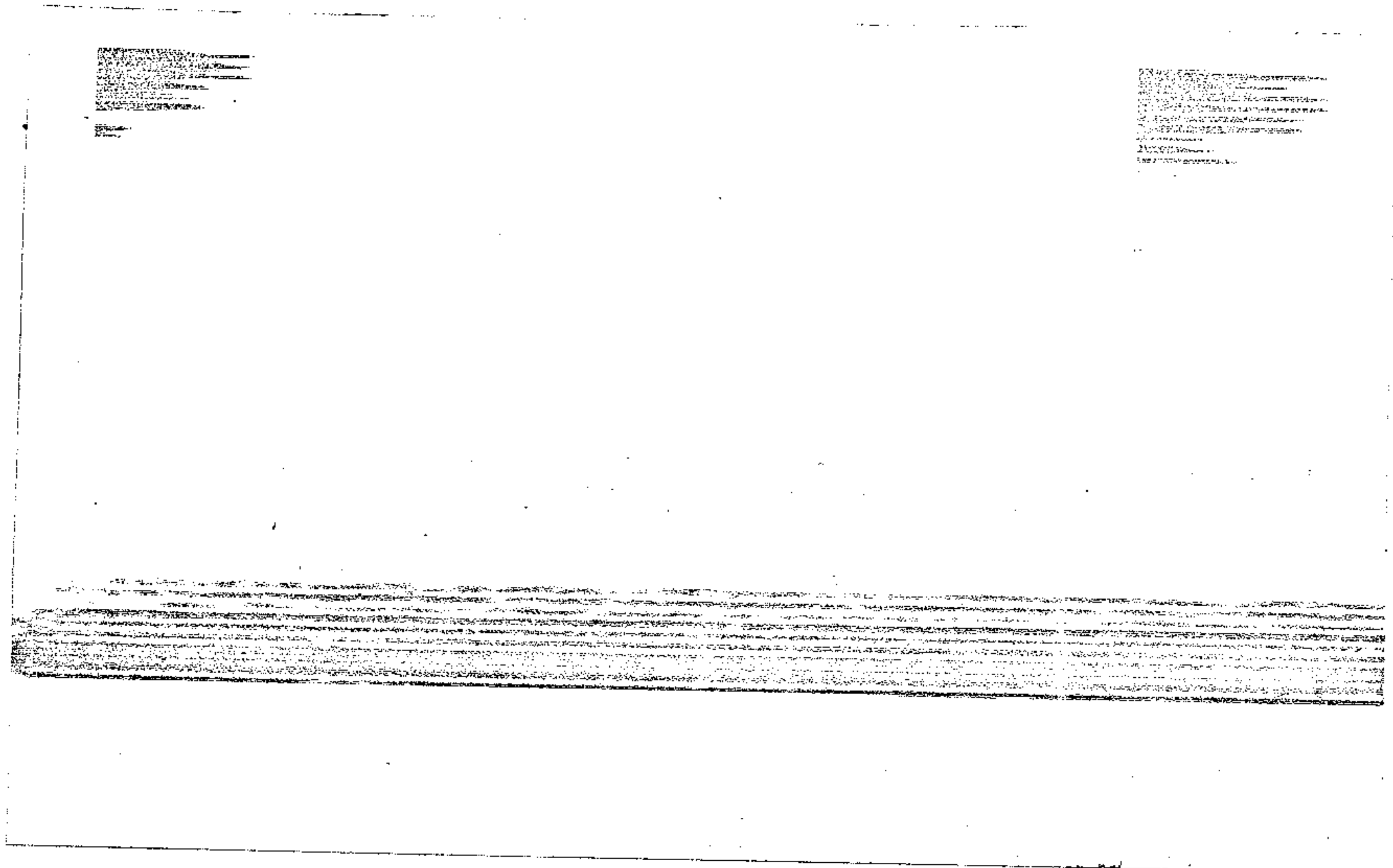
7 - 95 - J1G - ee(eh) - B - 6(3) 3 2 - 18

Fig. 31--A spectrogram of the vowel $\overline{ee}$ (i) sung by junior high school female voices on the pitch B (approximately 494 Hz). Rank of 18.



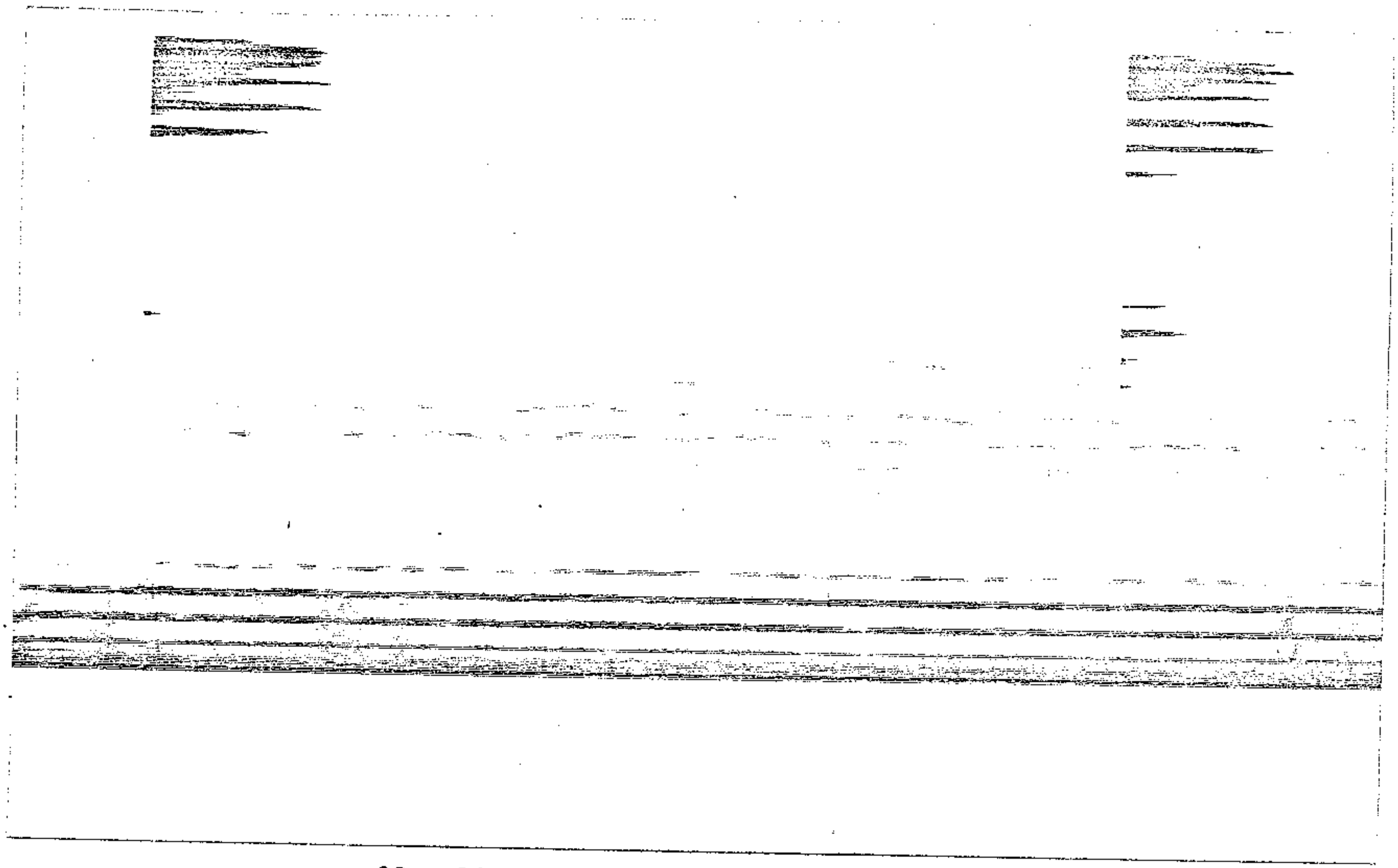
8 - 197 - J1G - ee(eh) - c - 9 3 1(1) - 18

Fig. 32--A spectrogram of the vowel ee (i) sung by junior high school female voices on the pitch c (approximately 523 Hz). Rank of 18.



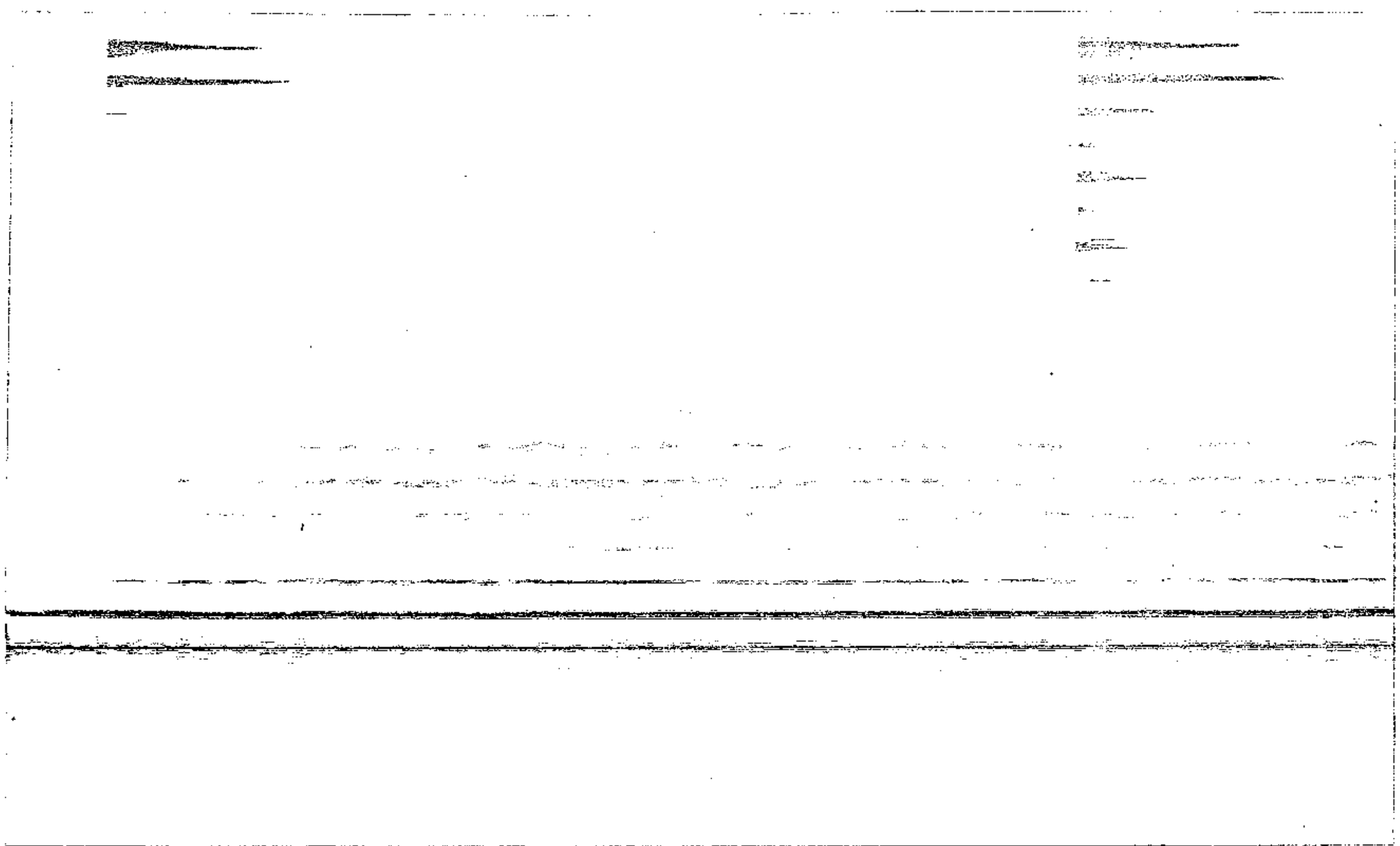
114 - 150 - S2B - ah - D - 9 3 2 - 18

Fig. 33--A spectrogram of the vowel ah(a) sung by senior high school male voices on the pitch D (approximately 147 Hz). Rank of 18.



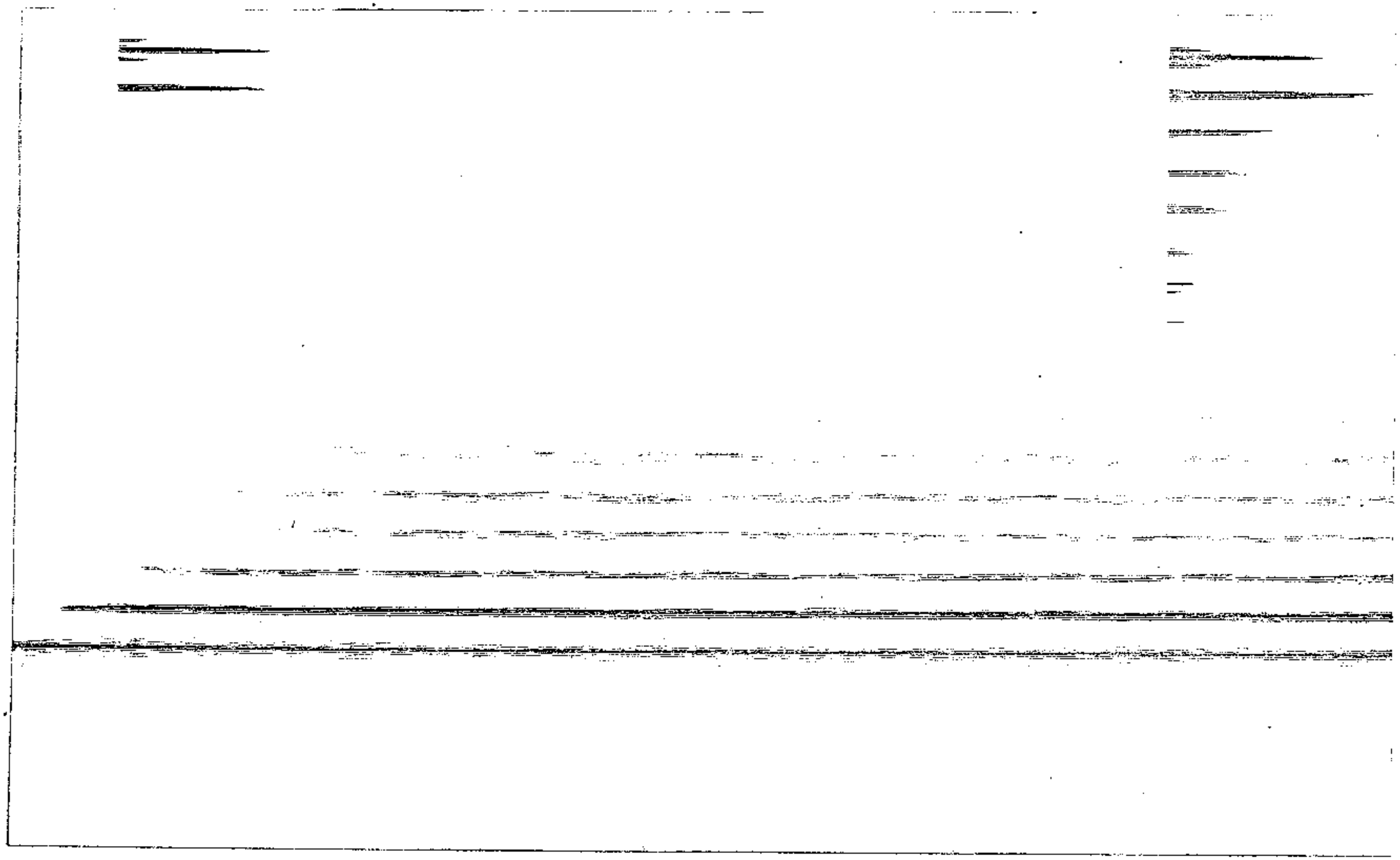
92 - 10 - S2G - ah - F - 8 6 0 - 23

Fig. 34--A spectrogram of the vowel ah (a) sung by senior high school female voices on the pitch F (approximately 349 Hz). Rank of 23.



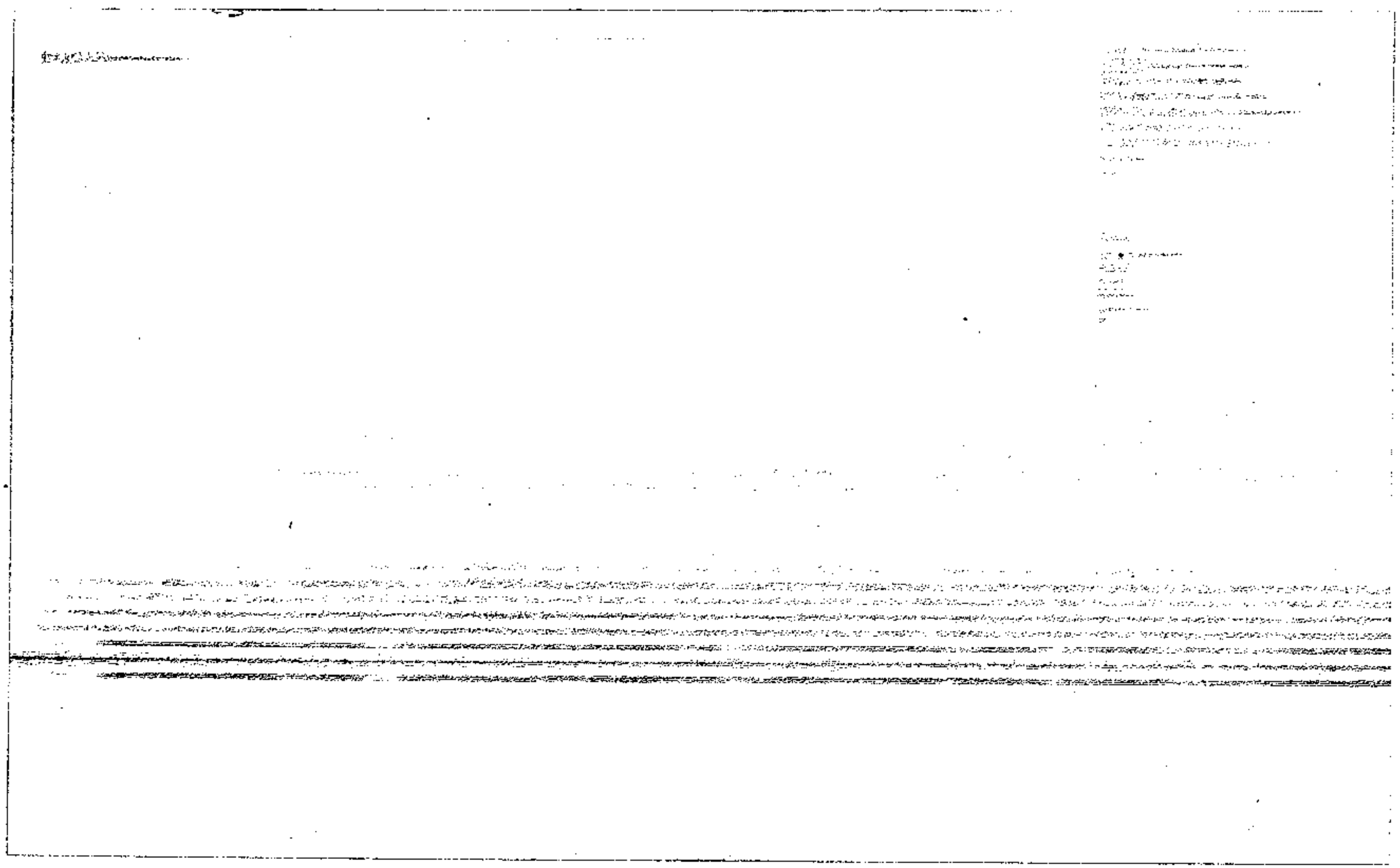
150 - 26 - C2G - ee - A - 8 6 0 - 23

Fig. 35--A spectrogram of the vowel $\overline{ee}$ (i) sung by college female voices on the pitch A (approximately 440 Hz). Rank of 23.



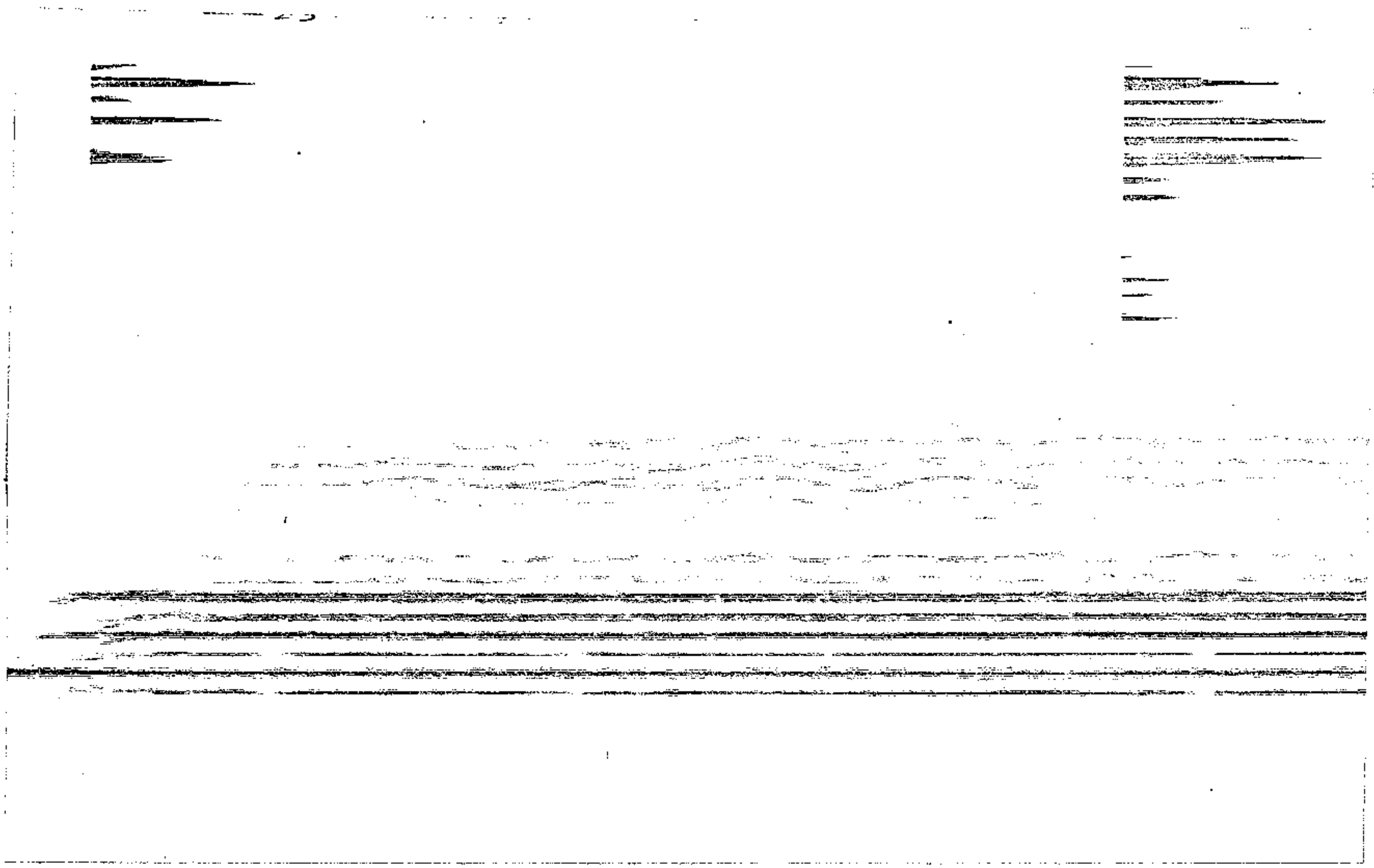
152 - 118 - C2G - ee(eh) - c - 7(1) 6 0 - 23

Fig. 36--A spectrogram of the vowel $\overline{ee}$ (i) sung by college female voices on the pitch c (approximately 523 Hz). Rank of 23.



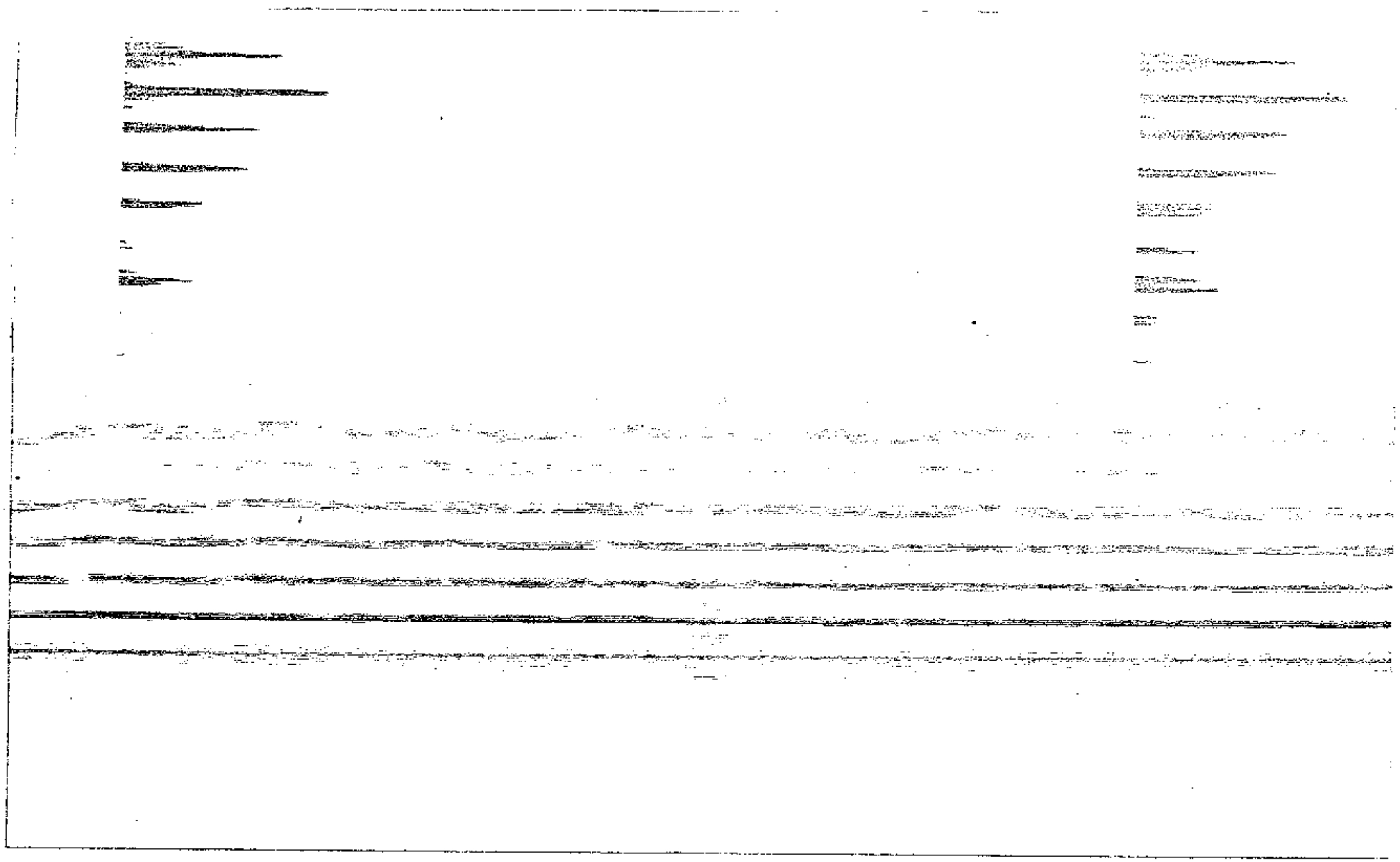
190 - 100 - C2B - ah - A - 8 6 0 - 23

Fig. 37--A spectrogram of the vowel ah (a) sung by college male voices on the pitch of A (approximately 220 Hz). Rank of 23.



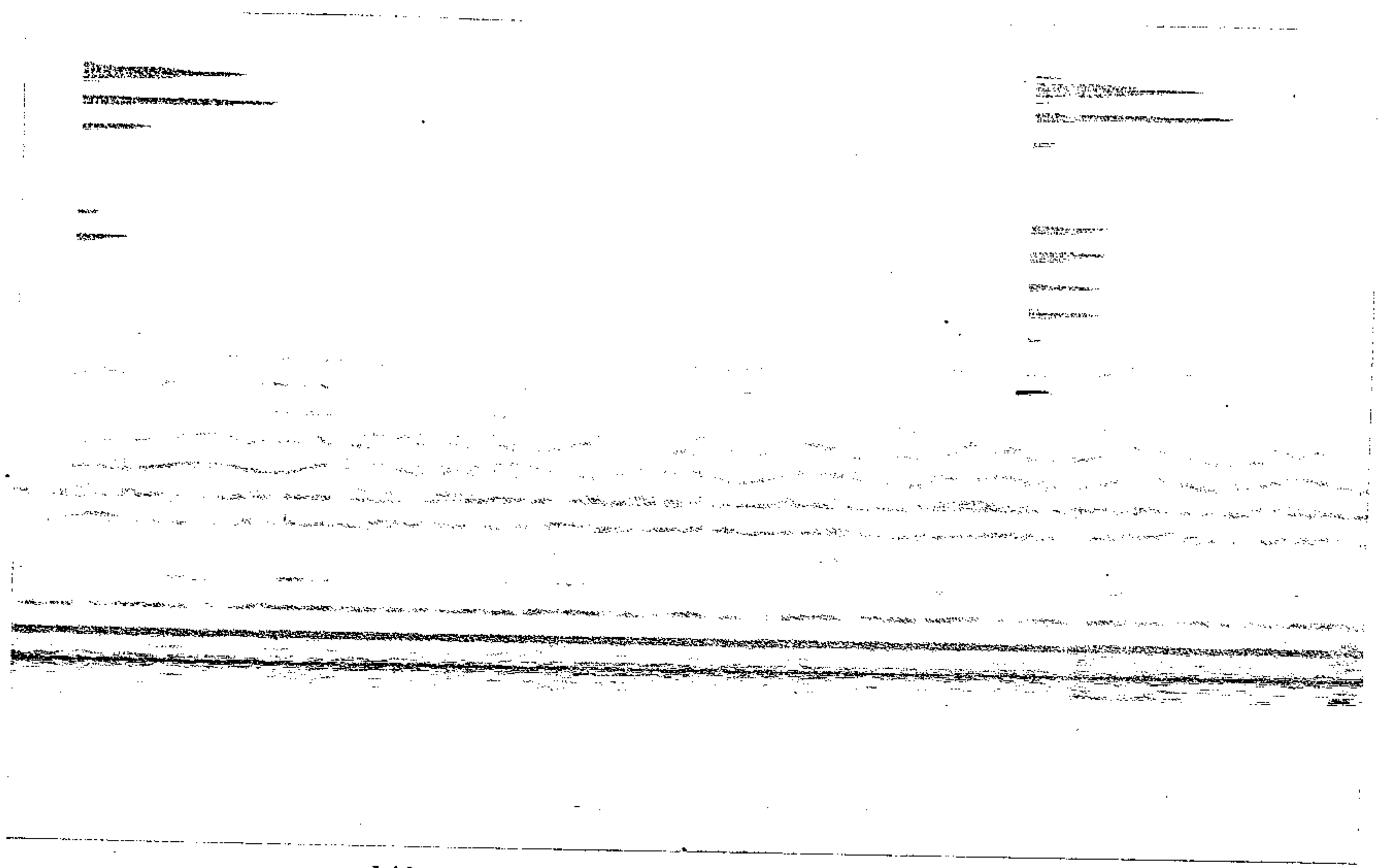
216 - 130 - ClM - ah - c - 8 6 0 - 23

Fig. 38--A spectrogram of the vowel ah (a) sung by college male and female voices combined on the pitch coded c (approximately 261.5 and 523 Hz). Rank of 23.



159 - 21 - C2G - eh - B - 8 5 1 - 26

Fig. 39--A spectrogram of the vowel eh (ε) sung by college female voices on the pitch B (approximately 494 Hz). Rank of 26.



149 - 192 - C1G - ee - G - 8 3 3 - 27

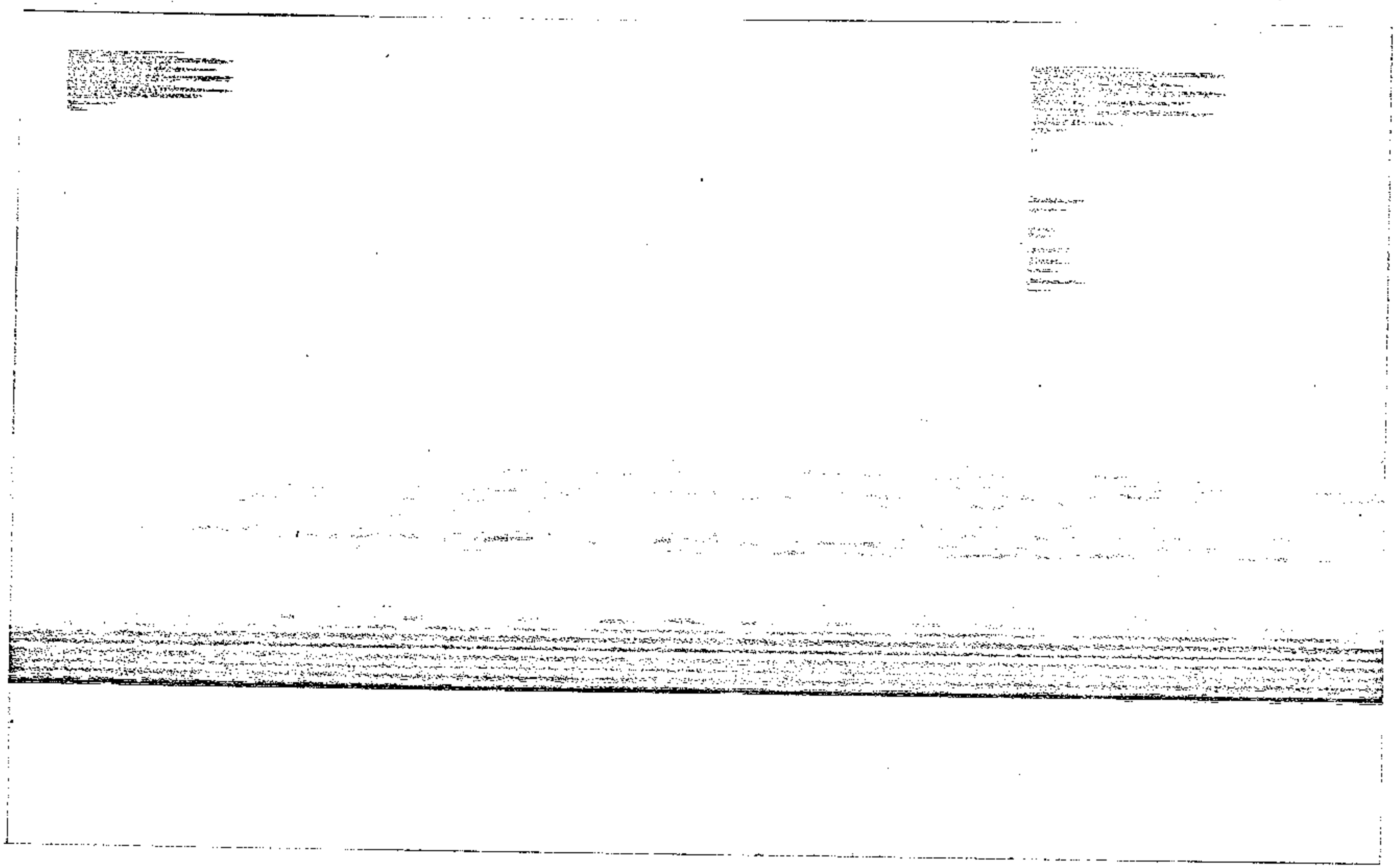
Fig. 40--A spectrogram of the vowel $\overline{ee}$ (i) sung by college female voices on the pitch G (approximately 392 Hz). Rank of 27.

APPENDIX D

This appendix contains sound spectrograms of the examples categorized as "Poor" by the panel of experts. The spectrograms are arranged in rank order according to the ratings of the panel. Of the 216 examples in the sample, 28 were considered in the "Poor" category, with ranks from 191 to 215.5.

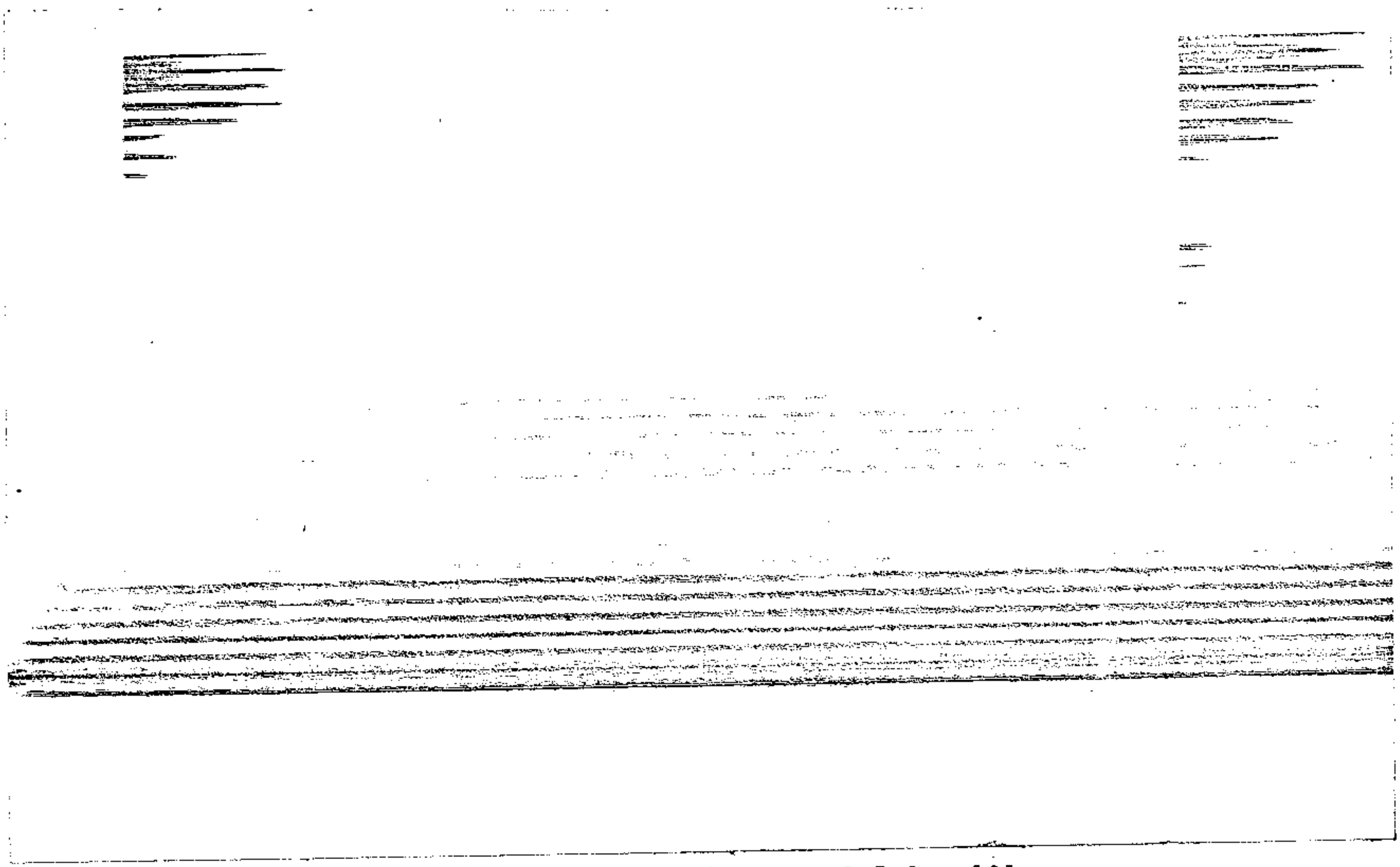
Each spectrogram exhibits two types of spectrographic display. The Type 1 display shows pitch frequency vertically, time duration horizontally, and intensity as shading between gray and black. The Type 2 display is a cross-section showing frequency vertically and intensity horizontally. The frequency scale of the cross-section is inverted on the spectrogram. The cross-sections were made approximately at the attack and 1.2 seconds later. The cross-section is shown on the spectrogram at the exact time spot which coincides with the Type 1 display.

Each spectrogram is identified by vowel sound, educational level, voice combination, pitch frequency, and rank.



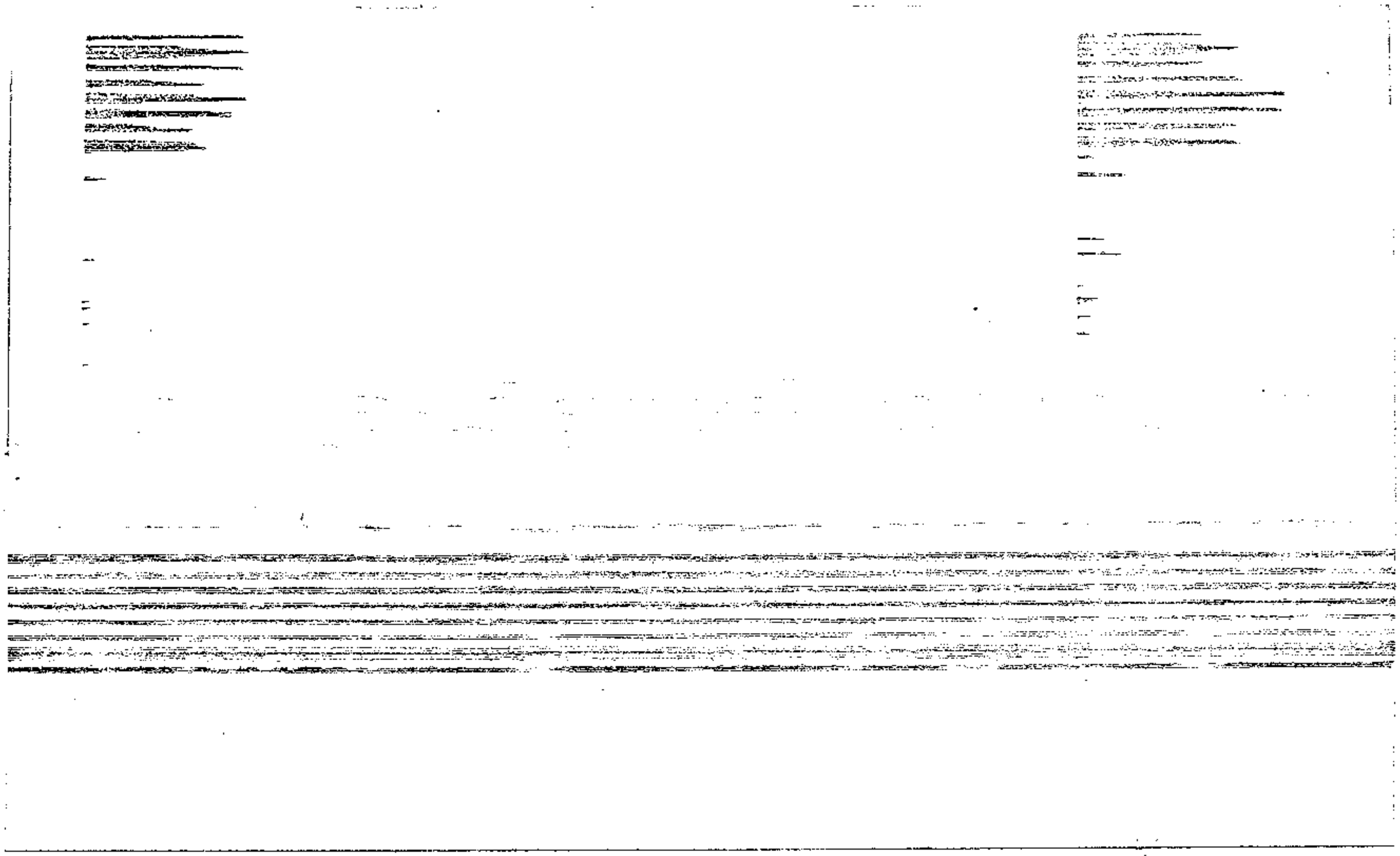
25 - 184 - J1B - ee - C - 0 5 9 - 191

Fig. 41--A spectrogram of the vowel $\overline{\text{ee}}$ (i) sung by junior high school male voices on the pitch C (approximately 131 Hz). Rank of 191.



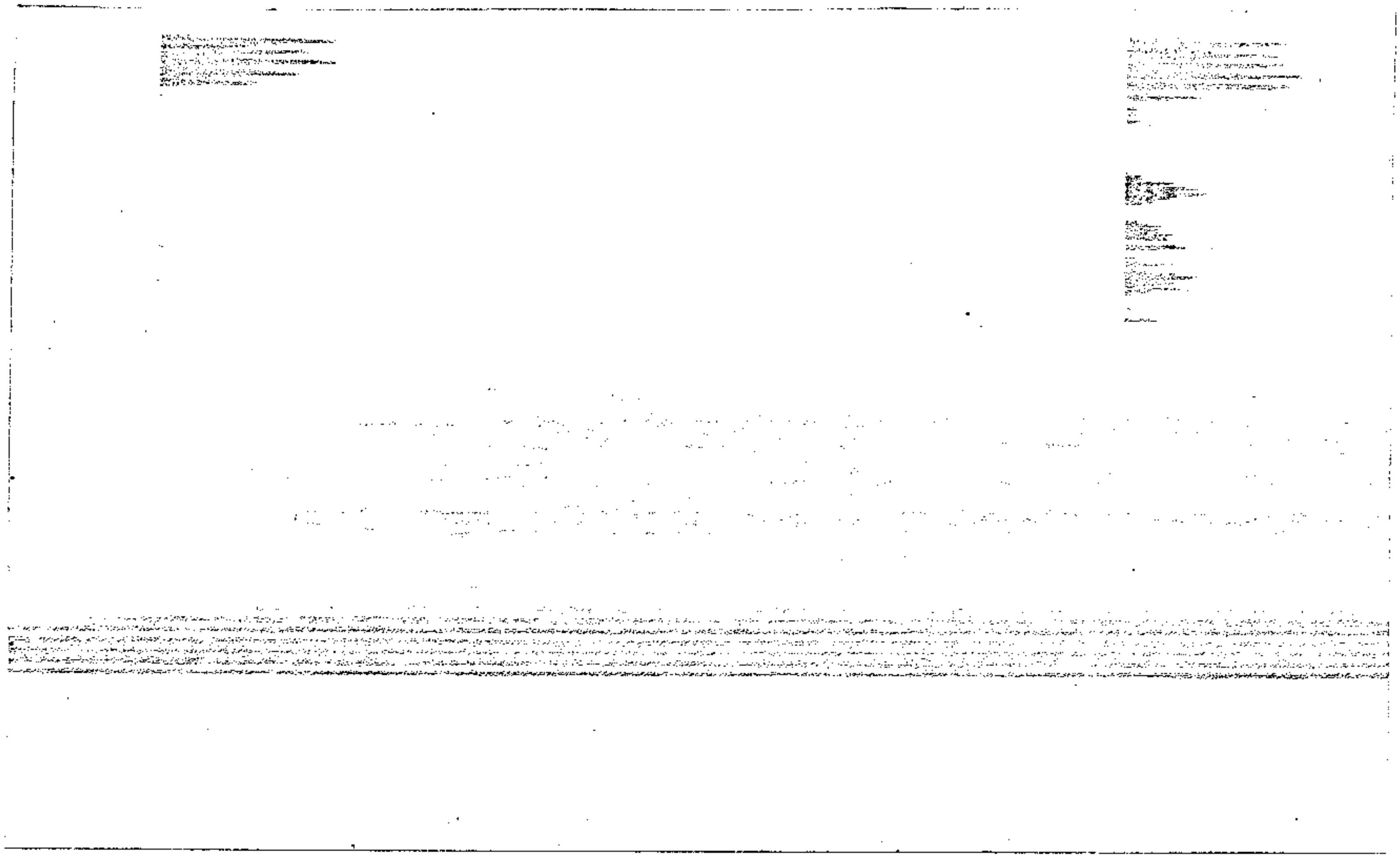
119 - 162 - S1B - ah - B - 0 5 9 - 191

Fig. 42--A spectrogram of the vowel ah (a) sung by senior high school male voices on the pitch B (approximately 247 Hz). Rank of 191.



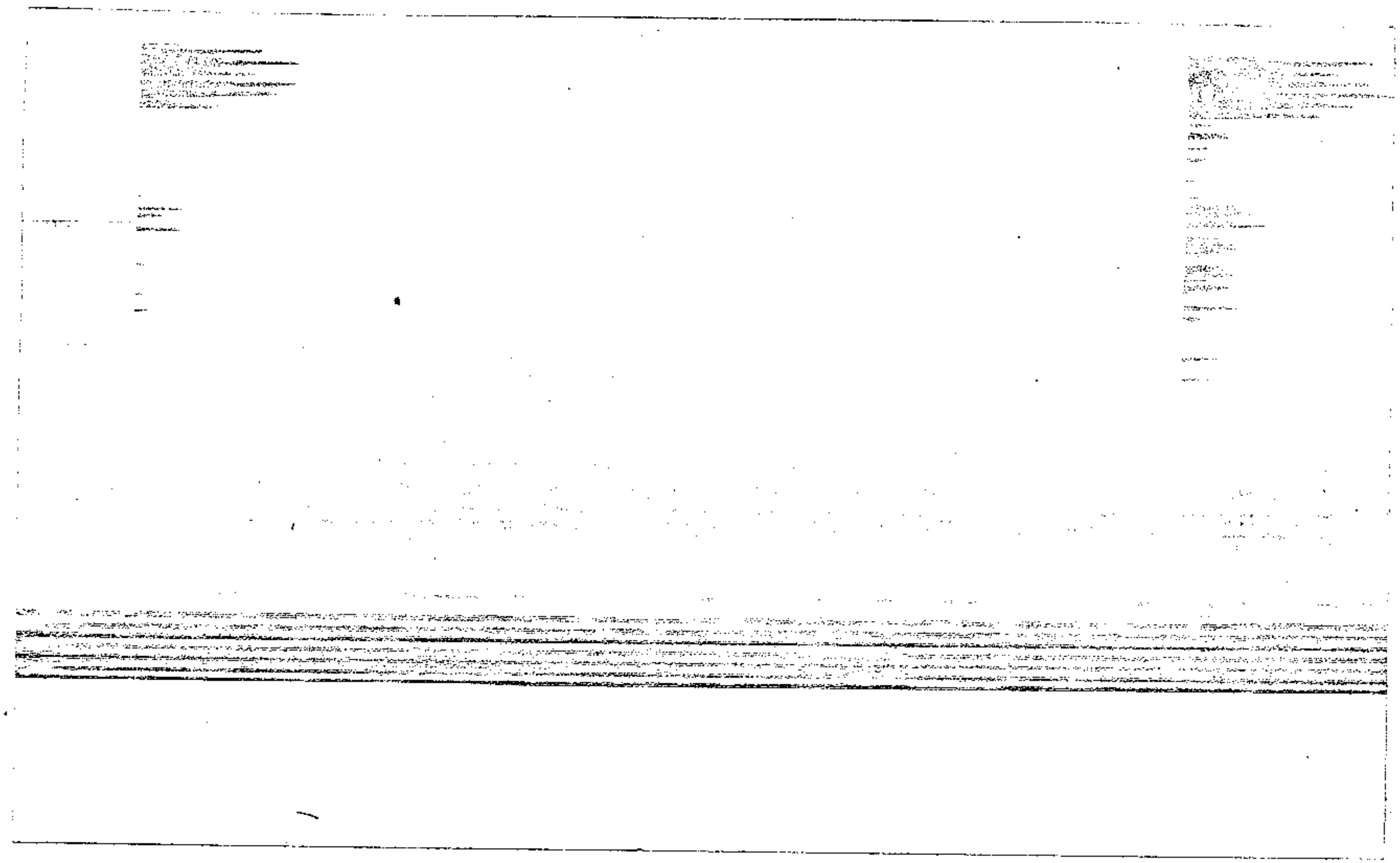
142 - 9 - SlM - ah - A - 0 5 9 - 191

Fig. 43--A spectrogram of the vowel ah (a) sung by senior high school male voices on the pitch A (approximately 220 Hz). Rank of 191.



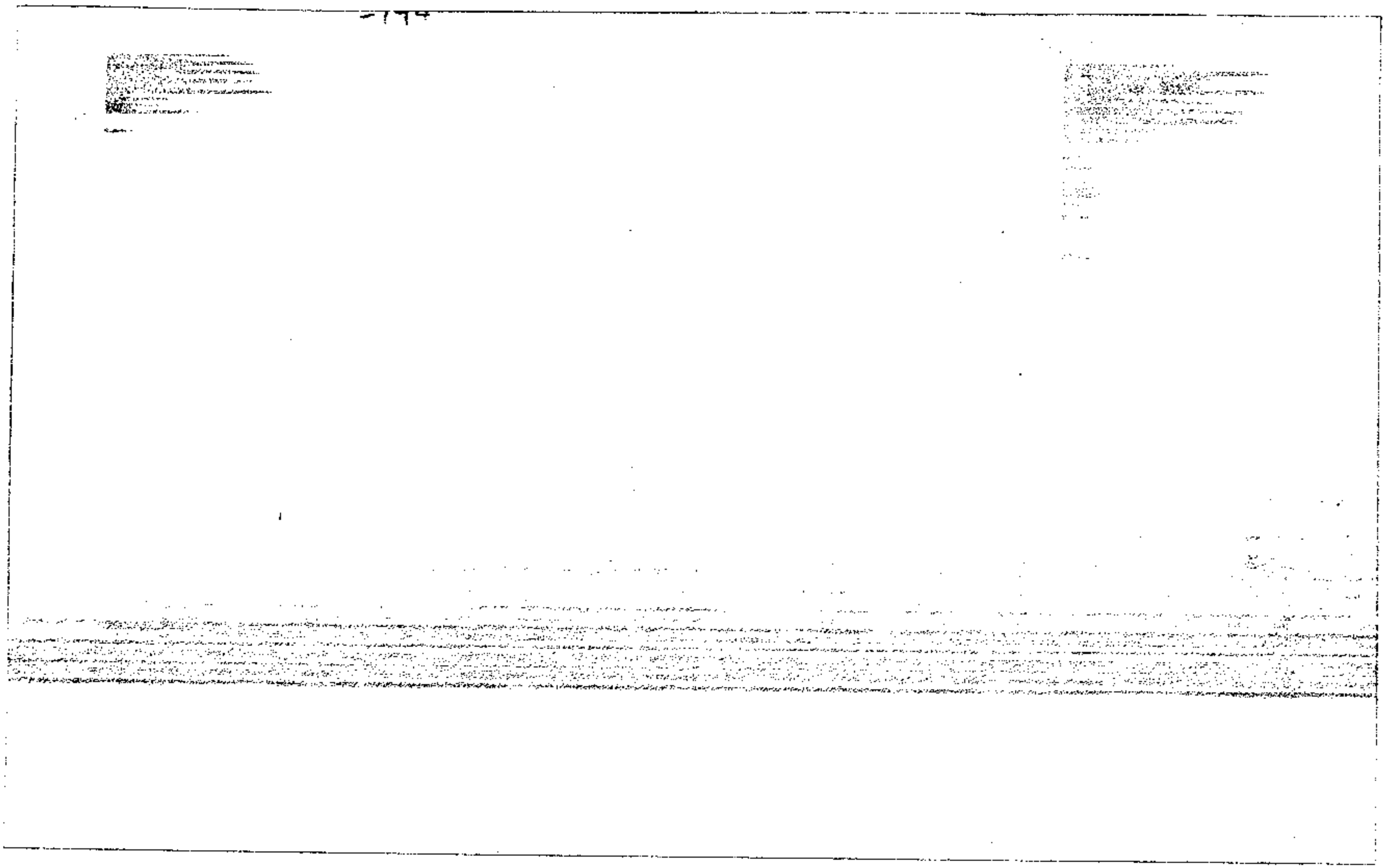
170 - 114 - C2B - ee - D - 0 5 9 - 191

Fig. 44--A spectrogram of the vowel ee (i) sung by college male voices on the pitch D (approximately 147 Hz). Rank of 191.



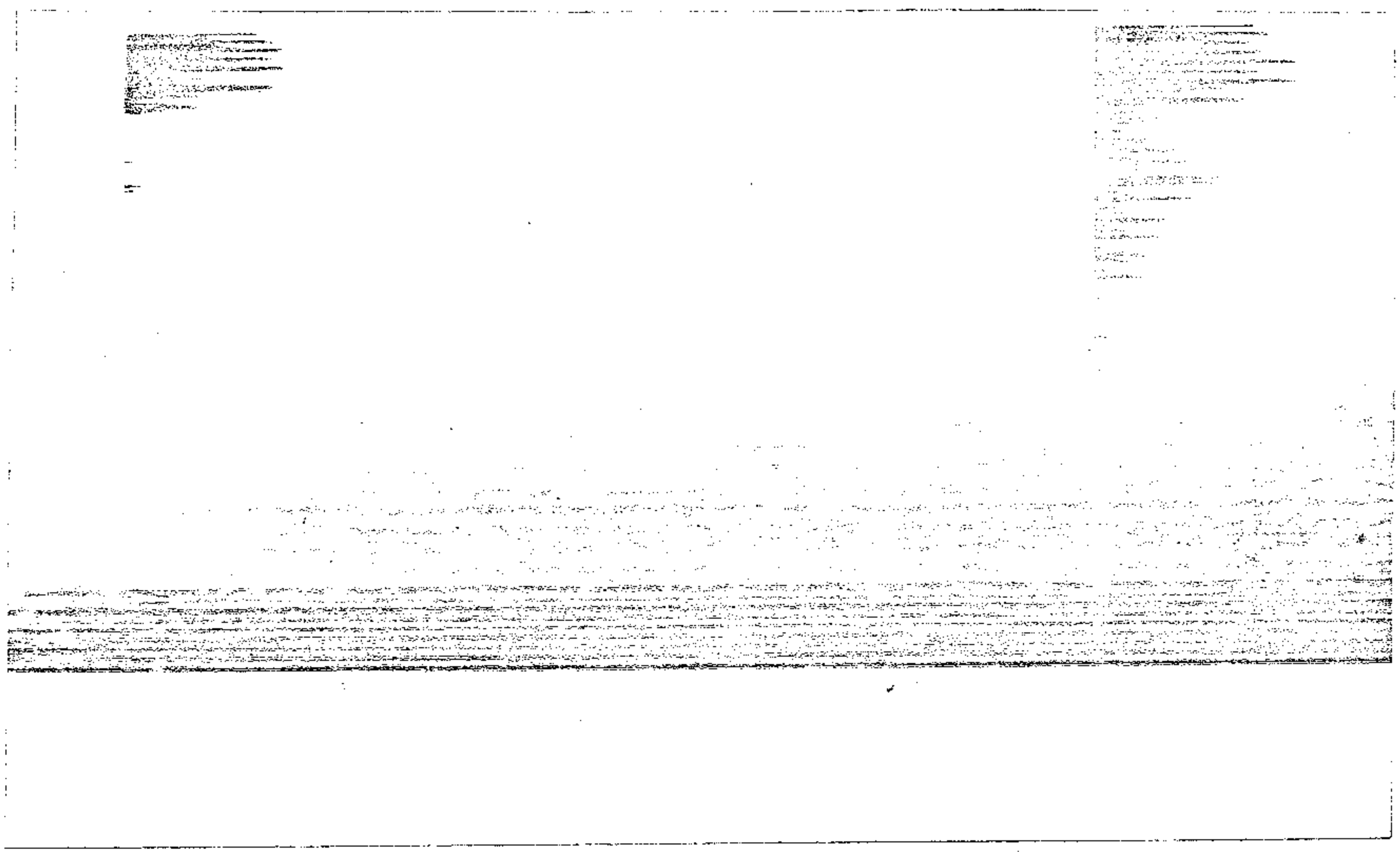
194 - 50 - ClM - ee - D - 0 5 9 - 191

Fig. 45--A spectrogram of the vowel $\overline{ee}$ (i) sung by college male and female voices combined on the pitch coded D (approximately 147 and 294 Hz). Rank of 191.



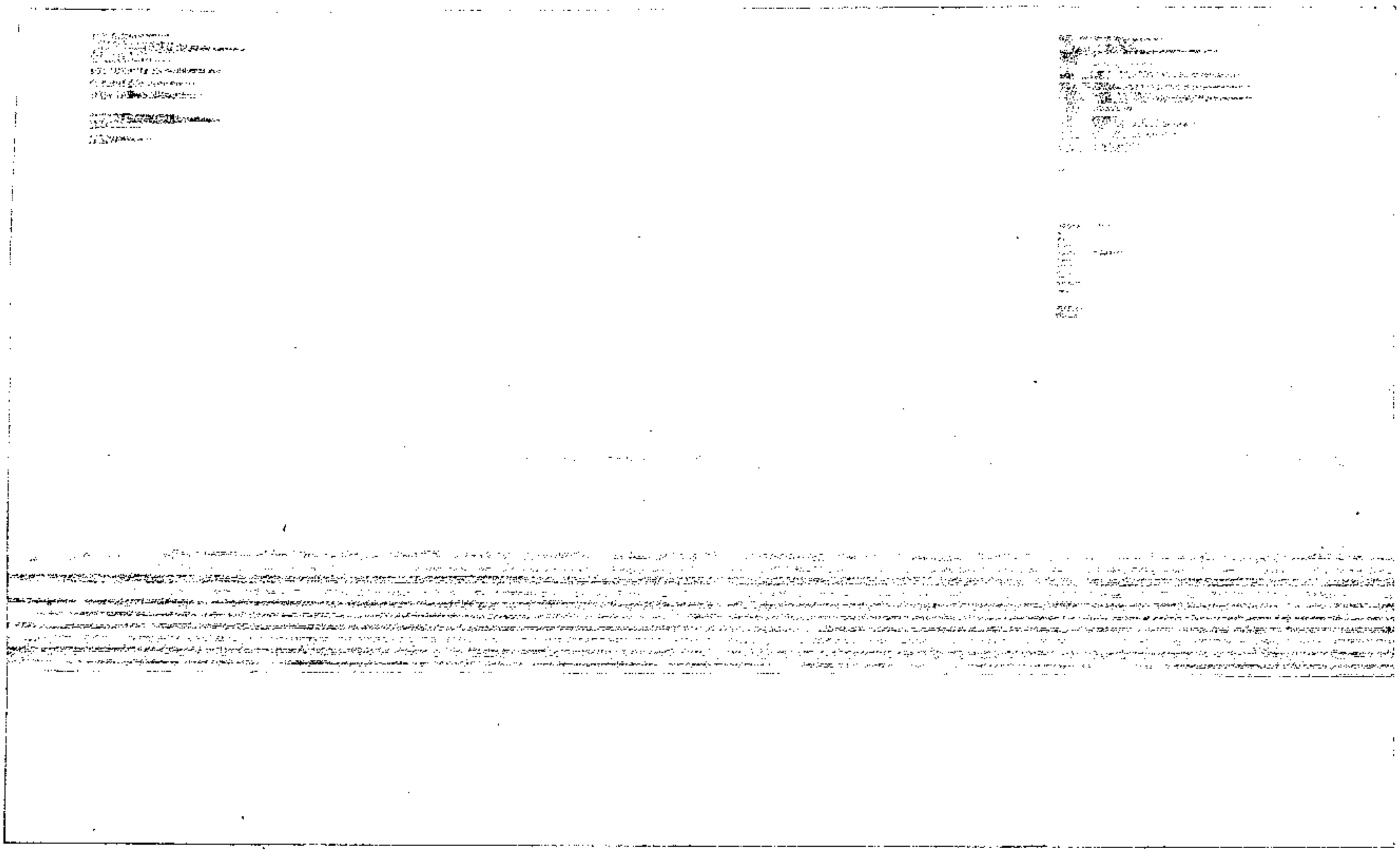
57 - 80 - J1M - eh - C - 2 2 10 - 194

Fig. 46--A spectrogram of the vowel eh (ε) sung by junior high school male and female voices combined on the pitches coded C (approximately 131 and 261.5 Hz). Rank of 194.



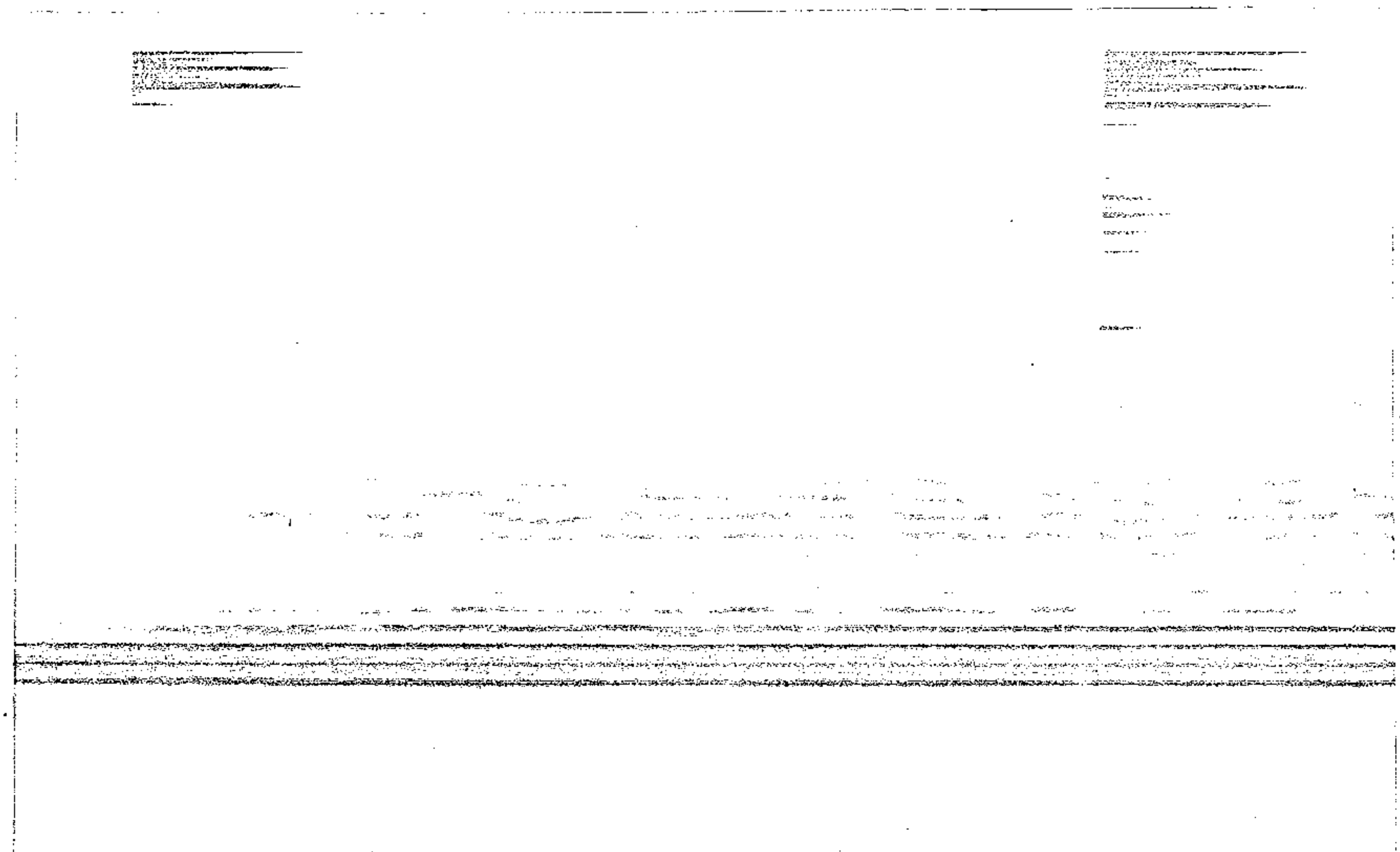
201 - 36 - ClM - eh - C - 1 3 10 - 195.5

Fig. 47--A spectrogram of the vowel eh (ε) sung by college male and female voices combined on the pitches coded as C (approximately 131 and 261.5 Hz). Rank of 195.5.



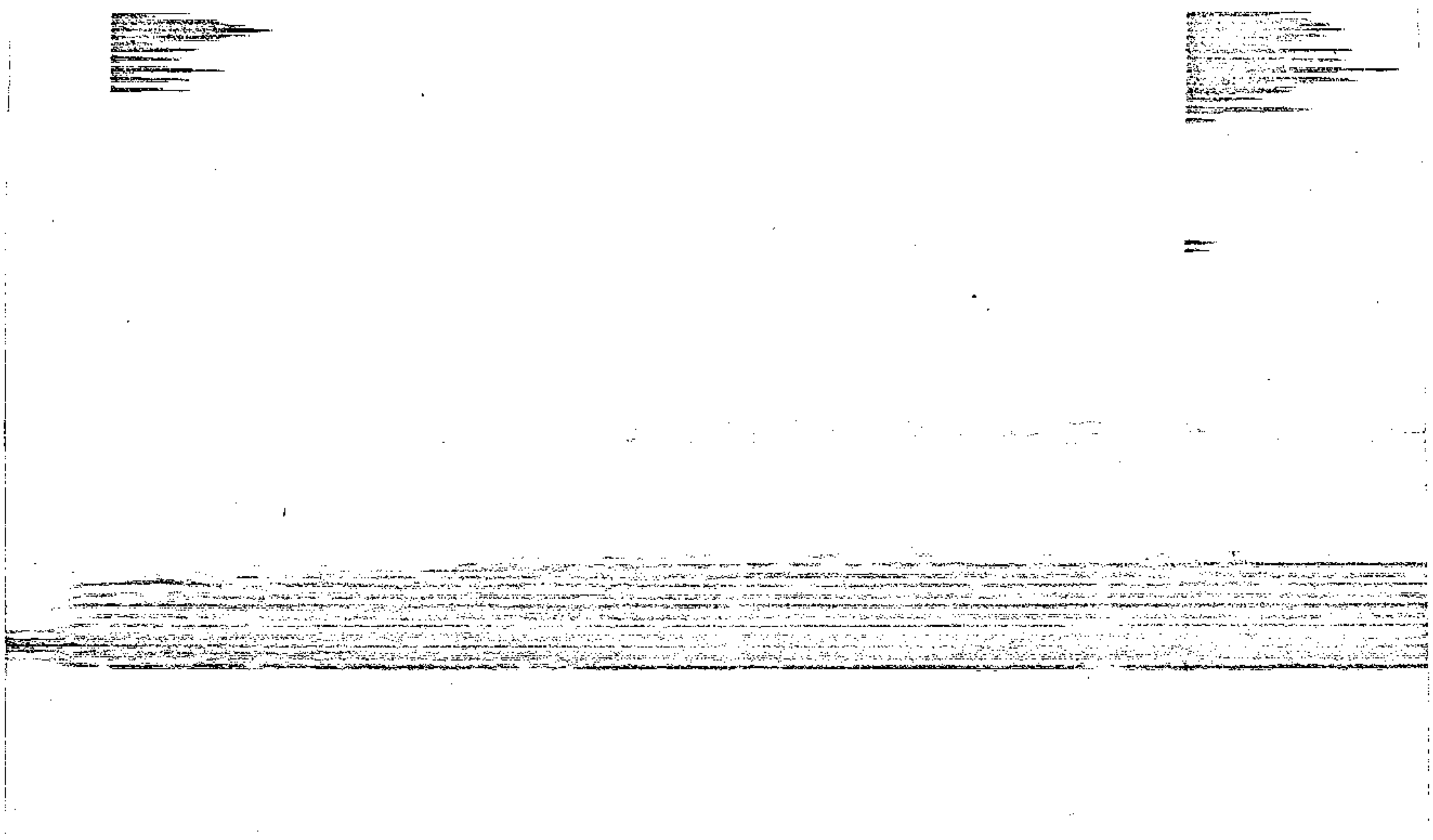
211 - 92 - C2M - ah - E - 1 3 10 - 195.5

Fig. 48--A spectrogram of the vowel ah (a) sung by college male and female voices combined on the pitches coded as E (approximately 165 and 330 Hz). Rank of 195.5.



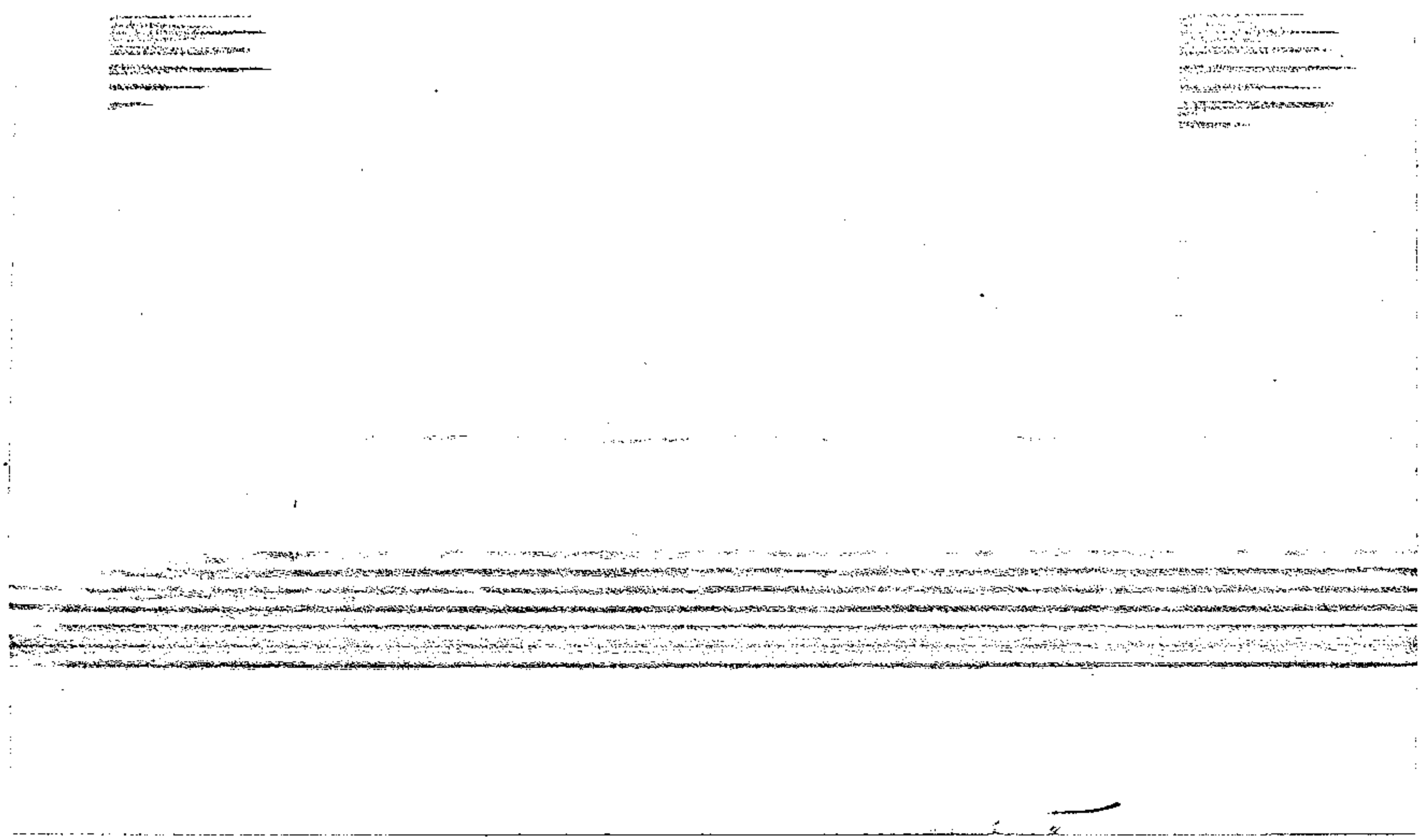
31 - 154 - J1B - ee - B - 0 4 10 - 198.5

Fig. 49--A spectrogram of the vowel $\overline{ee}$ (i) sung by junior high school male voices on the pitch B (approximately 247 Hz). Rank of 198.5.



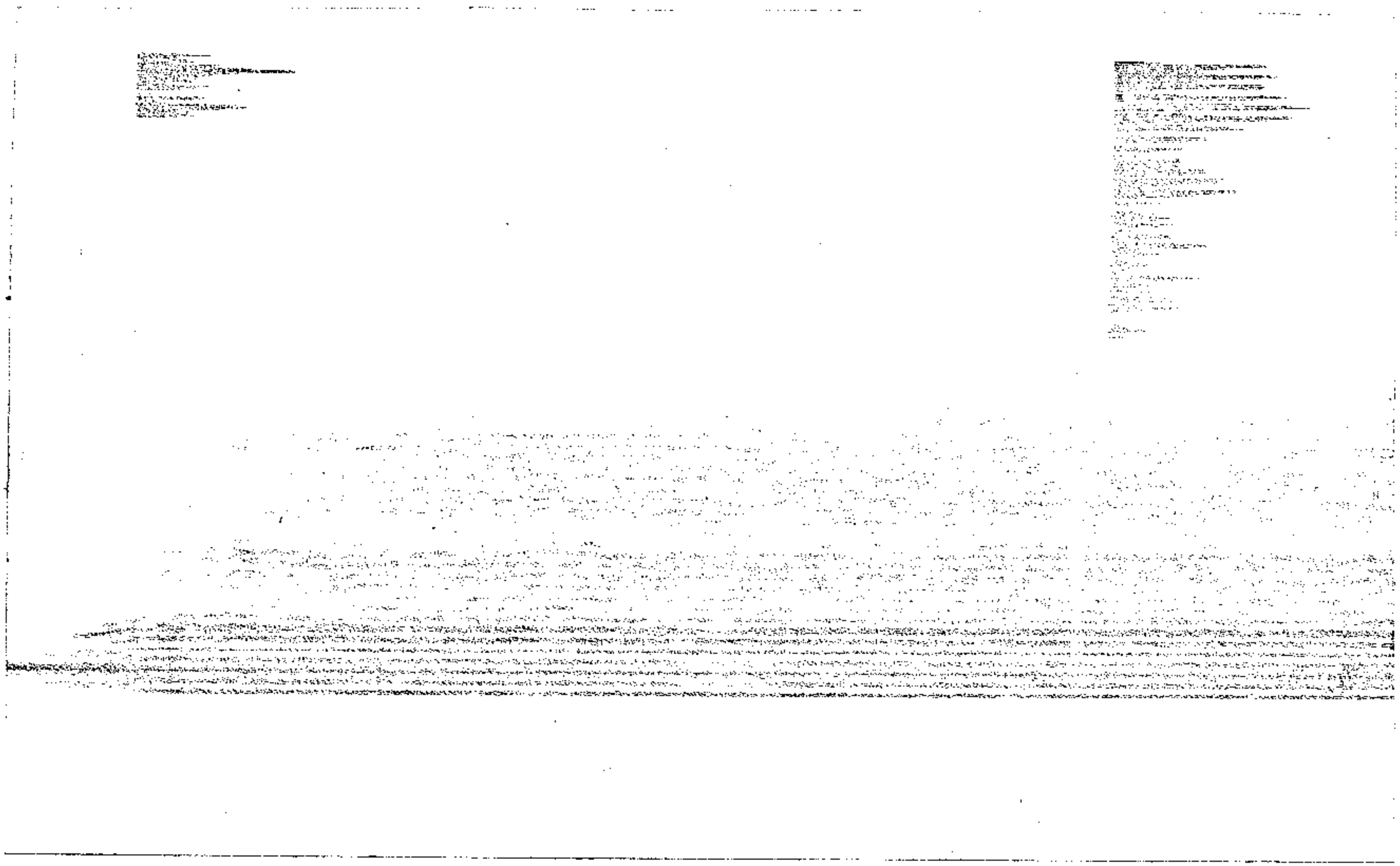
41 - 131 - J1B - ah - C - 0 4 10 - 198.5

Fig. 50--A spectrogram of the vowel ah (a) sung by junior high school male voices on the pitch C (approximately 131 Hz). Rank of 198.5.



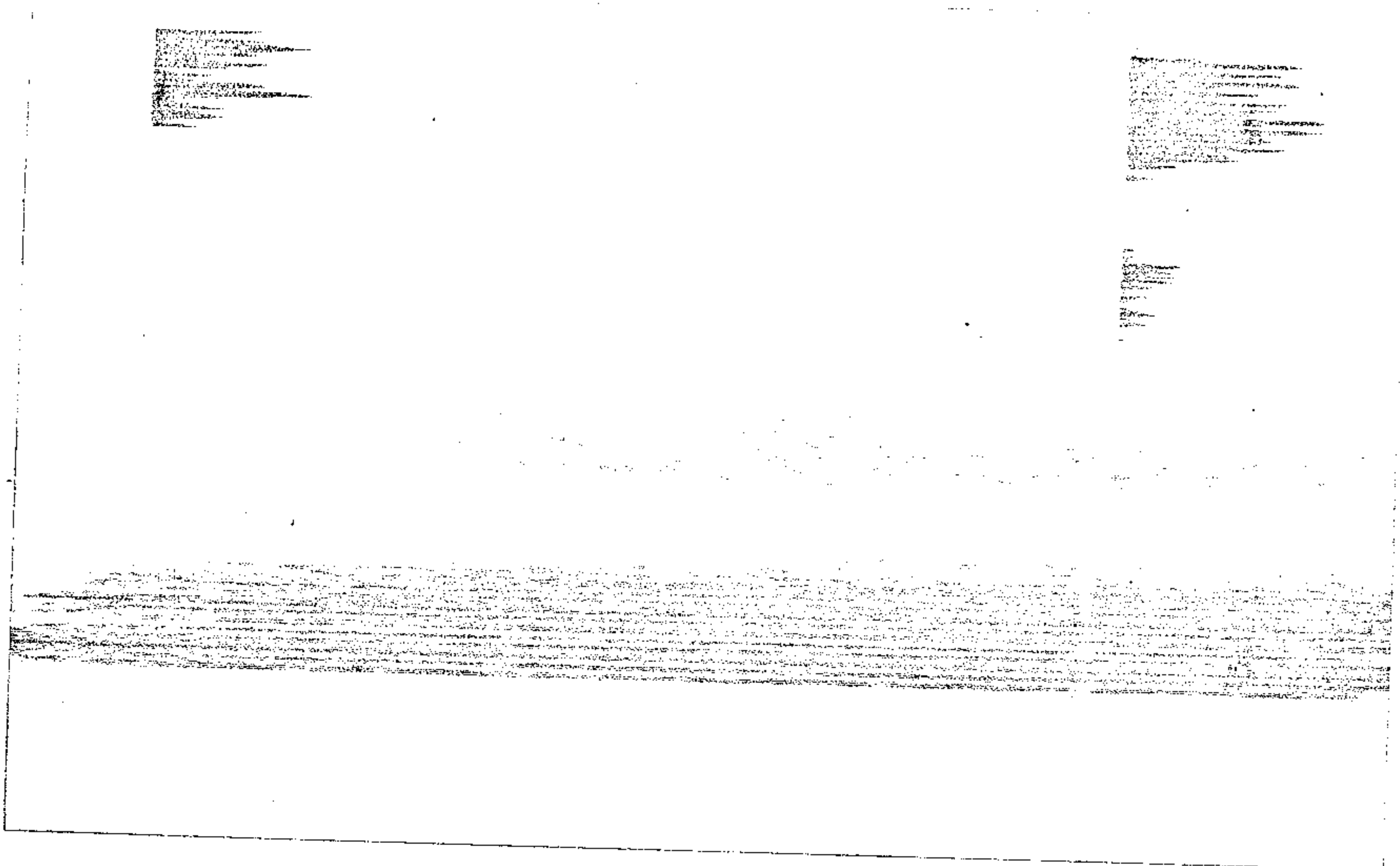
47 - 176 - J1B - ah - B - 0 4 10 - 198.5

Fig. 51--A spectrogram of the vowel ah (a) sung by junior high school male voices on the pitch B (approximately 247 Hz). Rank of 198.5.



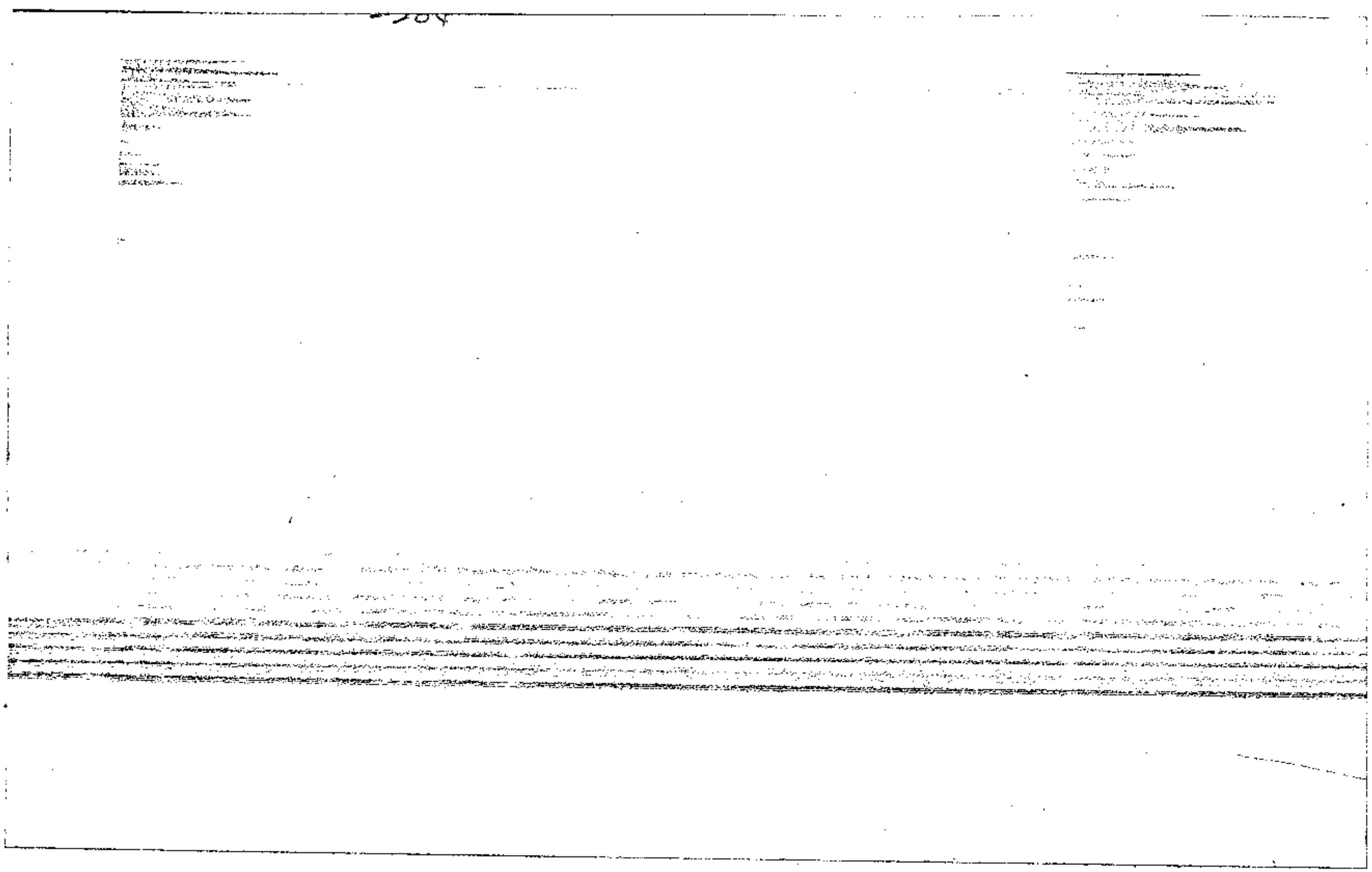
178 - 208 - C1B - eh - D - 0 4 10 - 198.5

Fig. 52--A spectrogram of the vowel eh (ε) sung by college male voices on the pitch D (approximately 147 Hz). Rank of 198.5.



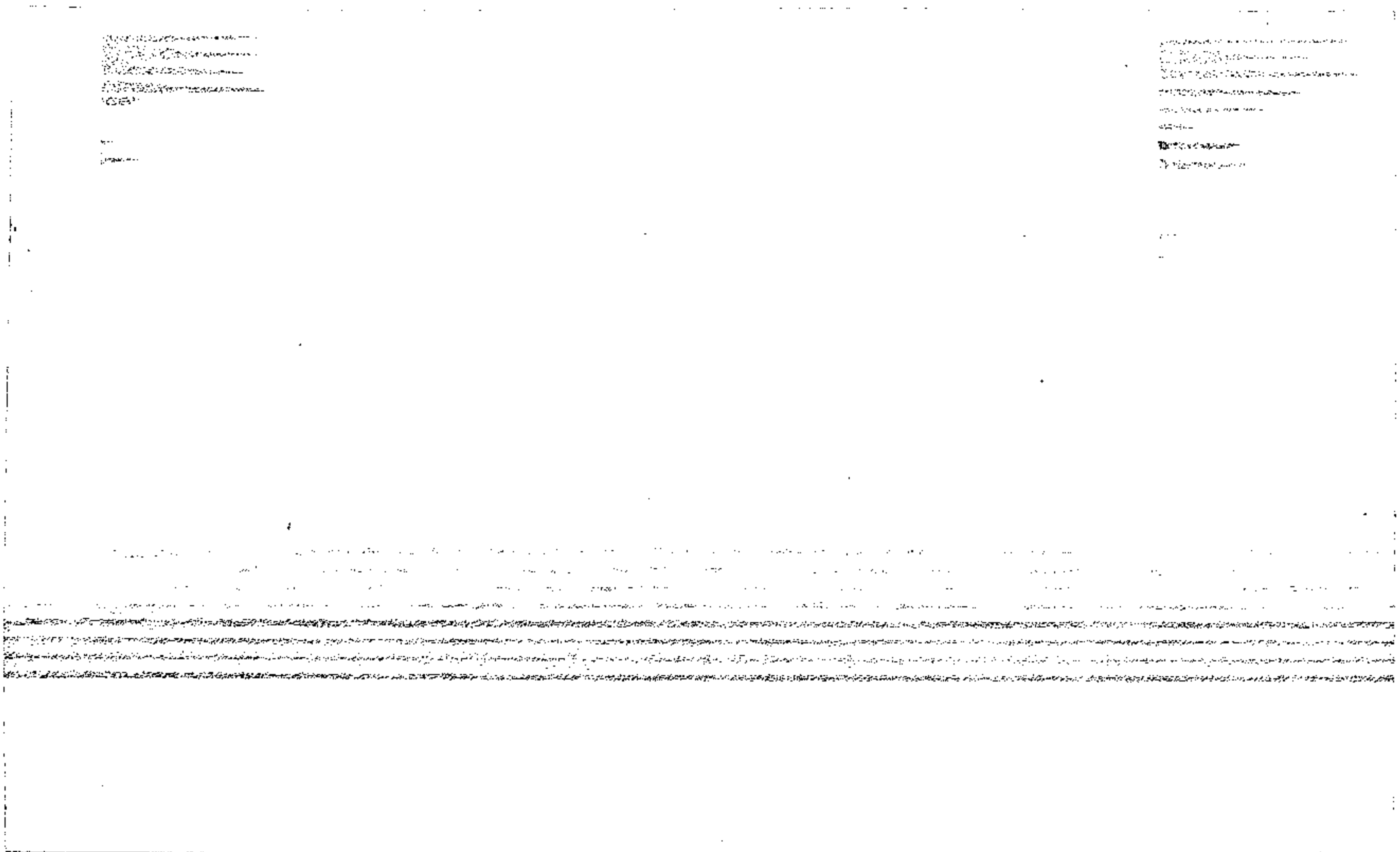
185 - 146 - C1B - ah - C - 1 2 11 - 201

Fig. 53--A spectrogram of the vowel ah (a) sung by college male voices on the pitch C (approximately 131 Hz). Rank of 201.



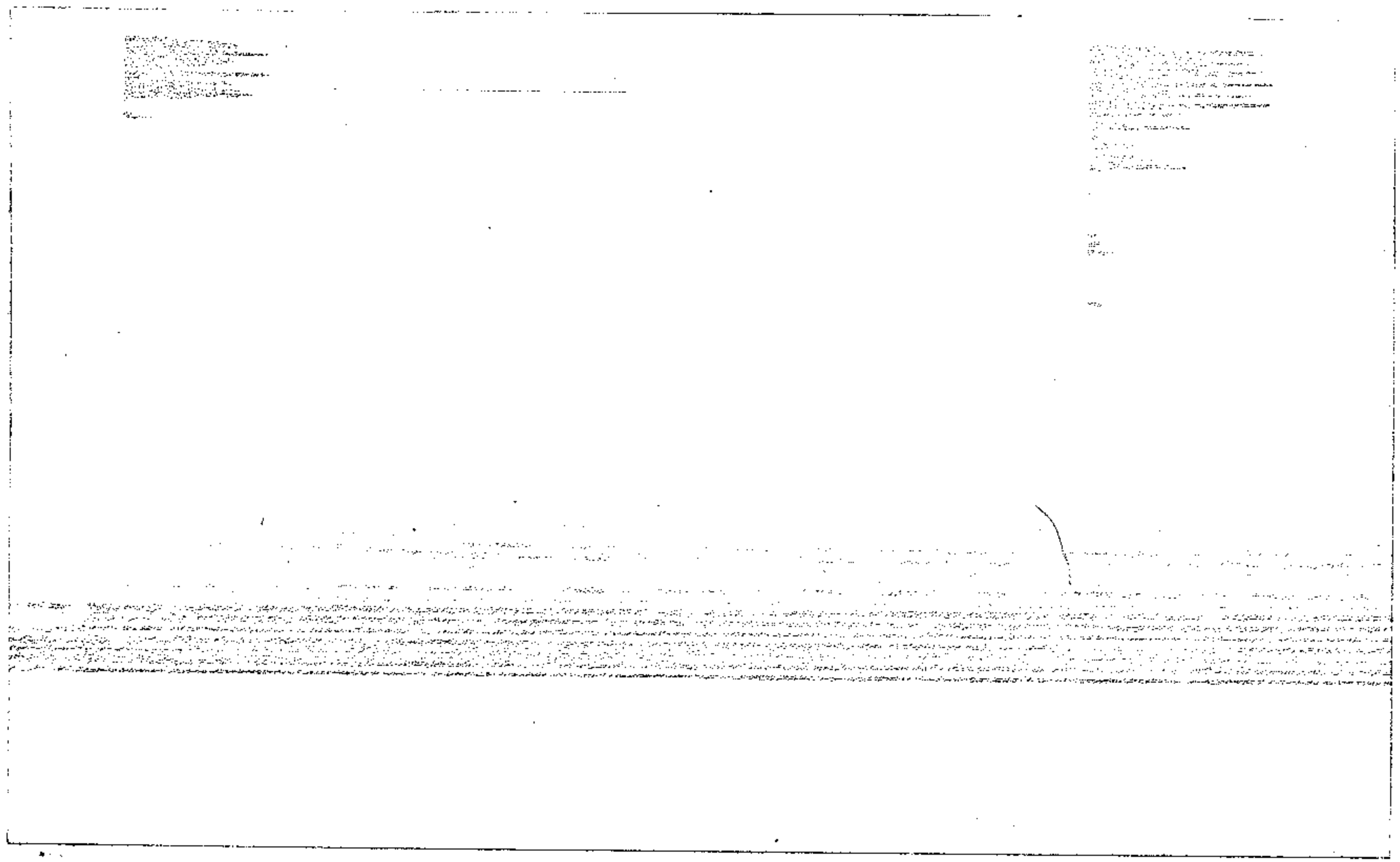
37 - 56 - J1B - eh - G - 0 3 11 - 204

Fig. 54--A spectrogram of the vowel eh (ɛ) sung by junior high school male voices on the pitch G (approximately 196 Hz). Rank of 204.



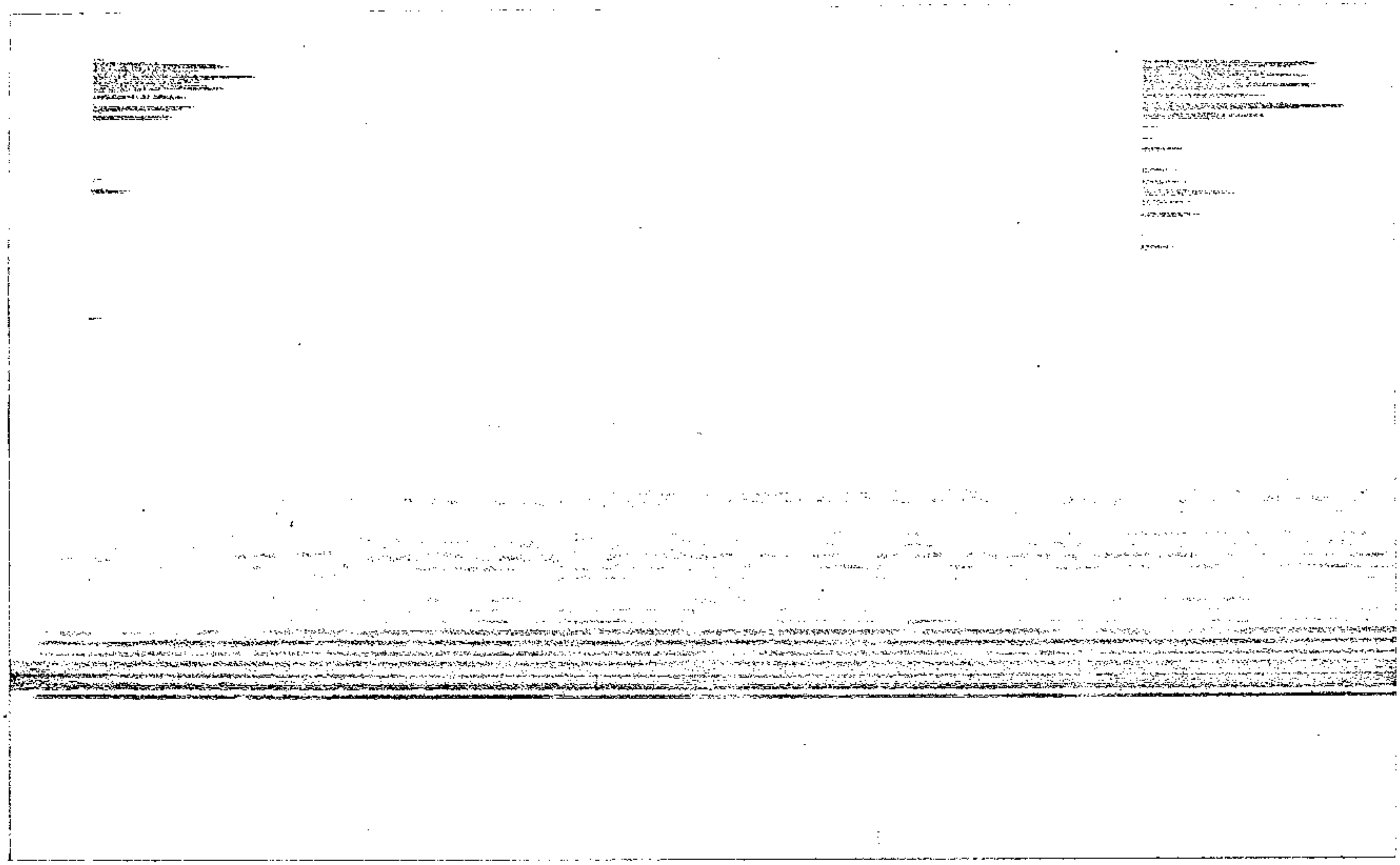
39 - 106 - J1B - eh - B - 0 3 11 - 204

Fig. 55--A spectrogram of the vowel eh (ɛ) sung by junior high school male voices on the pitch B (approximately 247 Hz). Rank of 204.



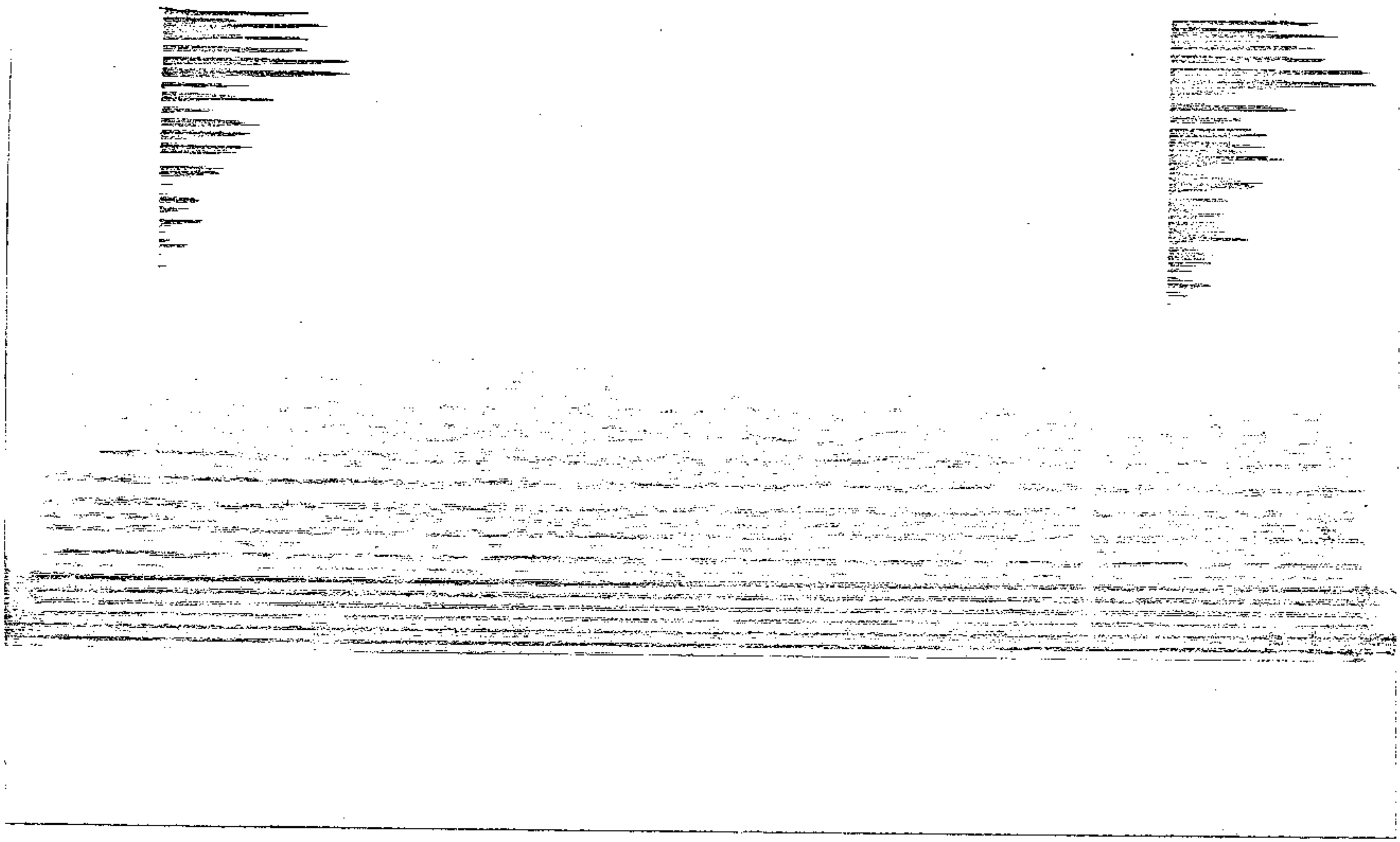
58 - 112 - J1M - eh - D - 0 3 11 - 204

Fig. 56--A spectrogram of the vowel eh (ε) sung by junior high school male and female voices combined on the pitches coded D (approximately 147 and 294 Hz). Rank of 204.



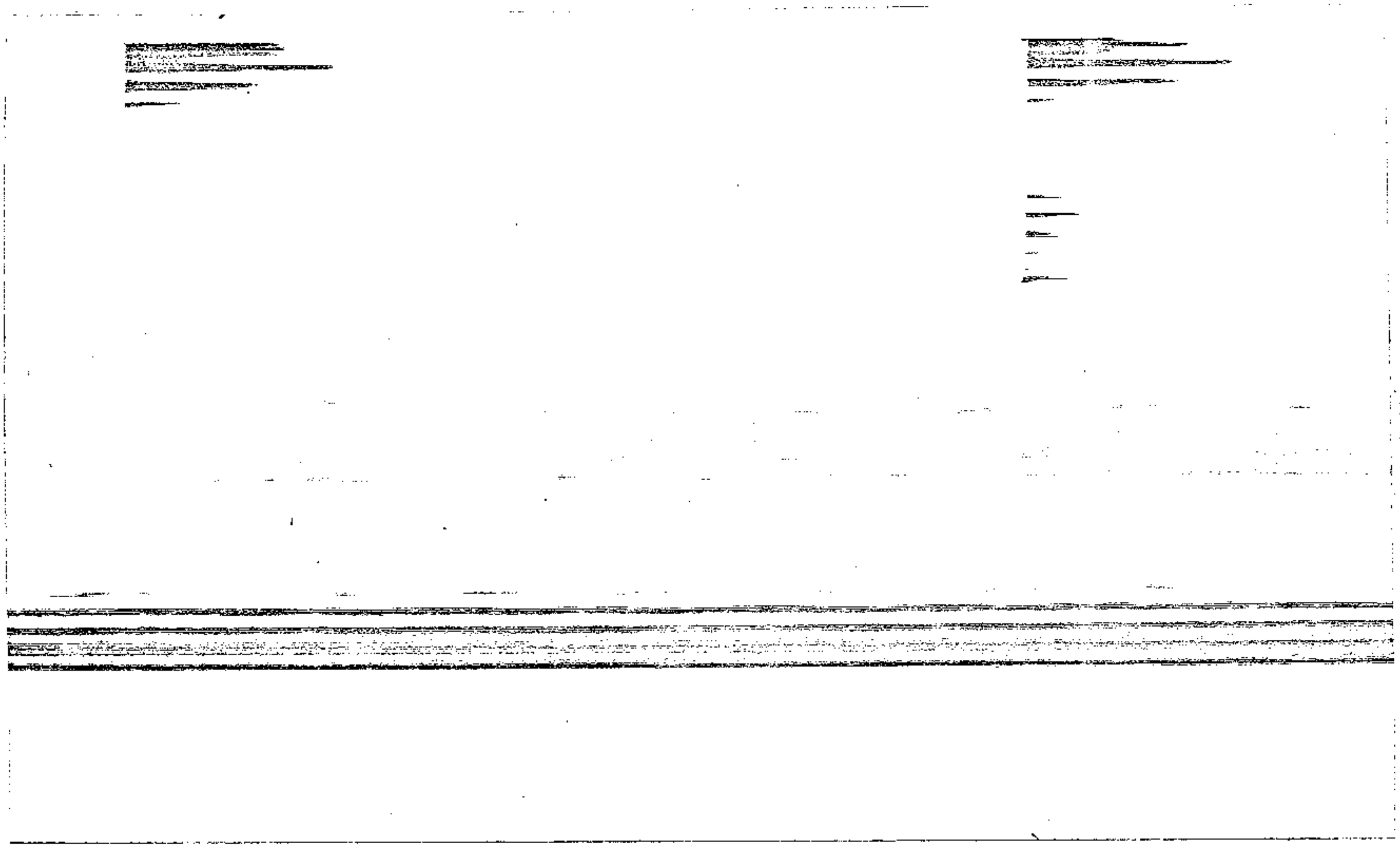
106 - 295 - S1B - eh - D - 0 3 11 - 204

Fig. 57--A spectrogram of the vowel eh (ɛ) sung by senior high school male voices on the pitch D (approximately 147 Hz). Rank of 204.



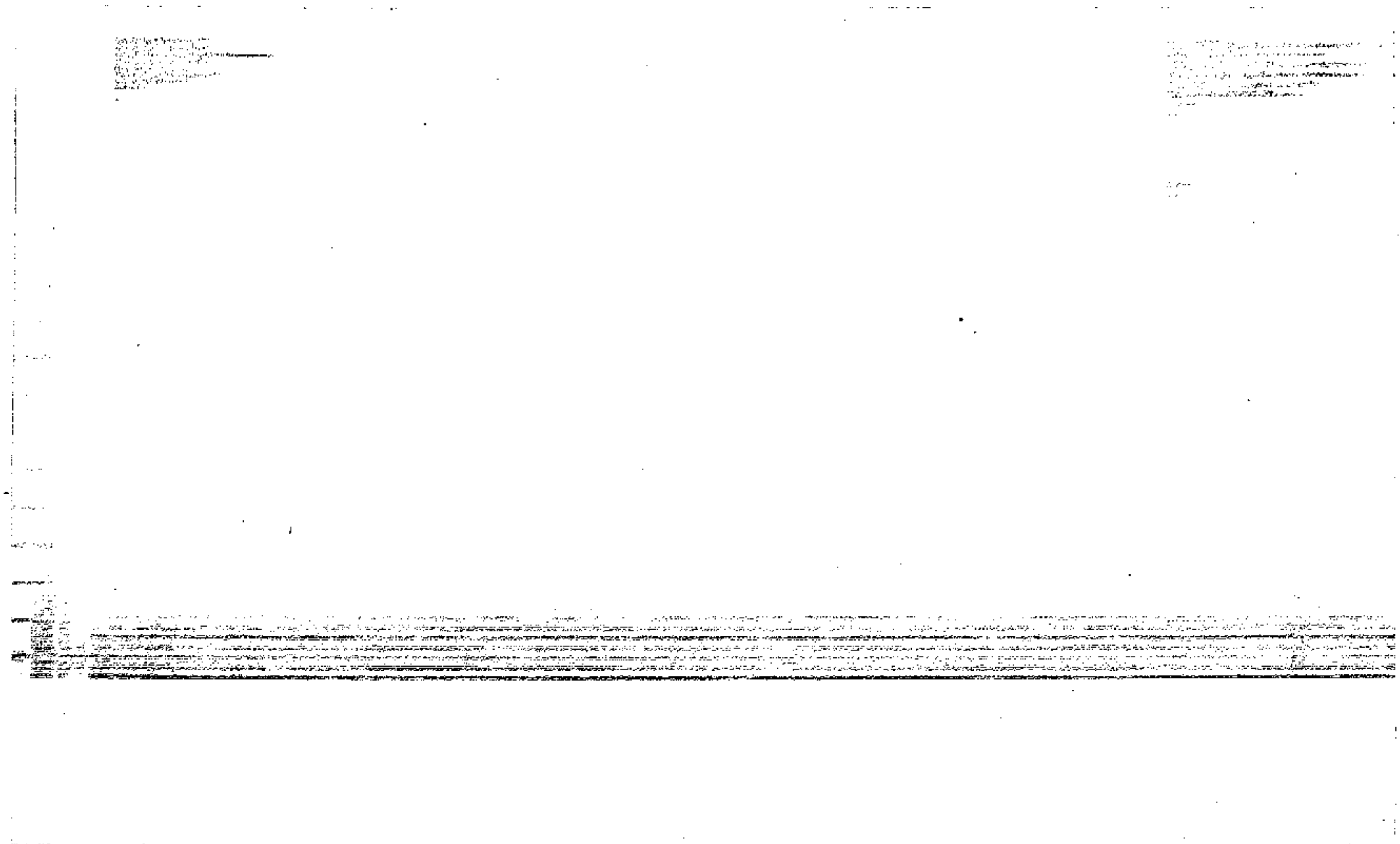
203 - 4 - ClM - eh - E - 0 3 11 - 204

Fig. 58--A spectrogram of the vowel eh (ɛ) sung by college male and female voices combined on the pitches coded E (approximately 165 and 330 Hz). Rank of 204.



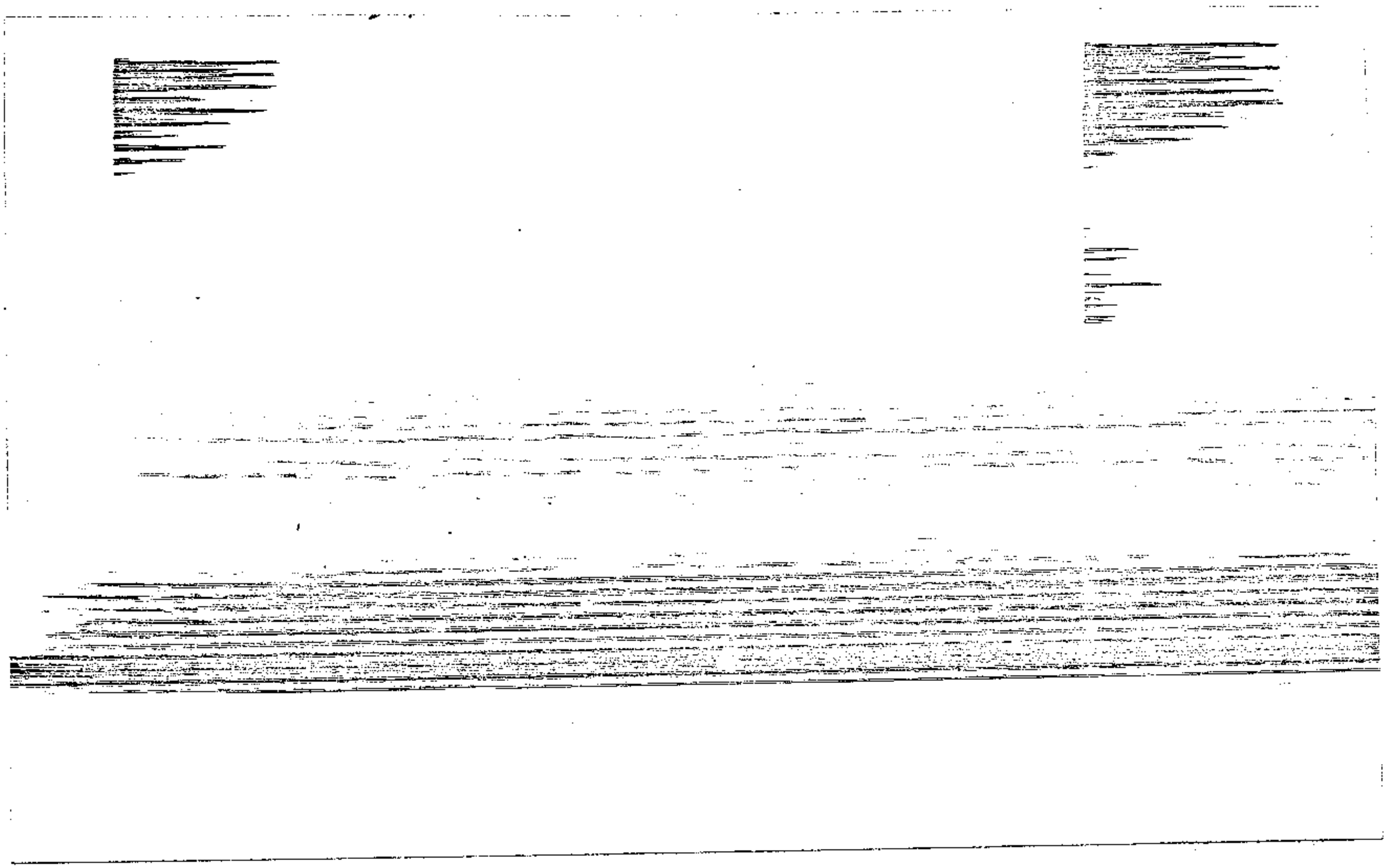
145 - 16 - C1G - ee - C - 1 1 12 - 207

Fig. 59--A spectrogram of the vowel $\overline{ee}$ (i) sung by college female voices on the pitch C (approximately 261.5 Hz). Rank of 207.



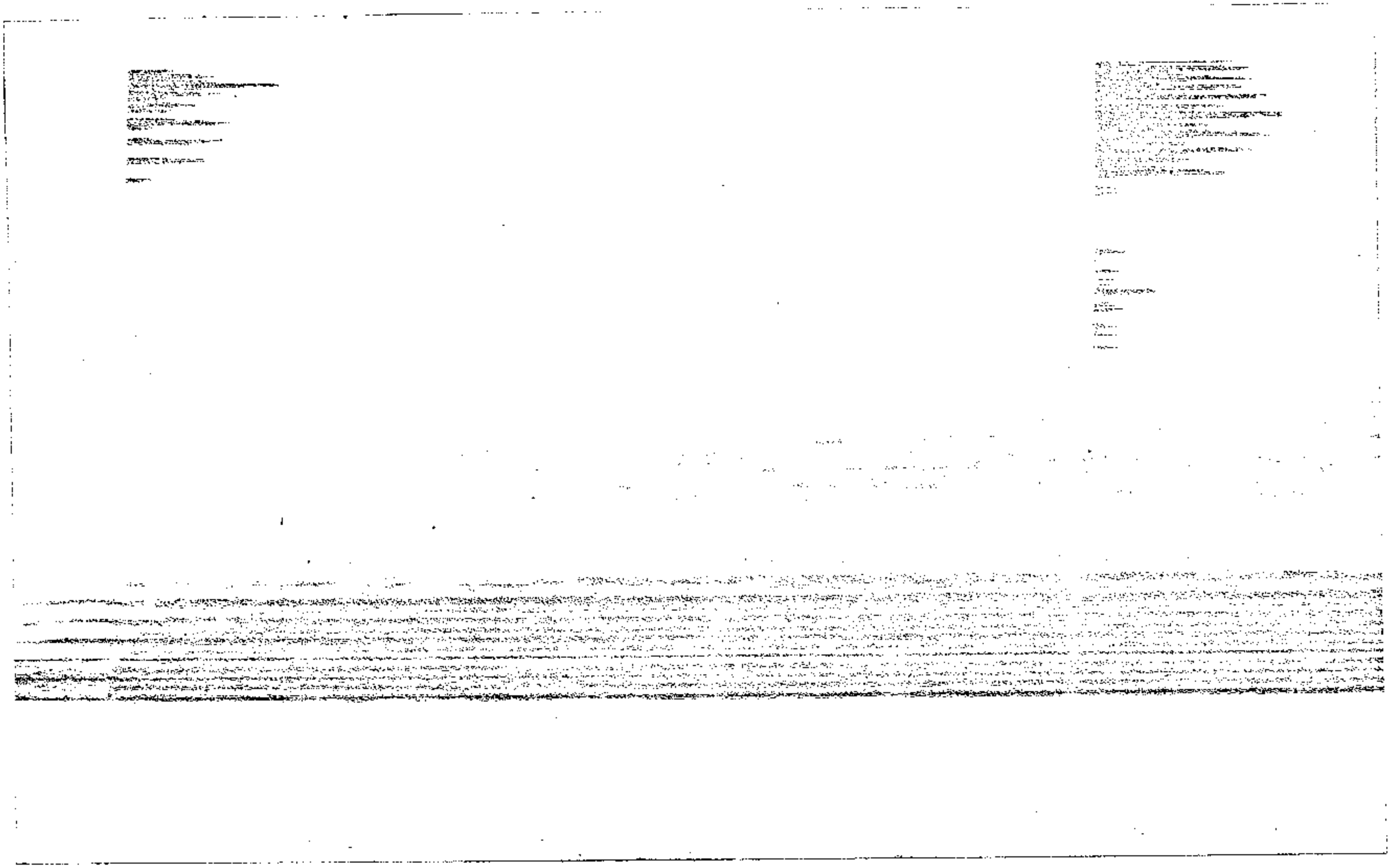
6 49 - 60 - J1M - ee - C - 0 2 12 - 209

Fig. 60--A spectrogram of the vowel $\overline{ee}$ (i) sung by junior high schcol male and female voices combined on the pitches coded C (approximately 131 and 261.5 Hz). Rank of 209.



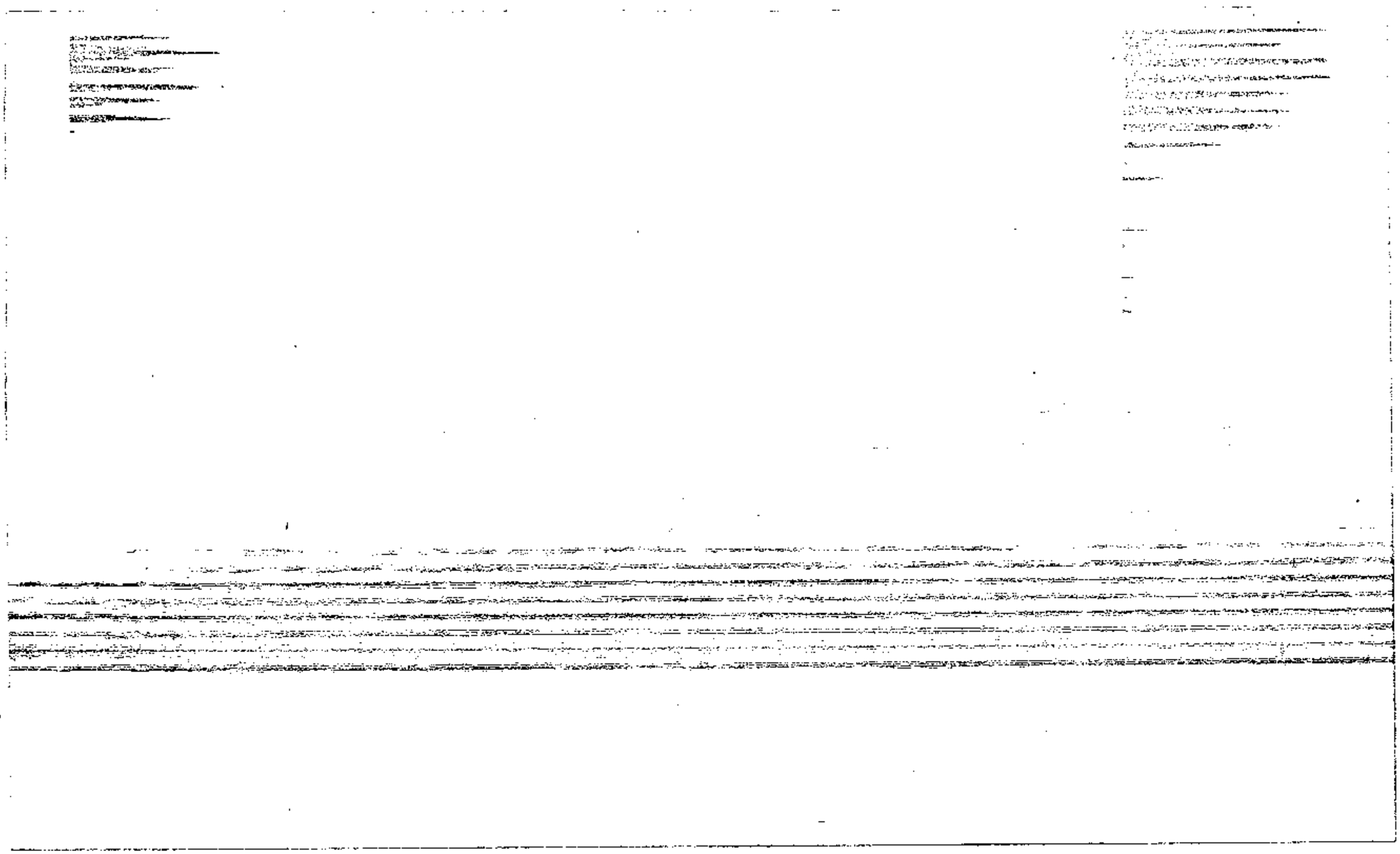
115 - 125 - S1B - ah - E - 0 2 12 - 209

Fig. 61--A spectrogram of the vowel ah (a) sung by senior high school male voices on the pitch E (approximately 165 Hz). Rank of 209.



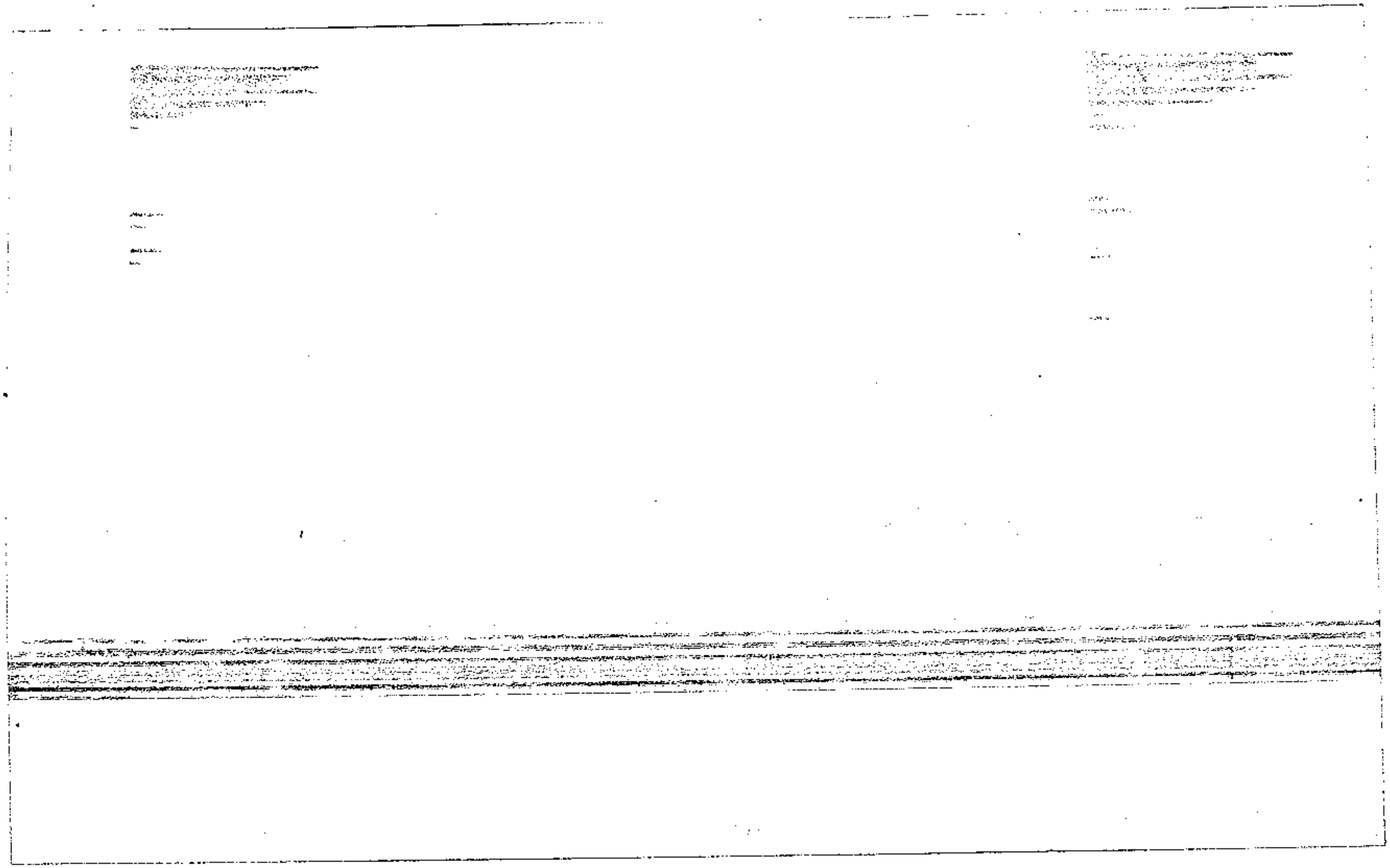
209 - 183 - C2M - ah - C - 0 2 12 - 207

Fig. 62--A spectrogram of the vowel ah (a) sung by college male and female voices combined on the pitches coded C (approximately 131 and 261.5 Hz). Rank of 209.



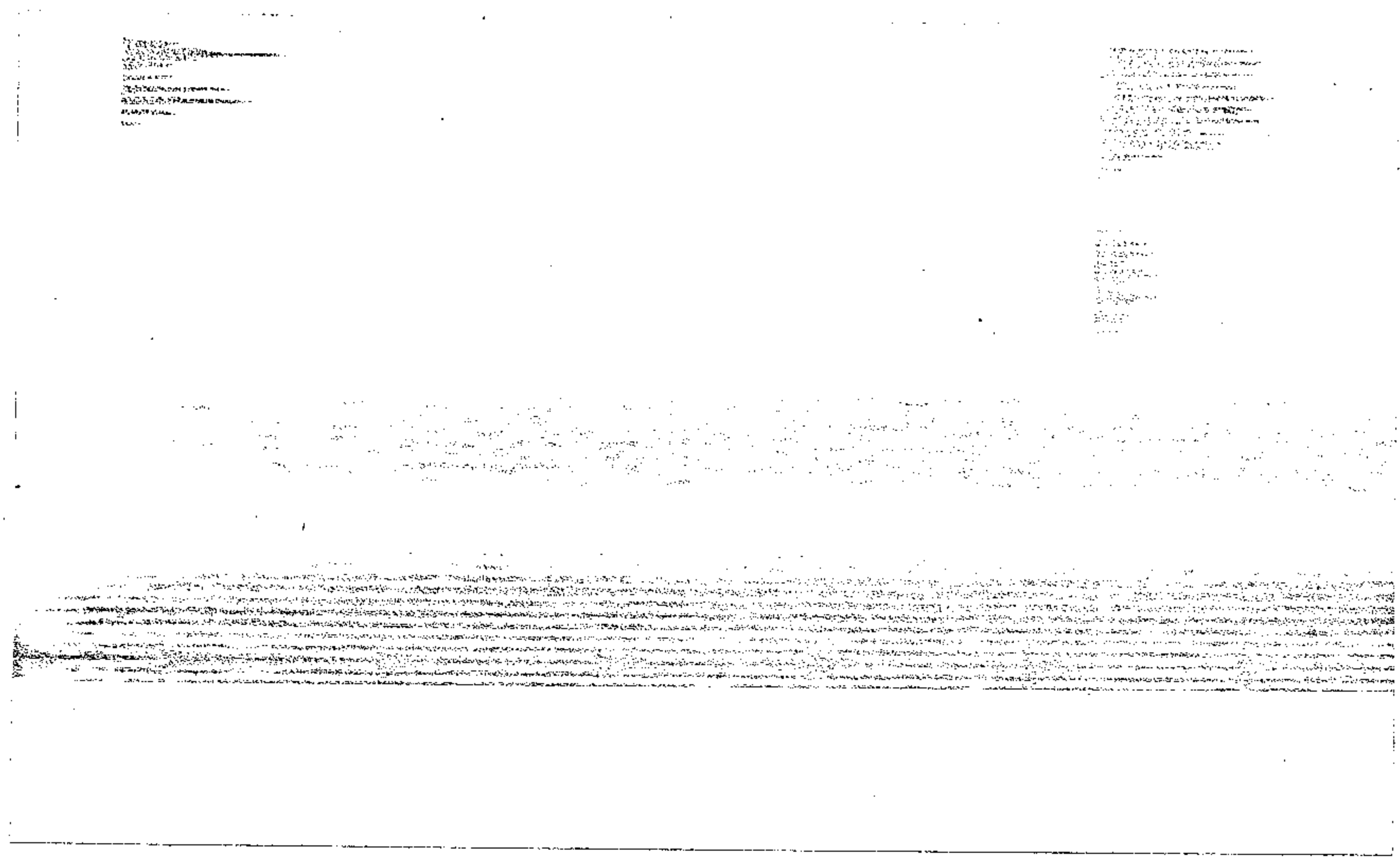
70 - 27 - J1M - ah - A - 1 0 13 - 211

Fig. 63--A spectrogram of the vowel ah (a) sung by junior high school male and female voices combined on the pitches coded A (approximately 220 and 440 Hz). Rank of 211.



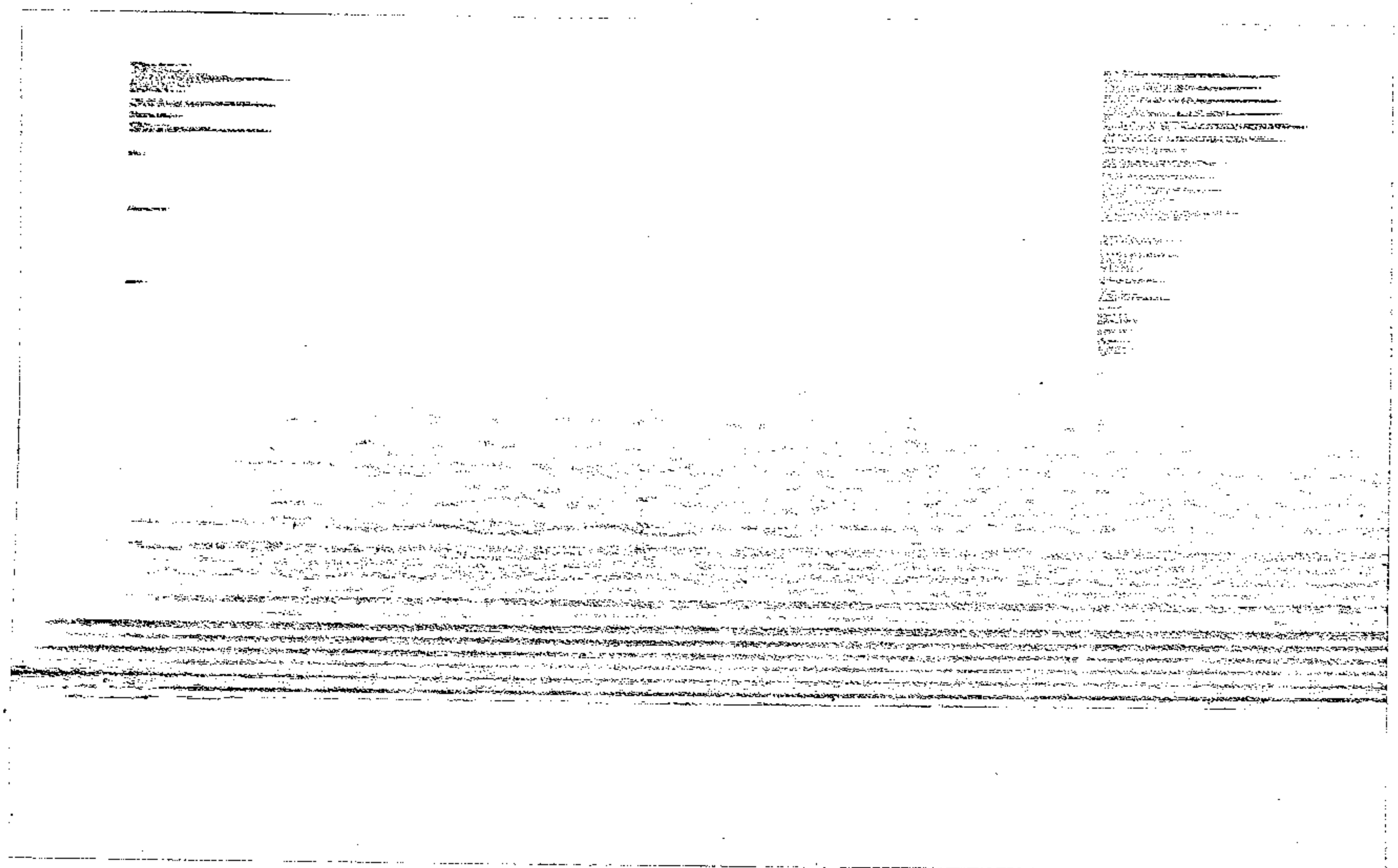
99 - 52 - S1B - ee - E - 0 1 13 - 212

Fig. 64--A spectrogram of the vowel $\overline{\text{ee}}$ (i) sung by senior high school male voices on the pitch E (approximately 165 Hz). Rank of 213.



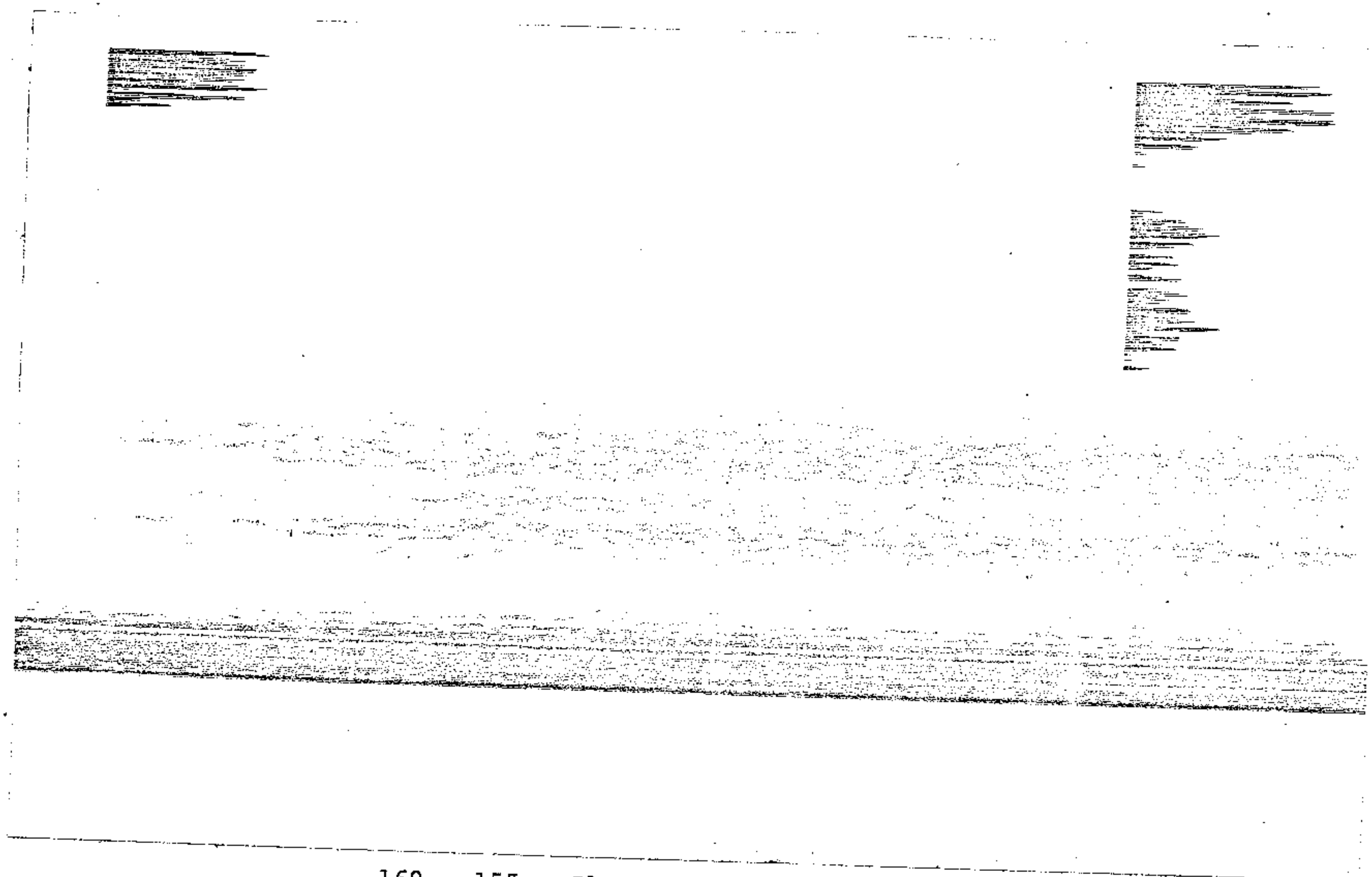
187 - 216 - C1B - ah(?) - E - 0 1 11(2) - 213

Fig. 65--A spectrogram of the vowel ah (a) sung by college male voices on the pitch E (approximately 165 Hz). Rank of 213.



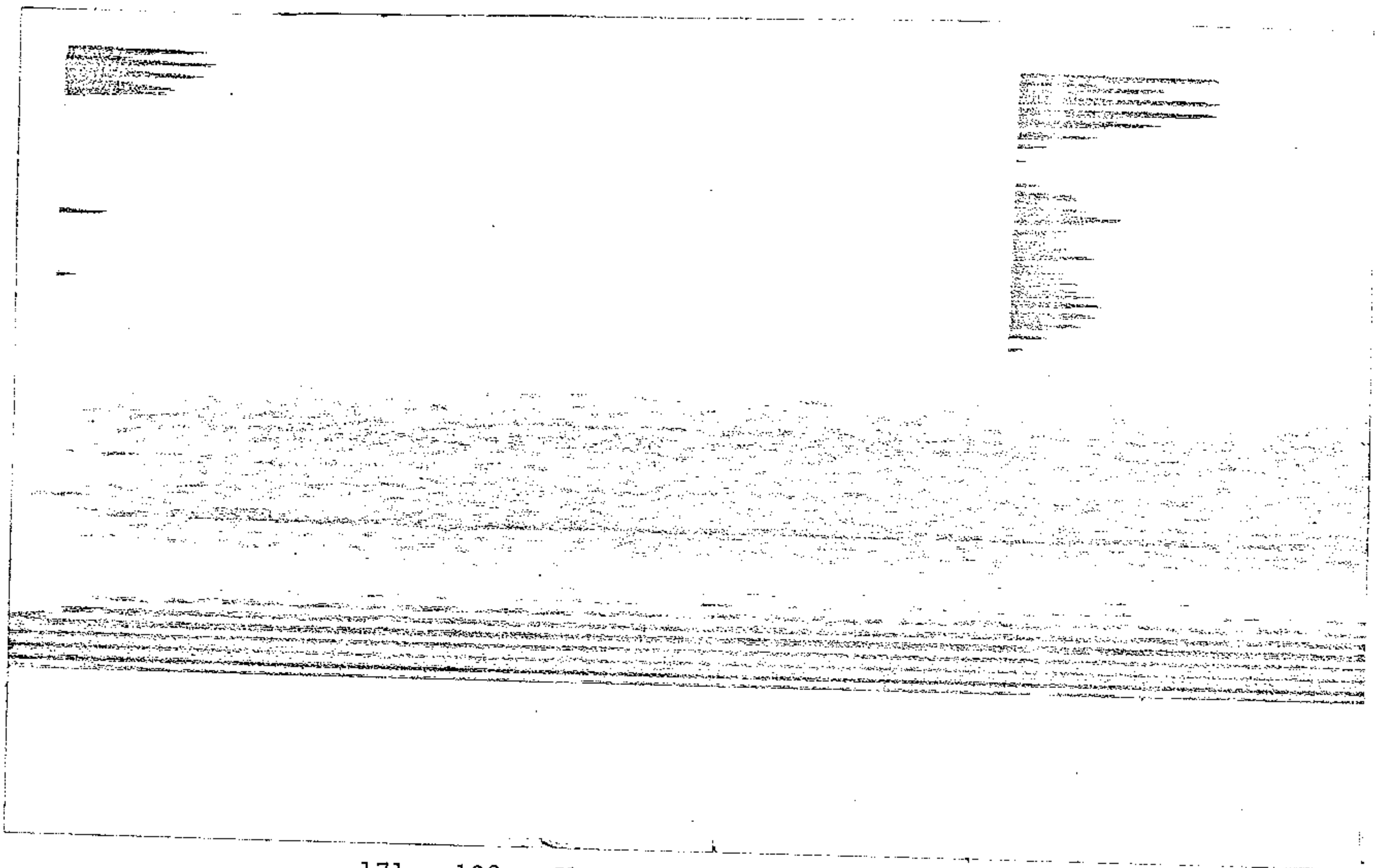
204 - 171 - C2M - eh - F - 0 1 13 - 213

Fig. 66--A spectrogram of the vowel eh (ɛ) sung by college male and female voices combined on the pitches coded F (approximately 174.5 and 349 Hz). Rank of 213.



169 - 155 - C1B - ee - C - 0 0 14 - 215.5

Fig. 67--A spectrogram of the vowel ee (i) sung by vollege male voices on the pitch C (approximately 131 Hz). Rank of 215.5.



171 - 138 - C1B - ee - E - 0 0 14 - 215.5

Fig. 68--A spectrogram of the vowel $\overline{ee}$ (i) sung by college male voices on the pitch E (approximately 165 Hz). Rank of 215.5.

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