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VOWEL SPECTRAL NOISE LEVELS AND ROUGHNESS SEVERITY RATINGS FOR VOWELS AND SENTENCES PRODUCED BY ADULT MALES PRESENTING ABNORMALLY ROUGH VOICE

A DISSERTATION

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WAYNE HANSON

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1970

VOWEL SPECTRAL NOISE LEVELS AND ROUGHNESS SEVERITY

RATINGS FOR VOWELS AND SENTENCES PRODUCED BY

ADULT MALES PRESENTING ABNORMALLY

ROUGH VOICE

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CHAPTER I

INTRODUCTION

In recent years, numerous studies of the human voice have been designed to investigate relationships between perceived quality disturbances and associated physiologic and acoustic phenomena. Generally, such studies have been useful because they have produced quantitative, repeatable findings which aid in understanding mechanisms underlying voice disorders. This study, utilizing subjects presenting clinical voice abnormality, investigated some of the perceptual and acoustic features of vocal roughness and certain of the relationships among such features.

Perceptually delineated, abnormal vocal roughness includes hoarseness, harshness, and similar voice quality disturbances (80). It now appears that excessive vocal roughness may be a symptom of many different underlying conditions (1, 13, 31, 91). Possibly most familiar as a transient symptom of acute laryngitis (25, 71), roughness may reflect more threatening diseases. Even in its early developmental stages laryngeal cancer, for example, may be associated with vocal roughness

(36, 72, 91). Relatively benign conditions including excessive laryngeal tension, on the other hand, may give rise to a comparable vocal symptom (13, 25, 90). Chronically abusive modes of phonation may produce lesions on the vocal folds or their supporting structures and vocal roughness (31, 60). Disturbances in laryngeal innervation and a large number of other vocal mechanism abnormalities may also be symptomatized by vocal roughness (46, 52, 91). There is evidence (1, 53, 93) that roughness is related to disturbances in the normal vibratory pattern of vocal cord movements in phonation; thus, it may be associated with any condition which effects the requisite physiologic disturbance in laryngeal phonatory function.

Clinicians commonly assess voice quality disturbances perceptually, although it is widely appreciated that the validity of such appraisals is questionable even when they are made by demonstrably reliable listeners under optimum listening conditions. Apart from direct inspection of the vocal mechanism in phonation, however, a procedure requiring specialized training and equipment (46, 56, 93), clinicians presently have few alternatives to reliance upon their perceptual skills in evaluating vocal adequacy. Though the acoustic voice wave is commonly available for study and evaluation, little is presently known about how its features are related to the perception of vocal roughness. It appears, therefore, that objective information concerning the relationship of vocal roughness to features of the phonatory acoustic signal would be useful. Such information may facilitate the clinical appraisal of vocal roughness and, thus, may aid in the mitigation of its underlying etiologies.

Previous investigations (49, 68, 98) suggest that acoustic features relating to the perception of vocal roughness are revealed by spectrographic analysis of the voice wave. For a sustained vowel, specifically, an increase in the perceived roughness of the sample is associated with an increase in the level of noise components in the production's acoustic spectrum. Recent investigations (49, 68) indicate that vowel spectral noise levels may be quantified when a suitable narrow-band spectrum of the phonation is produced. These studies reveal also that spectral noise levels measured in narrow-band (3-Hz) acoustic vowel spectra correlate highly and positively with listener judgments of roughness for normal and for simulated rough vowel productions.

Though it has been demonstrated that narrow-band spectrography is useful in delineating acoustic features related to vocal roughness, this technique has seldom been employed in the study of a clinical population. Because there are presently little data indicating that vocal roughness presented clinically is acoustically similar to simulated vocal roughness, it would seem desirable to utilize narrow-band spectrography in a clinical study. Moreover, it would appear that the information obtained by such investigation may aid in appraising further the usefulness of narrow-band acoustic spectrography as a research and clinical tool in the evaluation of vocal roughness. The present study, therefore, investigated spectral noise levels in narrow-band (3-Hz) acoustic spectra of selected vowels produced by individuals presenting vocal roughness clinically. Also investigated were the relationships between the measured vowel spectral noise levels and judgments of vocal roughness for the vowels and for short samples of connected discourse.

CHAPTER II

REVIEW OF THE LITERATURE

Increasingly, clinical and research interest has focused on the physical correlates of voice quality. Recent studies of rough voice (49, 68), aided by instrumentation advances, have demonstrated that spectrography facilitates the identification of acoustic features associated with vocal roughness. Few investigations, however, have analyzed spectrographically the rough phonations of clinical subjects. This study assessed quantitatively noise levels in the acoustic spectra of selected vowels phonated by subjects presenting vocal roughness associated with laryngeal pathology. Relationships between the vowel spectral noise levels and roughness judgments for the vowels and for samples of connected speech were also explored. Literature reviewed as background for this study is reported under two major headings: (a) Acoustic Correlates of Roughness in Analogs of Phonation and (b) Acoustic Correlates of Roughness in Human Phonation.

Acoustic Correlates of Roughness in Analogs of Phonation

To study the acoustic wave features associated with the perception of roughness, Wendahl (94) utilized an electronic laryngeal analog to produce a complex acoustic signal. This signal, generated by an oscillator, was computer controlled in both frequency and amplitude. He found that when signal frequency was varied as little as $\pm$ 1 Hz around a median frequency of 100 Hz the signal was perceived as rough. When the frequency variation was increased, the degree of perceived roughness increased. Wendahl also demonstrated that as the median fundamental frequency of the signal increased, larger cycle-to-cycle frequency variations (jitter) were required for the perception of roughness. For example, a 200 Hz $\pm$ 10 Hz signal was judged less rough than a 100 Hz $\pm$2 Hz signal. On the basis of these findings, Wendahl speculated that if male and female voices evidence equal amounts of jitter, the male will likely be judged to have the more deviant voice. Further, Wendahl (95) found that synthesized complex acoustic stimuli were perceived as rough when the intensities of successive cycles were attenuated randomly around a median amplitude causing the signal to shimmer. He concluded that either jitter or shimmer may cause a signal to be heard as rough.

To study further the role of frequency in the perception of roughness, Coleman (10), using the electrical laryngeal analog employed by Wendahl (94), investigated the relationship between median frequency levels and roughness perception for jittered stimuli. Stimuli were studied having five different median frequency levels (87, 123, 174, 247, and 349 Hz) and four different jitter excursions (0.0, 0.5, 1.0, and 1.5 semitones) from each of the median frequency levels. Coleman found that judges rated stimuli with lower median frequencies rougher than those with higher median frequencies, for all jitter conditions. Generalizing his findings to human phonation, Coleman suggested that two voices might be judged equal in roughness though one evidenced more jitter than the other. This could obtain, he thought, if the voice evidencing the greater jitter had a relatively high fundamental frequency.

Sherman and Linke (70) have suggested that as the duration of a harsh utterance is lengthened, its harshness may appear to increase. To study the perceptual effects of varying the relative length of jitter segments in acoustic signals, Coleman and Wendahl (11) synthesized complex acoustic stimuli containing jitter segments of various relative durations. They found that as the duration of a jitter segment within an otherwise nonjittered signal increased, the roughness of the signal increased. The combined effect of varying jitter duration and jitter magnitude was also studied. A large-jitter segment of short duration, within an otherwise periodic stimulus, caused the signal to be judged less rough than did a small-jitter segment of longer duration. The positioning of jitter segments at the beginning or end of otherwise periodic stimuli had little differential effect on the perception of roughness.

Some time ago, Carhart (8) employed a wave analyzer to study the spectra of rough and smooth model larynx tones. He found that the perception of roughness accompanied tones for which predominantly inharmonic spectra were obtained. Emanuel and Sansone (15) have more recently observed that the effect of varying the frequency of a previously periodic pulse train rapidly and randomly around a median frequency is to decrease the level of spectral harmonic components and to increase the level of inharmonic components. They indicated that there may be a relationship between the elevation of spectral noise or inharmonic components and the diminution of harmonic components, and frequency variations in the human phonatory signal.

Acoustic Correlates of Roughness in Human Phonation

Investigations of acoustic wave features related to roughness in human phonation have been few. Aperiodic vocal fold vibrations resulting in frequency and amplitude variations in the glottal area wave have, however, been associated with the perception of vocal roughness (53). As the magnitude of such variations increase, the voice tends to be heard as increasingly rough. Similarly, frequency and amplitude variations in the phonatory waves of rough-voiced subjects have been associted with roughness. Lieberman (48), for example, found that pitch perturbations, i.e., small but rapid variations in the fundamental frequency of phonations, not only increased as vocal roughness increased, but also were sensitive to the size and location of growths on the vocal folds. Large growths on the folds produced larger pitch perturbations than small growths similarly located. Large growths adjacent to but not on the folds tended to produce smaller pitch perturbations than small growths on the folds, however. Lieberman suggested that the measurement of pitch perturbations might serve as a useful screening procedure for the early detection of laryngeal pathology.

Moore and Thompson (53) used high-speed photography to study the glottal area wave and a phonellograph to visualize the phonatory acoustic wave for two hoarse subjects. Random cycle-to-cycle frequency variations were prominent in both the glottal area and phonatory acoustic waves of the hoarse phonations and served to distinguish them from normal phonations. The vibratory periods were considerably more variable for the subject presenting the more severe hoarseness. Coleman (9) reported that small random changes in fundamental vocal frequency occur less often in segments of normal phonation than in hoarse segments of comparable duration. Bowler (4) compared the acoustic waves of harsh and non-harsh phonations to listener judgments of harshness for each sample. His findings suggested that harsh quality is characterized by extreme and abrupt changes in fundamental frequency. These frequency breaks, occurring in both upward and downward directions, were not unique to a particular phase of phonation, but were found predominantly near the termination of phonation. Bowler also reported that harsh quality was characterized by lower than average median frequency values. It has been suggested (54), however, that the voice samples described as "harsh" by Bowler may have been samples of vocal fry phonation.

Koike (42), using a contact microphone coupled to the pretracheal skin, recorded sustained vowels phonated by normal speaking subjects and by subjects presenting laryngeal neoplasms or unilateral laryngeal paralysis. He then measured changes in the peak amplitude of the cycles of the acoustic signal picked up by the throat microphone. Serial correlation coefficients were computed and correlograms were made for each vowel sample to investigate the periodicity of amplitude modulation. Differences were revealed between correlograms for normal speaking subjects and those presenting laryngeal pathology. The correlograms for the normal phonations evidenced a long-term periodicity in amplitude modulations, while those for the abnormal phonations of subjects presenting laryngeal neoplasms tended to evidence shorter periodic amplitude modulations with periods of three to twelve fundamental periods. The phonations of subjects presenting vocal fold paralysis appeared to lack periodicity in amplitude modulations. Koike suggested that acoustic amplitude information may be useful in evaluating laryngeal dysfunction and may aid in the early detection of some laryngeal pathologies.

Studies concerned with the spectral characteristics of vocal roughness have also been few. Those studies which have been completed suggest, however, that spectral changes accompany changes in vocal quality. In an early attempt to show spectral differences between normal and abnormal voice quality, Van Dusen (87) studied four severely metallic, i.e., harsh, voices and four normal voices by harmonic analysis of sample phonations. The voices of two men and two women were studied in each classification. The female metallic voices evidenced a preponderance of energy in the fundamental frequency with a considerable reduction of energy in the higher components. The male metallic voices evidenced less energy in the first harmonic and a greater spread of energy into higher frequency components.

Later, Thurman (82) utilized a Sonagraph to analyze the spectra of vowels produced by a group of individuals presenting a variety of voice quality disorders. He reported that the differentiation of deviant from normal voice quality on the basis of sonagraphic analysis of the phonations was impracticable. Although formant bandwidth changes and formant frequency shifts occurred in the vowel spectra for hoarse speakers, they were not consistent. More recently, Isshiki, Morimoto, and Yanagihara (35) and Yanagihara (97, 98) have investigated the spectra of sustained vowels phonated by subjects exhibiting slight, moderate, and severe hoarseness associated with laryngeal pathology. Sonagrams (45-Hz) and amplitude sections were made from tape recordings of the subjects' phonations. Four types of hoarseness were differentiated on the basis of the location and intensity of inharmonic components in vowel spectra. These noise components were first evident in the higher frequency portion of the spectrum in mild hoarseness, and extended into the lower frequency range as hoarseness increased. With increasing hoarseness, noise components in the formant ranges predominated over the harmonics. For the most severely hoarse phonations, the harmonics in the main formant ranges were totally obscured or replaced by intensified noise components. As a further procedure, Yanagihara (98) mixed normal vowel phonations with bandpass filtered noise. As the level of noise first obscured the high frequency vowel harmonics and then intruded on the vowel formants, the normal phonations were heard to become increasingly hoarse.

Previous investigations suggest, therefore, that the distribution of acoustic energy is different in vowels produced by speakers presenting vocal roughness and speakers with normal quality. Specifically, the elevation of spectral inharmonic or noise components is characteristic of rough vowels. For the most part, such findings have been reported on the basis of investigations utilizing spectrum analyzers with filter bandwidths of 45 Hz or wider. It appears, however, that such wide filters may not provide an optimum display of spectral noise in rough phonations.

Nessel (57), using a sound-frequency spectrograph of narrow selectivity, compared frequency-by-amplitude spectra of sustained vowels produced by pathologically hoarse speakers to those produced by normal speakers. Characteristic of increasing hoarseness was a reduction of harmonic energy below 5000 Hz and an increase in noise throughout the spectral frequency range. Nessel indicated that his spectrographic findings suggest a method for defining and differentiating hoarseness.

Sansone (68) used a constant bandwidth wave analyzer to obtain graphic 3-Hz bandwidth frequency-by-intensity acoustic spectra of five vowels individually produced by adult males both normally and with simulated vocal roughness. The findings indicated that spectral noise was associated with normal as well as rough vowel productions, but rough productions evidenced spectral noise levels greater than those for normal productions. For both normal and rough productions of each vowel, spectral noise was most prominent in lower spectral frequencies and decreased toward the higher frequencies. High correlations were obtained between the spectral noise measures for the test vowels and judges' ratings of vowel roughness. Further, both the rough and the normal test vowels were ordered with respect to increasing spectral noise in the frequency range 100 Hz to 2600 Hz /u/, /i/, /ʌ/, /ɑ/, and /æ/. In general, vowels produced with relatively low tongue positions evidenced greater spectral noise levels than those with high tongue positions, within normal and within rough phonatory conditions. For each test vowel, vocal roughness tended to increase linearly with an increase in spectral noise levels. Sansone suggested that measures of vowel spectral noise might provide an objective index of vocal roughness, and suggested further that his investigation be extended to a study of clinically rough phonations.

Using the acoustic analysis procedure employed by Sansone, Lively (49) investigated spectral noise levels associated with vowels produced normally and with simulated vocal roughness by adult females. She explored possible relationships between spectral noise measures and ratings of vowel roughness. In general, her findings were consistent with those obtained by Sansone (68) for adult males. Lively found that spectral noise levels tended to be higher for rough than for normal productions of each vowel. For both normal and rough vowel productions, an increase in mean spectral noise level appeared to be associated with decreasing tongue height in vowel production. Lively found that as the mean spectral noise level of a vowel production increased, its median roughness rating tended to increase. She hypothesized that, because diminished spectral harmonic components as well as elevated noise components were associated with an increase in perceived vowel roughness, the information essential to the perception of vowel roughness may be a relationship between harmonic and inharmonic spectral energy.

Currently, there is little information regarding the level of spectral noise associated with the rough vowel phonations of clinical subjects. The present investigation, therefore, sought to measure the spectral noise levels associated with vowels produced by subjects presenting laryngeal pathology and vocal roughness. Possible relationships between vowel spectral noise levels and the severity of perceived vocal roughness in vowels and in connected speech were also investigated.

CHAPTER III

DESIGN OF THE INVESTIGATION

The purpose of this study was to analyze spectrographically the vowel phonations of persons presenting abnormal vocal roughness clinically. The study also sought to relate vowel spectral features to the degree of vowel and sentence roughness. Specifically, the level of noise components in the spectra of selected vowels was related to judges' ratings of vowel roughness and to the roughness of short segments of connected discourse. Twenty adult males with clinically rough voices individually produced five selected vowels and two short sentences for magnetic tape recording. These vowels and sentences, separately randomized, were individually rated for vocal roughness by eleven trained judges. The median of the judges' ratings provided an index of each production's roughness. The recording of each vowel production was also analyzed to produce a narrow-band (3-Hz) frequency-by-amplitude acoustic spectrum. A quantitative index of vowel spectral noise was then obtained by measuring in each vowel spectrum the lowest observable peak of energy in each of seventy-nine successive 100-Hz spectral sections from 100 Hz to 8000 Hz. These data were then applied to specific research questions. The research questions and the methods employed in this study are discussed in the following sections.

Research Questions

The following research questions concerning selected vowels and samples of connected speech produced by subjects with abnormally rough voices associated with laryngeal pathology were investigated:

1. What are the spectral noise features associated with the vowels?

2. What is the relative roughness of the selected vowels?

3. What relationships can be demonstrated between the vowel spectral noise levels and roughness ratings for the vowel productions and for samples of connected speech?

Subjects

Twenty adult males being followed medically by the ENT Clinic, Veterans Hospital, Oklahoma City, Oklahoma, were selected as subjects for this investigation. The subjects ranged in age from nineteen to seventy-seven years. Each subject was initially examined by an otolaryngologist and by an experienced speech pathologist to confirm that each presented laryngeal pathology and a rough voice. Medical diagnostic information regarding the history and nature of each subject's voice problem was obtained from available medical records and an interview of the examining physician. A summary of the medical findings for each subject is presented in APPENDIX D.

Five different types of laryngeal pathology were evidenced by the subject group. Four subjects presented vocal cord polyps; six, laryngeal carcinoma; three, vocal cord paralysis; three, benign laryngeal masses; and four, laryngeal inflammation and edema. On the basis of data derived from preliminary screening tests and available medical records, it was determined that each subject had essentially normal hearing in at least one ear and that he could be expected to perform the experimental task satisfactorily.

Speech Sample

Subjects individually sustained each of the vowels /u/, /i/, /ʌ/, /ɑ/, and /æ/. Each also produced two standard samples of connected speech: "Joe took father's shoe bench out," and "They have bought a new car." The connected speech samples were medium length sentences each containing high, mid, and low vowels in varied consonant environments. Each had been used in previous investigations (48, 75) of the acoustic characteristics of voice quality. All speech samples were recorded while the subjects maintained a constant mouth-to-microphone distance of six inches. Each vowel production was sustained for seven seconds at a comfortable intensity (75 dB SPL). The sentences were also produced at a comfortable intensity approximating 75 dB SPL. Isolated vowels sustained at one intensity provided samples suitable for narrow-band acoustic spectral analysis. The selected vowels permitted comparison of the present data for subjects exhibiting clinically significant vocal roughness to previous data (49, 68) for subjects simulating abnormal vocal roughness and phonating normally. The test vowels selected also permitted a consideration of the effects of varying vocal tract configuration on the degree of vowel roughness and on vowel spectral noise levels.

Instrumentation

Instrumentation used in this investigation included: a signal system, an audio recording system, a wave analyzing system, a playback system, and a calibration system.

Description

<u>Signal system</u>. A simple electro-mechanical cam timer, activated by the investigator, controlled the illumination of panel lights used to signal subjects to begin and terminate test vowel phonation. Productions of the connected speech samples were not timed.

<u>Audio recording system</u>. The audio recording system consisted of: (a) a sound level meter (General Radio, Type 1551-C) with an attached non-directional piezoelectric ceramic microphone (General Radio, PZT Type 1560-P3); (b) a magnetic tape recorder (Ampex, Model AG 440); and (c) a monitoring amplifier (Bruel and Kjaer, Type 2603).

The PZT microphone was designed to have a flat frequency response ($\pm$ 1 dB) from 20 Hz to 8000 Hz when at a 70° angle of incidence to the sound source. The sensitivity of the microphone was -60.3 dB re: 1v/microbar. The sound-level-meter indicated the sound-pressure level at its PZT microphone with an average signal-to-noise ratio from 20 Hz to 10,000 of at least 66 dB. The tape recorder had a flat frequency response ($\pm$ 2 dB) from 40 Hz to 12,000 Hz with a signal-to-noise ratio of at least 65 dB at a tape speed of 15 ips.

The output of the sound level meter was connected directly to the input of the tape recorder. The output of the recorder was led to the monitoring amplifier which served as a vocal-intensity monitoring meter. Subjects monitored vocal intensity by observing the amplifier's calibrated voltmeter. A simplified diagram of the audio recording system is presented in Figure 1.

<u>Wave analyzing system</u>. The experimental vowels were reproduced from tape loops by the tape recorder described above and were introduced as complex electrical signals into a graphic wave analyzer (General

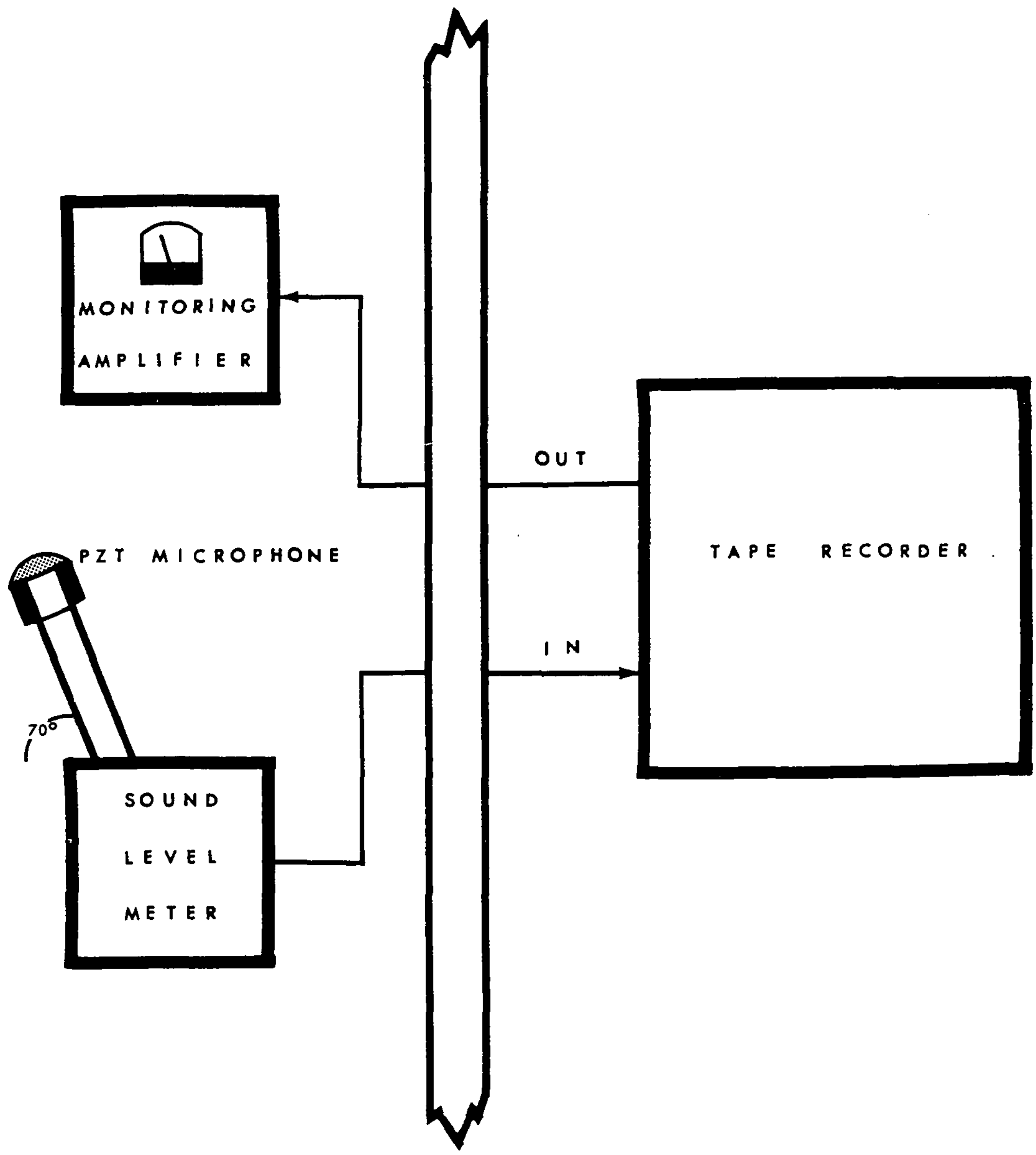

Figure 1.--Simplified diagram of the audio recording system.

Radio, Type 1910-A) for spectrum analysis. The analyzer's frequency range was from 0 Hz to 54,000 Hz. Its frequency accuracy to 50,000 Hz was ± ½% of frequency dial reading plus 5 Hz. When used in its 3-Hz bandwidth mode, the instrument functioned as a continuously tunable narrow-band filter with the intensity of frequency components in a complex signal at least 30 dB down at ± 6 Hz and at least 60 dB down at ± 15 Hz from center frequency. The analyzer's signal-to-noise ratio was at least 75 dB.

An electric motor drive system mechanically tuned the wave analyzer through its frequency range and coupled the analyzer to a graphic level recorder to permit automatic recording of the level of components in the complex electrical signal under analysis. The movement of the chart paper in the recorder was synchronized with the wave analyzer's frequency-tuning dial. The voltage output of the wave analyzer was proportional to the intensity of the frequency components in a 3-Hz band of the complex signal under analysis and served as an electrical input to the graphic level recorder. The recorder was equipped with an 80-dB input potentiometer designed for accuracy within ± 1% of full scale decibel value. The level recorder's output was proportional to the logarithm of changes in its input and, hence, was linear in decibels. A simplified diagram of the wave analyzing system is presented in Figure 2.

Playback system. The recorded vowels and connected speech samples were presented to judges for roughness rating. The playback system used for this purpose consisted of a dual-channel magnetic tape recorder (Ampex, Model 354) with a flat frequency response (± 2 dB) from 40 Hz to 12,000 Hz at a tape speed of 15 ips, an amplifier (Sherwood, Model S9900a) and a loud-speaker (Altec, Model 844A).

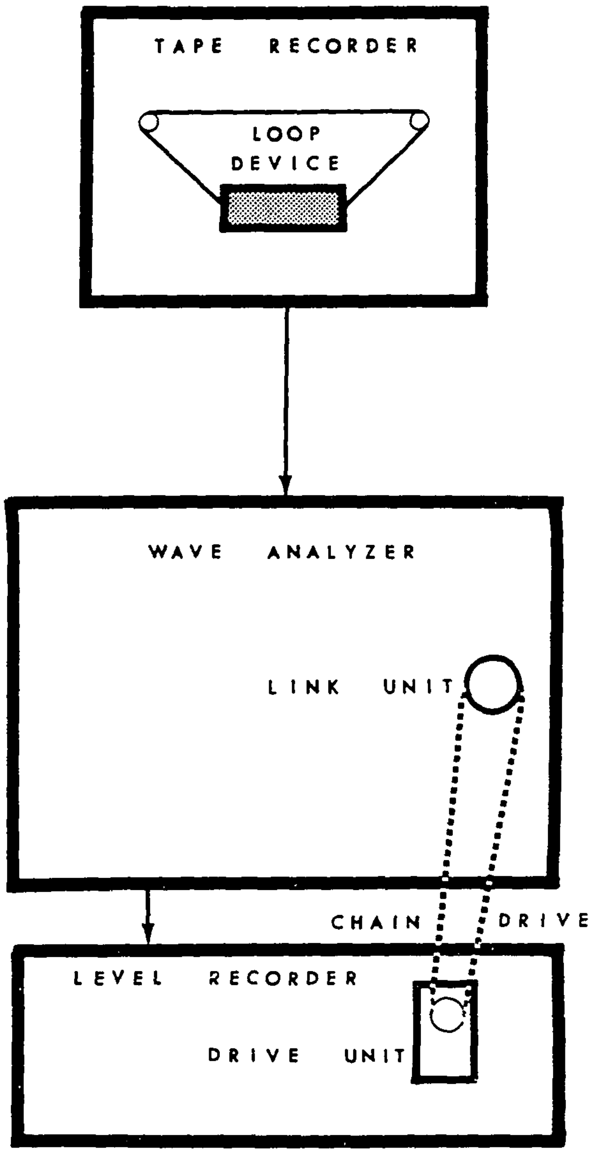

Figure 2.--Simplified diagram of the wave analyzing system.

Calibration system. Components employed in instrument calibration included a pure tone oscillator (Hewlett-Packard, Model ABR 200) which drove a loud speaker (Altec, Model 844A), a sound level meter (General Radio, Type 1551-c), and a manufacturer-calibrated condenser microphone assembly (Bruel and Kjaer, Type 2603). A simplified diagram of the calibration system is presented in Figure 3.

Calibration

Audio recording system. The magnetic tape recorder used in data collection was inspected and aligned by an audio engineer immediately prior to this investigation. The vocal-intensity-monitoring section of the audio recording system was calibrated to indicate when the subject's vocal intensity had reached 75 dB SPL. The monitoring amplifier's voltmeter was used as the subject's intensity indicator. To calibrate this meter, a 1000-Hz reference tone produced by the pure tone oscillator was led to the loud-speaker. The sound level meter PZT microphone was placed at a 70^{0} angle of incidence to and two feet in front of the loud speaker in an acoustically isolated room. The intensity of the pure tone was adjusted until it produced a 75 dB SPL sound level meter deflection. The output of the sound level meter was then connected directly to the input of the tape recorder, and the recorder was adjusted for a -2 dB deflection of its VU meter in response to the 75 dB SPL input. The output of the recorder was then led to the monitoring amplifier and the amplifier's input potentiometer was adjusted for a 15 dB deflection on the amplifier's voltmeter in response to the 75 dB SPL input. This deflection of the amplifier's voltmeter was marked as the level each subject was to maintain during experimental vowel production. The refer-

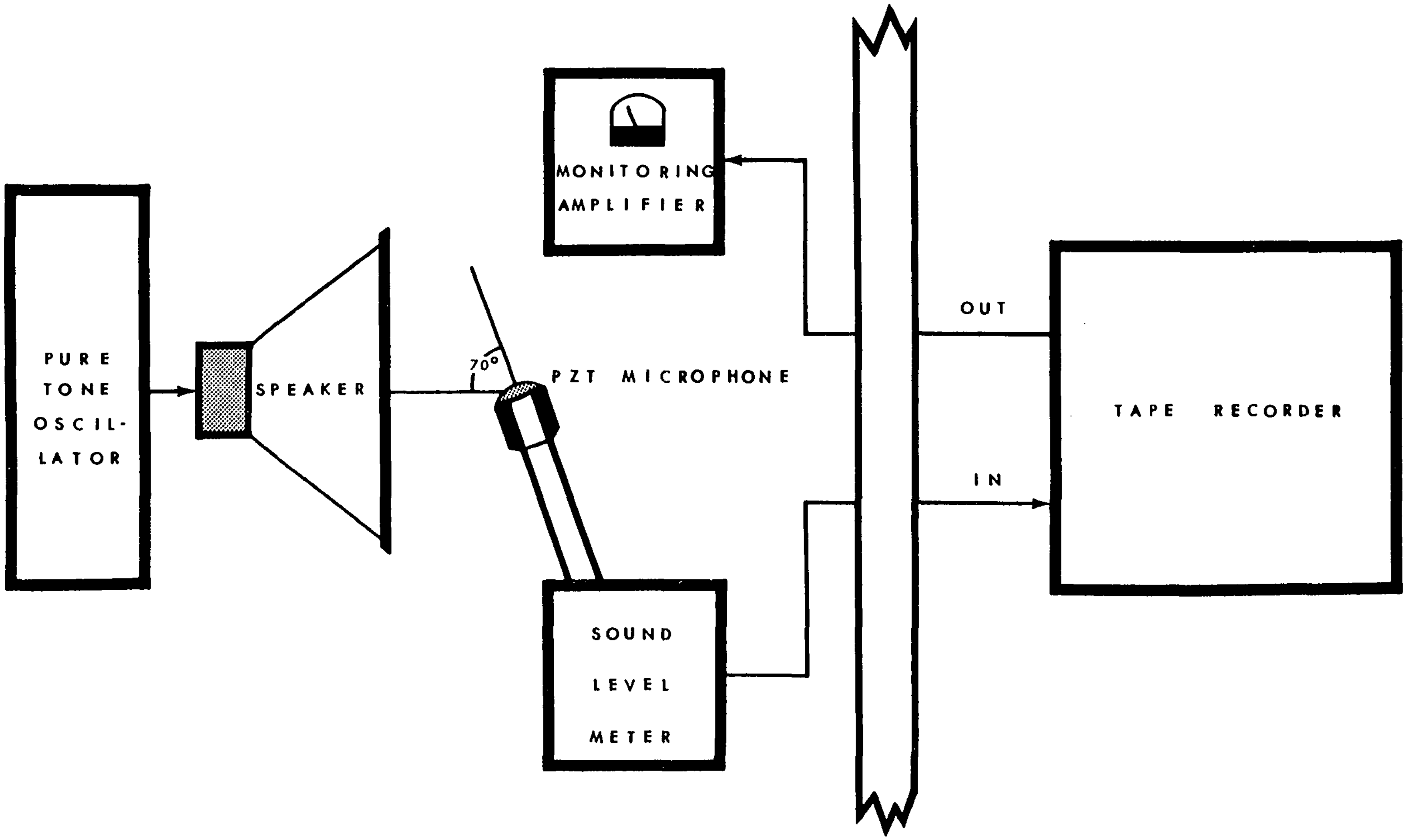

Figure 3.--Simplified diagram of the calibration system.

ence tone was then recorded and played back to adjust the audio recorder's reproduce level to match its record level. Thus, speech samples producing a 75 dB SPL indication on the vocal-intensity-monitoring voltmeter produced a -2 dB deflection on the recorder's record VU meter. When recorded and played back, the speech samples produced a -2 dB deflection on the recorder's reproduce VU meter.

The frequency response of the PZT microphone used in this study was designed for a flat (± 1 dB) response from 20 Hz to 8000 Hz. Immediately before and after collection of the experimental data, the PZT microphone frequency response was checked against the flat (± .5 dB from 20 Hz to 10,000 Hz) response of a calibrated condenser microphone and was found to be within the manufacturer's specifications.

Wave analyzing system. Before each use, the graphic wave analyzer was adjusted for minimal carrier frequency intensity at low frequencies and aligned for frequency analysis accuracy within design specifications. After this initial adjustment, intensity calibration was effected by introducing a recorded 75 dB SPL 1000-Hz reference tone into the wave analyzer from the tape recorder. The gain of the analyzer and the pen excursion of the graphic level recorder were adjusted for a 75 dB SPL indication on the graph paper. To insure stability of the wave analyzer's frequency calibration, a daily check was made of its response to a series of reference tones of known frequency produced by the pure tone oscillator.

Procedures

The experimental procedures in this study included: (a) recording the productions of the test vowels and connected speech samples, (b) presentation of the recorded vowels and sentences to judges for roughness rating, and (c) analyzing the recorded vowels to produce their frequency-by-amplitude acoustic spectra.

Recording Procedure

All vowel and connected speech samples were recorded in an acoustically isolated, two-room testing suite with a low ambient noise level. The test room contained the subject's chair, the sound level meter with its attached PZT microphone, the vocal-intensity-monitoring amplifier, and the signal lights to indicate the beginning and end of test vowel phonation. The adjoining control room contained the magnetic tape recorder and the cam timer which controlled signal light timing.

Each subject was first familiarized with the experimental procedures and was then seated in the examination chair. The chair's headrest was adjusted vertically for comfort, and a headstrap was employed to minimize changes in the subject's position with respect to the microphone during recording. The microphone was placed at a 70° angle of incidence to and six inches in front of the subject's mouth. The monitoring amplifier was positioned to allow the subject to observe readily the intensity of his phonations. A copy of the instructions read to the subjects is presented in APPENDIX A.

After being familiarized with the speech material, the subject practiced phonating each vowel at a constant intensity level as close to 75 dB SPL as was comfortably possible. The subject also practiced timing his phonations with the signal lights until he was able to sustain each vowel for seven seconds while maintaining the required intensity. The order of vowel presentation was randomized for each subject. The samples of connected speech, presented in random order, were produced at a comfortable intensity approximating 75 dB SPL. The investigator remained in the test room with each subject throughout the recording session to monitor the intensity of the speech samples and to cue the subject with printed cards bearing the vowel to be phonated and the connected speech sample to be spoken.

Each test phonation and spoken sample was carefully monitored by the experimenter. If the appropriate vowel or connected speech sample was not produced or if the subject did not maintain the required intensity, the trial was repeated until an acceptable performance was achieved. To provide data pertinent to an evaluation of the consistency of the subjects' performance of the experimental task, five subjects were required to repeat their productions of the test speech samples three times. On the basis of random selection, it was originally intended that consecutive subjects 9 through 13 serve in this portion of the study; however, subject 13 was unable to complete all three trials and he was subsequently replaced by subject 14 in this phase of the investigation. The three trials for each subject were completed on the same day with a ten minute rest period between trials. The experimental procedure was essentially the same over trials except that the order of presentation of the speech samples was randomized for each trial.

Rating Procedure

The speech samples produced by each subject were randomized by means of tape dubbing for rating. The vowels and sentences were rated in separate sessions. Eleven judges, all graduate students in speech pathology, independently evaluated the vocal roughness associated with each vowel and sentence production using a five-point-equal-appearing-intervals scale in which "1" represented least severe and "5" represented most severe roughness. The judges were seated in a semicircle facing the loudspeaker in an acoustically isolated room. The recorder used to reproduce the speech samples was located in an adjoining control room.

Prior to the listening sessions, the investigator made a preliminary rating of all vowel and sentence productions. Four vowel productions, two representing each of the extremes of the rating scale, were selected. These vowels were played several times to the judges before actual rating began to provide them with a common reference for the extremes of the roughness rating scale. A copy of the instructions given to the judges is presented in APPENDIX B.

The vowel judgment session was approximately two hours in length. The vowels were presented in four series each consisting of fifty vowels with ten minute rest periods between series. The final fifty vowels were productions selected randomly from those presented earlier and were included to evaluate intra-judge reliability. A Pearson $\underline{r}$ of .94 was obtained when the median values of the eleven judges' first and second ratings of the fifty vowels in the reliability sample were related. When percentages of intra-judge agreement $\pm$ 1 scale value for the two ratings of the fifty vowel productions were computed, the lowest percentage of agreement, 92%, was obtained for judges 8 and 11. The lowest percentage of inter-judge vowel roughness rating agreement, 88%, for the one hundred and fifty experimental samples, was obtained when the vowel ratings of judge 2 were compared to those of judge 8. These results, which are presented in APPENDIX C, appeared to indicate that intra- and inter-judge reliability was adequate for this study.

Before rating roughness of sentences the judges heard four sentence productions preselected by the researcher, two representing each of the rating scale extremes. A copy of the instructions given to judges for rating connected speech samples is presented in APPENDIX B.

The sentence judgment session was approximately one and one-half hours long. The sentences were presented in two series of fifty sentences each. The first series consisted of fifty samples of the sentence "Joe took father's shoe bench out." The second series consisted of fifty samples of the sentence "They have bought a new car." A ten minute rest period was provided between series. The final twenty sentences in each fifty sentence series were samples selected randomly from those presented earlier and were included to evaluate intra-judge reliability. For both test sentences, a Pearson $\underline{r}$ of .97 was obtained when the median values of the judges' first and second ratings of the reliability samples of each sentence were related. Percentages of intra-judge agreement $\pm$ 1 scale value for two ratings of the twenty sentences in each series were computed. For the sentence "Joe took father's shoe bench out," the lowest percentage, 90%, was obtained for judges 6 and 7. For the sentence "They have bought a new car," the lowest percentage, 95%, was obtained for judges 5 and 10. Percentages of inter-judge sentence roughness rating agreement $\pm$ 1 scale value for the thirty samples of each sentence not included in the reliability sample, were also computed. The lowest percentage obtained for the sentence "Joe took father's shoe bench out" was 87%. The lowest percentage for the sentence "They have bought a new car" was 86%. The results of these procedures are presented in APPENDIX C. The intra and inter-judge reliability indicated by these data appeared adequate for this study.

Spectral Analysis Procedure

Magnetic tape loops were constructed from the recordings of each vowel produced by each subject. The loops were two seconds in duration (tape speed of 15 ips) and were constructed from a central portion of the vowel recording displaying the most uniform intensity as monitored from the recorder's VU meter. Initial and terminal vowel inflections were omitted. The vowel loops were played individually into the graphic wave analyzer to obtain a 3-Hz bandwidth frequency-by-amplitude spectrum of each vowel. The analyzer was operated at a paper speed of 0.5 inches per minute and a writing speed of 20 inches per second to insure adequate data resolution and to minimize writing stylus overshoot.

To evaluate the level of test room and instrumental system noise during data collection, recordings of test chamber noise were made at various times during the day. Tape loops constructed from these recordings were analyzed to produce 3-Hz bandwidth room noise spectra. To provide an estimate of system noise levels the high peak of energy in each 100 Hz spectral section from 100 Hz to 8000 Hz was measured in each spectrum. Low noise levels attributable to the instrumental systems and test chamber were evident at all frequencies throughout the total spectral frequency range. Spectra derived from system noise recordings made at different times during the day evidenced low noise levels, and there was negligible variation in the spectra of all test-chamber noise recordings.

To provide a quantitative index of vowel spectral noise levels, the lowest observable peak graphic level recorder stylus marking in each 100-Hz section of each vowel spectrum was measured in dB SPL. Seventy-nine measures, one for each successive 100-Hz section from 100 Hz to 8000

Hz, were obtained from the spectrum of each vowel. Stylus marking overlap, in some instances, may have precluded measurement of the true low peak in a 100-Hz section; however, measurement of the lowest observable peak provided a numerical index of vowel spectral noise levels. Occasionally, vowel noise levels did not exceed system levels. When this occurred, the high peak system noise level in that 100-Hz spectral section was recorded as the highest noise level possible at the measurement point.

CHAPTER IV

RESULTS AND DISCUSSION

Results

This study investigated vowel spectral noise levels and roughness ratings for vowels and for samples of connected speech. Twenty adult males presenting clinically significant vocal roughness associated with laryngeal pathology individually produced each of five vowels /u/, /i/, /ʌ/, /ɑ/, and /æ/ at one intensity, and each of two sentences, "Joe took father's shoe bench out" and "They have bought a new car." Tape recordings of the vowels and each of the two sentences were presented to a group of eleven judges who rated each production for roughness on a five-point equal-appearing intervals scale. The vowel productions were judged together, but the productions of each of the two sentences were judged separately. Each recorded vowel production was also analyzed to produce and 3-Hz bandwidth frequency-by intensity spectrum from 0 Hz to 8000 Hz of its acoustic components. Noise levels were measured in successive 100-Hz sections of each vowel spectrum and these measures were related to the roughness rating for the vowels and sentences. The roughness ratings for each vowel were also related to those for each of the two sentences.

Ratings

Table 1 presents the median roughness ratings for each of the five vowels and two sentences produced by each of the twenty subjects. For this and subsequent presentations the sentence "Joe took father's shoe bench out" is identified as "Sentence 1;" "They have bought a new car" is identified as "Sentence 2". It may be seen in Table 1 that the median ratings for individual productions of each test vowel and each sentence represented a range of roughness, but the range was not the same for all test vowels. Generally, ratings for the high vowels /u/ and /i/ tended to cluster toward the low-roughness end of the rating scale, while ratings for the low vowels /ɑ/ and /æ/ and the mid vowel /ʌ/ were more frequently toward the high-roughness end of the scale. The range of median roughness ratings assigned to each test vowel was: /u/, 1.11 to 4.00; /i/, 1.11 to 4.89; /ʌ/, 1.19 to 5.00; /ɑ/, 1.60 to 5.00; /æ/, 1.94 to 5.00. Because they were judged independently, however, the productions of each of the two sentences received roughness ratings ranging over the entire five-point scale.

Table 2 presents median roughness ratings for productions of each vowel and each sentence averaged over the twenty subjects. This Table reveals that the high vowels /u/ and /i/ tended to be rated less rough than the other test vowels, with /u/ rated less rough than /i/. There was little separation among the average median ratings for the mid vowel /ʌ/ and the low vowels /ɑ/ and /æ/. The scale value separation between the vowel extremes is .93. Identical average roughness ratings, between those representing the vowel extremes, were obtained for each of the two sentences.

To investigate the degree of association among the median

TABLE 1

MEDIAN ROUGHNESS RATINGS FOR EACH OF FIVE VOWELS AND EACH OF TWO SENTENCES PRODUCED BY TWENTY ADULT MALES PRESENTING CLINICAL VOCAL ROUGHNESS

	Vowels					Sentences*	
Subject	/u/	/i/	/ʌ/	/ɑ/	/æ/	1	2
1	3.75	4.59	2.06	4.81	3.42	4.00	3.14
2	4.00	4.89	5.00	4.95	5.00	4.95	4.89
3	3.81	2.92	5.00	4.89	4.89	3.75	4.00
4	3.71	3.14	3.89	2.42	4.00	2.94	3.86
5	1.42	1.11	1.19	1.60	2.11	1.05	1.19
6	3.81	4.06	4.89	4.19	4.89	4.05	4.81
7	2.00	2.06	3.80	3.14	2.71	4.08	3.81
8	1.42	1.29	4.19	3.59	3.08	3.00	2.94
9	1.11	1.59	2.42	1.81	2.05	1.19	1.00
10	2.20	2.59	2.19	2.60	2.81	2.00	1.80
11	1.89	2.14	3.95	2.71	3.00	1.95	1.94
12	2.14	1.60	2.29	3.71	2.62	1.95	2.00
13	3.60	4.42	5.00	5.00	4.95	4.95	4.95
14	2.20	2.95	3.89	4.42	4.71	4.40	4.71
15	1.29	1.75	1.75	1.60	1.94	1.81	1.95
16	3.75	4.89	5.00	5.00	5.00	5.00	5.00
17	2.14	4.42	3.00	3.86	3.00	1.62	2.00
18	3.71	4.14	5.00	4.95	5.00	4.25	3.86
19	1.11	1.29	2.00	2.40	2.94	1.00	1.00
20	2.92	2.25	3.14	2.86	2.29	2.59	1.81

* Sentence 1 - "Joe took father's shoe bench out."
Sentence 2 - "They have bought a new car."

TABLE 2

MEDIAN ROUGHNESS RATINGS FOR EACH VOWEL AND EACH SENTENCE AVERAGED OVER TWENTY SUBJECTS

Speech Sample	Average Median Roughness Rating
/u/	2.60
/i/	2.90
/ʌ/	3.48
/æ/	3.52
/ɑ/	3.53
Sentence 1	3.03
Sentence 2	3.03

roughness ratings for the vowels and the sentences, a correlation statistic (Pearson $\underline{r}$) was employed. A very high coefficient (.96) was obtained when the roughness ratings for Sentence 1 were related to those for Sentence 2. Table 3 shows that the correlation coefficients obtained when the roughness ratings for each test vowel were related to those for each sentence were all high ($\geq .72$) and significant ($P < .05$). When ratings for each test vowel were related to those for Sentence 1, the vowels could be ranked in order of increasing coefficients: /i/, /u/, /ʌ/, and /ɑ/ and /æ/ tied. When vowel ratings were related to those for Sentence 2, the order was: /i/, /u/, /ɑ/, /ʌ/, and /æ/. When the coefficients shown in Table 3 for high vowels are contrasted to those for low vowels, it is evident that the larger coefficients tended to be associated with the low vowels.

TABLE 3

CORRELATION COEFFICIENTS INDICATING THE RELATIONSHIP BETWEEN THE RATINGS FOR EACH TEST VOWEL AND THOSE FOR EACH SENTENCE

Vowel	Correlation Coefficients [a]	
	Sentence 1 [b]	Sentence 2
/u/	.78	.77
/i/	.73	.72
/ʌ/	.80	.84
/ɑ/	.84	.79
/æ/	.84	.89

[a] All coefficients significant at .05 level as determined by analyses of variance.

[b] A coefficient of .96 was obtained when the ratings for Sentence 1 were related to those for Sentence 2.

Spectral Noise Levels

Example acoustic spectra for relatively smooth and relatively rough productions of one of the test vowels are presented in Figures 4 and 5 respectively. Figure 4 presents the spectrum of an /ɑ/ having a median roughness rating of 1.11 produced by subject five. Figure 5 presents the spectrum of an /ɑ/ having a median roughness rating of 5.00 produced by subject thirteen. It may be seen that, for both productions, the levels of harmonic and noise components tend to diminish from low to high spectral frequencies. Because the harmonic level diminishes more rapidly than the noise level with an increase in frequency, the harmonics tend to be obscured by noise at the higher spectral frequencies.

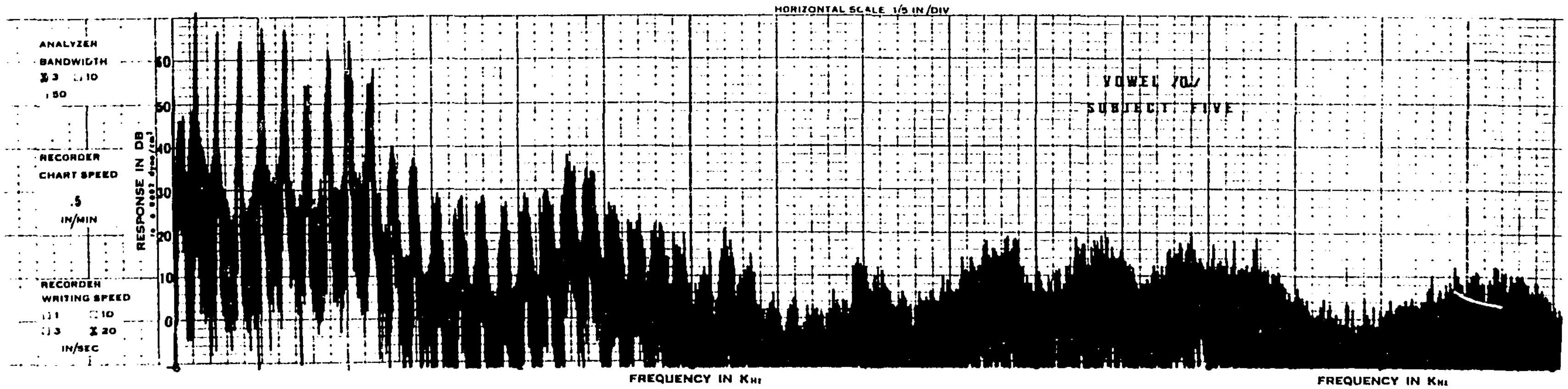

Figure 4.--Spectrum of an /ɑ/ having a median roughness rating of 1.11.

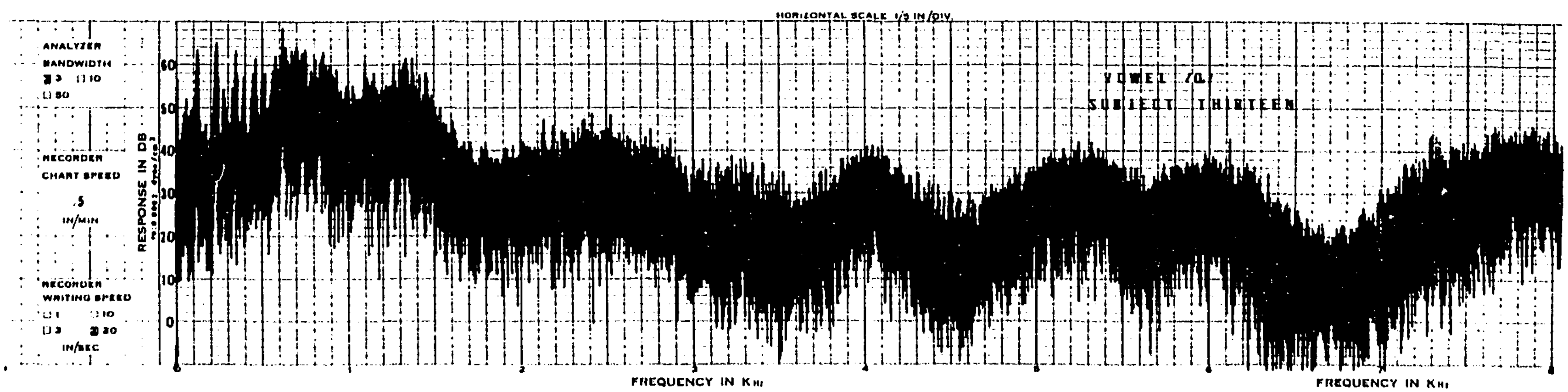

Figure 5.--Spectrum of an /ɑ/ having a median roughness rating of 5.00.

Figures 4 and 5 also reveal a tendency for the spectral noise levels to reflect the vowel formants. That is, relatively low spectral noise levels are seen between formants and increased levels are evident at formant locations. When Figures 4 and 5 are contrasted, however, it is evident that the relatively smooth vowel production was characterized by prominent harmonics and comparatively low spectral noise levels, while the relatively rough production evidenced diminished harmonics and elevated noise levels. In general, features similar to these for /ɑ/ were evident for all the test vowel spectra.

Spectral noise level (SNL) means and their standard deviations for each of the test vowels are presented in Table 4. The SNLs in Table 4 are averaged over all subjects, over the total spectral range (TSR), and, separately, over each of four spectral segments (SSs). The SSs studied were: segment one (S-1), 100 Hz to 2600 Hz; segment two (S-2), 2600 Hz to 5100 Hz; segment three (S-3), 5100 Hz to 8000 Hz; and segment four (S-4), 100 Hz to 5100 Hz. These segments were selected because earlier studies (49, 68) suggest that they may relate somewhat differently to perceived vowel roughness; possibly, because they differ in the extent to which they include the formant frequencies of the vowels. Table 4 shows that for each SS and the TSR the smallest SNL mean was obtained for /u/, and the largest for /æ/. When SNL means for S-1, S-4, and the TSR were considered, the order of vowels with respect to increasing means was: /u/, /i/, /ʌ/, /ɑ/, and /æ/. Reversals in this order occur among the SNL means for S-2 and S-3. Table 4 reveals a decrease in the SNL mean from S-1 to S-3 for the mid vowel /ʌ/ and the low vowels /ɑ/ and /æ/. The decrease from S-1 (100 Hz to 2600 Hz) to S-2 (2600 Hz to 5100 Hz) is approximately ten dB; from S-2 to S-3 (5100 Hz to 8000 Hz)

TABLE 4

VOWEL SPECTRAL NOISE LEVEL (SNL) MEANS AND STANDARD DEVIATIONS FOR EACH OF FIVE VOWELS PRODUCED BY TWENTY ADULT MALES PRESENTING CLINICAL VOCAL ROUGHNESS

Spectral Segment S-1 (100 Hz to 2600 Hz)		
Vowel	SNL Mean	Standard Deviation
/u/	18.8	4.9
/i/	20.1	7.1
/ʌ/	30.3	5.4
/ɑ/	31.0	6.6
/æ/	34.3	4.9
Spectral Segment S-2 (2600 Hz to 5100 Hz)		
Vowel	SNL Mean	Standard Deviation
/u/	6.7	4.8
/i/	20.9	7.9
/ʌ/	19.8	13.0
/ɑ/	20.1	7.9
/æ/	23.4	6.3
Spectral Segment S-3 (5100 Hz to 8000 Hz)		
Vowel	SNL Mean	Standard Deviation
/u/	7.3	7.7
/i/	16.7	8.9
/ʌ/	14.9	11.3
/ɑ/	14.1	10.5
/æ/	18.4	11.4

TABLE 4-- Continued

Vowel	Spectral Segment S-4 (100 Hz to 5100 Hz) SNL Mean	Standard Deviation
/u/	12.7	4.4
/i/	20.5	6.6
/ʌ/	23.5	5.3
/ɑ/	25.6	6.3
/æ/	28.9	5.2

Vowel	Total Spectral Range (100 Hz to 8000 Hz) SNL Mean	Standard Deviation
/u/	10.9	4.9
/i/	19.2	6.6
/ʌ/	20.7	6.9
/ɑ/	21.8	6.9
/æ/	25.3	6.6

approximately five dB. For the high vowel /u/, the SNL mean decreases from S-1 to S-2 by approximately twelve dB; however, a slight increase in the mean occurs from S-2 to S-3. The SNL mean for the high vowel /i/ is approximately the same for S-1 and S-2, but decreases by about five dB from S-2 to S-3.

Examination of the standard deviations for the vowel SNL means shown in Table 4 reveals that, in general, the greatest variability was associated with S-2 (2600 Hz to 5100 Hz) and S-3 (5100 Hz to 8000 Hz), while least variability was associated with S-1 (100 Hz to 2600 Hz). It may also be seen that the standard deviations for the vowel /u/ are generally smaller than those for the other vowels regardless of the spectral segment considered.

Spectral Noise Level and Roughness Rating Relationships

An objective of this study was to investigate possible relationships between vowel spectral noise levels and roughness severity ratings. To study these relationships, scatter diagrams relating SNL means and median roughness ratings for each of the test vowels were plotted. Separate plots were made to show relationships between vowel roughness and SNL means for the TSR and each SS. The diagrams suggested a positive relationship between SNL means over each SS and the TSR and the median roughness ratings for each of the test vowels. In general, vowel roughness tended to increase with an increase in the level of spectral noise, regardless of the spectral frequency range over which the SNL means were computed. Because spectral noise levels and vowel roughness appeared to be most closely associated when S-1 SNL means were considered, a portion (100 Hz to 1600 Hz) of the S-1 frequency range (100 Hz to 2600 Hz) was selected for a more detailed inspection. The frequency range considered was thus limited because it was of interest to study the possibility that a high degree of relationship would obtain between SNLs for a limited frequency range and vowel roughness ratings.

For the individual productions of each test vowel, a multiple regression analysis was performed relating the SNLs in each of fifteen 100-Hz spectral sections from 100 Hz to 1600 Hz to the production's median roughness rating. Table 5, presents the multiple correlation coefficients obtained for each vowel. The magnitude of these coefficients indicates a high degree of linear relationship between the first fifteen 100-Hz spectral section SNLs and the median roughness ratings for each of the test vowels. Because the multiple correlation coefficients were

TABLE 5

CORRELATION COEFFICIENTS FOR THE MULTIPLE REGRESSION BETWEEN SPECTRAL NOISE LEVELS IN EACH OF FIFTEEN SEQUENTIAL 100-Hz SPECTRAL SECTIONS FROM 100 Hz to 1600 Hz AND ROUGHNESS RATINGS FOR EACH TEST VOWEL

Vowel	Correlation Coefficients *
/u/	.96
/i/	.99
/ʌ/	.98
/ɑ/	.96
/æ/	.98

* All coefficients significant at .05 level as determined by analyses of variance.

uniformly high and significant, the median roughness rating for each test vowel production could be predicted from its first fifteen 100-Hz section SNLs. For each vowel production the multiple linear regression equation used for the prediction was:

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots + B_{15}X_{15}$$

where Y equals the roughness prediction, B_0 the Y intercept determined by the regression analysis, B_{1-15} the regression coefficients determined by the regression analysis, and X_{1-15} the successive 100 Hz section SNLs from 100 Hz to 1600 Hz for each vowel production.

Table 6 shows the judge's median roughness rating, roughness ratings predicted by the linear model, and residuals (the observed roughness rating minus the predicted rating) for each subject's production of the vowel /ɑ/. Residuals for this vowel were the largest obtained and are presented to show the magnitude of the greatest residuals resulting from use of this regression equation. It can be seen in Table 6 that the roughness predictions for only two of twenty vowel productions deviated more than .50 scale value from the median roughness rating actually obtained for those productions.

It was also of interest in this study to investigate possible relationships between spectral noise levels for the five test vowels and the median roughness ratings for each of the two test sentences. To provide pertinent data, a series of multiple regression analyses were performed. Each analysis related vowel SNLs to the roughness judgments for the samples of connected discourse. The analyses differed, however, with respect to the way in which the vowel SNL measures of interest were delineated. In all, the vowel SNLs were considered in five different

TABLE 6

MEDIAN ROUGHNESS RATINGS FOR ELEVEN JUDGES, ROUGHNESS RATINGS PREDICTED BY THE REGRESSION EQUATION, AND RESIDUALS FOR TWENTY SUBJECTS' PRODUCTIONS OF THE VOWEL /ɑ/

Subject	Roughness Rating	Prediction	Residual
1	4.81	5.26	-.45
2	4.95	4.66	.28
3	4.89	4.90	-.01
4	2.42	2.34	.07
5	1.60	1.82	-.22
6	4.19	3.71	.47
7	3.14	2.97	.16
8	3.59	3.40	.18
9	1.81	2.26	-.45
10	2.60	2.33	.26
11	2.71	2.69	.01
12	3.71	3.94	-.23
13	5.00	5.27	-.27
14	4.42	3.88	.53 *
15	1.60	1.91	-.31
16	5.00	4.41	.58 *
17	3.86	4.28	-.42
18	4.95	5.11	-.16
19	2.40	2.78	-.38
20	2.86	2.48	.37

* Residual > .50 scale value

ways. First, the S-1 (100 Hz to 2600 Hz) SNL means for each of the five vowels were related to the median roughness ratings for each of the two sentences (Method 1). Then, in independent analyses, the S-2 (2600 Hz to 5100 Hz), S-3 (5100 Hz to 8000 Hz), and TSR (100 Hz to 8000 Hz) SNL means for each of the five vowels were related to the roughness ratings for each of the two sentences (Methods 2, 3, and 4 respectively). Finally, the S-1, S-2, and S-3 SNL means for each of the five vowels were related to the roughness ratings for each sentence (Method 5). Table 7

TABLE 7

CORRELATION COEFFICIENTS FOR THE MULTIPLE REGRESSION BETWEEN VOWEL SPECTRAL NOISE LEVELS AND ROUGHNESS RATINGS FOR EACH TEST SENTENCE

Method of Multiple Regression Analysis	Correlation Coefficient	
	Sentence 1	Sentence 2
1	.84	.79
2	.65	.68
3	.72	.78
4	.77	.81
5	.97	.97

presents the multiple correlation coefficients obtained when vowel SNLs delineated by each of the five Methods described above were related to the roughness ratings for each of the two sentences. The highest coefficients were obtained when the SNLs were specified by Method 5. The magnitude of the coefficients associated with Method 5 (.97) suggested that the roughness ratings for both of the test sentences might be predicted from vowel SNLs specified by this Method. When such predictions were made utilizing a suitable multiple regression equation, it was found that the obtained residuals (observed rating minus predicted rating) for only three of twenty productions of each of the sentences exceeded .50 scale value.

Pathology Groups

The subjects in this study each presented one of five different types of laryngeal pathology: (a) vocal cord polyps, (b) laryngeal carcinoma, (c) vocal cord paralysis, (d) benign laryngeal masses, and (e) laryngeal inflammation and edema. Though the small number of subjects in each pathology group precluded extensive generalization concerning group differences, the vowel and sentence productions of subjects presenting vocal cord paralysis and vocal cord polyps tended to be rated slightly more rough and to exhibit higher vowel SNLs than those of subjects presenting the other types of pathology. Regardless of the type of pathology presented, subjects generally evidenced a tendency to produce the high vowels /i/ and /u/ with less roughness and smaller SNL means than the low vowels /ɑ/ and /æ/ and the mid vowel /ʌ/. The vowel and sentence roughness ratings and vowel SNLs averaged over S-1 and the TSR are presented for each pathology group in APPENDIX E.

Repeated Trials

Because it was of interest in this study to evaluate the reliability of subjects' performance of the experimental task, five subjects were required to repeat the test vowels and connected speech samples three times. Subjects 9 through 12 and subject 14 participated in this portion of the study. Table 8 presents vowel SNLs for S-1 (100 Hz to 2600 Hz) and the TSR (100 Hz to 8000 Hz) and vowel and sentence median roughness ratings for each trial by each subject. Findings for the individual subjects shown in Table 8 reveal that SNLs and roughness ratings for each of the three trials by each subject were generally similar, although some variation over trials is evident. When the difference between the lowest and the highest SNL in each three-trial series was computed for each vowel produced by each subject, it was found that the average SNL difference among trials was 4.2 dB for S-1 and 4.8 dB for the TSR. Table 8 shows that roughness ratings for repeated sentence productions tended to be less variable than those for repeated vowel productions. The average difference between the lowest and highest roughness rating in a three trial series for all subjects was .84 scale value for vowels, and .25 and .37 scale value for Sentence 1 and Sentence 2.

Discussion

Because this study paralleled in many of its design features earlier studies of normal phonation and simulated "abnormal" vocal roughness by Sansone (68) and by Lively (49), numerous comparisons of the present findings with those reported by Sansone and Lively were possible. As the following discussion reveals, an assumption of the Sansone and Lively investigations that the study of simulated "abnormal" vocal roughness in vowels would aid in understanding the clinical voice problem tends to be supported by the present findings. The present study, however, investigated vocal roughness in connected speech as well as in

TABLE 8

VOWEL SPECTRAL NOISE LEVEL MEANS FOR S-1 AND THE TSR, AND VOWEL AND SENTENCE MEDIAN ROUGHNESS RATINGS (MRR) FOR FIVE VOWELS AND TWO SENTENCES PRODUCED THREE TIMES BY EACH OF FIVE SUBJECTS

Vowel	Subject	Trial	S-1 (100 Hz to 2600 Hz)	TSR (100 Hz to 8000 Hz)	MRR
		1	16.0	8.4	1.11
	9	2	14.4	5.5	1.05
		3	15.0	6.2	1.75
		1	19.7	9.5	2.20
	10	2	22.2	12.3	2.71
		3	18.7	7.2	1.75
		1	24.0	13.0	1.89
/u/	11	2	20.2	8.8	2.40
		3	19.6	11.8	2.00
		1	18.4	7.9	2.14
	12	2	15.8	8.1	2.59
		3	17.4	10.4	2.59
		1	17.1	13.8	2.20
	14	2	20.8	16.2	3.40
		3	19.4	15.4	2.40
		1	17.9	19.9	1.59
	9	2	18.6	17.7	1.19
		3	16.6	16.3	1.75
		1	24.6	21.8	2.59
	10	2	23.8	20.1	3.25
		3	20.1	18.5	2.06
		1	10.8	11.5	2.14
/i/	11	2	6.6	10.3	2.08
		3	8.9	13.4	2.08
		1	16.1	13.2	1.60
	12	2	13.1	16.9	2.19
		3	15.4	17.3	2.71
		1	16.1	16.7	2.95
	14	2	19.0	26.3	3.92
		3	13.4	21.2	3.25

TABLE 8--Continued

Vowel	Subject	Trial	S-1 (100 Hz to 2600 Hz)	TSR (100 Hz to 8000 Hz)	MRR
		1	25.3	17.2	2.42
	9	2	26.6	19.1	1.11
		3	31.8	20.5	2.42
		1	26.6	16.1	2.19
	10	2	25.7	15.0	2.29
		3	33.3	22.0	2.81
		1	33.7	23.5	3.95
/ʌ/	11	2	33.0	21.6	2.95
		3	19.6	13.8	2.11
		1	31.1	14.1	2.29
	12	2	32.6	22.2	3.25
		3	34.2	19.4	3.08
		1	29.6	22.7	3.89
	14	2	35.4	31.0	4.71
		3	34.7	30.9	4.59
		1	29.0	16.2	1.81
	9	2	28.6	19.4	2.06
		3	30.2	17.6	2.80
		1	23.2	18.4	2.60
	10	2	26.3	19.3	2.94
		3	27.3	18.9	2.11
		1	25.7	21.1	2.71
/ɑ/	11	2	26.8	20.5	2.60
		3	25.1	17.9	2.00
		1	39.4	24.8	3.71
	12	2	34.8	20.1	3.14
		3	30.9	17.4	2.80
		1	33.0	31.5	4.42
	14	2	34.4	28.3	4.25
		3	35.3	29.7	4.42

TABLE 8--Continued

Vowel	Subject	Trial	S-1 (100 Hz to 2600 Hz)	TSR (100 Hz to 8000 Hz)	MRR
		1	32.8	22.1	2.05
	9	2	35.0	21.6	2.81
		3	35.8	25.7	2.86
		1	30.2	16.4	2.81
	10	2	34.3	22.7	2.29
		3	33.8	23.8	2.42
		1	33.4	22.7	3.00
/æ/	11	2	31.8	18.4	2.60
		3	35.1	26.7	4.59
		1	38.1	21.6	2.62
	12	2	34.4	21.9	3.19
		3	36.5	22.5	3.00
		1	39.1	33.1	4.71
	14	2	39.3	37.0	4.71
		3	37.5	32.2	4.42

Sentence	Subject	Trial	MSR	Sentence	Subject	Trial	MRR
		1	1.19			1	1.00
	9	2	1.19		9	2	1.00
		3	1.19			3	1.11
		1	2.00			1	1.80
	10	2	2.29		10	2	2.14
		3	2.05			3	2.00
		1	1.95			1	1.94
1	11	2	2.11	2	11	2	1.75
		3	1.29			3	1.60
		1	1.95			1	2.00
	12	2	1.89		12	2	2.00
		3	1.95			3	2.42
		1	4.40			1	4.71
	14	2	4.06		14	2	4.25
		3	4.42			3	4.89

isolated vowels, while only vowels were studied by the cited investigators.

The present judgment findings indicated that the order of vowels with respect to increasing roughness was: /u/, /i/, /ʌ/, /æ/, and /ɑ/. These findings are consistent with those of other investigators (49, 68, 65, 70) and appear to support a hypothesis that the degree of vowel roughness tends to be inversely related to tongue height.

The finding that there was, in general, a high degree of relationship between the judged roughness for the vowels and that for the sentences suggests that the roughness rating for the samples of connected speech produced by each subject might be estimated from the roughness ratings for his isolated vowel productions. The strongest vowel and sentence relationship was observed between the ratings for the vowels /ʌ/, /ɑ/, and /æ/ and those for each of the sentences. When vowels are considered individually, therefore, it appears that ratings for a mid or low vowel might serve better than those for a high vowel as a basis for estimating sentence roughness when the sentences are similar to those studied in this investigation. Both of the sentences for this study contained high, mid, and low vowels, and both received similar roughness ratings. The high degree of relationship observed between the roughness ratings for the low and mid vowels and those for the two test sentences suggest that the judgment of sentence roughness may be predicated primarily upon the perceived quality of the roughest phonetic elements within the sentence, for sentences containing a variety of vowels. It may be, however, that the present vowel and sentence rating-relationships will not hold when the samples of connected speech are constituted differently from those in this study. Sherman and Linke (70) found that the vowel content of a connected speech sample tends to influence the degree of harshness perceived for the sample. They reported that passages containing predominantly low vowels tended to be perceived as more harsh than those containing predominantly high vowels, when read aloud by harsh-voiced subjects.

The present judgment findings may be considered with respect to Sherman's (69) observation that harshness ratings for connected speech may be confounded by the presence of "irrelevant factors" such as "pitch usage, articulation, effectiveness in conveying meaning," and other speech characteristics. This statement may be interpreted to imply that such factors would tend to affect the roughness ratings for sustained vowels less than those for sentences and, thus, might tend to minimize the roughness-rating relationship between vowels and sentences produced by the same subject group. While it cannot be ascertained that "irrelevant factors" did not affect the perceived roughness of the present speech samples, subjects producing relatively rough vowels tended to produce relatively rough sentences and vice versa. Thus, it would seem that the differential effect of any "irrelevant factors" on vowels and sentences in this study may have been of minimal importance. These findings for vocal roughness stand in marked contrast to those reported by others for nasality. Van Hattum (88), for example, studying cleft palate subjects, observed that nasality ratings for isolated vowels were not highly related to those for connected speech. In his study of cleft palate speakers, Bryan (7) reported that substantial prediction error may occur when nasality ratings for vowels are used to estimate those for connected speech.

In general appearance, the present vowel spectra were similar to those for normal and simulated rough productions reported by Sansone (68) and by Lively (49). With regard to measured SNLs, the values for the present vowel productions tended to be larger than those for the normal vowel productions and smaller than those for the simulated rough productions analyzed by Sansone and by Lively. Possibly, the subjects for this investigation tended to produce the test vowels with less roughness than that simulated by the subjects in the cited investigations. On the basis of this comparison of findings, the observation seems appropriate that SNLs for "abnormally rough" vowel productions tend to exceed those for normal productions both when the roughness is simulated by normal-speaking subjects and when it is presented clinically by subjects evidencing laryngeal pathology.

The finding that increases in vowel roughness were associated with increases in vowel spectral noise levels is generally consistent with the results of previous studies. Nessel (57) observed, for vowels produced by pathologically hoarse speakers, an elevation of spectral noise both in the formant ranges and in higher frequencies. Yanagihara and his associates (35, 98) studied sonagrams of hoarse and normal vowel productions and noted for hoarse voices an increase in spectral noise levels and additional noise components in the formant and higher frequency regions. Both Sansone (68) and Lively (49) found that simulated rough vowel productions evidenced higher spectral noise levels than did normal vowel productions.

The present results also indicated that the test vowels tended to differ with respect to their spectral noise levels. In general, the low vowel SNL means tended to be larger than those for the higher vowels. For example, when S-1 (100 Hz to 2600 Hz) was considered, the order of vowels with respect to increasing SNL means was: /u/, /i/, /ʌ/, /ɑ/, and /æ/. This order is the same as that reported by Sansone (68) both for normal and for simulated rough vowels produced by males, and it closely resembles that reported by Lively (49) for normal and simulated rough vowels produced by females. For Lively's study, the order of both simulated rough vowels and normal vowels with respect to increasing S-1 SNL means was: /i/, /u/, /ɑ/, /ʌ/, and /æ/. These findings appear to support a hypothesis that the level of vowel spectral noise is influenced by the acoustic damping imposed by the configuration of the vocal tract during vowel production. Because different vocal tract configurations associated with different vowels are effected in part by tongue position adjustments, a relationship is seen between tongue position in vowel production and vowel SNLs. Specifically, the vowel SNLs tend to be inversely related to tongue height. The generation of noise components in vowels, however, may be attributable mainly to source function variations, i.e., to variations in glottal valving and in the related glottal volume-velocity wave (49, 35). Consideration of both glottic and supra-glottic factors appears necessary, therefore, to account for the presence and relative level of noise in the spectra of both normal and abnormally rough vowels.

The vowel SNL variability associated with each of the spectral segments in this study was of interest since it seemed possible that this information might be pertinent to the use of SNL measures in clinical voice evaluations. The present findings indicate that less vowel SNL variability was associated with the low frequency spectral segment S-1 (100 Hz to 2600 Hz) than with segments having a higher frequency range. Both Lively (49) and Sansone (68) also reported that less normal vowel SNL variability was associated with S-1 than with other spectral segments. It has been noted (62, 18, 22) that the formants of greatest importance to perceptual vowel identification are those located in the low frequency portions of the acoustic spectrum. It may be as Sansone (68) has suggested, therefore, that subjects tend to control the distribution of acoustic energy in the low spectral frequencies to preserve vowel identity, thus limiting SNL variability in that spectral frequency region.

In this study, less SNL variability was associated with /u/ than with the other test vowels, regardless of the spectral segment considered. Similar findings were reported by Sansone (68) for normal vowels produced by adult males. In her analysis of vowels produced normally by adult females, however, Lively (49) found that, when all spectral segments were considered, /u/ did not consistently evidence less SNL variability than her other test vowels. At this time, therefore, the diminished SNL variability associated with /u/ would seem to be a sex dependent phenomenon. Further study will be needed, however, to ascertain whether this tentatively identified sex difference is reliable.

Generally, the present results indicated that the level of vowel spectral noise was closely related to the degree of perceived vowel roughness. High and significant ($p < .05$) coefficients were obtained when the vowel SNL measures over a very limited spectral frequency range (100 Hz to 1600 Hz) were related to the roughness ratings for each vowel utilizing a multiple correlation procedure. The coefficients for /u/ and /ɑ/ were .96, those for /ʌ/ and /æ/ were .98, and the coefficient for /i/ was .99. These coefficients are comparable to those obtained by Lively (49) and by Sansone (68) when SNLs for a broader frequency range (100 Hz to 2600 Hz) were similarly related to the roughness ratings for the normal and simulated rough vowel productions of females and males respectively. Sansone (68) reported multiple regression coefficients of .98 for the vowels /i/, /u/, /ʌ/, and /æ/, and .97 for /ɑ/. Lively (49) reported coefficients of .97 for the vowels /ʌ/ and /ɑ/, .98 for /i/, and .99 for /u/ and /æ/. When a multiple regression equation was used in the present study to predict vowel roughness ratings from fifteen 100 Hz spectral section SNL measures from 100 Hz to 1600 Hz, the residuals indicating the difference between the predicted and obtained roughness rating for each vowel production tended to be small. Thus, it appears that accurate predictions of vowel roughness may be made from SNL measures taken over a limited spectral frequency range. This finding may have important implications with regard to the development of economical, objective procedures for the assessment of rough voice.

The present findings also indicate that vowel spectral noise levels and listener judgments of roughness in connected speech tend to be related. That is, increases in the level of vowel spectral noise were generally associated with increases in sentence roughness. Thus, sentence roughness could be predicted from vowel SNL measures when a suitable regression equation was employed. These findings suggest that, under the conditions of this study, meaningful inferences concerning the roughness of a subject's connected discourse may be made on the basis of information obtained from the spectrographic analysis of his isolated vowel productions. It may be, therefore, that vowel spectral noise measures could provide a useful quantitative index of vocal roughness in connected speech, though the validity of this hypothesis should be tested for a greater variety of vowels and sentences than were investigated in this study.

The possibility was considered in this investigation that immediately repeated utterances of the same vowel or sentence might differ markedly in perceived vocal roughness or in SNLs. The findings revealed that, for five subjects, neither the vowel SNLs nor the perceptual ratings of vowel and sentence roughness varied greatly over three repeated productions of each vowel and sentence. Possibly, however, greater voice quality and SNL changes would have been observed had the period of time between trials been longer. Because there was some variation in SNLs and in roughness ratings over consecutive trials, however, it may be that the SNL measures and roughness ratings most representative of a subject's behavior at a given time would be an average over repeated trials.

The results of this investigation have possible clinical implications. Currently, medical and speech clinicians tend to rely upon their perception of vocal roughness to alert them to the possible presence of laryngeal pathology (91). When abnormal roughness is detected, its severity is usually estimated in terms of a perceptual scale, e.g., mild, moderate, or severe, which is practical and seems meaningful to the listener. Individuals vary, however, in their ability to detect vocal roughness and to estimate its severity reliably. There is a need, therefore, for objective procedures which supplement and verify the perceptual impressions of clinicians in their evaluations of vocal quality. The present findings suggest that measures of vowel spectral noise might be utilized as an objective index of the roughness associated with vowel and isolated connected speech samples; thus, such measures may be useful in the clinical assessment of vocal roughness.

Lieberman (48) has previously suggested that measures of pitch perturbation in phonation may be similarly useful in the objective assessment of rough vocal quality. He found, however, that an accurate determination of pitch perturbation was not possible when large laryngeal growths interfered with normal vocal fold closure producing an acoustic wave that was "filled in". In contrast, the present investigation suggests that vowel spectral noise measures would be feasible even for severely rough voices. The fact that all of the subjects for this study were able to complete the experimental task at least once, regardless of the type or extent of their laryngeal pathology, lends support to the assumption that a procedure similar to that employed in this investigation may be clinically useful.

Further, the simplicity of the present spectral analysis and noise-level measurement procedure suggests the possibility of a practical screening test based on vowel SNL measures for the early detection of laryngeal pathology evidenced by vocal roughness. It would seem doubtful, however, that such a test would be sufficient in itself to identify the nature and extent of laryngeal pathology. Lieberman (48), for example, noted that a small growth directly on the vocal cord could produce larger pitch perturbations than a large growth which was near but not on the folds. Vowel SNLs may be similarly influenced by the location of the laryngeal involvement. This study did not permit an adequate test of this hypothesis, however, and further research would appear to be indicated.

In general, the present findings appear to be consistent with theoretical concepts indicating that the perception of vocal roughness for both normal and abnormal phonations is related to variations in the vibratory pattern of the vocal folds in phonation. With regard to normal phonation, it has been suggested (18, 84, 21, 23) that slight variations in the cyclic movements of the vocal folds are characteristic. Variations may occur, for example, in the periods of successive glottic cycles and in the symmetry of movements of the two vocal folds within and across cycles. Such normal variations are thought to create variations in the shape, amplitude, and period of the glottal volume-velocity wave (21, 23, 34, 35, 97). These glottal volume-velocity wave variations, in turn, are thought to produce variations in the acoustic voice wave; specifically,in the shape, amplitude, and period of that wave. Finally, acoustic voice wave variations would appear to be manifested spectrographically as spectral noise which is distributed over a broad spectral frequency range. Because vocal fold movements in normal phonation are at best quasi-periodic, therefore, measurable spectral noise levels are reported for normal vowel productions (49, 68).

As indicated by the present study, however, spectral noise levels tend to be elevated for subjects presenting laryngeal pathology, apparently because the pathology disturbs the periodicity and symmetry of vocal fold movements in phonation beyond normal limits (35, 97, 98). It may be hypothesized too that elevated spectral noise levels would characterize vocal roughness attributable to functional laryngeal hypo- or hyperkinesis; or, to extend the hypothesis, to any underlying etiology which effects the requisite disturbance in vocal fold function. In this regard, the similarity in appearance of the present vowel spectra to those reported by Sansone (68) and by Lively (49) for vowels produced with simulated roughness suggests that simulated roughness is acoustically quite similar to that associated with laryngeal pathology. It would appear, therefore, that investigations of the spectral features of simulated vocal roughness might be expected to provide information pertinent to an understanding of the vocal roughness associated with laryngeal pathology.

It is of interest that the present findings did not seem to lend support to a hypothesis that there are subtypes of vocal roughness which are readily discernable on the basis of an analysis of narrow-band acoustic vowel spectrographs. For example, no patterns were seen sharply differentiating the rough vowels into distinct spectral categories which might relate to the perceptual differentiation of hoarseness and harshness. Possibly, therefore, this study suggests the acoustic basis for Thurman's (82) observation that listeners tend to be unreliable in their attempts to differentiate hoarse and harsh voices. The present findings raise a question by implication, therefore, regarding the possibility that terms like "hoarseness", "harshness", and "roughness" are often merely different labels applied to essentially the same percept. Further investigation to test the validity of these hypotheses is indicated.

The present findings also suggest the possibility of defining the limits of normal and abnormal vocal roughness in terms of the level of spectral noise associated with vowels. If it may be assumed that listeners can make reliable judgments regarding the normality and abnormality of the roughness associated with vowel samples, then the range of SNLs associated with normal and with abnormal samples could then be specified. Such an objective delineation of normal and abnormal vowel productions might have important clinical and research implications.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate spectral noise levels (SNLs) in narrow-band (3-Hz) spectra of vowels produced by adult males presenting vocal roughness associated with laryngeal pathology. Also investigated were possible relationships between the vowel SNLs and the perceived roughness of the vowels and connected speech samples. The need for this investigation became evident when studies by Sansone (68) and by Lively (49), utilizing adult male and adult female subjects respectively, indicated that measures of spectral noise for normal and for simulated rough vowel productions were correlated highly and positively with the roughness of the vowels. This study sought to investigate the possibility that similar relationships would obtain for the phonations of clinical subjects. Because major features of the experimental design employed by Sansone and by Lively were replicated in this study, comparisons of the present findings for clinical subjects to those from the cited investigations were possible.

Twenty adult males presenting laryngeal pathology and rough voices served as subjects for this investigation. The subjects individually produced each of the vowels /u/, /i/, /ʌ/, /ɑ/, and /æ/, and each of the sentences "Joe took father's shoe bench out," and "They have bought a new car." Each vowel production was sustained for seven seconds at 75 dB SPL at a mouth-to-microphone distance of six inches. Similarly, the sentences were produced at a comfortable intensity approximating 75 dB SPL. The vowel and sentence productions were recorded on magnetic tape and were randomized for presentation to eleven trained judges for roughness rating. The vowels and the sentences were judged separately. Anchor samples representing the rating scale extremes were presented to the judges at the beginning of each of the judgment sessions. Each judge rated the vowels and sentences on a five-point equal-appearing intervals scale in which "1" represented least severe and "5" represented most severe roughness. The median of the eleven judges' ratings for each speech sample was computed as an index of its roughness. The recording of each vowel production was also analyzed to produce a narrow-band (3-Hz) frequency-by-amplitude spectrum of its acoustic components from 0 Hz to 8000 Hz. This analysis was made from two-second tape loops constructed from a central portion of each vowel production evidencing a uniform intensity. To provide a quantitative index of vowel spectral noise, the lowest observable peak of energy in each of seventy-nine successive 100-Hz sections from 100 Hz to 8000 Hz was measured in dB SPL in each vowel spectrum.

The findings indicated that the high vowels /u/ and /i/ tended to be rated less rough than the other test vowels, with /u/ rated less rough than /i/. There was little separation among average median ratings for the mid and low vowels. Average median roughness ratings for each of the two sentences were equal and were between those for the vowel extremes.

When roughness ratings for each test vowel were related to those for each sentence, the obtained correlation coefficients were all high ($\geq$ .72) and significant at the .05 level. Roughness ratings for low vowels appeared to be more highly related to sentence ratings than did those for high vowels. A very high correlation (.96) was obtained when the roughness ratings for each of the two sentences were related.

The findings also indicated that increases in vowel roughness were associated with elevated spectral noise levels. Relatively smooth vowel productions were characterized by prominent harmonics throughout much of the spectral frequency range, while the rougher productions evidenced diminished harmonics and elevated noise levels across the total spectral range. For each test vowel, the levels of harmonic and noise components tended to diminish from low to high spectral frequencies. Vowel spectral noise levels tended to be relatively high in formant ranges and relatively low in interformant and higher frequency ranges. Increases in vowel spectral noise levels appeared to be associated with decreases in tongue height in test vowel production. When spectral segment S-1 (100 Hz to 2600 Hz) was considered, vowels were ranked with respect to increasing mean spectral noise levels: /u/, /i/, /ʌ/, /ɑ/, and /æ/. Inter-subject spectral noise level variability for each vowel was less for SNLs averaged over S-1 (100 Hz to 2600 Hz) than for SNLs averaged over the other spectral segments studied. Among the vowels, /u/ evidenced the least SNL variability for all SS's and the TSR.

A major purpose of this study was to explore possible relationships between vowel spectral noise levels and roughness ratings for vowels and for sentences. For each vowel, multiple correlation coefficients relating SNLs in each 100-Hz section of the frequency region 100 Hz to 1600 Hz and vowel roughness ratings were computed. The correlation coefficients obtained were: /u/, .96; /i/, .99; /ʌ/, .98; /ɑ/, .96; /æ/ , .98. Thus, only small residuals were obtained when a multiple linear regression equation was employed to predict each vowel production's median roughness rating from noise levels measured in each 100-Hz section of the spectral frequency range 100 Hz to 1600 Hz. When vowel spectral noise levels were related to sentence roughness utilizing a multiple correlation procedure, the highest coefficients (.97) were obtained when the S-1, S-2, and S-3 SNL means for each of the five vowels produced by each subject were related to the roughness rating for each sentence he produced. When predictions of sentence roughness were made from vowel SNL means utilizing a suitable multiple regression equation, the obtained residuals were generally small. Only three of twenty residuals for each sentence exceeded .50 scale value.

To evaluate the consistency with which subjects could perform the experimental task, five subjects produced the vowels and connected speech samples three times. The findings indicated that SNLs and roughness ratings for three trials for each subject were generally similar, although some differences among trials were observed.

The subjects in this study presented five different types of laryngeal pathology: (a) vocal cord polyps, (b) laryngeal carcinoma, (c) vocal cord paralysis, (d) benign laryngeal masses, and (e) laryngeal inflammation and edema. For all pathology groups, the high vowels /i/ and /u/ tended to be associated with lower roughness ratings and smaller SNLs than the low vowels /ɑ/ and /æ/ and the mid vowel /ʌ/. The findings indicated that the vowel and sentence productions of subjects presenting vocal cord paralysis and vocal cord polyps tended to be rated slightly more rough and to exhibit slightly higher vowel SNLs than those of subjects presenting the other types of pathology. The small size of the pathology groups precluded generalizations from these findings, however.

Possible clinical and research implications of the present study include the following. It appears that the measurement of spectral noise for vowels may provide the basis for an objective index of vocal roughness in vowels and in connected speech. Further, it would appear possible to differentiate normal and abnormally rough vowel productions on the basis of vowel spectral noise level measures. Possibly, therefore, a practical screening test based on spectral noise level measures could be devised for the early detection of laryngeal pathology evidenced by vocal roughness. Another application of vowel SNL measures might be in assessing the effects of voice therapy to reduce vocal roughness. The finding that there was a high degree of relationship between vowel SNLs for a very limited spectral frequency range (100 Hz to 1600 Hz) and vowel roughness, and the simplicity of the present spectral analysis procedure, tends to support the hypothesis that such measures might be practical clinically. Further research will be required, however, before the clinical potential of the present findings will be fully realized.

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APPENDIX A

Instructions to Subjects

Instructions to Subjects

In this experiment a recording will be made of your voice while you are producing vowel sounds and short sentences into the microphone. The vowel sounds you are to produce are the underlined sounds in the words printed on the cards: /i/ as in bee, /æ/ as in cat, /ɑ/ as in hot, /ʌ/ as in but, and /u/ as in boot. You are not to say the entire word, but only the vowel sound that is underlined. The cards will be held so you can see them easily during recording. I will also say each vowel immediately before you speak it.

You should say the vowel sounds loudly enough so that the needle on the meter will reach the red mark. You will be given two signals from the signal lights. The yellow light will come on briefly, indicating that you are to begin speaking and to keep the needle of the meter steadily at the mark. When the red light comes on, you are to continue to keep the needle steadily at the mark as long as the red light is on. Be very careful to keep the needle on the meter as close to the mark as possible. You will have an opportunity to practice saying the vowel sounds before actually making the recording.

Following the vowel recordings you will be asked to say two sentences: "Joe took father's shoe bench out" and "They have bought a new car." I will say each sentence before you speak it. The sentences are printed on cards and will be held so that you may see them during recording. The needle on the meter will not remain steady while you are speaking but try to keep the needle as close to the red mark as possible while you say each sentence. Are there any questions?

APPENDIX B

Instructions to Judges

Instructions to Judges: Vowel Ratings

You are asked to listen to 200, seven-second sustained vowel samples produced by adult males. The samples are comprised of the vowels /u/, /i/, /ʌ/, /ɑ/, and /æ/, and represent a range of vocal production from smooth to rough. The vowel samples will be presented to you one at a time, and you are to judge each in relation to a five point scale of severity of vocal roughness. Make your judgments on the basis of the severity of vocal roughness perceived.

Each vowel is to be rated on a scale of equal appearing intervals with scale values from <u>1</u> to <u>5</u>. Scale value <u>1</u> represents least severe vocal roughness and <u>5</u> represents <u>most</u> severe. Do not attempt to rate vowel samples between any two scale points.

Four vowels representing the extremes of the judgment scale will be presented now to help you locate the extremes of the scale. The first two vowels will represent <u>least</u> severe vocal roughness and the second two will represent <u>most</u> severe. You may listen to these productions as many times as you wish before the judging begins.

The vowels to be judged will now be presented to you in random order. There will be a short interval between productions and each will be preceded by a number announcement.

You are to judge each of the vowel samples in relation to the five point scale of severity of vocal roughness. Record on your response sheet the scale value from <u>1</u> to <u>5</u> you think each production should be assigned. Because you are asked to scale <u>your perceptions</u> of the severity of vocal roughness, there are no right or wrong scale values. Thus, a scale value you record for a vowel may not be the scale value the person sitting next to you records for that same vowel. For this reason, be sure to make your judgments independently. Record the scale value assigned to each vowel to the right of its number on your response sheet. You may hear each vowel production to be judged as many times as you wish. Notice that you will start at the top of a column and work down. Be sure to record a judgment for every vowel sample. Leave no blank spaces. The vowels will be presented in four segments of fifty vowels each with short rest periods between segments. The instructions and vowel samples representing the scale extremes will be presented again at the beginning of each segment. Are there any questions?

Instructions to Judges: Sentence Ratings

You are asked to listen to 50 brief samples of connected speech. The samples, consisting of the sentence "Joe took father's shoe bench out" or ("They have bought a new car") spoken by adult males, represent a range of vocal production from smooth to rough. The samples will be presented to you one at a time, and you are to judge each in relation to a five-point scale of severity of vocal roughness. Make your judgments on the basis of the severity of vocal roughness perceived.

Each sample is to be rated on a scale of equal-appearing intervals with scale values from 1 to 5. Scale value 1 represents least severe vocal roughness and 5 represents most severe. Scale value 3 is in the middle of the scale - - half way between 1 and 5 - - with the other numbers falling at equal distances along the scale. For example, the distance between scale values 2 and 3 should be the same as the distance between 4 and 5. Do not attempt to rate samples between any two scale points.

Four samples representing the extremes of the judgment scale will be presented to help you locate the extremes of the scale. The first two samples will represent least severe vocal roughness (1's) and the second two will represent most severe (5's). You may listen to these productions as many times as you wish before the judging begins.

The samples to be judged will be presented to you in random order. There will be a short interval between productions and each will be preceded by a number announcement.

You are to judge each of the samples in relation to the five-point scale of severity of vocal roughness. Record on your response sheet the scale value from _1_ to _5_ you think each production should be assigned. Because you are asked to scale _your_ perceptions of the severity of vocal roughness, there are no right or wrong scale values. Thus, a scale value you record for a sample may not be the scale value the person sitting next to you records for that same sample. For this reason, be sure to make your judgments independently. Record the scale value assigned to each sample to the right of its number on your response sheet. You may hear each sample to be judged as many times as you wish. Notice that you will start at the top of a column and work down. Be sure to record a judgment for every sample. Leave no blank spaces. Are there any questions?

APPENDIX C

Percentages of Inter- and Intra-Judge Roughness Rating Agreement

TABLE 9

PERCENTAGE OF INTER-JUDGE ROUGHNESS RATING AGREEMENT
$\pm$ 1 SCALE VALUE FOR ONE HUNDRED AND FIFTY
VOWEL PRODUCTIONS

	Judge									
Judge	11	10	9	8	7	6	5	4	3	2
1	94	98	99	98	97	95	96	97	97	96
2	93	95	94	88	96	90	95	92	94	
3	92	96	96	92	96	93	91	96		
4	95	99	97	90	95	91	93			
5	92	95	95	90	91	90				
6	91	95	93	90	93					
7	95	95	97	97						
8	89	95	96							
9	95	98								
10	97									

TABLE 10

PERCENTAGE OF INTRA-JUDGE ROUGHNESS RATING AGREEMENT $\pm$ 1 SCALE
VALUE FOR TWO RATINGS OF FIFTY VOWEL PRODUCTIONS

Judge										
1	2	3	4	5	6	7	8	9	10	11
100	96	96	96	98	96	94	92	96	96	92

TABLE 11

PERCENTAGE OF INTER-JUDGE ROUGHNESS RATING AGREEMENT ± 1 SCALE VALUE FOR THIRTY PRODUCTIONS OF THE SENTENCE "JOE TOOK FATHER'S SHOE BENCH OUT"

	Judge									
Judge	11	10	9	8	7	6	5	4	3	2
1	97	93	100	100	97	93	100	97	100	100
2	97	97	100	93	97	93	93	100	100	
3	97	93	100	100	97	93	97	97		
4	100	97	100	97	100	93	97			
5	93	93	100	100	90	87				
6	100	97	100	97	90					
7	97	100	100	93						
8	100	93	97							
9	100	97								
10	97									

TABLE 12

PERCENTAGE OF INTRA-JUDGE ROUGHNESS RATING AGREEMENT ± 1 SCALE VALUE FOR TWO RATINGS OF TWENTY PRODUCTIONS OF THE SENTENCE "JOE TOOK FATHER'S SHOE BENCH OUT"

Judge										
1	2	3	4	5	6	7	8	9	10	11
100	100	100	100	100	90	90	100	100	100	100

TABLE 13

PERCENTAGE OF INTER-JUDGE ROUGHNESS RATING AGREEMENT ± 1 SCALE VALUE FOR THIRTY PRODUCTIONS OF THE SENTENCE "THEY HAVE BOUGHT A NEW CAR"

	Judge									
Judge	11	10	9	8	7	6	5	4	3	2
1	100	97	100	97	97	93	100	90	100	93
2	97	90	90	87	90	86	87	93	90	
3	100	100	97	97	97	100	100	97		
4	100	93	100	100	100	93	97			
5	100	97	100	97	97	93				
6	97	97	97	97	97					
7	100	100	97	100						
8	100	100	100							
9	100	100								
10	100									

TABLE 14

PERCENTAGE OF INTRA-JUDGE ROUGHNESS RATING AGREEMENT ± 1 SCALE VALUE FOR TWO RATINGS OF TWENTY PRODUCTIONS OF THE SENTENCE "THEY HAVE BOUGHT A NEW CAR"

Judge										
1	2	3	4	5	6	7	8	9	10	11
100	100	100	100	95	100	100	100	100	95	100

APPENDIX D

Clinical Summary of Subjects

TABLE 15

OTOLARYNGOLOGIST'S CLINICAL SUMMARY OF SUBJECTS GROUPED ACCORDING TO TYPE OF LARYNGEAL PATHOLOGY

Clinical Group 1 - Vocal Cord Polyps

Subject	Age	Clinical Description
14	42	Bilateral vocal cord polyps located on the posterior one-third of the true cords. Rough voice for one month prior to examination.
16	77	Bilateral, white, fibrotic vocal cord polyps extending the length of the anterior two-thirds of the true cords. History of vocal roughness since childhood.
1	46	Vocal cord polyp located on the anterior one-third of the right true cord. Intermittent rough voice for several years.
3	56	Bilateral vocal cord polyps located on the posterior one-third of the true cords. Persistent vocal roughness lasting four years previous to examination,

Clinical Group 2 - Laryngeal Carcinoma

Subject	Age	Clinical Description
4	56	Carcinoma of the larynx. Extensive granular tumor mass from anterior commissure to the right arytenoid involving all of the right true cord. Rough voice lasting two months prior to examination.

TABLE 15--Continued

Subject	Age	Clinical Description
		Clinical Group 2 - Laryngeal Carcinoma
6	57	Squamous cell carcinoma of the larynx. Tumor extending down from the left ventricular fold to the anterior free edge of the left true vocal cord. Vocal roughness for one month prior to examination.
7	60	Squamous cell carcinoma of the larynx and hypopharynx. A granular, ulcerative lesion of the posterior pharynx extending from the tip of the epiglottis to the inferior tip of the uvula. The left arytenoid is markedly edematous. Inflammation and edema of both the true and false vocal folds. Vocal roughness present for three weeks previous to examination.
10	73	Squamous cell carcinoma of the larynx. A small localized lesion on the anterior one-third of the right true cord extending to the anterior commissure. Intermittent rough voice for six months prior to examination.
15	55	Squamous cell carcinoma of the larynx involving the entire left true vocal cord. Radiation therapy has resulted in inflammation and edema of both true cords. A mild vocal roughness is present.
17	58	Squamous cell carcinoma of the epiglottis. Supraglottic laryngectomy has been performed leaving both the ventricular and true vocal folds intact. A mild vocal roughness is present

TABLE 15--Continued

Clinical Group 3 - Vocal Cord Paralysis		
Subject	Age	Clinical Description
11	53	Left vocal cord paralysis. The left vocal fold lies in the paramedian position and does not move to mid line during phonation. Vocal roughness lasting three years previous to examination.
2	[illegible]9	Left vocal cord paralysis and partial loss of the right true cord due to traumatic injury. Severe vocal roughness is present.
18	72	Right vocal cord paralysis following right thyroid lobectomy. Vocal roughness is present.

Clinical Group 4 - Benign Laryngeal Mass		
Subject	Age	Clinical Description
12	73	Benign polypoid mass in the interarytenoid space. A mild vocal roughness has been present for six months.
8	72	A benign mass, of moderate size, in the area of the left ventricular fold. Some asymmetry and edema of the right arytenoid cartilage. Rough voice for six weeks prior to examination.
9	61	Benign polypoid mass in the crypt of the right piriform sinus impinging upon the right arytenoid. Vocal roughness is present.

TABLE 15--Continued

Clinical Group 5 - Laryngeal Inflammation and Edema		
Subject	Age	Clinical Description
5	46	Inflammation and edema of the true vocal cords. Evidence of vocal abuse resulting in intermittent rough voice for several years.
19	52	Inflammation of the right arytenoid cartilage. Left ventricular fold is edematous. Rough voice for six months prior to examination.
20	45	Inflammation and edema of the true vocal cords. Intermittent vocal roughness for two years prior to examination.
13	55	Inflammation of the true vocal cords and arytenoids. Vocal roughness associated with vocal abuse has persisted for ten days prior to examination.

APPENDIX E

Spectral Noise Levels and Median Roughness Ratings for Subjects Grouped According to Type of Laryngeal Pathology

TABLE 16

AVERAGE VOWEL SPECTRAL NOISE LEVELS AND VOWEL AND SENTENCE MEDIAN ROUGHNESS RATINGS FOR TWENTY SUBJECTS GROUPED ACCORDING TO TYPE OF LARYNGEAL PATHOLOGY

	Speech Samples						
Pathology	/u/	/i/	/ʌ/	/ɑ/	/æ/	Sentence 1	Sentence 2
Vocal Cord Polyps N=4							
S-1	20.78	25.53	33.15	36.15	37.20		
TSR	14.20	24.65	25.10	25.90	31.55		
Roughness Rating	3.38	3.84	3.99	4.78	4.51	4.28	4.21
Laryngeal Carcinoma N=6							
S-1	20.62	20.07	29.50	28.05	32.58		
TSR	11.67	19.45	19.20	19.17	22.07		
Roughness Rating	2.52	3.00	3.25	2.97	3.23	2.75	3.04
Vocal Cord Paralysis N=3							
S-1	21.37	17.53	35.30	30.10	37.90		
TSR	12.47	18.03	25.93	24.23	29.10		
Roughness Rating	3.20	3.72	4.65	4.20	4.33	3.72	3.56
Benign Laryngeal Mass N=3							
S-1	15.63	15.87	26.70	32.37	33.30		
TSR	7.60	17.20	18.43	22.73	23.73		
Roughness Rating	1.56	1.49	2.97	3.04	2.58	2.05	1.98

TABLE 16--Continued

	Speech Samples						
Pathology	/u/	/i/	/ʌ/	/ɑ/	/æ/	Sentence 1	Sentence 2
Laryngeal Inflammation and Edema N=4							
S-1	14.38	19.60	27.75	30.03	32.13		
TSR	7.83	15.85	16.28	18.88	22.45		
Roughness	2.26	2.28	2.83	2.97	3.07	2.40	2.24