Emotions and Speech: Some Acoustical Correlates *

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This paper describes some further attempts to identify and measure those parameters in the speech signal that reflect the emotional state of a speaker. High-quality recordings were obtained of professional "method" actors reading the dialogue of a short scenario specifically written to contain various emotional situations. Excerpted portions of the recordings were subjected to both quantitative and qualitative analyses. A comparison was also made of recordings from a real-life situation, in which the emotions of a speaker were clearly defined, with recordings from an actor who simulated the same situation. Anger, fear, and sorrow situations tended to produce characteristic differences in contour of fundamental frequency, average speech spectrum, temporal characteristics, precision of articulation, and waveform regularity of successive glottal pulses. Attributes for a given emotional situation were not always consistent from one speaker to another.

Subject Classification: 9.5, 9.3.

INTRODUCTION

Long before the availability of modern instrumentation for the analysis of speech, researchers attempted to identify and measure those parameters in the speech signal that reflect the emotional state of a speaker. This paper describes one of a series of studies undertaken in a further attempt to delineate some of the acoustic correlates of the emotions of a speaker.

There are two principal reasons why it is of interest to examine the parameters in the speech signal that are related to the emotional state of a speaker. (1) There are situations in which the physiological and emotional state of an individual needs to be monitored, and it would be convenient if an indication of this state could be obtained through analysis of the acoustic characteristics of his utterances. (2) Studies of speech attributes related to emotional state may help to contribute toward a general theory of speech performance. Such a theory should have two components: one that specifies the acoustic correlates of the linguistic units used for communication between speakers of a given language, and the other that describes the extralinguistic aspects of speech communication.

I. APPROACH

In planning the study, two approaches were considered: (1) a detailed analysis of "field" recordings where there would be no question as to the emotion present in the individual speaking, and (2) an analysis of high-quality recordings of professional actors simulating various emotions. The second approach was selected for the major portion of our work since it seemed to afford the best opportunity for obtaining good recordings that could be subjected to both quantitative and qualitative analyses. Because actors are presumably able to portray clear and unambiguous emotions, their utterances provide a means for exploring the basic manifestations of emotional speech. Field recordings often reflect the simultaneous presence of several emotions and the lack of control of the speech material. While an approach using actors is not novel, investigators employing it have never performed, to our knowledge, a spectrographic analysis of the recorded speech material.

Since we believed that the emotions of interest might best be described in terms of specific situations involving emotional interaction among several people, the decision was made to make use of a short play. Getting the actors involved in clearly defined situations would, hopefully, result in their experiencing and expressing the various emotions to be studied. The primary function of the play was to elicit the desired emotions from the actors and to serve as the carrier for selected phrases and sentences to be embedded in different emotional situations. These phrases and sentences, so-called
“control clusters,” could then later be subjected to detailed acoustical analyses. Because changes in the speech signal due to the presence of some emotions might be subtle, it was considered necessary to be able to compare utterances of identical material as they occurred in different emotional situations.

A detailed scene-by-scene outline of a short play involving three male characters was constructed. The outline was then given to a playwright who wrote the dialogue for the three characters who would be speaking in various situations. For each character, the playwright was instructed to include identical speech material—the control clusters—as part of the dialogue for that character speaking in different situations. In addition to analysis of the speech material in the control clusters, longer portions of the dialogue, usually several sentences surrounding a control cluster, were selected for study.

The services of a professional director and three professional actors were employed in recording the scenario. All four individuals were former members of the Actor's Studio in New York and had past experience with the so-called "method" style of acting. The recordings were made in a professional recording studio, with the actors rotating in each of the three roles.

In addition to the analysis of recordings of the short play, this study included a comparison of recordings from a real-life situation in which the emotions of the speaker were clearly defined, and recordings from an actor who simulated this situation. The purpose of this subsidiary investigation was to attempt to validate the use of actors to simulate emotions, as well as to obtain additional data on the acoustic correlates of various emotions.

II. SELECTION OF PARAMETERS FOR ANALYSIS

On the basis of the results of a preliminary study and an examination of the literature on the physiological and acoustic correlates of emotion, only a few kinds of acoustic parameters were selected for detailed analysis in the present study. Before the data are presented, a brief review is given of the acoustic correlates upon which attention was focused, indicating reasons for selecting particular kinds of data.

Studies of the effects of emotion on the acoustic characteristics of speech have shown that average values and ranges of fundamental frequency \( F_0 \) differ from one emotion to another. In the preliminary study, the acoustic properties that appeared to be among the most sensitive indicators of emotion were attributes that specified the contour of \( F_0 \) throughout an utterance. There are several reasons why changes in \( F_0 \) with time are potentially capable of providing information concerning the emotional state of a speaker. First, considerable latitude is possible in the variations of \( F_0 \), since only certain aspects of the \( F_0 \) contour carry information with regard to the linguistic content of a message. The principal linguistic functions of \( F_0 \) changes are to indicate stress, and to mark boundaries of different types of sentence-length or phrase-length units. Subject to these constraints, a speaker is relatively free to use changes in \( F_0 \) to convey nonlinguistic information, such as his emotions, or to convey special emphasis of some kind. Furthermore, the fundamental frequency can undergo variations that may not be intended or be under overt control of the speaker, and hence may provide an indication of the speaker's emotional state.

Further justification for the preoccupation with \( F_0 \) contours as indicators of emotions comes from a study of the literature on the physiological correlates of stress. It has been stated, for example, that "... respiration is frequently a sensitive indicator in certain emotional situations, especially startle, conscious attempts at deception, and conflict. The respiratory pattern is frequently disturbed in anxiety states." An increase in respiration rate would presumably result in an increased subglottal pressure during speech. This heightened subglottal pressure would give rise to a higher \( F_0 \) during voiced sounds in speech. The increased respiration rate could also lead to shorter durations of speech between breaths, with a consequent effect on the basic temporal pattern of speech.

Other relevant physiological effects of certain emotions are dryness of the mouth often observed under conditions of emotional excitement, anticipation, fear, and anger, and tremor and disorganization of motor response, observed under conditions of emotional conflict. These effects can have an influence on various components of the speech system, including the larynx, which is directly involved in the control of \( F_0 \). Muscle activity in the larynx and the condition of the vocal cords are likely to have a more direct influence on the sound output and, in particular, on the fundamental frequency, than changes in muscle activity in other parts of the speech generating system, such as the tongue, lips, and jaw. The reason is that the vibrating vocal cords have a direct effect on the volume velocity through the glottis, whereas the other muscles and vocal-tract components simply shape the resonant cavities for sound that is generated at the vocal cords. Thus, any analysis of the speech signal that reflects vocal-cord activity is more likely to be influenced by physiological changes brought about by the emotional state of the speaker.

Such physiological changes as increased subglottal pressure, excessive dryness or salivation, and decreased smoothness of motor control can have an influence on the waveform of the pulses from the vocal cords, as well as on their frequency. For example, increased subglottal pressure generally gives rise to a narrowing of individual glottal pulses, and hence to a change in the spectrum of the pulses. Under some circumstances, such as excessive salivation, there may be irregularities
in the waveform of the glottal output from one pulse to the next. In the present study, a rough indication of glottal waveform was obtained from the average acoustic spectrum of an utterance, measured by means of an octave-band analyzer. Qualitative evidence of changes in glottal waveform and of irregularities in successive glottal pulses was obtained by observation of wide-band (300-Hz filter) spectrograms.

Although primary attention in this study was focused on acoustic parameters related to laryngeal activity, some observations were also made on parameters that reflect control of the supralaryngeal structures. These included measurements of the rate of talking, analysis of acoustic attributes that provide an indication of the precision with which articulatory targets for certain vowels and consonants are achieved, and spectrographic observations of vowel formant frequencies and of intensity of release for stop consonants.

III. RECORDINGS OF SCENARIO

Although a vast amount of data was made available by the various recordings of the scenario, only selected samples will be presented in order to demonstrate some of the ways in which the data were examined. The data to be reported include both quantitative results, which were obtained by making various measurements from wide- and narrow-band spectrograms and graphic level recordings, and qualitative observations, which consisted simply of setting down impressions derived from visual examination of a number of spectrographic patterns.

Figure 1 shows $F_0$ contours of selected control clusters as uttered by one of the three voices, Voice B, in different situations in the scenario. These contours were obtained by tracing harmonics in narrow-band spectrograms of the utterances. For neutral utterances, the changes in $F_0$ were relatively slow, and the shape of the contour throughout each utterance was smooth and continuous.

The contour shapes for utterances produced in anger situations showed an $F_0$ that was generally higher throughout the utterances, suggesting that they were generated with greater emphasis. Furthermore, one or two syllables in each phrase were characterized by large peaks in $F_0$, again indicating strong emphasis on these syllables. Although the excursions in $F_0$ were quite great, there appeared to be a relatively smooth overall contour with one or two major peaks, but with no large discontinuities.

The contour shapes for utterances made in situations involving the emotion sorrow were relatively flat with few fluctuations, and the $F_0$ was usually lower than that for neutral situations. For Voice B (Fig. 1), there was a slowly falling contour during the first half of the utterance, and a more level contour toward the end. Only rarely was emphasis placed on syllables in utterances by any of the three voices in a sorrow situation.

The contours for utterances made in fear situations often departed from the prototype shape for neutral
situations. Occasionally there were rapid up-and-down fluctuations within a voiced interval, as in cluster 4 for Voice B. Sometimes sharp discontinuities were noted from one syllable to the next.

From narrow-band spectrograms prepared of the longer speech samples and control clusters, measurements of $F_0$ were obtained every 0.15 sec, and distribution curves were drawn to determine the median $F_0$ and a measure of the range of $F_0$ (10th-90th percentile). Figure 2 shows, for each of the three voices (A,B,C), the median $F_0$ and range of $F_0$ (on a logarithmic scale) for these long speech samples. The lowest $F_0$ was obtained for the emotion sorrow, and the highest for anger. Measurements for the neutral and fear situations were very similar for Voices B and C, but the fear situations showed a wider and higher range of $F_0$, and the distribution for fear was somewhat skewed, with occasional excursions to very high values of $F_0$. The widest range of $F_0$ (on a linear frequency scale) tended to occur for
anger. Ranges for sorrow and neutral were very similar, but median values of $F_0$ for the neutral situations were higher than those for sorrow.

Figure 3 shows wide-band spectrograms of one control cluster spoken by Voice B in five situations. For this cluster the total duration was least for the neutral situation, and greatest for sorrow. The lengths of the utterances for fear and for anger were about the same. The increases in duration for the utterances made in anger, fear, and sorrow situations came in part from increases in vowel durations, but primarily from lengthened intervals of closure or vocal-tract constriction for the consonants. Comparison of the initial consonant in the word "God's" in the various spectrograms shows a longer stop gap and a more intense burst at the consonantal release for the various emotional situations than for the neutral situation.

The vocal-cord vibrations for the utterance exemplifying sorrow appeared to have considerable fluctuations in shape from one glottal pulse to the next. This voicing irregularity was manifested by a variation in darkness of individual voicing pulses, particularly in the high-frequency region above 2000 Hz. This effect is particularly evident in the word "God's" at the bottom of Fig. 3 (0.8–1.3 sec on the time scale), in the entire frequency region above 2000 Hz. The spectrograms for the anger situation also demonstrate some anomalies that were presumably due to irregularities in the glottal output. For example, the pattern of glottal vibration is not uniform in the words "God's" and "sake," as evidenced by the irregular spectral pattern at high frequencies (above 3 kHz).

The narrow-band spectrograms shown in Fig. 4 for the same utterances, again indicate that the highest
average frequency and the most rapid frequency changes occurred in the anger situation; there were sharp rises in \( F_0 \) in the second and third syllables. Rapid rises in \( F_0 \) also occurred in the neutral situation (cluster location number 3, upper left of Fig. 4), but the rising contour was smoother, and the peak \( F_0 \) was lower. The contour for the fear situation also showed some rapid fluctuations or tremor in \( F_0 \); in the middle syllable of utterance number 23, the \( F_0 \) starts high at the beginning of the syllable, and then falls, with an initial bump or fluctuation. This kind of contour seemed to occur often, but not always, in fear situations.

Measurements of the formant frequencies for particular vowels uttered in the various emotional situations showed some small differences. Of particular interest is the fact that, for anger situations, vowels in the syllables uttered with emphasis had higher first-formant frequencies than the corresponding vowels in neutral situations. Apparently a wider mouth opening was used in the emphatic anger situations, and this yielded a higher first-formant frequency. An example is the first formant of the word "God's" in Fig. 3, which was higher for the anger situation than for the neutral situation.

The effects of the various emotions on the utterances of Voice A were qualitatively similar to those on Voice B, as exemplified by the wide- and narrow-band spectrograms in Figs. 5 and 6, respectively. The neutral utterance (Fig. 5) shows a uniform formant structure and glottal vibration pattern, whereas irregularities in formant amplitudes and amplitudes of successive glottal pulses at high frequencies are evident for sorrow, anger, and fear. In the stressed vowel of the word "understand," the amplitudes of the second and third for-
nants relative to that of the first formant appear to be greater for the anger and fear situations than for the neutral utterance, presumably reflecting a change in the spectrum of the glottal pulses. The consonant closures seem to be better defined in the anger and fear spectrograms than in the neutral one, since the intensity changes at the consonantal closures and releases are more abrupt; the durations of these particular utterances, however, are not significantly different from that of the neutral utterance. The narrow-band spectrogram for the fear situation (Fig. 6) again indicates some tremors and rapid fluctuations in $F_0$.

Mean rates of articulation in syllables per second were determined for each of the three actors' utterances of certain longer speech samples selected from points in the scenario where the emotional situation was clearly defined. Table I shows the mean rate of articulation, in syllables per second, for each of the three voices speaking in neutral, anger, fear, and sorrow situations. The ranking of the emotions according to rate of articulation, from fastest to slowest, was the same (with one exception) for each of the three voices: neutral, anger, fear, and sorrow. The rate of articulation obtained in sorrow situations was less than half that found for the other situations. This finding is in agreement with the results of a study by Fairbanks and Hoaglin, which involved the use of amateur actors to simulate different emotional states; they found marked decreases in rate for grief as compared with anger, sorrow, and indifference.

Measurements of the average spectrum of the speech signal were made for a number of the control clusters in the scenario. The spectrum was obtained by means of an octave-band analyzer, and the outputs of in-
Fig. 7. Average spectra of selected control clusters as spoken by each of the three voices in different situations in the scenario. These spectra were obtained by taking the long-term average output from octave filters. (Spectra of Voice C in neutral and sorrow situations were identical.)

Fig. 7 shows some of the results. The absolute level for each spectrum was normalized by setting the level for the 250-Hz octave band arbitrarily at 0 dB. Octave-band spectra of these kinds demonstrate two kinds of gross acoustic effects. The low-frequency bands (125 and 250 Hz) are in a frequency region occupied by $F_0$ during voiced sounds. If $F_0$ is low (in the range of 90–175 Hz), then it remains in the 125-Hz octave band, and hence there is appreciable average energy in this band. If $F_0$ remains high most of the time (above 175 Hz), then there is less energy in the 125-Hz band. Hence, the relative levels in the 125- and 250-Hz bands provide a very rough indication of the average fundamental frequency.

The spectra in Fig. 7 show relatively less energy in the 125-Hz band for utterances made in anger situations (for which the $F_0$ is high) than for utterances made in neutral situations. For the one voice where data corresponding to the emotion fear were obtained (Voice C), there is also relatively less low-frequency energy for that emotion. Utterances made in sorrow situations do not differ in a consistent way from utterances for neutral situations, at least as far as the low-frequency energy is concerned. Consistent differences among emotions are also observed at the high-frequency end of the spectrum. The level at high frequencies (above 1000 Hz) relative to low frequencies is always greatest for the emotion anger and least for sorrow. The implication is that anger is manifested in a higher subglottal pressure and a narrower glottal pulse, while the reverse is true of sorrow.

The changes in average spectrum for the emotion fear, together with the incidental observation from spectrograms of a decrease in low-frequency energy (in a range up to, say, 500 Hz) relative to energy at higher

<table>
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<th>Sorrow</th>
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WILLIAMS AND STEVENS

Well here it comes, ladies and gentlemen

a terrific crash, ladies and gentlemen

I, I can't talk, ladies and gentlemen

Fig. 8. Radio announcer speaking before (top) and after (middle and bottom) the crash of the HINDENBURG. Narrow-band. (From Williams and Stevens, Ref. 1.)

frequencies, are consistent with some measurements of average spectra of a Soviet cosmonaut under various critical situations during a space flight. The situations where the emotion fear was expected to be greatest in space flight also led to an upward shift in the centroid of the spectrum within the frequency range 300-1200 Hz.

IV. COMPARATIVE ANALYSIS OF ACTUAL AND SIMULATED DESCRIPTIONS OF HINDENBURG DISASTER

In order to provide some justification for the use of actors in studies of the acoustic correlates of emotion, some recordings were obtained of utterances spoken in real-life situations in which the circumstances gave a clear indication of the emotions being experienced by the speakers. The object was to compare the acoustic characteristics of the voices in these situations with the characteristics in the voices of the actors in similar situations. One recording that was acquired was that of the radio announcer who was describing the approach of the HINDENBURG at Lakehurst, New Jersey, when the Zeppelin suddenly burst into flames. The announcer continued his description (with one or two short breaks) throughout the disaster.

Figure 8 shows three narrow-band spectrograms that were made from excerpts of the announcer's voice before and after the crash occurred. The announcer's normal voice had a great deal of inflection, as indicated by the smooth up-and-down movements of $F_0$ in the upper spectrogram. The shape of the contour changed
EMOTIONS IN SPEECH

here it comes, ladies and gentlemen

terrific crash, ladies and gentlemen

I can't talk, ladies and gentlemen

Abruptly immediately after the crash, as the spectrograms in the middle and lower portion of the figure demonstrate. The average $F_0$ in those portions is considerably higher, and there is apparently much less fluctuation in frequency. Quantitative analysis of longer samples of the announcer’s speech has indicated, however, that there was, in fact, a greater fundamental-frequency range after the disaster than before. There are some irregular bumps in the contour, which might be interpreted as a kind of tremor; examples of these irregularities can be seen in the bottom spectrogram of Fig. 8, near 0.6 sec and again near 0.8 sec. The irregularities may reflect a loss of precise control of musculature and an irregular respiratory pattern.

The actor designated as Voice C was provided with a transcription of the radio announcer’s words (but not the actual recording) and was asked to study and then to read the script as if he were the radio announcer describing the event. He reported that he had never heard the recorded radio account of the disaster. A recording was made of Voice C’s “simulated” description of the events before and after the crash. Spectrograms taken from this simulation are shown in Fig. 9. The excerpts are the same as those examined for the radio announcer, shown in Fig. 8.

Voice C on the before-the-crash recording had less inflection than the announcer, but the smooth fluctuations in his $F_0$ followed the expected form. Following the crash, there was an increase in fundamental frequency, and there were erratic changes in $F_0$ throughout a phrase. Voice C showed greater up-and-down fluctuations than did the radio announcer, but the irregular bumps and atypical contours are reminiscent of the spectrograms for the emotion fear in the scenario (Figs.

Fig. 9. Voice C simulating announcement of HINDENBURG crash before (top) and after (middle and bottom) the disaster. Narrow-band.
1, 4, 6). The similarities, as well as the differences, between the radio announcer’s voice during the crash and Voice C’s simulation of the same announcement can be seen in Fig. 10. In both narrow-band spectrograms, there are instants in time at which rapid jumps or “tremors” in F0 occur.

These comparative data and some additional limited data obtained from real-life emotional situations are not inconsistent with the data obtained from the actors in this study.

Quantitative data on the median F0 and the range of F0 for the radio announcer and for Voice C simulating the description are given in Table II. The data were derived from samples of speech of several seconds’ duration before the crash and after the crash. The increased median F0 and the greater range of F0 for the emotional situation are quite apparent both for the announcer and for Voice C. The increase in both the median F0 and in the range of F0 was greater for Voice C than for the announcer.

### V. SUMMARY OF GROSS ACOUSTIC ATTRIBUTES ASSOCIATED WITH VARIOUS EMOTIONS

#### A. Anger

The most consistent and striking acoustic manifestation of the emotion anger was a high F0 that persisted throughout a breath group. This increase was, on the average, at least half an octave above the F0 for a neutral situation. The range of F0 observed for utterances spoken in anger situations was also considerably greater than the range for the neutral situations. Some syllables were produced with increased intensity or emphasis, and the vowels in these syllables had the highest fundamental frequency. These syllables also tended to have weak first formants, and were often generated with some voicing irregularity (i.e., irregular fluctuations from one glottal pulse to the next). The basic opening and closing articulatory gestures characteristic of the vowel-consonant alternation in speech appeared to be more extreme when a speaker was angry.
the vowels tended to be produced with a more open vocal tract (and hence to have higher first-formant frequencies), and the consonants were generated with a more clearly defined closure. The durations of utterances spoken in anger were usually longer (and the syllabic rate lower), but this effect was not great and was not always consistent for all voices. Although the general manifestations of anger were similar for the three voices, there were some individual differences. The increase in fundamental frequency was greater for some voices than for others, and there were differences in the way duration and other characteristics changed.

B. Fear

The average $F_0$ for fear was lower than that observed for anger, and for some voices it was close to that for utterances spoken in neutral situations. There were, however, occasional peaks in the $F_0$ that were much higher than those encountered in a neutral situation. These peaks were interspersed with regions where the fundamental frequency was in a normal range. The pitch contours in the vicinity of the peaks sometimes had unusual shapes (irregular humps or discontinuities), and voicing irregularity was sometimes present. The duration of an utterance tended to be longer than in the case of anger or neutral situations. As was observed for anger, the vowels and consonants produced in a fear situation were often more precisely articulated than they were in a neutral situation. Although these various characteristics were found for some utterances of some voices, observations of spectrograms revealed no clear and consistent correlate for the emotion fear.

C. Sorrow

The average fundamental frequency observed for the actors speaking in sorrow situations was considerably lower than that for neutral situations and the range of $F_0$ was usually quite narrow. This change in $F_0$ was accompanied by a marked decrease in rate of articulation (by a factor of two or more in syllabic rate, on the average) and an increase in the duration of an utterance. The increased duration resulted from longer vowels and consonants and from pauses that were often inserted in a sentence. Perhaps the most striking effect on the wide-band spectrogram was voicing irregularity. On occasion the voicing irregularity reduced simply to noise; i.e., the voiced sounds became whispered, in effect.

D. Neutral

In neutral situations the spectrograms of the actors generally showed a well-defined structure during the vowels, with little noise or irregularities either between the formants or in the high-frequency regions where formants are often not visible. Consonants were frequently uttered in an imprecise manner, particularly when they appeared in unstressed syllables. Sentences were usually generated with shorter durations than for the emotional situations.

VI. CONCLUSIONS

The aspect of the speech signal that appears to provide the clearest indication of the emotional state of a talker is the contour of $F_0$ vs time. This contour has a prototype shape for a breath group that is generated in a normal manner, without marked emotions of any kind. The normal contour is characterized by smooth, slow, and continuous changes in $F_0$ as a function of time, the changes occurring in syllables on which emphasis or linguistic stress is to be placed. Emotions appear to have several effects on this basic contour shape.

While at present it is certainly not possible to specify any quantitative automatic procedures that reliably indicate the emotional state of a talker, measurements of the median $F_0$ and range of $F_0$ for a sample of speech of several seconds' duration may at least serve to classify a talker's emotional state as one of sorrow (reduced $F_0$ and decreased range), or of anger or fear (increased $F_0$ and range), assuming that the normal $F_0$ and range of $F_0$ for the talker are known. Further identification of the emotions must be done by an experienced observer who must look for certain attributes of the $F_0$ contour, shifts in spectrum, changes in duration, and voicing irregularities.

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† This article is based on portions of a monograph cited in Ref. 2 below. Refer to the monograph for a more detailed description of this study, a review of the literature, a description and results of some listener tests, and a bibliography.


