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# Application of Some Acoustic Measures for the Evaluation of Laryngeal Dysfunction*

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The minor, abrupt changes observed in the pitch periods of human phonation have drawn the attention of researchers from various scientific disciplines. Many linguists, phoneticians, and laryngologists have investigated the significance of these pitch changes, or pitch perturbation, using the tools of their disciplines for their investigations. Considerable data have come from these studies. The pitch perturbations discovered in the phonation of the pathologic larynx have been of keen medical interest, because of the practical applicability of the pattern of them as a diagnostic measure. Some important pioneering works on pitch perturbation in the pathologic larynx has been reported by Lieberman (1). Such studies have been continued by Smith and Lieberman (2) and by many other investigators. These works have contributed significantly towards a clearer understanding of the phenomenon of pitch perturbation in the pathological larynx. They have also suggested that measures for assessing pitch perturbation may be applied in the evaluation of laryngeal dysfunction. The purpose of the present paper is to improve their procedure to some extent, and to increase the efficiency of the measure, for the evaluation of laryngeal dysfunction.

## Method

The general procedure is shown in Fig. 1. The pitch signal was obtained with the use of a microphone coupled to the pre-tracheal skin of the subject with

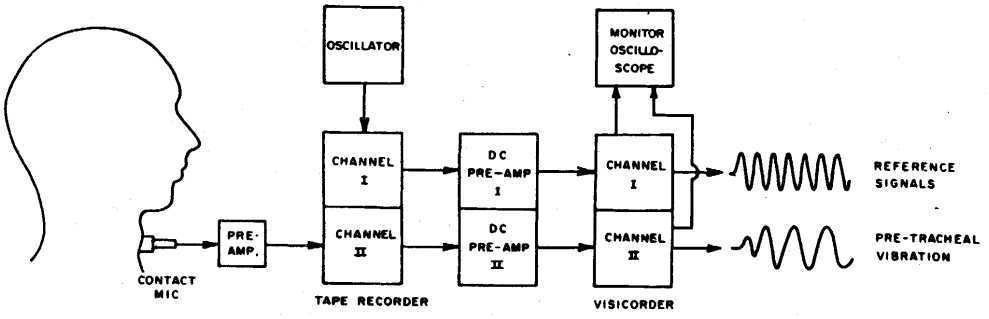


Figure 1. Block diagram of the equipment arrangement.

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special attention to the maintenance of an air-tight coupling. The disadvantages of using this type of throat microphone have been pointed out by Mckinney (3) and by other investigators. In the present study, however, the adoption of the throat microphone was preferable because of its high signal-to-noise ratio. The voices of patients with a pathology of the larynx are often quite hoarse, and

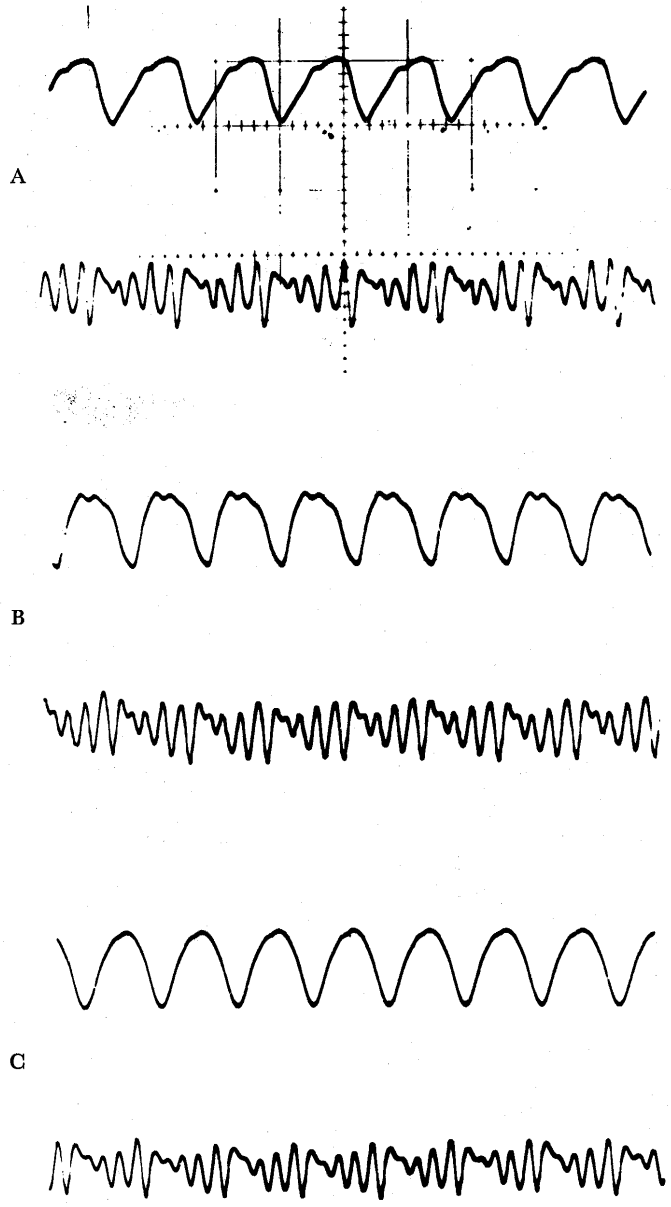


Figure 2. The effect of the position of the contact microphone upon the throat microphone waves. The upper tracings of the samples A, B, and C illustrate the contact microphone waves picked up at different heights on the midline of the pre-tracheal skin, and the lower tracings show the acoustic speech wave.

show complex wave shapes, and it is extremely difficult to extract the fundamental pitch from the acoustic wave.

*Throat Microphone Waves*

Examples of waves obtained from the throat microphone are shown in the upper tracings of Fig. 2. The lower tracings illustrate the usual acoustic waves. The top sample was obtained from the microphone placed just below the cricoid cartilage; the bottom sample was obtained just above the sternum; and the middle sample was obtained at a point intermediate to the other two. The actual distance of microphone placement from one position to the next was approximately 0.5 cm. It is apparent from this figure that the position of the contact microphone has an effect upon the throat microphone waves. The fundamental periodicity of the waves, however, did not seem to be affected. It was considered, therefore, that the information yielded from the throat microphone is more suitable to the needs of the present investigation.

The signal was recorded on one channel of an Ampex two-channel tape recorder. Simultaneously, reference signals of 1 KHz or 5 KHz from an oscillator were recorded on the other channel of the tape recorder. The recorded signals were then fed into a Honeywell Visicorder, and were registered on the photosensitive recording paper. The visual records were then measured with the aid of an optical enlarging device. Fig. 3 demonstrates an example of the record.

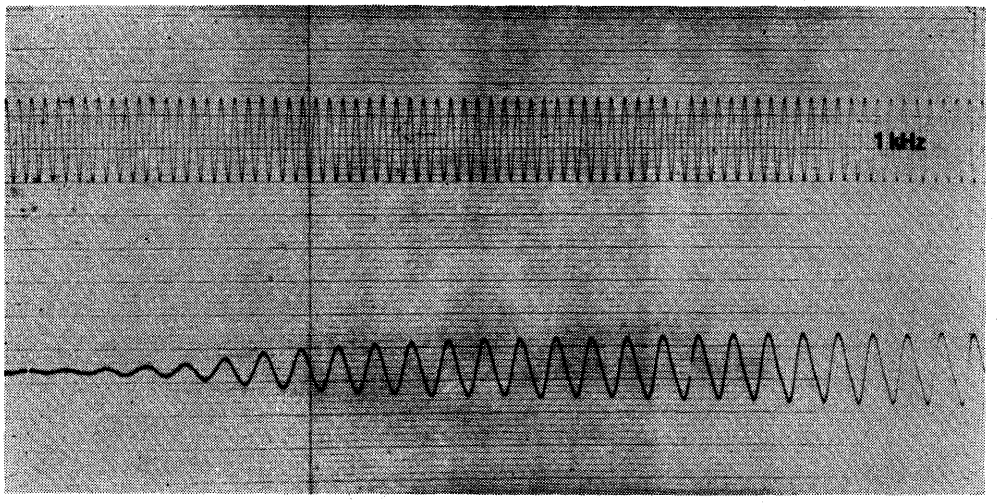


Figure 3. An example of the contact microphone signal displayed on the photosensitive paper. Reference signal 1 KHz.

*Subject and Material*

The subjects were 30 patients with laryngeal diseases while the control group consisted of 30 people without pathology of the larynx. All subjects were asked to sustain the vowel /a/ for several seconds. The author was particularly interested in studying two different types of vocal initiation; (1) the breathy or aspi-

rate type of initiation, and (2) soft, or simultaneous type of initiation. Measurements of the pitch periods were therefore made not only for the steady parts of the phonations, but for the initiation periods as well. For the vocal initiations, 17 pitch periods were measured: this number was selected because a preliminary study revealed that most of the remarkable perturbations occured within the initial 15 periods of phonation. For the steady state, 32 successive cycles were measured. Most of the computations were made with the aid of a PDP-8 digital computer.

*Smoothed Trend Line*

Various slow, and relatively smooth changes or shifts in pitch are normally present in human phonation, as is evident in the vibrato. There may also be rapid, and abrupt changes in the pitch periodicity, however, which may be called "pitch perturbations." If we measure the pitch period cycle by cycle, and define the perturbation to be the difference between adjacent periods, the value could be contaminated considerably by the period-to-period changes which are due to the slow and relatively smooth changes in the pitch. It is necessary to exclude the effect of the slow and smooth changes if we are to adequately investigate the rapid variations of pitch periodicity. This consideration led the author to seek after a properly smoothed version of the graph of the pitch period as a function of time. Although many methods for obtaining trend lines from time series were available, preliminary investigations suggested the adoption of a "three point moving average" technique for the purpose of the present study. The method of obtaining the smoothed trend, however, may possibly be improved by further studies of this problem. Perturbation then was determined on the basis of the distances of each period from the smoothed trend line. The distances are shown as thick vertical lines in Fig. 4.

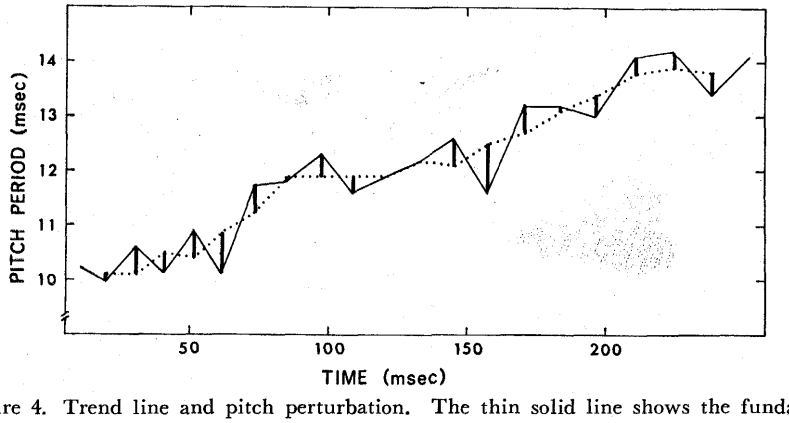


Figure 4. Trend line and pitch perturbation. The thin solid line shows the fundamental period as a function of time. The broken line indicates a smoothed trend line of fundamental pitch. The pitch perturbations are then defined to be the distances from the trend line, as are depicted by the thick solid lines in this figure.

## Results and Discussion

*Pitch Perturbation and Mean Pitch*

The absolute magnitude of the average perturbation showed a considerable positive correlation with the average pitch period as is illustrated in Fig. 5. This finding tends to support the absolute perturbation data found by Lieberman. He found that higher frequencies of occurrence of large perturbation result as the median periodic duration is increased. This fact poses a problem for the comparison of the perturbation data obtained from phonations that have different average pitches.

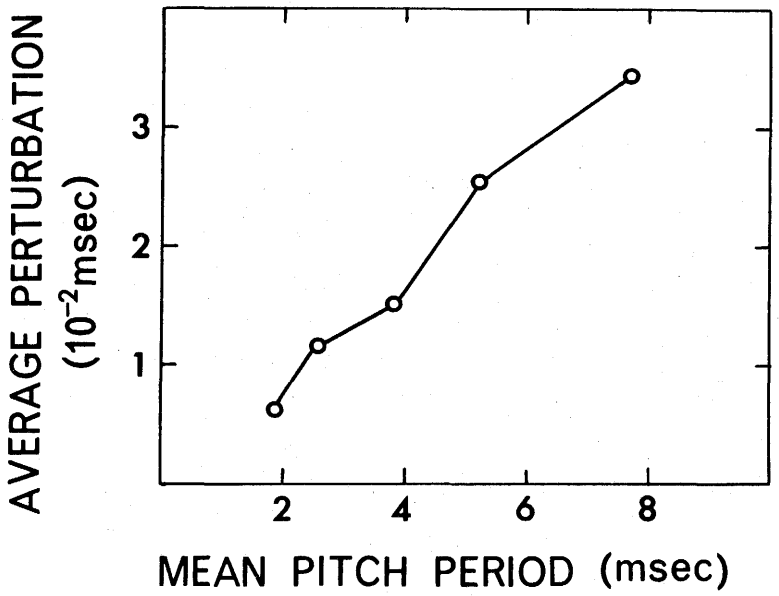


Figure 5. The average perturbation as a function of mean fundamental period in one normal subject. An apparently positive relationship is observed between the two parameters.

*Relative Perturbation*

In view of these points concerning absolute perturbation, a *relative* value, rather than an absolute value, was computed. This value is defined by a simple formula:

$$\text{Relative Average Perturbation} = \frac{\frac{1}{n-2}\sum_{i=2}^{n-1}\left|\frac{P_{i-1}+P_i+P_{i+1}}{3}-P_i\right|}{\frac{1}{n}\sum_{i=1}^{n}P_i}$$

The numerator expresses the average absolute perturbation, and the denominator indicates the average pitch period. The results of computation are summarized in the following tables.

Table 1 shows the remarkable differences to be observed in terms of pitch perturbation, on the one hand between the degrees of dispersion of the different types of initiations, and on the other hand, between the initiation and the steady

Unbiased Variance of Relative Average Perturbation

| | | |
|---|---|---|
| Initiation | Soft | $453.30 \times 10^{-6}$ |
| | Breathy | 30.73 |
| Steady State | | 2.66 |

Table 1. The unbiased variances of the relative average perturbations for different portions of utterances. The large values for the initiations indicate a considerable variability of the perturbation measure during the initial periods of phonation.

Mean Values of Relative Average Perturbation

| | Initiation | | Steady State |
|---|---|---|---|
| | Soft | Breathy | |
| Tumors | $33.7 \times 10^{-3}$ | $31.5 \times 10^{-3}$ | $17.6 \times 10^{-3}$ |
| Paralysis | 76.0 | 15.0 | 12.5 |
| Normal | 27.6 | 12.3 | 4.6 |

Table 2. The mean values of the relative average perturbations for different subject groups. The differences are statistically significant.

part of the phonations. The soft initiation showed extremely wide dispersion, while the steady state of the vowel showed only a small variance.

The mean values of the relative average perturbation are shown in Table II. The differences among the values for the steady state phonations of the different groups of subjects, i.e., the tumor group, the paralysis group, and the normal group, were statistically highly significant.

The difference between the mean values for different types of initiations was also significant, which suggests the existence of different mechanisms for the different types of initiations. In consideration of the wide variability, the perturbation during the initial period was not believed to be useful for evaluating laryngeal dysfunction. The perturbation during the steady state, however, did seem to be a good indicator for the detection of laryngeal pathology.

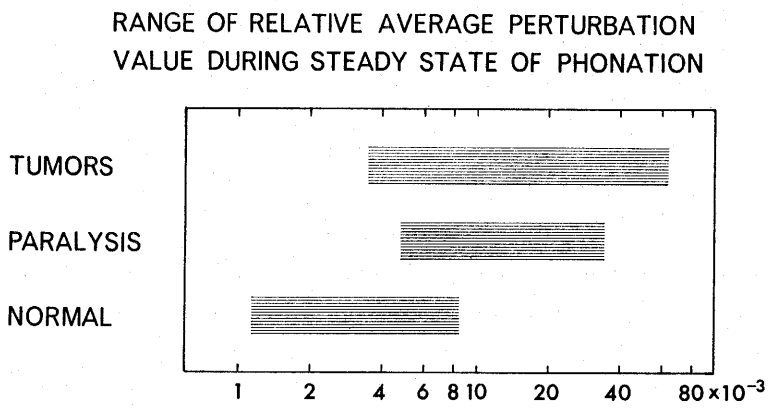


Figure 6. The ranges of the values of the relative average perturbations for different subject groups.

The ranges of the values of the relative average perturbations for the different classes of subjects are illustrated on a logarithmic scale in Fig. 6. Of course, some overlapping of the values is observed between the normal and the pathologic groups. The present data are still limited in many respects, and it may not be justifiable to generalize the results widely. It does appear, however, that the approach presently being submitted can be both a useful screening procedure, and a reliable supplementary diagnostic procedure for laryngeal disorders. If in the near future an electronic device could be developed that would replace the tedious manual measurement of the pitch period, the efficiency of this type of approach would be greatly increased.

## Summary

Perturbation of pitch period of voice was studied both on patients with laryngeal diseases and on normal subjects. Sound was extracted through the skin and other tissues in front of the trachea by a contact microphone during vowel phonation. Special attention was paid to the initial period of phonation and the data of this period were compared with those of steady periods of phonation. It was revealed that in the initial period there exist marked perturbations of pitch, and they were closely related with the type of initiation. Fundamental frequency was also found to affect the pitch perturbation. A relative average perturbation was defined on the basis of a smoothed trend line of the pitch. Pathologic cases showed essentially different values in respect to this measure according to the degree and nature of changes in the physical properties of the glottis, caused by the diseases. Possibility of applying this measure for screening and evaluating laryngeal disorders was discussed.

## Acknowledgement

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