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Subglottal and oral air pressures during phonation—preliminary investigation using a miniature transducer system*

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Abstract—*Pressure and flow are important parameters in the study of phonation. From a physiological point of view, they are used in determining the efficiency of the glottis as a sound generator and in phonetic research they are basic to an understanding of the control of intonation. Traditional methods for obtaining records of the pressure below and above the glottis during phonation often suffer from bad linearity and frequency response. In this paper, we report the application of a miniature transducer system to the study of aerodynamic events during phonation and illustrate the type of records which can be obtained.*

Keywords—*Laryngeal function, Miniature pressure transducers, Phonation*

Introduction

PRESSURE and flow are important parameters in the physiology of phonation; according to the myo-elastic-aerodynamic theory of voice production (VAN DEN BERG, 1958) an air flow through the glottis caused by a pressure drop at the level of the vocal folds is a necessary condition for glottal vibrations to occur. Moreover, subglottal pressure and trans-glottal flow are used in studies of the efficiency of the glottis as a sound generator under normal and pathological conditions (VAN DEN BERG, 1956; CAVAGNA and MARGARIA, 1965, 1968; BOUHUYS *et al.*, 1968; PERKINS and YANAGIHARA, 1968).

From a linguistic point of view, the same parameters are of interest in determining how various language functions are expressed in speech and how they are controlled, e.g. the control of intonation where there is continuing controversy about the role of subglottal pressure and laryngeal mechanisms (LIEBERMAN, 1967; OHALA, 1970; SHIPP and MCGLONE, 1971; ATKINSON, 1973).

A technical problem in such investigations is that of obtaining an accurate record of the relevant parameter. To record subglottal pressure on non-tracheotomised subjects, various methods have been used; (*a*) a needle has been inserted into the trachea through the cricothyroid membrane (STRENGER, 1959); (*b*) a catheter has been introduced into the trachea through the glottis (VAN DEN BERG, 1956); (*c*) a balloon has been swallowed into the oseophagus, filled with air and used for indirect measurement of the subglottal pressure (VAN DEN BERG, 1956); (*d*) a miniature transducer has been introduced into the trachea through the glottis (PERKINS and KOIKE, 1969). The methods (*a*)–(*c*) all have in common the fact that the air pressure is delivered to a transducer outside the subject through a needle and tubes. A needle and tube will, however, affect the frequency response of the recording system by reducing the upper frequency limit and introducing unwanted resonances into the system (FRY, 1960; EDMONDS *et al.*, 1971).

Furthermore, the oesophageal-balloon technique has been criticised by KUNZE (1964) on the grounds that the lung volume changes during phonation. On the other hand, LADEFOGED (1964), BOUHUYS *et al.* (1966), LIEBERMAN (1968), and KLINGHOLZ and SIEGERT (1972) are of the opinion that the error mentioned can be eliminated by correcting for the simultaneously recorded changes in lung volume. This may be feasible in studies not involving long sequences of speech on one breath.

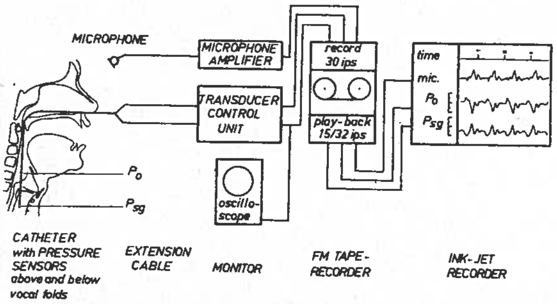

Fig. 1 Block diagram of apparatus. Two pressure transducers placed 50 mm apart in a semi-flexible catheter are placed on each side of the glottis. Subglottal pressure P_{sg} and oral pressure P_o, together with the speech signal, are recorded on magnetic tape and then played back at a reduced speed on an ink-jet recorder

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The problem of a limited frequency response and unwanted resonances also arises when the supraglottal air pressure is recorded by a tube inserted into the mouth or directed into the pharynx through the nose. Besides, the tubes and especially the tracheal needle must be cleaned continuously or they will clog and give faulty pressure records.

As will be shown the use of probes such as tubes and needles is no longer necessary to measure subglottal and oral air pressures. Instead, miniature transducers are placed directly into the air stream, yielding electrical signals of excellent linearity proportional to the pressure changes developed. In this way, the variations in subglottal and oral air pressure during phonation, as well as continuous speech, can be studied simultaneously and in great detail.

Method

The principal parts of the measuring system used are shown in Fig. 1. The pressure transducer consisted of a semiflexible Dacron catheter with two pressure sensors, one at the tip of the catheter (diameter 1·7 mm) and the other at a distance of 50 mm from the first. After local anaesthesia, the catheter was inserted through the nose of the subject into the upper airway, placing the pressure sensors above and below the vocal folds. The signals from the two pressure sensors were recorded on magnetic tape together with an acoustic signal from a microphone. The signal originating from the subglottic pressure sensor was monitored on an oscilloscope during the experiment. The three signals were played back at reduced tape speed and recorded on paper by an ink-jet recorder.

Equipment

Pressure transducer, pressure sensors and transducer control unit according to MILLAR and BAKER (1973). F.M. tape recorder Lyrec, Copenhagen, type TR 86. Ink-jet recorder Mingograph 800, Elema-Schönander, Stockholm. Dynamic calibration according to ASMUSSEN *et al.* (1974).

Experiment

The subject was a middle-aged male with a normal speech and voice function. To tolerate the catheter in the upper airway, the mucous membranes of his pharynx and larynx had to be anaesthetised in the same way as for a contrast radiograph of the larynx (LANDMAN, 1970). The correct position of the catheter in the posterior commisure of the larynx with the upper pressure sensor about 20 mm above the vocal folds was controlled by indirect laryngoscopy. In spite of the catheter being placed between the arytenoid cartilages, it was possible to accomplish a perfect closure of the glottis. This was checked visually by indirect laryngoscopy and audibly during forced expiration against the closed vocal folds.

The catheter was not found to interfere with the vibrations of the anterior membraneous parts of the

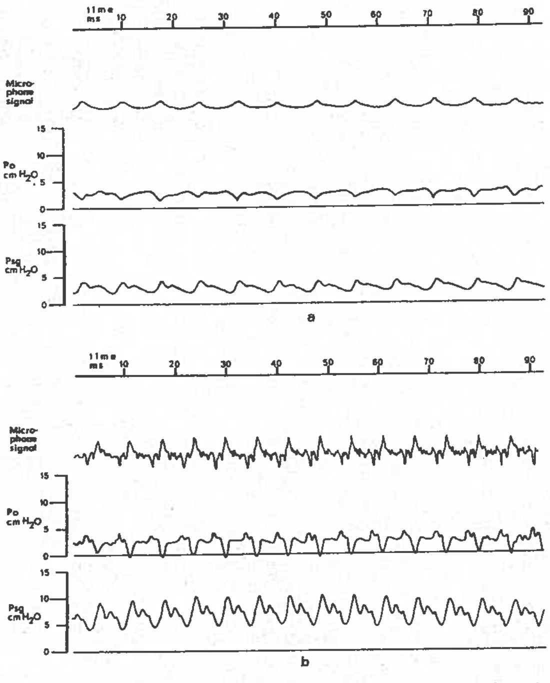

Fig. 2 Record of microphone and pressure signals during phonation: (a) low intensity; (b) high intensity

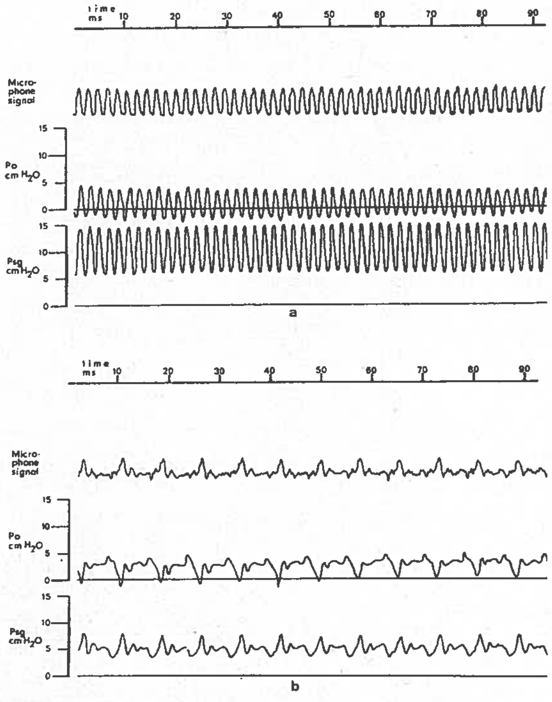

Fig. 3 Record of microphone and pressure signals during phonation: (a) high frequency; (b) low frequency

vocal folds and there was only a slight voice change to be heard in comparison with an audio tape recording made immediately before the experiment. The voice change was of a slight muffling type due to abundant mucus, and no air leakage seemed to occur. Leakage is otherwise easily identified by the characteristic high-frequency noise. The pressure above and below the glottis was recorded during continuous phonation on a neutral vowel (æ) at various frequencies and intensities, as well as during pronunciation of various speech samples.

Results and discussion

We shall concentrate on a few selected points to illustrate the types of recording it is possible to produce with the pressure system used.

Fig. 2 shows the subglottal pressure, oral pressure and microphone signal when the subject is producing tones of low and high intensity. In the pressure curves there are variations which presumably correspond to the open and closed phases of each glottal cycle. When the glottis is closed there is a peak in the P_{sg} curve and a valley in the oral pressure. The subglottal pressure then falls to a minimum while the oral pressure increases to a maximum during the open portion of the glottal cycle. Overlaid on this basic pattern are pressure variations of a higher frequency which are obviously due to resonances in the trachea and in the supraglottal cavities—this is particularly evident in the high intensity tone and in the records shown below.

The mean subglottal pressure on this occasion was 30 mm H_2O for the low intensity tone and 70 mm H_2O for the high intensity tone. If we look at the variations which take place during each vibratory cycle, we find that they are about 31% of the mean pressure for the low intensity condition and about 37% for the high intensity; these figures are considerably higher than those given by VAN DEN BERG *et al.* (1957) where these fluctuations are calculated to be less than 5%.

Fig. 3 compares the high and low fundamental frequencies. During the tone with a high F_o the variations in pressure both above and below the glottis are almost sinusoidal. The fluctuations of the subglottal pressure around the mean value are greater for the high F_o, but this is probably related to the higher average subglottal pressure in this case.

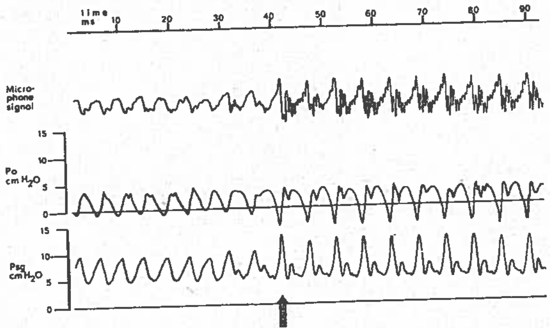

Fig. 4 Record of microphone and pressure signals during phonation with decreasing frequency demonstrating voice break at arrow

An interesting phenomenon is illustrated in Fig. 4, which shows a break in vocal register as the subject is phonating a tone of decreasing fundamental frequency. The shift is clearly visible in the pressure curves and in the oscillogram; when this change from falsetto to chest register takes place the acoustic characteristics of the sound produced by the glottis changes and the number of harmonics increases (VAN DEN BERG, 1968).

The vowels [i, a, u] produced in a stressed syllable are illustrated in Fig. 5. The same temporal relationship obtains between maxima and minima in the two pressure curves. At the same time, the differences in

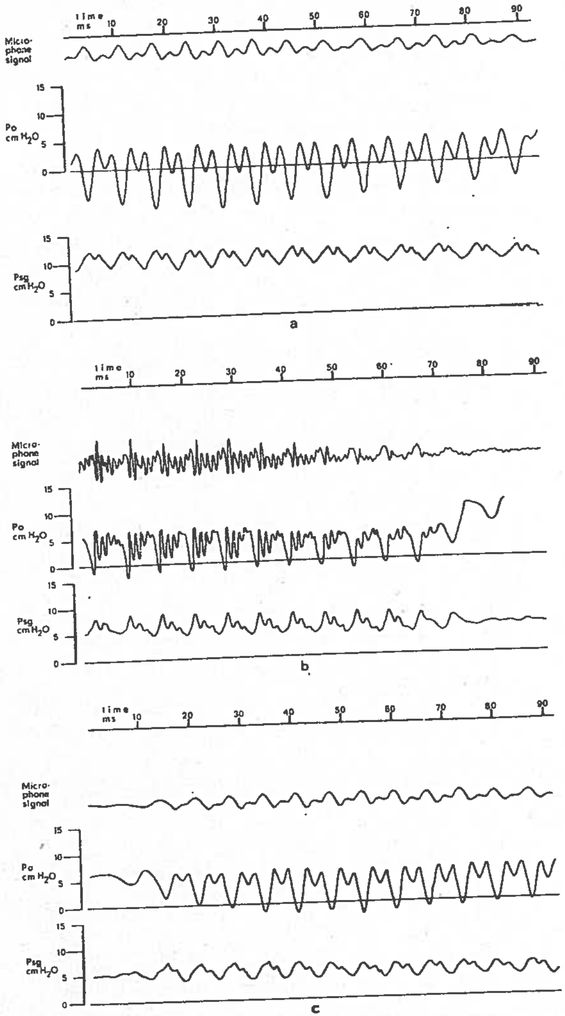

Fig. 5 Record of microphone and pressure signals during the production of the vowels: (a) [iː]; *(b)* [aː]; *(c)* [uː]

vocal-tract resonances between the vowels are visible in the record of the supraglottal pressure as well as in the oscillogram. It is less certain, however, whether there is any difference in the P_{sg} curve which can be correlated with vowel quality. The P_{sg} curve appears to be more peaked for (a) than for (i, u) but variations in the mean subglottal pressure associated with a different F_o and intensity might be the real cause of this difference.

In Fig. 6, the transitions from voiceless aspirated and voiced stop to vowel are illustrated. For the voiceless stop, the Figure only includes part of the period of aspiration and the onset of the vowel. The glottis has been open during the period of oral closure and is in the process of returning to the adducted position, suitable for voicing when the stop release takes place.

A longer time is required for full glottal vibrations to develop in this case than for the vowel following the voiced stop. This is presumably because of the fact that the vibrations start before the vocal folds have been completely adducted. The rate of air flow through the glottis is high and before full closure of the glottis has occurred the forces due to the Bernoulli effect will be great enough to suck the vocal folds together and start the vibrations. To judge from the pressure record, the vibrations start with an inward movement of the vocal folds, which is to be expected from the aerodynamic events governing the glottal vibrations, and this has also been recorded with other methods, e.g. photoelectrical glottography (Kitzing and Sonesson, 1974).

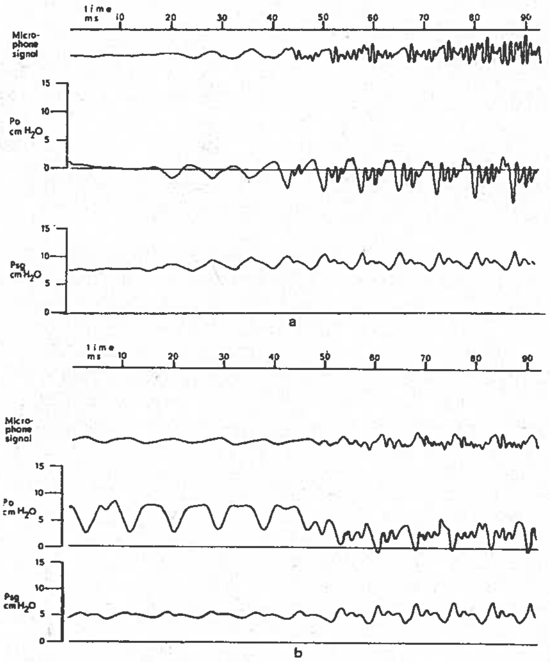

Fig. 6 Record of microphone and pressure signals during the transition from (a) voiceless aspirated and (b) voiced stop to vowels, [pa] and [ba]; respectively

For the voiced stop we find low-frequency vibrations in the pressure curve during the period of oral closure—the low frequency being a consequence of the decreasing pressure drop across the glottis. When the oral closure is released, the vibrations for the vowel develop almost immediately, since the pressure drop across the glottis is restored to values suitable for voicing to occur.

Conclusion

Our first records of air pressure above and below the vocal folds illustrate that it is possible to obtain data as reliable as those recorded by other techniques and in some respects even better, especially as far as linearity and frequency response are concerned.

The system has thus proved itself to be an excellent tool for further studies of the basic phenomena and processes in the physiology of the larynx during phonation, for the determination of the efficiency of the glottis as a sound generator under normal and pathological conditions, and for phonetic investigations of how prosodic information is conveyed during speech communication. In these studies, the pressure records will be supplemented by records of the air flow through the vocal tract and of variations in the glottal area during phonation.

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La pression de l'air au-dessous et au-dessus de la glotte pendant la phonation—étude preliminaire avec un système miniaturisé des transducteurs

Sommaire—La pression et le débit d'air sont des paramètres importants dans l'étude de la phonation. Ils sont utilisés dans les experiments physiologiques pour déterminer l'efficacité de la glotte comme producteur de son; aussi sont-ils primordials dans la recherche phonétique pour étudier le control de l'intonation dans la communication. Cependant, les méthodes traditionnelles pour enregistrer la pression de l'air au-dessous et au-dessus de la glotte sont souvent peu linéaires et ne peuvent enregistrer qu'un nombre limité de fréquences. Dans ce rapport nous avons décrit l'application d'un système miniaturisé des transducteurs de pression à l'étude des processus aérodynamiques pendant la phonation et illustré les enregistrements que l'on peut en obtenir.

Luftdruck unterhalb und oberhalb der Stimmritze bei Phonation—eine vorläufige Untersuchung mit einem Miniaturtransducersystem

Zusammenfassung—Druck und Strömung der Atemluft sind zwei wichtige Parameter beim Studium der Stimmfunktion. Aus physiologischer Sicht sind sie notwendig zur Berechnung der Effektivität des Kehlkopfes als Tongenerator, und bei phonetischen Untersuchungen bilden sie den Grund zum Verständnis der Intonationsvorgänge. Traditionelle Druckmessmethoden unterhalb und oberhalb der Stimmritze während der Phonation sind öfters mit Unzulänglichkeiten betreffs Linearität und Frequenzgang beheftet. In der erscheinenden Arbeit wird die Anwendung eines Miniaturtransducersystems zur Messung der genannten aerodynamischen Grössen während der Stimmgebung beschrieben und die Art der durch die Methode ermöglichten Registrierungen an Hand einiger typischer Beispiele illustriert.