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THE AIRWAY INTERRUPTION TECHNIQUE FOR MEASURING EXPIRATORY AIR PRESSURE DURING PHONATION

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Introduction

Evaluation of aerodynamic conditions at the glottis is very important in studying the physiology and pathophysiology of voice production. Use of a modern hot-wire flow meter[1 2] has enabled us to make an accurate measurement of the air flow rate in both normal and pathological phonation, and a clinical device for the simultaneous recording of the air flow rate, vocal pitch and intensity[3] is now commercially available from several manufacturers in Japan. In order to obtain more comprehensive data on the aerodynamic conditions, however, we need to know the mean subglottic pressure simultaneously with the air flow rate. Then the glottal resistance can be reasonably defined as the ratio of subglottic pressure to the air flow rate, and subglottic power as the product of the subglottic pressure and the air flow rate. Also, the efficiency of voice production at the glottis can be defined as the ratio of the total acoustic power of the voice to the subglottic power.[4]

Several techniques for measuring subglottic pressure during phonation have been reported. These are tracheal puncture, the transglottal approach, the measurement of intraesophageal pressure and the airway interruption method. A technique which is also useful in clinical examinations is, however, still to be found. Tracheal puncture is a straight forward method, but the procedure does not suit routine clinical examinations which must be safe and non-invasive. The transglottal approach has been recently developed since a minituarized pressure transducer has become available.[5] The method is a type of direct measurement achieved by placing a small pressure transducer in the subglottic cavity through the glottis. The output of the transducer is recorded outside the body via a thin cable containing lead wires passing through the posterior end of the glottis. The method is non-invasive, but the placement of the transducer needs the trained hand of a laryngologist, including surface anesthesia of the glottis. The procedure may also interfere with the natural phonation of the patient. Another difficulty with this method is that the transducer seems to be somewhat unreliable for measuring the mean subglottic pressure because of its variability in sensitivity due to temperature changes. The measurement of the intraesophageal pressure is an indirect method and has been utilized in the field of experimental phonetics.[4 6 7] An air-balloon with a tube is swallowed into the esophagus and the pressure inside the balloon is recorded through the tube. Swallowing the balloon may be easier than placing the transducer into the subglottic cavity. This does not mean, however, that the procedure is an easy one for routine

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clinical examinations. The subglottic pressure is calculated using the value of the intraesophagecal pressure thus obtained. Here, the air volume in the lungs should be taken into account because the relationship between the two pressure values is reported to be variable depending on changes in the lung air volume.[8]

The three techniques mentioned above appear to all have some difficulties to be solved before being utilized as tools in clinical examinations.

The airway interruption method was originally developed as a technique for measuring alveolar pressure and was utilized for estimating the resistance of the lower respiratory tract in pulmonary deseases.[9] The technique was then applied to the study of aerodynamic conditions during phonation.[10 11] In this method, respiratory air flow is momentarily interrupted by a shutter attached to a mask covering the face of the subject. The air pressure at the shutter is measured at the moment when it reaches complete equilibrium with the alveolar pressure. In phonation, this technique provides us the expiratory air pressure with an abrupt cessation of voice.[10 11] Thus the air pressure obtained by this method is not the same as that obtained by the other methods mentioned above, where the air pressure at the subglottic cavity is estimated with the air flow uninterrupted. However, it has been reported that the expiratory air pressure measured by the interruption method shows good agreement with the subglottic air pressure measured during phonation.[10] Thus, airway interruption is a nonivasive method and the procedure appears to be fairly easy if a reliable air-shutter is available, although a continuous recording and dynamic analysis of the expiratory air pressure pattern during speech is not possible. In the clinical examination of voice disorders, we are interested in the static aerodynamic condition in sustained phonation rather than in the dynamic patterns of speech. Thus, a momentary recording during sustained phonation meets our clinical purpose. In conclusion, we consider that the airway interruption technique is a good candidate for estimating subglottic pressure during phonation in the clinic.

For the purpose of clinical use, we are now developing a system of the airway interruption method combined with the measurement of the air flow rate, vocal pitch and intensity. In this paper, a description of the system and preliminary results of the measurements obtained with it will be presented.

Instrumentation

The airway shutter was designed to be connected to the commercially available PS-77 of the Nagashima Medical Instrument Co.,[3] for the simultaneous measurement of the air flow rate, vocal pitch and intensity. The whole system is outlined in Fig. 1 a. The air shutter, which is shown in Fig. 1 b, is a rotating cylinder shaft with a hole for the air passage. When the shutter is set in the open position, the air flow passes from the mouth piece through the hole and reaches the flow transducer. The shutter is set in the closed position by the rotation of the sylinder shaft at a right angle in order to make a complete interruption of the air flow. The open/close motion of the shutter is controlled by a stepping motor driven by a pulse train. When we press the switch, the shutter is closed very rapidly and again returns to the open position after a preset time interval. A pressure transducer is connected to the air passage between the mouth piece and the shutter.

Figure 1c shows the pressure curve at the moment of air flow interruption during sustained phonation with the mouth piece held airtight by the lips. The pressure increases rapidly with the interruption and reaches equilibrium with the lung pressure after the cessation of voicing. When the shutter is released, the pressure decreases rapidly to the baseline, and the resumption of voicing takes place. The upward pointing arrows in the figure indicate the time points of the equilibrium as defined on the pressure curve. It can be noted that the time delay from the onset of the pressure increase to equilibrium is approximately 200 msec in our experiment. This means that the closed period of the shutter must be longer than 200 msec. On the other hand, various kinds of reaction on the part of the subject may interfere with the steady state of expiratory control during phonation if the interruption continues too long. Thus, the closed period of the shutter is set at 400 msec in actual experimental runs.

Simultaneous Recording of the Expiratory Air Pressure, Air Flow Rate, Vocal Pitch and Intensity

Procedures

The subjects were normal adult males. The output signals of a F_0 extractor, flow meter, sound pressure level meter and pressure transducer were recorded in a PCM data recorder, and the measurements were made on visicoder traces as shown in Fig. 2. In the figure, the arrows indicate the time point of the measurement on the traces. It can be seen that the flow rate, intensity and F_0 curves each shifts to the baseline immediately after the interruption. The average level of each curve before the onset of the downward shift was taken as the value of each parameter.

Measurements were made on the following conditions of the sustained phonation:

1) Phonation at low, middle and high vocal pitch levels within the range of the chest register of the subject at different intensity levels.
2) Phonation of normal and breathy voices at a comfortable vocal pitch for the subject, the intensity being maintained the same as much as possible.
3) Phonation of chest and falsetto voices, the F_0 and intensity being maintained the same as much as possible.

During each of the sustained phonations, the subjects monitored their F_0 and intensity of voice on the indicators installed with the instruments. Care was taken for each of the subjects to hold the mouth peace firmly with his teeth and lips and with tense cheeks, in order to prevent the air leakage at the lips due to an increase in the intraoral pressure. The interruption was repeated 3 times with an interval of 2 to 3 seconds for each sustained phonation.

Results

The results obtained for the chest voice are displayed in Fig. 3a–c. The graphs in the figure summarize the relationships of intensity to pressure, intensity to flow rate, intensity to resistance and intensity to efficiency. In the graphs, the ordinates indicate the intensity of the voice measured at 20 cm from the outlet of the flow transducer, and the abscissas indicate other parameters along a logarithmic scale.

The value of the expiratory air pressure in cmH_2O ranged 4.2 to 17.6 in Subj. 1 (Fig. 3a), 3.1 to 12.8 in Subj. 2 (Fig. 3b); and 2.5 to 16.7 in Subj. 3 (Fig. 3c). These ranges are in good agreement with the subglottic pressure measured by the tracheal puncture method.[12 13] In all the subjects, there was a linear increase in expiratory pressure along the logarithmic scale, with the increase in the intensity of voice in SPL. The air flow rate in ml/sec ranged 85 to 282 in Subj. 1; 113 to 340 in Subj. 2; and 94 to 212 in Subj. 3. In Subjs. 1 and 2, the air flow rate appears to have been greater with a low F_0 than with a high F_0, and also tended to increase with an increase in intensity. But this was not so in Subj. 3. The resistance shown here is the value of the expiratory air pressure/air flow rate. Thus, the value includes the resistance of the lower respiratory tract together with that of the glottis. The value in $cmH_2O/L/sec$ ranged 36 to 80, 19 to 52 and 23 to 80 in Subjs. 1, 2 and 3, respectively. This range is in agreement with the glottal resistance obtained by tracheal puncture.[12] The value of the resistance appears to have slightly increased with the increasing intensity. The efficiency here is the ratio of the total acoustic power of the voice to the aerodynamic expiratory power. The latter is the product of the air flow rate and the expiratory pressure. The total acoustic power of the voice was calculated from the sound pressure level, assuming that the acoustic energy of the voice was evenly distributed on the surface of the hemisphere in front of the flow transducer.[4] The value of the efficiency ($\times 10^{-4}$) ranged 0.3 to 2.0, 0.3 to 4.9 and 0.2 to 6.7 in Subjs. 1, 2 and 3, respectively. This range roughly agrees with that obtained by tracheal puncture.[12] It can be noted that the efficiency along the logarithmic scale increased linearly with the increase in intensity in SPL for all of the subjects. It was also noted that the value of the efficiency for the same intensity appears to have been greater with high pitch than with low pitch in Subjs. 1 and 2.

A comparison of the normal and breathy voices is shown in Fig. 4a–c. In the Subjs. 1 and 2, there was little difference in expiratory pressure between the two voices, while an increase in the air flow rate was noted with the breathy voice. The result was a reduction in resistance and efficiency with the breathy voice. In Subj. 3, on the other hand, both expiratory air pressure and air flow rate were greater with the breathy voice than with the normal voice. The result was a reduction of efficiency with the breathy voice, the resistance showing little change compared to the normal voice.

A comparison of the chest and falsetto voices is shown in Fig. 5a, b. In both of the subjects there was no discernible difference in expiratory pressure between the two registers. In contrast, the air flow rate was greater in the falsetto voice, and, as a consequence, the resistance and efficiency were less in the falsetto as compared to the chest voice.

Comments

The airway interruption technique presented here is a practical and useful method of estimating expiratory air pressure during sustained phonation. The pressure value thus obtained is an aerodynamic representation of the expiratory force during phonation. It is also felt that the pressure value is in good agreement with the real subglottic pressure when the flow resistance of the lower respiratory tract is negligible compared to the glottal resistance, as in normal phonation. Whether this is also true for the pathological cases with a marked reduction in glottal resistance is a question to be answered by future research.

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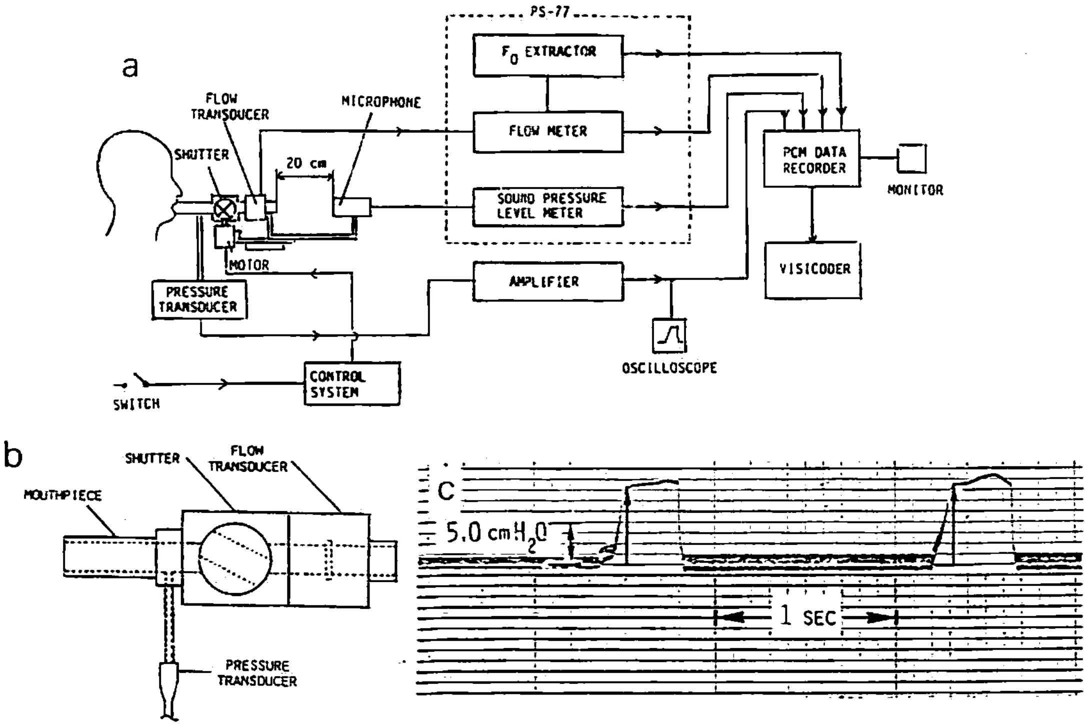

Fig. 1 *Block diagram of the system of airway interruption and measurements of air flow rate, vocal pitch and intensity (a); arrangement of air shutter and pressure transducer (b); and pressure curve of airway interruption during phonation.*

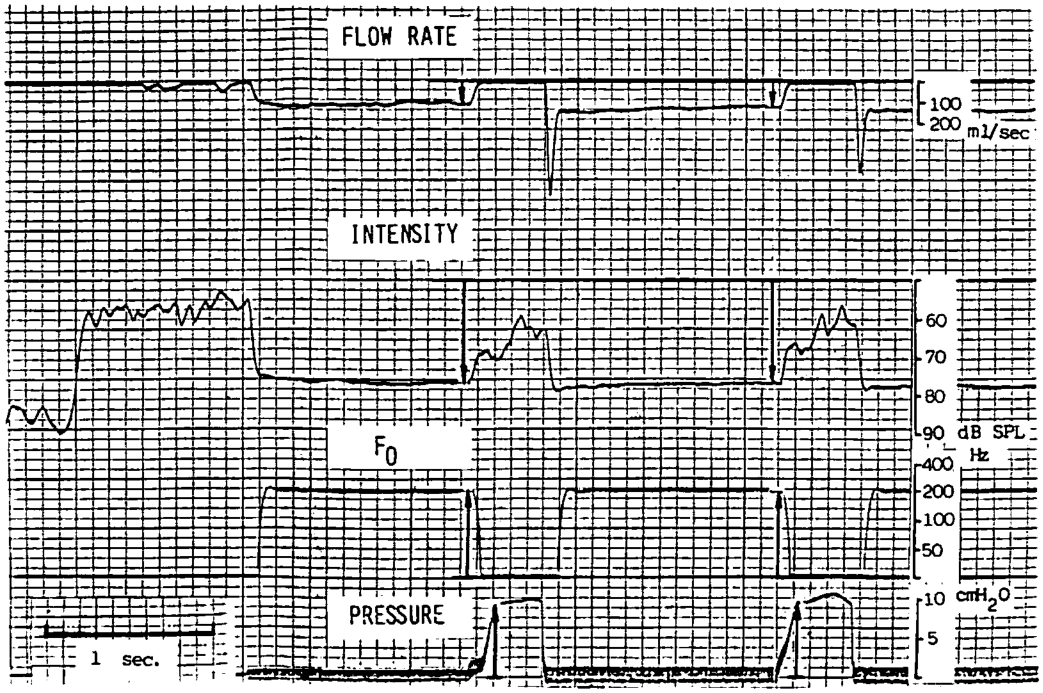

Fig. 2 *An example of visicorder traces of air flow rate, intensity of voice, F_0 of voice and expiratory air pressure during sustained phonation with airway interruption.*

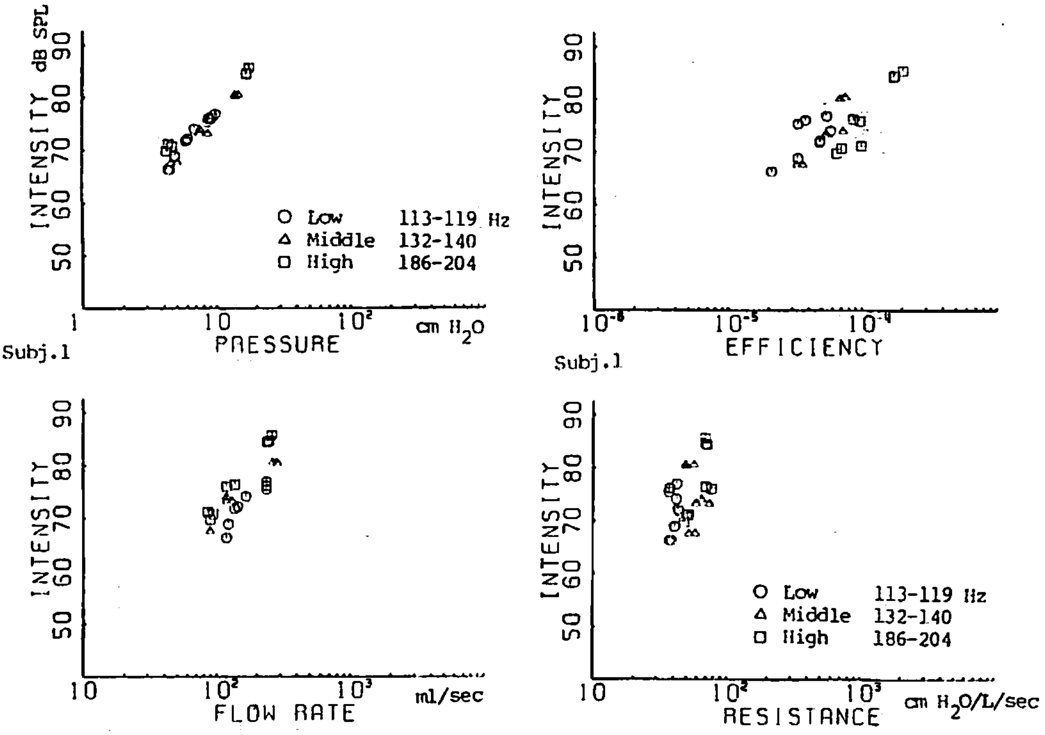

Fig. 3 a *Graphs showing the relationships of intensity to expiratory pressure, intensity to air flow rate, intensity to resistance and intensity to efficiency (Subj. 1).*

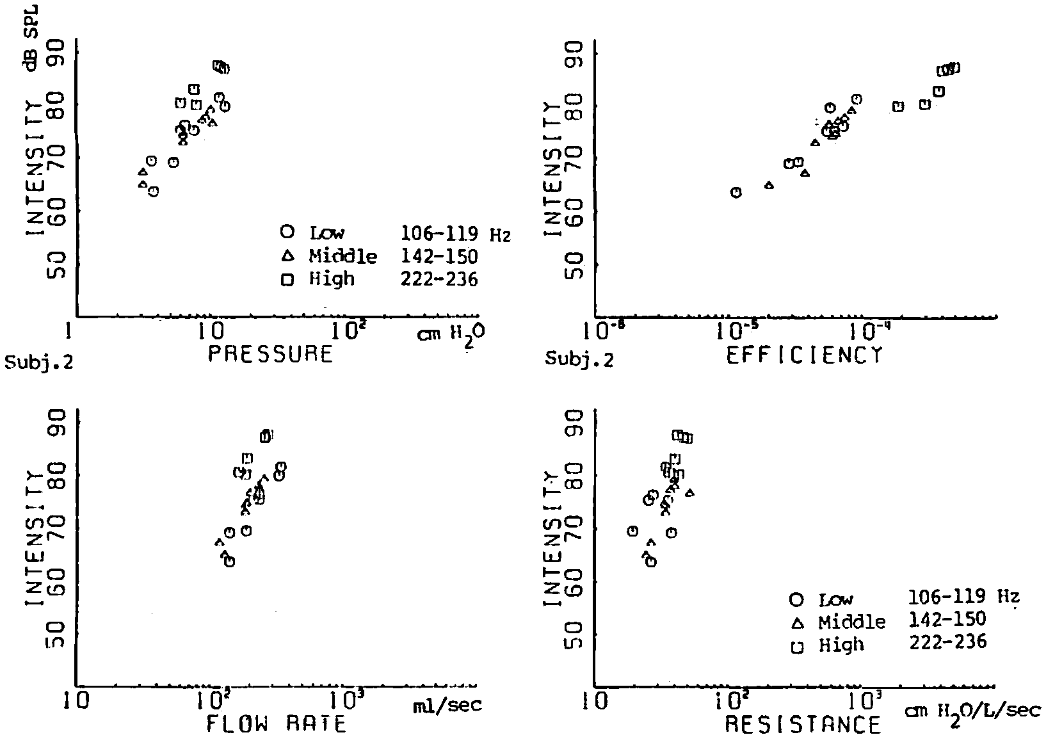

Fig. 3 b *Same display as Fig. 3a (Subj. 2).*

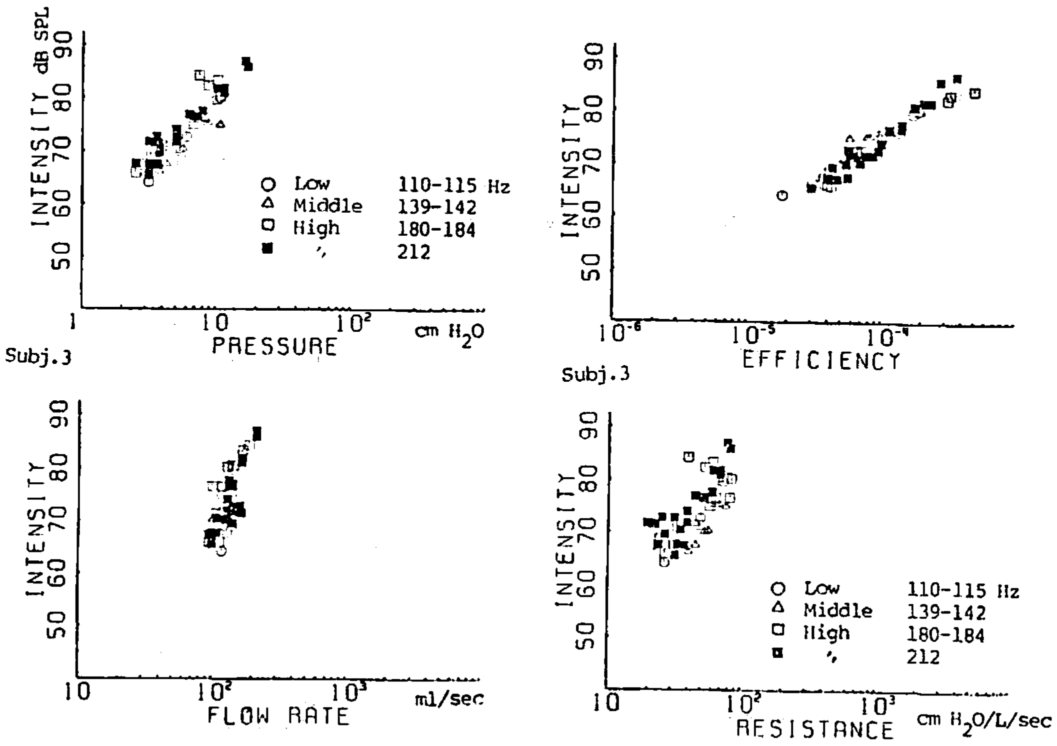

Fig. 3c *Same display as Fig. 3a (Subj. 3).*

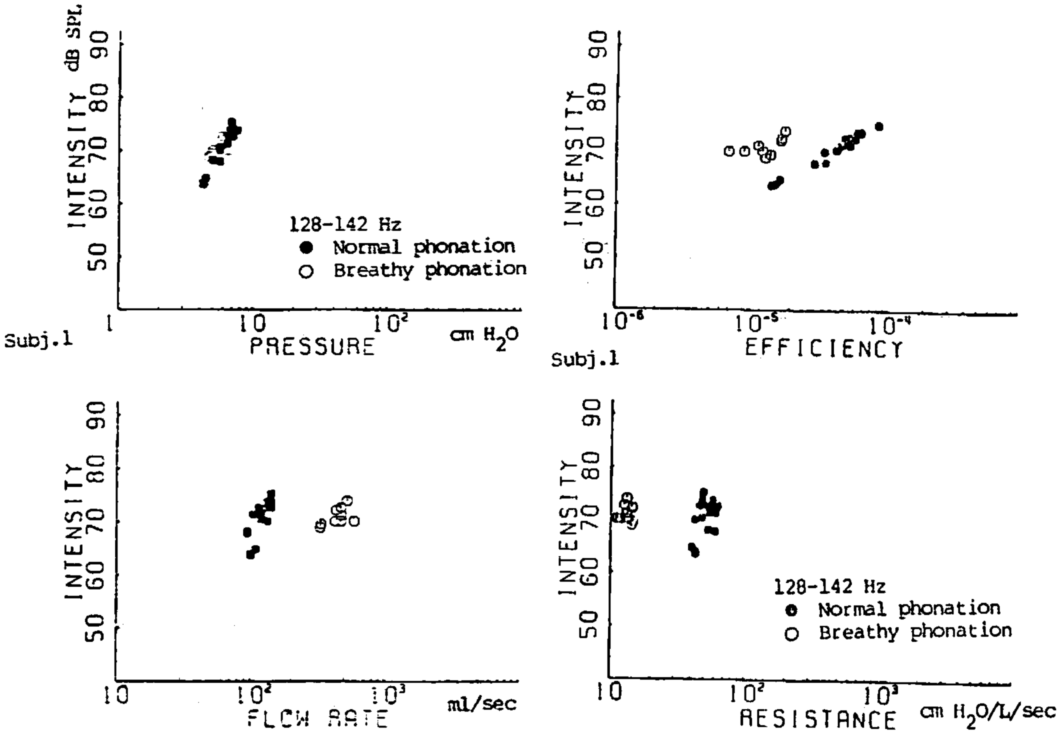

Fig. 4a *Comparison of normal and breathy voices (Subj. 1).*

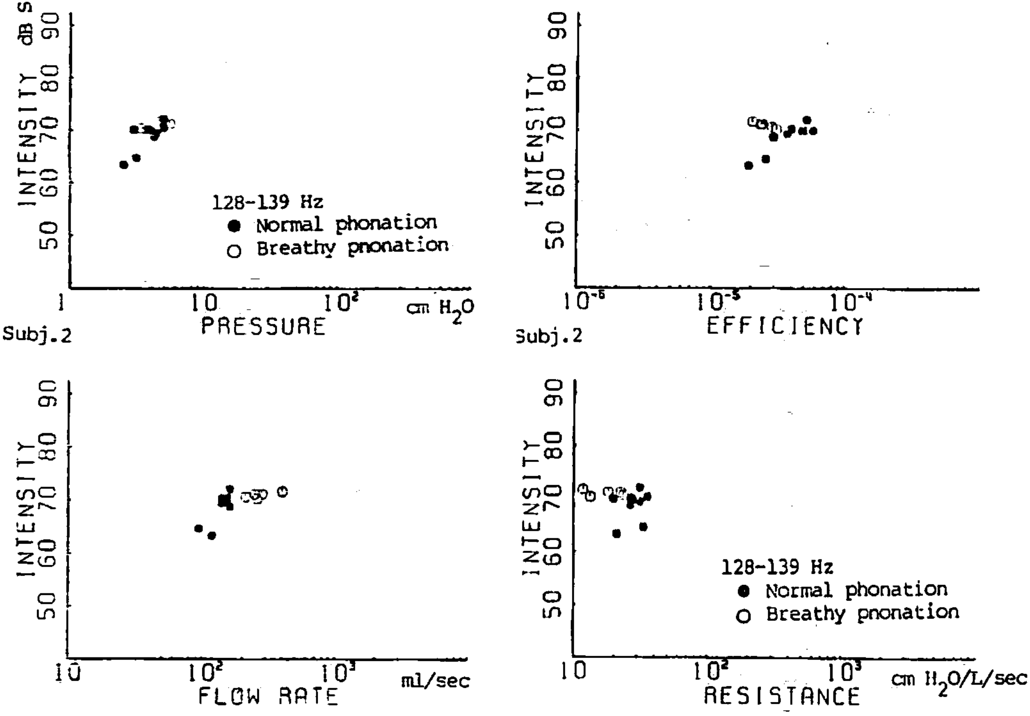

Fig. 4b *Same display as Fig. 4a (Subj. 2).*

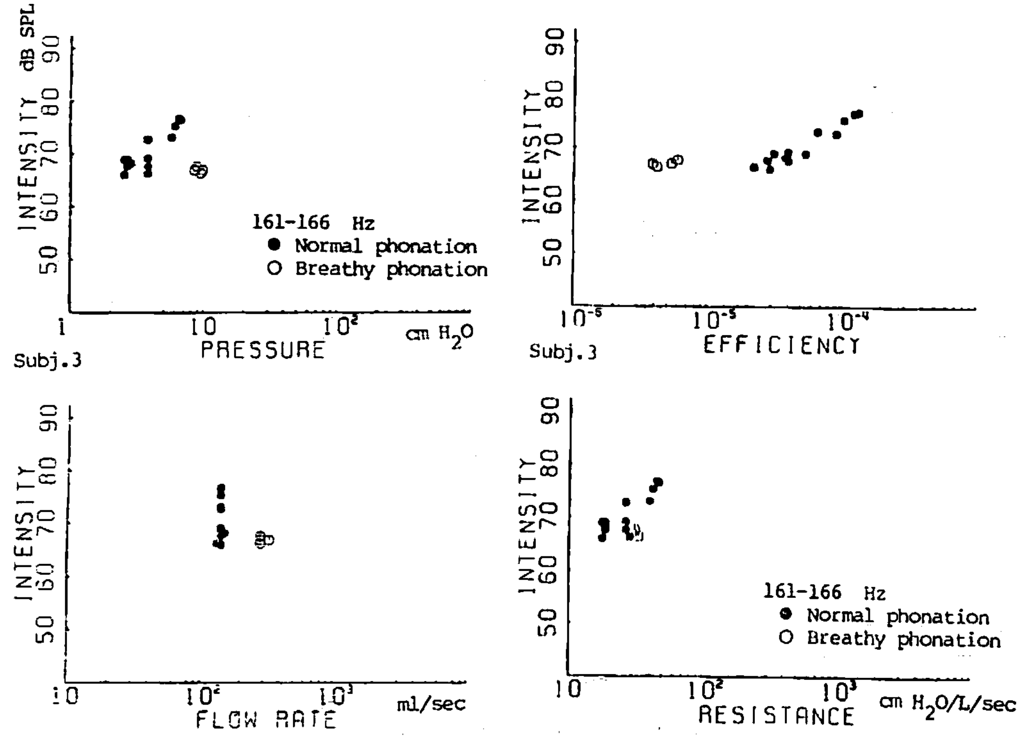

Fig. 4c *Same display as Fig. 4a (Subj. 3).*

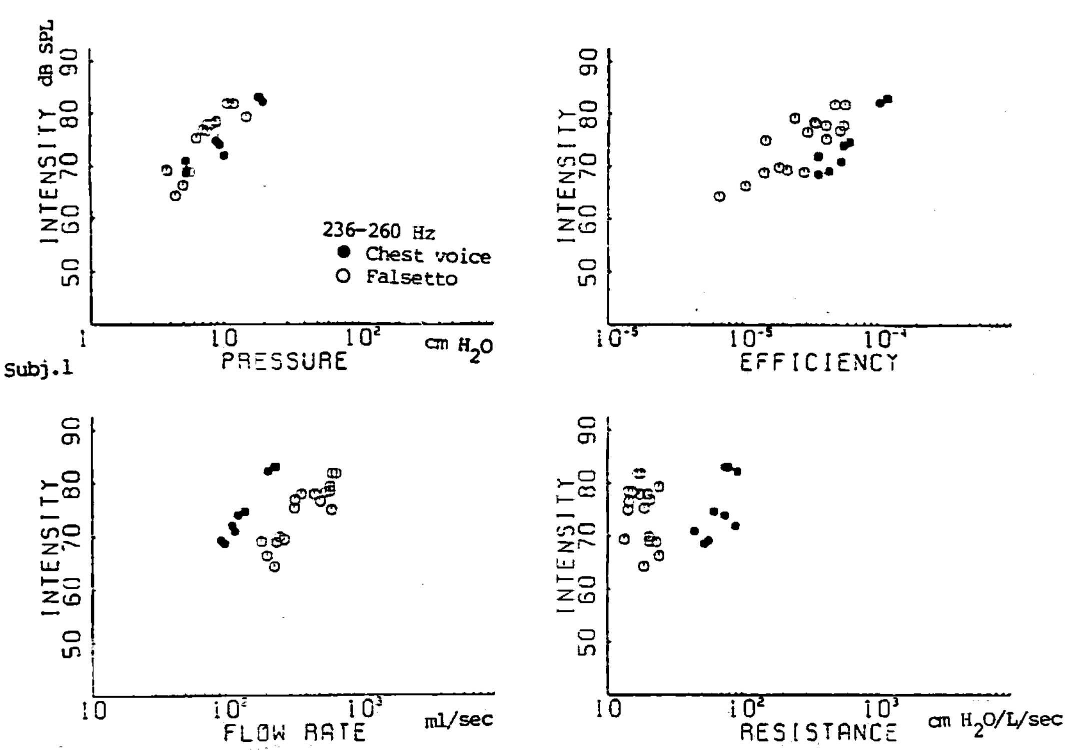

Fig. 5a *Comparison of chest and falsetto voices (Subj. 1).*

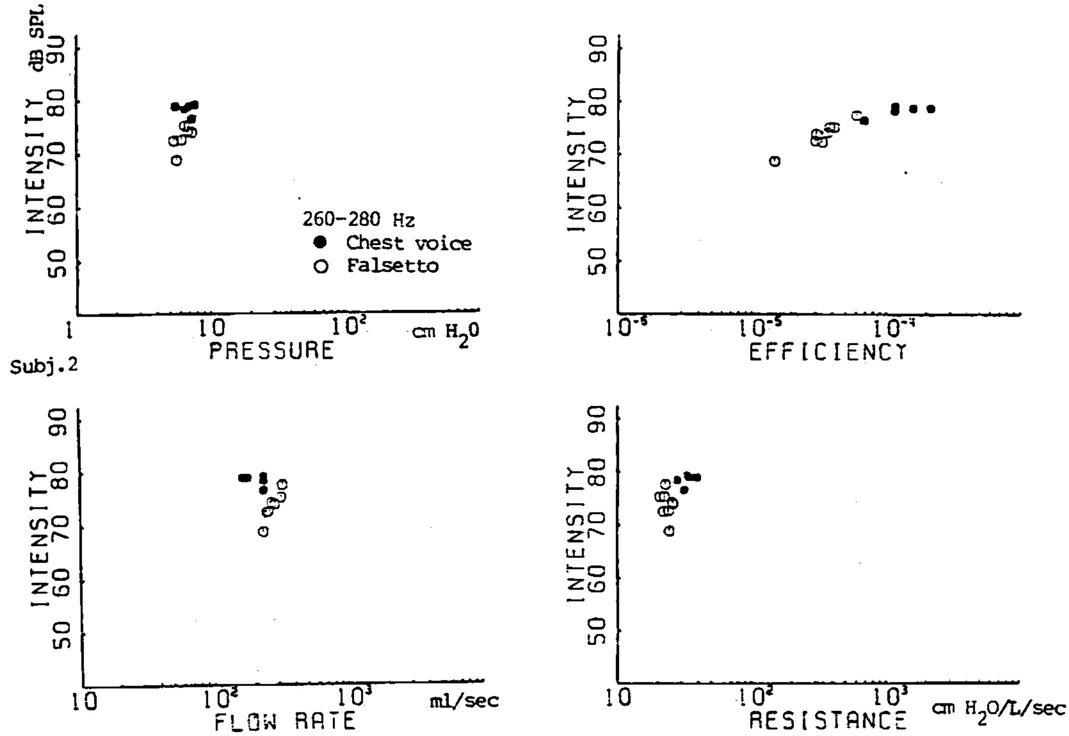

Fig. 5b *Same display as Fig. 5a (Subj. 2).*