Ann.Bull.RILP(1987)No.21, 101-110

ON THE CLINICAL EVALUATION OF AERODYNAMIC DATA IN PHONATION: A STUDY OF NORMATIVE DATA USING THE AIRWAY INTERRUPTION METHOD

Masayuki Sawashima, Seiji Niimi, Satoshi Horiguchi and Hiroya Yamaguchi*

Introduction

For clinical purposes, we developed a system to measure expiratory lung pressure during phonation using the airway interruption method combined with measurements of the mean air flow rate, vocal pitch and intensity[1)-4)]. Expiratory lung pressure measured by this method is not the same as subglottic pressure during phonation with the transglottic air flow uninterrupted. A preliminary experiment indicated that the difference between the two values was reasonably estimated as a function of the air flow rate[2),4)], the data indicating the difference to be negligible when the air flow rate was relatively small. The airway interruption method is non-invasive and easy to perform in clinical cases. Thus, this method is useful for evaluating aerodynamic conditions at the glottis, as well as expiratory force, during phonation.

Preliminary clinical data were presented in the last issue of the Ann. Bull. concerning the appropriate format for evaluation[5)]. The results suggested that the values of I-P and I-U in relation to I, where I, P and U were intensity of voice in dB SPL, $10\log_{10}p$ (p: pressure in mmH_2O) and $10\log_{10}u$ (u: flow rate in ml/sec), respectively, provided good references for evaluation.

This paper reports on a more systematic study along the same lines using data obtained from normal subjects.

Procedures

Subjects were 66 normal adults, 30 males and 36 females. None had special training for singing. Measurements were made on sustained spoken voice in the modal register at two pitch conditions and with three intensity conditions: at usual spoken pitch (USP) and at a higher pitch of 7 semitones above USP, and with soft, normal and loud voice for each pitch condition. The vocal pitch was controlled by reference to tones from a musical instrument, while the vocal intensity was controlled by the subjective judgment of each subject.

The data were collected in sound-proof rooms at the ENT clinics of the University of Tokyo Hospital and Tokyo Senbai Hospital.

* Tokyo Senbai Hospital

Results and Comments

Pressure and Flow Rate in Relation to Intensity

Fundamental frequencies at the USP and the higher pitch were in the ranges of 100 Hz to 160 Hz and 140 Hz to 280 Hz, respectively, for the male group, and 160 Hz to 280 Hz and 240 Hz to 400 Hz, respectively, for the female group.

Figure 1 shows the expiratory lung pressure in relation to voice intensity in the two pitch conditions for the male and female groups. In each graph, the ordinate indicates the pressure in mmH_2O on a logarithmic scale, and the abscissa the intensity in dB SPL as measured at 20 cm from the outlet of the flow transducer attached to the mouth piece. The intensity values were in the range of approximately 60 dB to 90 dB for the two pitch conditions, for both the male and female groups. The data points for soft, normal and loud voice are connected by solid lines for each of the subjects. The pressure values were in the range of 20 mmH_2O to 150 mmH_2O for the two pitch conditions, for both the males and female groups.

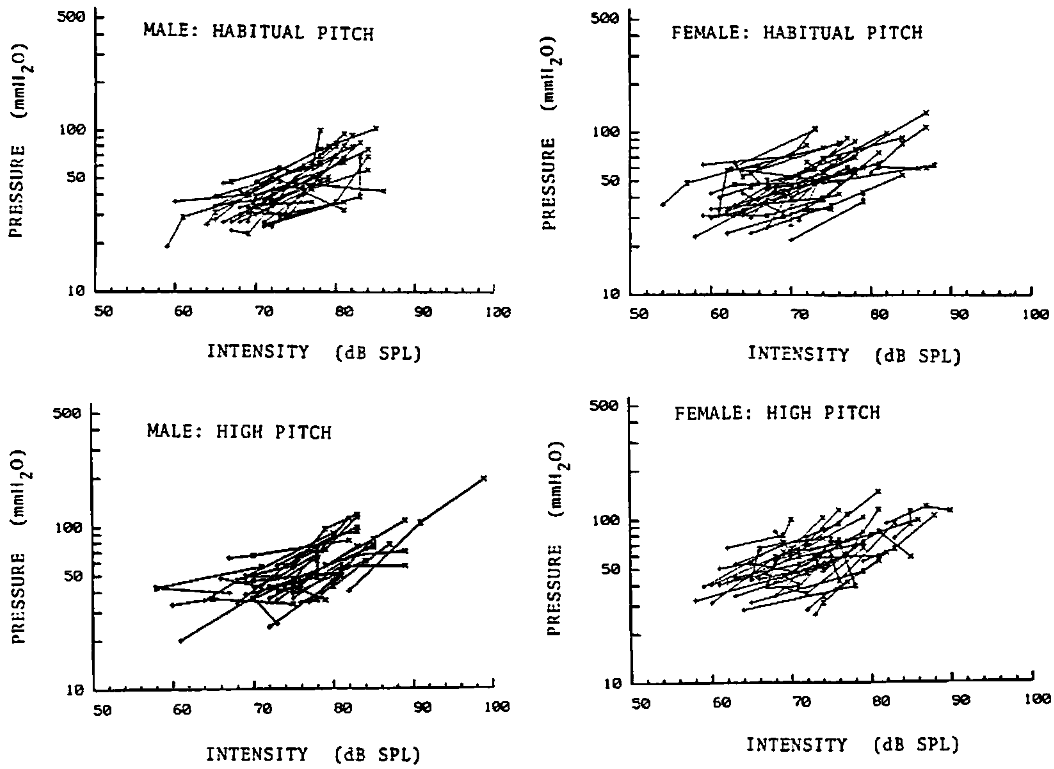

Fig. 1 Expiratory lung pressure plotted in relation to vocal intensity.

There was considerable variation in the intensity values among individual subjects. Some variation in the pressure values was also seen. It was noted, however, that almost all the subjects showed an increase in pressure with an increase in vocal intensity. This result is consistent with our previous reports[1),4)], and reports on the measurement of subglottic pressure during phonation [6)-8)]. There appears to be a general tendency for the logarithm of the pressure values to show a linear relationship to vocal intensity, which is also consistent with reports on subglottic pressure[6),8)]. It was also noted that the increase in pressure was much less than that in intensity. Isshiki[6)] has reported that vocal intensity, measured at 20 cm from the outlet of the flow transducer, as in our present study, is approximately proportional to the 3.3 power of the subglottic pressure. Our data on average appear to be comparable to Isshiki's, although no mathematical analysis was made in our study.

Comparing the data for the two pitch conditions, it was noted that there was little difference in the distribution of data points between the two conditions. This indicates that a vocal pitch change within a range of half an octave above USP causes little change in pressure data. In other words, we may practically disregard the pitch change in this range when we measure expiratory lung pressure.

Figure 2 shows the flow rate in relation to the vocal intensity. In each graph, the ordinate indicates the flow rate in ml/sec along a logarithmic scale. Data points for soft, normal and loud voice are connected by solid lines for each of the subjects. The values are in the ranges of approximately 60 ml/sec to 300 ml/sec for the male group, and approximately 60 ml/sec to 360 ml/sec for the female group, in the two pitch conditions. It was noted that there was an increase in the flow rate with an increase in intensity for some of the subjects but not for others. Thus, the relationship between the flow rate and the intensity was not as consistent as that between the pressure and the intensity. This result is consistent with our previous reports[1),4)] and that of Isshiki[6)].

It was also noted that there was little difference in the distribution of the data points between the two pitch conditions for both the male and female groups. This finding indicates that a pitch change in the range of the present study may be practically disregarded for the measurement of flow rate, as it was for pressure measurement.

Aerodynamic Efficiency in Phonation

According to Van den Berg[9)], glottal efficiency is defined as the ratio of the total voice power to the subglottic power, where the subglottic power is the product of the mean subglottic pressure and the mean flow rate. In our clinical study, an absolute value for Van den Berg's "glottal efficiency" is not

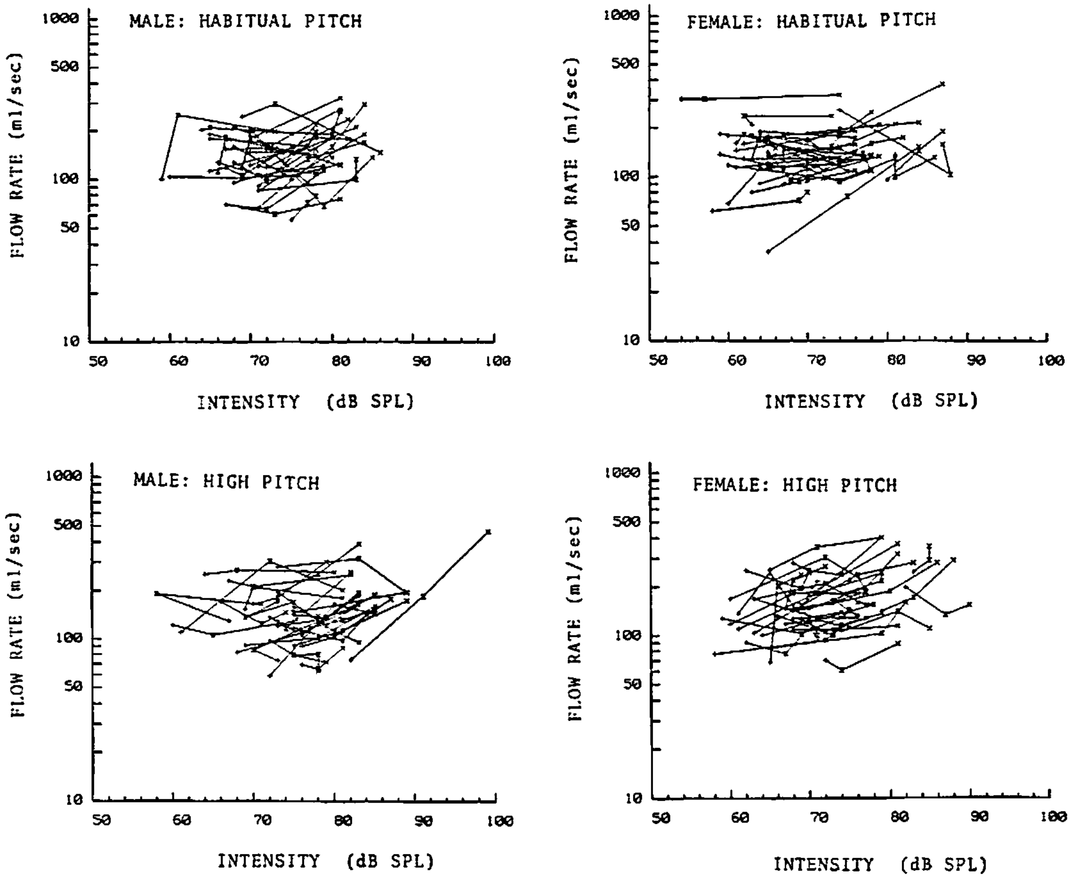

Fig. 2 Flow rate plotted in relation to vocal intensity.

indispensable. We were rather concerned with establishing some practical measure for evaluating the glottal efficiency of clinical cases in reference to that of normal subjects. In this sense, the total voice power may be better replaced by the intensity of voice (dB SPL) in clinical practice. We measure the expiratory lung pressure instead of the subglottic pressure. Then, we use the "expiratory power" instead of the "subglottic power". Thus, our measure here is the ratio of the voice intensity to the expiratory power, where expiratory power is the product of the expiratory lung pressure and the mean flow rate. Our data on the expiratory pressure in relation to the voice intensity have been in good agreement with these for subglottic pressure. Therefore it is reasonable to assume that the glottal efficiency is well represented by our measures described above.

We first obtained the values of $10\log_{10}p$ and $10\log_{10}u$, where p and u were the pressure in mmH_2O and the flow rate in ml/sec, respectively. Then, we calculated the value of $I-10\log_{10}p \cdot u$, where I was the voice intensity in dB SPL. Figure 3 shows the values of $I-10\log_{10}p \cdot u$ in relation to I. In each graph the ordinate indicates the values of $I-10\log_{10}p \cdot u$. The data points for the 3 intensity conditions are connected by solid lines for each of the subjects. There are some individual variations among the subjects. It is clear, however, that the aerodynamic efficiency increases with the increase in the intensity, showing a nearly linear relationship to the intensity. Variation in glottal efficiency with an increase in vocal intensity has already been reported[6),7)], and the distribution of the data points in Figure 3 can be taken as a good representation of the glottal efficiency in relation to the vocal intensity.

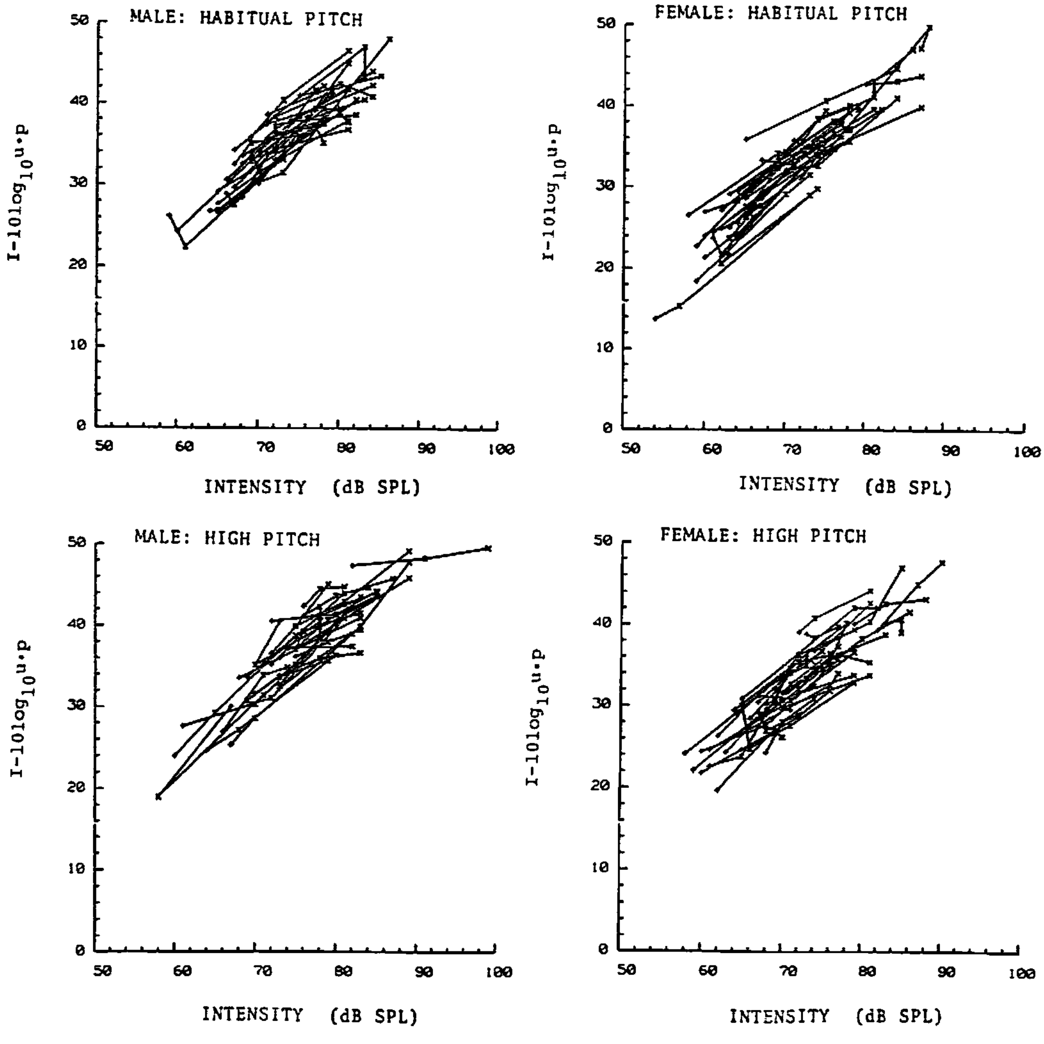

Fig. 3 Aerodynamic efficiency plotted in relation to vocal intensity.

In pathological cases, we can expect an abnormal reduction in aerodynamic efficiency. Theoretically, this abnormal reduction may be characterized by an abnormal increase in either the expiratory pressure or the flow rate, or both, for a given vocal intensity. Our preliminary study[5)] revealed that a reduction in aerodynamic efficiency in some patients with recurrent nerve palsy was characterized by an abnormal increase in their flow rate. This was apparently due to an incomplete glottal closure for phonation, in other words, an abnormal reduction in glottal resistance. On the other hand, some of our patients with vocal cord polyp showed an increase in expiratory pressure with little increase in flow rate. This was an indication of an abnormal increase in glottal resistance. The pathophysiologies at the glottis for these two groups of patients is quite different, although they both result in a reduction in aerodynamic efficiency.

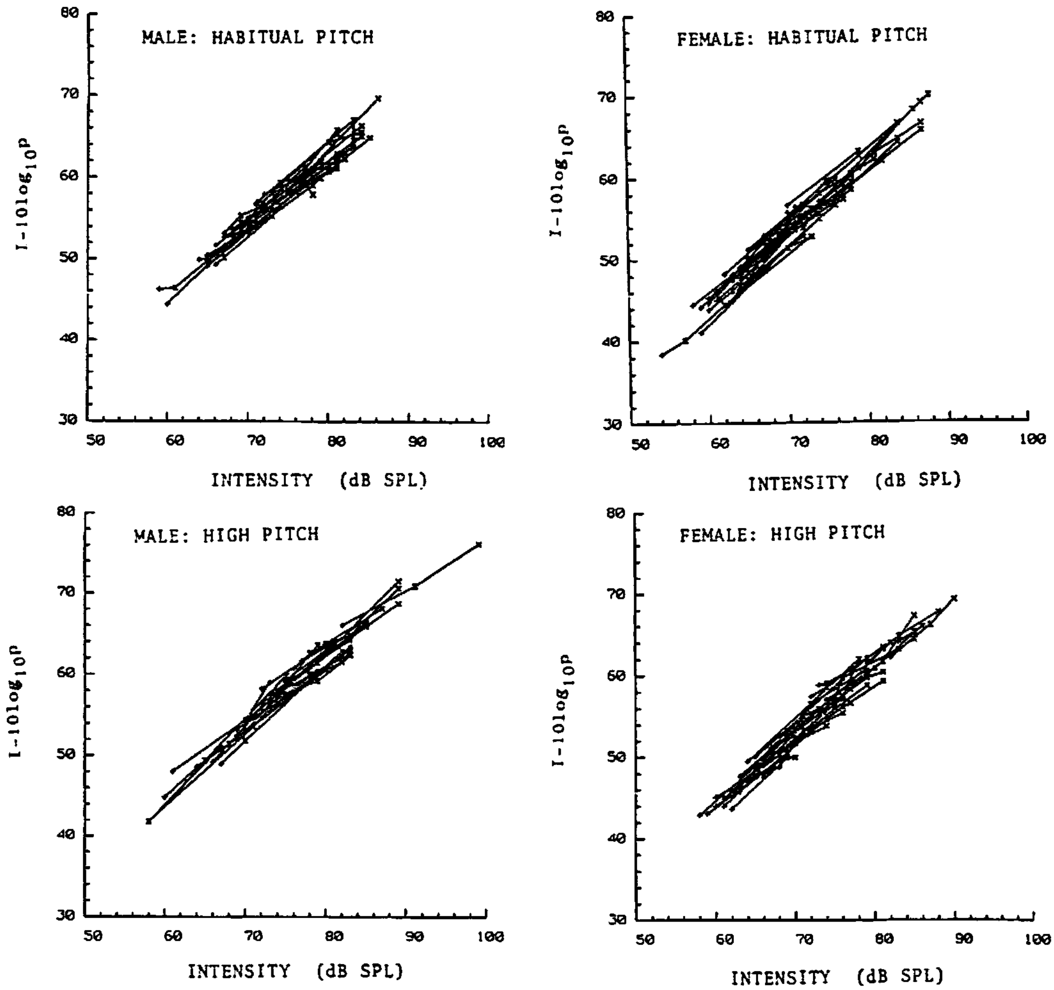

Fig. 4 The pressure component of aerodynamic efficiency plotted in relation to vocal intensity.

For analyzing the pathophysiology of the vocal function, the pressure component and the flow component of the aerodynamic efficiency should be evaluated separately. The pressure component of the aerodynamic efficiency may be represented by $I-10\log_{10}p$, and the flow component by $I-10\log_{10}u$.

Figure 4 shows the pressure component in relation to the vocal intensity. In each graph, the ordinate indicates values for $I-10\log_{10}p$. The graphs show a consistent and linear increase in this value with an increase in the vocal intensity in dB SPL for all the subjects.

Figure 5 shows the flow component in relation to the vocal intensity, where the ordinate of each graph indicates values for $I-10\log_{10}u$. Here also, all the subjects show a linear increase in this value with an increase in the vocal intensity.

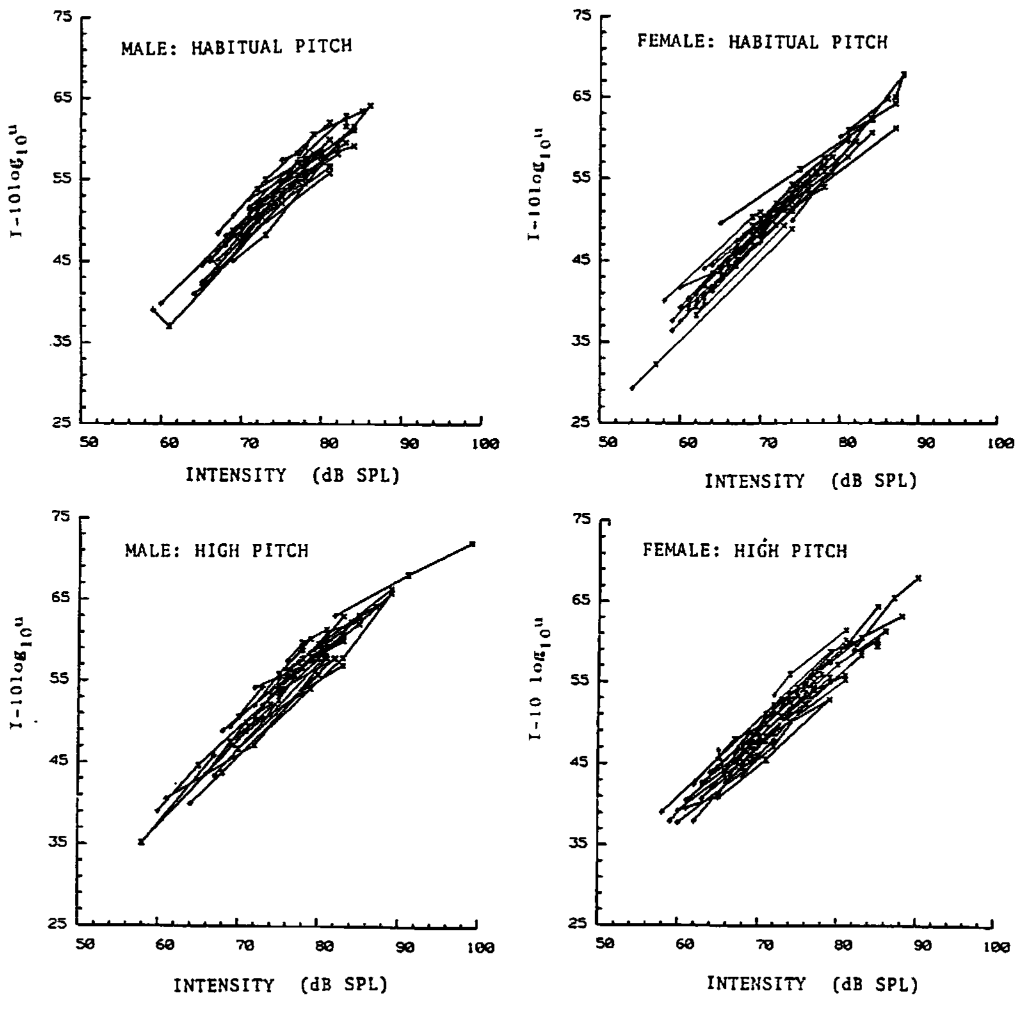

Fig. 5 The flow component of aerodynamic efficiency plotted in relation to vocal intensity.

There is little difference between the two pitch conditions for either the pressure or the flow component in either the male or female group. In Figure 6, the data points for the two pitch conditions are plotted together. The distribution of the pooled data points provides a good normative reference in evaluating the aerodynamic conditions at USP of the pathological cases. In the case of an abnormal reduction in the efficiency of the use of air in phonation, the data points in the pertinent graphs shift downward and away from the normal group.

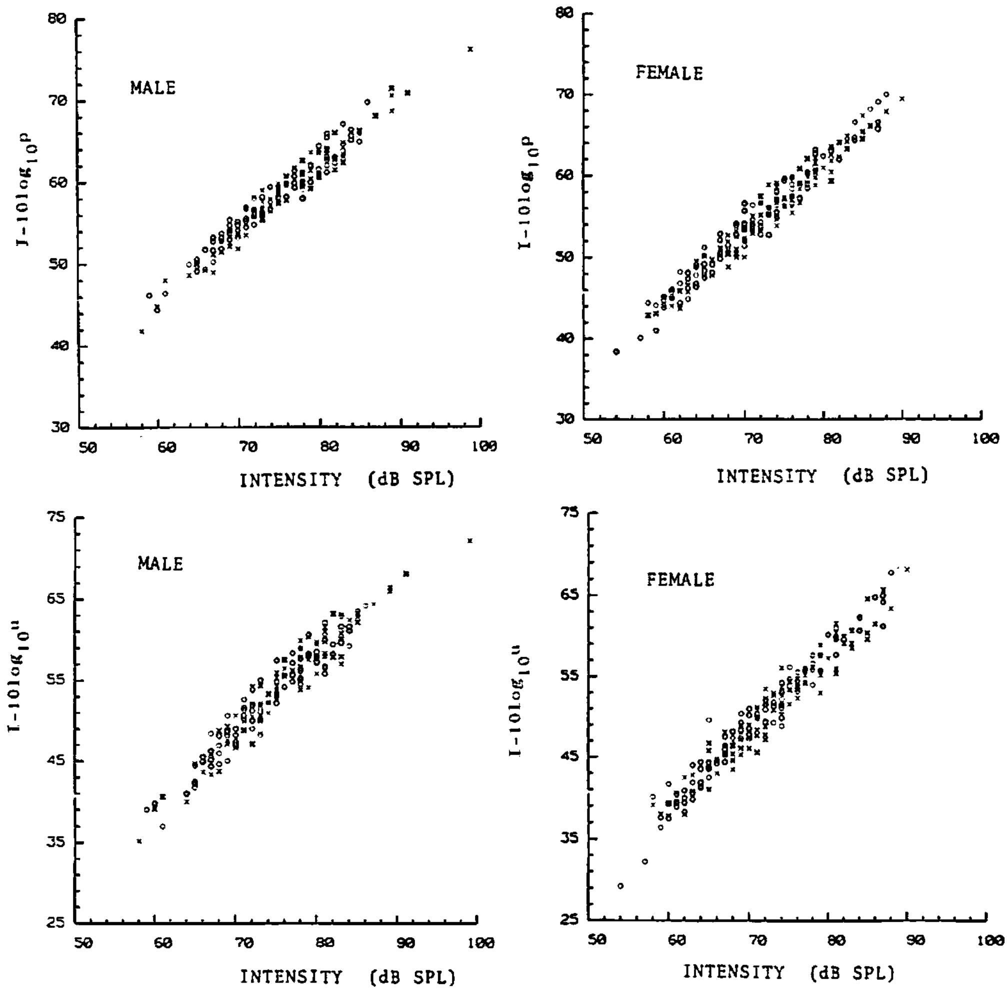

Fig. 6 The pressure component and flow component of aerodynamic efficiency plotted in relation to vocal intensity (pooled data).

Summary

In order to establish an appropriate format for the clinical evaluation of aerodynamic conditions for phonation, we examined expiratory lung pressure and air flow rate in relation to vocal intensity for spoken voice in normal subjects. The data revealed the following.

1. A change in vocal pitch within half an octave above USP could be disregarded in measurement.

2. The relationship between expiratory lung pressure and vocal intensity showed good agreement with that between subglottic pressure and vocal intensity. Thus, expiratory pressure can be considered a good substitute for subglottic pressure.

3. Aerodynamic efficiency in normal voice increased systematically with an increase in vocal intensity, for both pressure and flow components.

4. Values for $I-10\log_{10}p$ and $I-10\log_{10}u$ in relation to I--where I, p and u were the vocal intensity in dB SPL, pressure in mmH_2O and flow rate in ml/sec, respectively--were proposed for evaluating aerodynamic conditions in phonation.

Acknowledgement

The work was in part supported by the Grant-in-Aid for Scientific Research (No. 61570818) from the Japanese Ministry of Education, Science and Culture.

References

1) Sawashima, M., S. Kiritani, S. Sekimoto, S. Horiguchi, K. Okafuji and K. Shirai: The airway interruption technique for measuring expiratory air pressure during phonation. Ann. Bull. RILP, 17, 23-32, 1983.
2) Sawashima, M., K. Honda, S. Kiritani, S. Sekimoto, S. Ogawa and K. Shirai: Further works on the airway interruption method of measuring expiratory air pressure during phonation. Ann. Bull. RILP, 18, 19-26, 1984.
3) Sawashima, M., K. Honda and Y. Aoki: Measurement of expiratory lung pressure during phonation by use of the airway interruption method. Proceedings of XXth IALP Congress, 424-425, 1986.
4) Sawashima, M. and K. Honda: An airway interruption method for estimating expiratory air pressure during phonation. In T. Baer, C. Sasaki and K. Harris eds.: Laryngeal Function in Phonation and Respiration, College-Hill Pub., Boston, 439-447, 1987.
5) Sawashima, M., K. Honda, S. Niimi and H. Hirose: Some clinical data on aerodynamic examination using the airway inter-

ruption method. Ann. Bull. RILP, 20, 217-224, 1986.
6) Isshiki, N.: Regulatory mechanism of voice intensity variation. Journal of Speech and Hearing Research 7, 17-29, 1964.
7) Nishida, Y.: Aerodynamic studies on voice regulation. Otologia Fukuoka, 13, (Supplement 1), 44-66, 1967.
8) Ladefoged, P.: Three Areas of Experimental Phonetics, Oxford Univ. Press, 1970.
9) Van den Berg, J.: Direct and indirect determination of the mean subglottic pressure. Folia phoniat., 8, 1-24, 1956.