PARATASIS-GRAM OF THE VOCAL FOLDS AND THE DIMENSIONS OF THE VOICE

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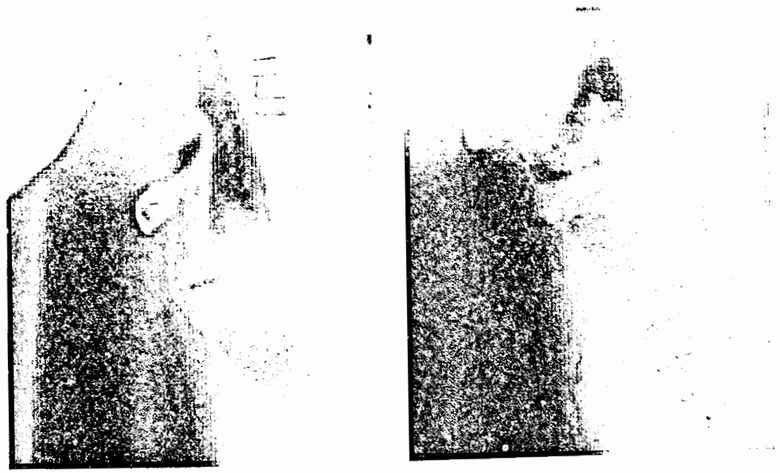
Our knowledge of phonation is based largely on theory or on observations made under conditions differing from the normal, for example using a laryngeal mirror, or excised human larynges, etc. Few direct, objective observations have been made owing to the technical difficulties involved.

Paratasis, or stretching in the ascending scale, of the vocal folds has not yet been dealt with exhaustively (Luchsinger and Arnold, p. 62). The relationship of paratasis to the various dimensions of the voice (volume, pitch and quality) has been even less studied. Since changes in the length of the vocal folds can produce changes in tension and in mass, there is good reason to believe that changes in length essentially control the vibration patterns of the vocal folds. It is the purpose of the present work – as a pilot study – to throw light on this question on the basis of observations on a test subject. The subject was a middle-aged actress actively interested in singing; her total physiological voice range was studied in half-tone steps in different voice habits. In this way we were able to draw a series of connected curves representing the lengthening of the vocal folds. These curves will be referred to here by the term paratasisgram.

METHOD

Measurements of the length of the vocal folds has been performed by numerous investigators with the aid of either a laryngeal mirror (11, 12, 14, 21, 33, 38) or X-rays (7, 22, 28, 29, 37). However, to my knowledge, no studies covering the total voice range have been made so far. Roentgen examination has the advantage over the laryngeal mirror that it does not interfere with phonation. Both methods are associated with disadvantages, for example the difficulty of finding suitable points of measurement, and errors in projection. Since the year 1954 the author has utilized measurement of the calcification centres in the laryngeal cartilage, which are visible in lateral roentgenograms and become more sharply defined with increasing age (9, 24, 28, 29). The anterior point of attachment of the vocal folds, the centre of calification in the anterior margin of the thyroid cartilage, was seen in 58 per cent of the 150 cases studied; the posterior point of attachment of the vocal folds, the calcification centres of the arytenoid cartilages, were seen in 40.6 per cent. If small holes are made in the X-ray films at the sharply defined edges of these points, it is not difficult to measure the distance between them with 0.1 mm. accurracy, using dividers adjustable with a screw. The puncturing of the holes of course presents the chief difficulty and is also most dependent on subjective factors:



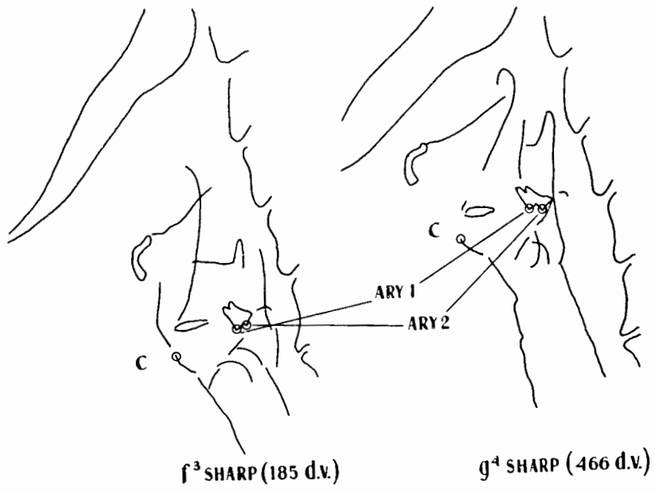


Fig. 1.

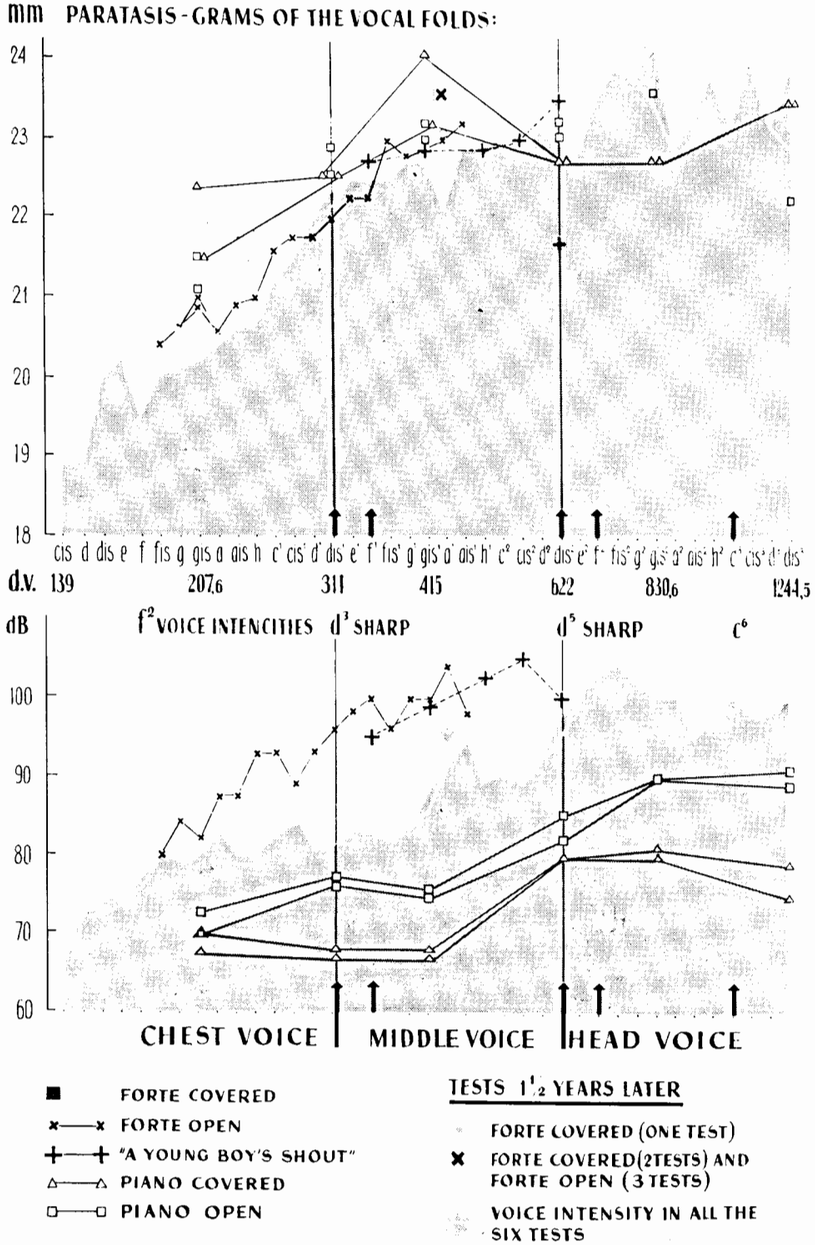


Fig. 2. Paratasis-grams of the vocal folds (above) and voice volumes (below) obtained in X-ray studies of physiological voice range of an actress.

the points must be exactly comparable. Another difficulty arises from the fact that the calcification centres in the arytenoid cartilage may be projected one on top of the other, but this can be avoided in part by measuring separately the distance to each arytenoid cartilage and calculating the average. In Fig. 1 we can see roentgenograms taken of our subject singing at the pitches f 3 sharp (185 d.v.) (at left) and g4 sharp (466 d.v.) (at right). It is easily seen from the pictures that the distance from the anterior point of attachment C to the posterior points ary 1 and ary 2 is clearly greater at higher pitch. Without attempting to calculate possible errors due to projection, I wish to state that, in a number of selected cases, the best measurement result was obtained in one in which there were *eight roentgenograms of one subject taken during the same phonation period; the dispersion was 0.1 mm.* The examinations for my study were carried out in November, 1959. One and a half years later a control test was made with the subject singing at the pitch a4. The measurements obtained from the six X-ray films differed at most 1.5 mm. from the corresponding previous measurements. It may be noted that the quality and intensity of the voice were not exactly similar at the two occasions of measurement, and so the difference was hardly due to measurement error alone. Though it must be admitted that, in unselected cases, the measuring technique here employed may be subject to considerable error, as claimed by Zenker and Zenker (p. 6), I would maintain that, in this selected case, the limit of accuracy is certainly reliable at least in regard to differences in length exceeding 1 mm. - perhaps even to smaller differences if the changes show a similar trend. Fig. 2 shows the paratasis-grams obtained for our test subject. Below are seen the corresponding voice intensity curves measured with the sound level instrument. We shall now hear voice samples recorded during a study session.

(Voice sample)

Some of the voice samples recorded during the roentgenography were analysed with a sonagraph.[1] It appeared that the open voice habit was governed by a richer partial tone spectrum reaching a higher level of frequency than the covered voice at corresponding pitch. Formants of other vowel sounds (æ, e and i) were also of greater number than with the covered voice. These differences did not seem to be essentially related to voice intensity. With a rise in pitch the number of partial tones decreased in all voice habits. The change was especially clear during the transition from the middle register to head voice. The number of partial tones was 3-5 in the head register in all voice habits, whereas the maximum in the chest register was 30.

RESULTS

Figure 2 shows the results of length measurements of the vocal folds with an accuracy of 0.1 mm. Changes exceeding 1.0 mm. may be considered absolutely reliable. It is seen that

(1) The vocal folds lengthened fairly abruptly with a rise in pitch in the chest register from f2 (174 d.v.) to d3 sharp (311 d.v.).
(2) The length of the vocal folds was approximately the same in the head voice area from d5 sharp (622 d.v.) to c6 (1046 d.v.).
(3) The lengthening of the vocal folds was considerably slower in the middle register than in the chest register. It is possible that the lengthening of this area differs

[1] K. Wiik, Phonetic Labor., University of Turku.

in various voice habits and occurs more rapidly in open than in covered voice. This change was particularly clear in forte.

(4) The vocal folds were longer in piano voice in the chest and middle registers than at the corresponding pitch when singing forte.

It may be mentioned, among *other roentgenological findings*, that in the open voice habit the Morgagni sinuses appeared distinctly smaller, the ventricular folds closer to each other, and the epiglottis more inclined backward than with the corresponding covered voice. With a rise in pitch in the chest register, the larynx ascended cranially. In the middle register, using the covered voice, the larynx moved abruptly downward to rise again in the head voice area. In the open voice habit, however, the larynx displayed throughout a steady tendency toward the cranial direction. This difference was more evident in piano voice than in forte. The distance from the larynx to the spine was smaller in open than in covered voice.

DISCUSSION

Even though our test subject coped with the difficulties of the study very well, it is clear that the singing performances are a long way from both "pure" open voice and from voice fulfilling aesthetic requirements. Here too, it seems proper that the singing performances are taken as "mainly open" or "mainly closed", as pointed out by some previous investigators. In this study it was also necessary to disregard the "dynamic features of the onset and the decay of the tone" (6, 35, 36) though these affect decisively the impression gained from the voice heard. In spite of this, the results obtained seem to provoke further thought.

It was supposed earlier that register transitions might be associated with coupling of the vocal cavities. This view is reflected in the terms "chest voice" and "head voice" still in use today. However, Trendelenburg in 1938 (34) demonstrated that this opinion is unsatisfactory (cf. 3). It has been shown that vocal cord vibrations differ according to register (5, 15, 18, 19, 25, 26, 27, 31, 32, etc.) A shift in register is due above all to a change in the mode of vibration of the vocal folds. The cause of this change is to some extent obscure. "Changes in vocal cord tension and in mass are of essential importance in this respect" (Trendelenburg p. 226).

Van den Berg (4), in his meritorious study with excised larynges, in 1960 arrived at the conclusion that longitudinal tension in the vocal muscles are the important parameters determining the response in the main registers. Six years earlier the present writer had already directed attention to the same question, and was probably the first to do so: I showed in 1954 (28) and later (29, 30), on the basis of objective observations, that the lengthening of the vocal cords is basically linked to the question of registers. The present study seems to confirm these observations and to justify agreement with Garcia who claimed, as early as 1840 (10), that there exist only two main registers and these two have a common area, "la partie commune", i.e. the middle register, which represents a transition area from one main register to the other.

Vocal folds thick: forte chest *open*	Vocal folds short: forte chest covered
Vocal folds thin: piano head covered	Vocal folds long: piano head *open*

Fig. 3.

In the chest register the lengthening of the vocal folds causes above all a decrease in the vibrating mass, while in the head register there is an increase in tension chiefly in the vocal ligaments, with a consequent rise in voice. Faaborg-Andersen's observation (1957) (8) concerning electrical activity of the vocalic muscle may be related to these phenomena. According to him "With phonation with increasing pitch the increase in electrical activity was considerable, as long as the increase in pitch occurred within the same register. If the increase in pitch occurred with a simultaneous shift in register, the increase in electrical activity in most instances was only slight."

It is evident that the question of open and covered singing is in some way associated with the question of register. In head voice – although the test subject did her best – her open and covered singing were practically identical, and this applies both to forte and piano. In the chest register, however, the sonagraph examination showed a distinct difference between open and covered voice. Open singing was possible both forte and piano and a shift to a higher register produced no break. It is probable that "covering" in the chest register consists chiefly in a change of the shape of the resonance cavities, the function of the vocal folds remaining practically the same as in open singing. In the middle register, however, the vocal folds showed a greater tendency to stretch in open than in covered voice. Open singing was possible only forte, and a shift to head voice was only possible by means of a break. "Covering" in the middle register seems to be a question of phonation rather than one of resonance (cf. i.e. 1, 2, 16, 17, 23).

We know from earlier studies that the vocal folds are thicker in forte than in piano voice ((20) p. 91, (27) p. 70); thicker in the chest register than in the head register (13, 20); and also thicker in open than in covered voice (20). The results of this study seem to indicate that the vocal folds are shorter in forte than in piano, shorter in the chest than the head register, *but* longer in open than in closed voice. Thus covered singing in the middle register would seem to resemble the head register and piano voice – apart from the fact that the vocal folds are short; open singing, again, seems to resemble forte and the chest register apart from the vocal folds being long. This may also be expressed in a diagram (Fig. 3), which may help to make the matter clearer.

The reason why open singing in the middle register is so tiring and in our experi-

ence so dangerous to the vocal folds is not yet fully known and this question requires further objective investigations. It remains a matter for the future to determine the final value of the vocal fold paratasis-gram in solving the interesting and important problem of the factors affecting voice dimensions.

SUMMARY

A middle-aged actress's vocal folds were studied by length measurements through the entire physiological voice range in half-tone steps in different voice habits. The lateral X-ray technique reported by the present author in 1954 was used. This method, utilizing the calcification centres in the larynx, gives a minimum accuracy of 1 mm. The results are shown in the form of paratasis-grams representing the changes in length of the vocal folds. The voice samples obtained in the course of the study were analysed with a sonagraph and the voice intensities measured with the sound level instrument.

The results seem to indicate that *there are only two main registers*: the chest and the head register, and that the middle register should be regarded as a transition area; also that a shift in register is related above all to changes in the length of the vocal folds and not to coupling of the vocal cavities. Thus *key to the problem of register seems to be primarily laryngeal and not pharyngeal.*

In the chest register there occurs intense stretching of the vocal folds and possibly a slight increase in longitudinal tension in the vocal ligaments. This results above all in gradual decrease of the vibrating mass. In head voice, the vocal folds apparently remain equally long, and further rise in pitch then seems to be associated above all with an increase in longitudinal tension of the vocal ligaments.

The results finally allow the following points to be made:

(1) "Dangerous" open singing in the middle register is associated with fairly thick vocal folds – thus resembling the chest register and forte voice; but this mode of singing is also associated with fairly long vocal folds – thus resembling the head register and piano voice.

(2) "Correct" covered singing in the middle register is associated with fairly thin vocal folds – thus resembling the head register and piano voice; but also with fairly short vocal folds – thus resembling the chest register and forte.

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