VOCAL CHORDS ACTIVITY: ITS DYNAMICS AND ROLE IN SPEECH PRODUCTION*

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The activity of the vocal chords can be investigated from a variety of points of view, which is why this subject is a matter of interest to a variety of specialized fields, the first and foremost being various branches of medicine. Among the specialized disciplines which fall within the field of linguistics, it is chiefly phonetics which deals with this subject. The main interest of the latter has been characterized by van den Berg (1968), who says: "The phonetician, however, is more interested in the dynamic speech process".

As is the case with all physiological activities, that which is characteristic for the production and perception of speech are changes proceeding within time.[1] A condition for their analysis in physiological circumstances is to record them not segmentally and statically but, on the contrary, to record them throughout their whole duration in time, and to also evaluate them from this standpoint (Peterson 1968). It is for instance possible to study anatomical structure from static records, but no judgement as to physiological activity can be made from them. Nowadays this fact is regularly recognized by a number of authorities: Janota (1970), Koževnikov *et al.* (1968), Lindblom (1963), Öhman (1966), Romportl (1951), Sovijärvi (1970), are but a few of the many who accept this idea.

Like the theory of the production of F_0, the study of the movements of the vocal chords continues to be a matter of lively interest to many authors: they have dealt with it mainly from the physiological point of view, but also from the acoustic point of view.[2]

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[1] The dynamics of speech and the dynamics of hearing are not, according to Lane (1970), the same thing.

[2] The following are examples of acoustic studies of vocal chord movement: Abramson and Lisker (1965), Abramson, Lisker and Cooper (1965), Arndt (1966), Berendes (1960), van den Berg (1968),

There is no doubt that indirect laryngoscopy combined with high-speed cinematography is of great value in tracing the movements of the glottis. It cannot, however, be applied in the investigation of the physiological activity of the vocal chords during the production of natural continuous speech (van den Berg 1968).

For phonetic purposes, such recording methods must be used as will permit both undisturbed phonation and articulation in the course of continuous speech. The degree of naturalness of the conditions of the experiment will then be specific according to the method applied.

A number of other indirect methods, which we may bring together under the joint heading glottography, have also arisen out of the endeavour to record the movements of the vocal chords in the course of natural phonation. Today GLOTTOGRAPHY, in the investigation of the function of the vocal chords, is a broader concept. In accordance with the terminology of Fant's Stockholm laboratory, we draw a distinction between OPTICAL and ELECTRICAL glottography. Both may be modified in a variety of ways: the first — Sonesson's optical glottography — may be modified by the use of an oral or nasal probe and by the location of the light source;[3] and the second may usually be modified by making various technical adjustments on the original Fabre electrical glottograph.[4] The (latter) electrical method has evoked considerable interest because of the possibility it offers of recording the activity of the vocal chords without the disturbance caused by an intrusion into physiological phonation. It enables us to observe phenomena which take place in natural continuous speech and for which it is undesirable to apply methods whereby "the experiments are so unphysiological that they prove nothing", as Charvát (1970) puts it.

Fabre's electrical glottography has been applied by Husson (1959 and subsequently), Bordone-Sacerdote and Righini (1965), Ondráčková (1965 and subsequently), van Michel (1966 and subsequently), Fischer-Jørgensen *et al.* (1966), Fant *et al.* (1966), Chevrier-Muller (1967), Gabershek (1967), and Frøkjaer-Jensen (1969), to give only a few examples.

New possibilities for the investigation of the movements of the vocal chords have been opened up by the use of the flexible fiberscope with the application of a nasal probe (Sawashima, Hirose and Fujimura (1967) and subsequently; Lisker *et al.* (1969).

Whatever indirect method (i.e., one not affording a view of the vocal chords themselves) we use to register the activity of the vocal chords, it is evident that we

Damsté (1968), Fant (1960), Farnsworth (1939-40), Flanagan (1965), Fujimura and Lindqvist (1971), Hollien and Coleman (1970), Husson (1962), Lafon (1961), von Leden *et al.* (1966), Lisker *et al.* (1969), Luchsinger (1954), Malécot and Peebles (1965), Mankin *et. al.* (1971), van Michel (1966), Moore and von Leden (1958), Ohala (1966), Perkins and Koike (1969), Sawashima *et al.* (1970), Smith (1964), Sonesson (1968), Soron (1967), Tarnóczy (1947), Timcke, von Leden and Moore (1958), (1959), Vallancien (1968), and Vencov (1968). There are many others.

[3] See Sonesson (1960), Lisker *et al.* (1969), Malécot and Peebles (1965), Ohala (1966), Slis and Damsté (1967), Frøkjaer-Jensen (1969), among others. A review of the literature on the various types of glottographs is given in Frøkjaer-Jensen (1969).

[4] E.g., Fant *et al.* (1966), van Michel and Raskin (1969), Ondráčková, Lindquist and Fant (1970), to mention a few.

must have a guarantee that it will be possible to interpret the recordings obtained accurately. Thus, whenever a new method presents itself, it is perfectly natural that it will be accompanied by the aim of verification and confrontation with a method which is already clear from the point of view of interpretation.

The usefulness of verifying methods by combining them is probably what led Sawashima and his colleagues to their interesting experiments with the fiberscope and the photoelectric glottograph (Sawashima and Hirose 1968) and with the fiberscope and transillumination technique (Sawashima *et al.* 1970).

We were led by the same intentions when, in 1966 at the Stockholm laboratory, we compared the method of inverse filtering with Sonesson's optical glottography and with Fabre's electrical glottography (Fant *et al.* 1966).

Since 1964, and in collaboration with Professor Romportl and Dozent Janota, we have been carrying out, at the Phonetics Laboratory of the Institute for the Czech Language within the Czechoslovak Academy of Sciences, experiments confronting a synchronous record of the movements of the vocal chords made by indirect laryngoscopy in combination with high-speed cinematography on the one hand, with a record obtained by Fabre's electric glottography likewise in combination with high-speed cinematography on the other hand (Ondráčková 1968).

In 1969, in collaboration with Professor Arndt[5], we obtained at the Institut für den wissenschaftlichen Film[6] synchronous optical records of the movements of the vocal chords (also with the application of indirect laryngoscopy) and records of their graphic correlates (again made by recording on the Fabre electrical glottograph). For the synchronous records, high-speed cinematography was used.[7]

Prior to our experiment, fourteen persons were subjected to a laryngoscopic inspection. Professor Arndt then chose four of them, three men and one woman, as suitable subjects for the application of indirect laryngoscopy. Their task was to phonate a sustained 'low and high tone' according to their own interpretation of this. The criterion of low and high tones was given by the subject's consciousness of them in his own vocal range. All the pitch areas fall within the chest register since we are primarily interested in the application of electrical glottography during speech. The phonations were realized at frequencies of 100 Hz, 125 Hz, 150 Hz, 160 Hz, 165 Hz, 200 Hz, and 250 Hz (some frequencies were the same for two persons; also, one subject phonated twice at the same frequency).

Simultaneous with the indirect laryngoscopy electrical glottography was applied (Fabre 1957). We will mention the principle of recording with this method only briefly here. When the glottis opens, the resistance in the circuit of the electric current passing between electrodes located externally on the neck increases. When the glottis closes, this resistance decreases. When the vocal chords are tightly closed up, the resistance value is at its minimum. These changes in the flow of the electric current

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[6] Göttingen, Direktor Professor G. Wolf.

[7] A similar experiment is described in van Michel, Pfister and Luchsinger (1970).

can be recorded, as they proceed, from the oscillograph screen in the form of a curve.

The resultant scientific films, "The Activity of Human Vocal Chords" (Göttingen 1969) and "Glottographical Progress of Human Vocal Chords" (Göttingen, 1969), contain altogether ten shots.[8] The principle of synchronous records when these methods are used, together with the correspondence between them, are demonstrated in our short film "Laryngoscopy and Glottography" (Prague 1970), to be projected at this congress.

We compared the synchronous records obtained and attempted to make an interpretation of the glottograms on the basis of the optical records of the movements of the vocal chords. Comparison is considerably complicated by the fact that vocal chord movements are highly individual, that is, the complication lies in individual modifications in the formation of the closure, which can also be seen in the two-dimensional horizontal representation. The interpretation of the corresponding glottograms is also made more difficult by the fact that we do not have a sufficient amount of data to use as a basis concerning the physiological activity of the vocal chords during phonation. The last remark is merely a makeweight to the works of competent authors (e.g., Damsté, 1968) who themselves recommend systematic research in this area.

An attempt at the mathematical expression of the correlation between the optical record of the movements of the vocal chords and the corresponding glottographic curve has been carried out by J. Machek.[9]

During the application of various correlational functions we have encountered considerable difficulties, the cause of which lies in the familiar fact that physiological events of any kind are difficult to express in this way.

Let us mention a few facts: the duration in time of the individual periods of the vibrations of the vocal chords is not the same with constant F_0 (Lieberman 1961); the relative time relations between the opening and closing time of the glottis during one period show considerable variability (Rosenberg 1971); the closure of the glottis is not always created in the same way, the vibrations in the two vocal chords may be out of phase, asymmetry of the larynx is quite frequent, and "the movements are three, dimensional and highly non-linear, especially those of the vocal folds in chest voice" (van den Berg 1968); "greater intra-subject variability in laryngeal area and thickness may exist than was previously noted" (Hollien and Coleman 1970).

From analyzing the synchronous records mentioned for phonation at a frequency of 200 Hz, and comparing them with each other, we have discovered that the minimum of the glottograph curve need not mark exactly the moment of complete

[8] The technical data of the apparatus used for the synchronous record of the movements of the vocal chords by indirect laryngoscopy and electrical glottography are contained in Höfling *et al.* (1969). The diagram of the glottograph used, as modified by Lindqvist (Fant *et al.* 1966) and Kopecký has been published by Ondráčková (1970a).

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closure of the glottis as it appears on the optical record of the movements of the vocal chords. There is a slight shift here (the situation is similar in van Michel, Pfister and Luchsinger 1970).

On the basis of the material elaborated by Machek we may conclude that the complete closure of the fold area takes place, at the pitch in question (200 Hz), on an average of 0.002 seconds (and in isolated cases as much as 0.003 seconds) later. To date, this correlation has been calculated for 200 closures of the glottis.

We have not so far succeeded in finding a satisfactory explanation for the shift in the phases of the oscillation of the vocal chords, as recorded on the glottogram in contrast to the optical record.

In spite of the fact that it is not possible, from the glottogram alone, to determine with accuracy (or at least with a close approximation) the moments when a change in phase of the movement of the vocal chords sets in (e.g., when they open or close), it seems that it is possible to determine with considerably greater accuracy the average duration of the individual phases (e.g., the average duration of closure), and also the average duration of one period, and so also the average quotient of the duration of the period to the duration of the closure. The extent of fluctuation in these quantities can also be estimated, and it will even be possible to determine how long the vocal chords have been closed in a given period. With such an approach the error will evidently be much lower than the error in determining the moment at which the vocal chords closed right up.

In the first 50 periods (of the record in question, of phonation at a frequency of 200 Hz), the average duration of the closure was found by optical recording to be 0.001624 sec. (0.1624 of the interval between two time marks) and by the glottogram to be 0.001524 sec. (0.1524 of the interval between two time marks). The quotient of the average length of a period to the average duration of the closure was 3.0505 (by optical recording) and 3.2651 (from the glottogram). The error in determining the quotient is then approximately 7% of the correct value (Machek).[10]

Since the application of the methods of mathematical statistics to our material is extremely laborious and time-consuming, we are putting off the elaboration of representative material until the next stage of our investigation, in the hands of a computer.

Any specialized method has certain restrictions in the possibilities it offers for registration. These restrictions become manifest in the interpretation of records. Thus, we have discovered, for example, in the analysis of the above mentioned glottographic records *vis-à-vis* the optical representation of the vocal chords, that glottograms may well, under certain circumstances, contain more information or, to be more precise, other information than that supplied by the corresponding synchronous record made by indirect laryngoscopy. This information may concern, for instance, the reaction to the way the closure is made in its progression, while on

[10] Ondráčková and Machek, 1971.

the synchronous optical record the closing of the glottis appears, over the same stretch of time, as constant (because here we have a two-dimensional representation on the horizontal plane). The use of the given methods does not of course enable us to verify this information. The given discovery evidently tells us something about the familiar fact that the closure of the vocal chords does not take place at once over their whole mass, but gradually. In this connection it is fitting to quote van den Berg again, in that given the asymmetry of the vocal chords, which is not an uncommon state of affairs, the vocal fold area may appear quite differently, according to whether we look at it "perpendicularly" or "under an oblique angle" (van den Berg 1968).

Changes in the resistance may apparently also be caused by other factors, and not merely by a change in the width of the vocal fold area. I am of the opinion that glottograms may also show qualitative differences in the formation of the closure, as well as changes in the thickness of the vocal chords. At the same time, I think that certain directly proportional dependences (for instance, of the width of the vocal fold area and the thickness of the vocal chords) on changes in the pitch of the fundamental tone during phonation need not affect the degree of resistance in the same way. In other words, if, as shown e.g., by Hollien and Coleman (1970), the vocal fold area is reduced, the higher the tone becomes, this fact ought (according to our experience so far) to make itself apparent by a reduction in resistance and thus a higher flow of electric current. But, according to the same authors, the vocal chords grow thinner the higher the frequency of the fundamental tone is. How this thinning of the vocal chords itself affects the amount of the resistance cannot be stated with certainty.

When dealing with the expression of the activity of the vocal chords during phonation, we are certainly concerned mainly with time relations between the various phases of the phonational vibration. This breaking up into phases of a natural continuous movement is advantageous from the point of view of method, and is also to a degree a traditionally recognized convention; however, on the other hand it is not entirely satisfactory because it can never express the true dynamism of a physiological process.

If we consider the dynamics of the glottis in the ten shots mentioned (on the basis of the optical record) from the point of view of the quantitative relations between the phases of open and closed glottis in a single period, the most remarkable fact about it is that it is highly individual. Rosenberg (1971) has recently discovered, during experiments with simulated excitation of the glottal pulse, classified by perception tests, a "fairly large tolerance for different combinations of relative opening and closing times".

In our material, quite a tendency seems to appear to preserve these relative time relations for individual persons rather than to preserve them for the categories of 'high and low' tones. These time relations between the individual phases are not, in our material, constant at absolute values throughout the whole shot. Their relative

relation is retained, however.[11] In view of the fact that the differentiation between low and high phonated tone was left to the subject being investigated, the frequency differences are in some cases fairly small (e.g., the high tone is only 21% higher than the low tone). In one person, who considerably distinguished between high and low tone (in one case the high tone is 66% higher and in another 56%), the relative time relation between the open phase and phonation time works out in agreement with what has been established by, for example, Sonesson (1968) and Tarnóczy (1947), namely that opening-time is extended for higher tones. This means then that in the subject in question, the opening coefficient of the glottis was in both cases greater with the 'high' tone as against the 'low' tone. With the 66% differentiation the opening coefficient of the glottis is 0.44 in the case of the low tone, and with the 56% differentiation the opening coefficient in the case of the low tone reached 0.69. The values are related to the same high tone, whose opening coefficient is 0.75. In the remaining cases, where there is no conspicuous increase in the coefficient with the higher tones, it is impossible to say whether or not the cause lies in the above-mentioned small differentiations between the low and high tones.

In establishing the dynamics of the movements of the glottis from the qualitative point of view, we again observe that there are individual differences. In all test subjects who phonated at different frequencies, the opening of the glottis took place in the direction from the back commissure to the front, and not at once but gradually, as described by e.g., Sonesson (1968).

In two persons, the formation of the closure of the vocal chords proceeded such that the edges of the vocal chords came together in the middle first of all; in one person, the closure continued at first towards the back commissure and finally from the middle to the front commissure; in the other person the closure was completed almost equally in both directions from the middle. In the course of one shot there was no complete closure (it is possible that there is a light contact near the front commissure but this is not ascertainable on our record). In the same person's shot of phonation on a tone 28% higher, the closure of the vocal fold area took place only in the central and front part. In the case of another person, phonating on the highest tone (250 Hz in our material), there was also no complete closure — a small slit remained by the back commissure. It is certainly a matter of interest that this way of forming the closure will evidently not be dependent on the higher frequency of the fundamental tone, since we discovered the same small slit in this subject ALSO in the closure phase of phonation on a lower tone (160 Hz), while phonation at practically the same frequency (150 Hz) led to a complete closure of the vocal fold area. In the remaining cases, the closure period of the glottis proceeds gradually from the front to the back commissure.

Similarly, the glottograms which correspond to these shots of the vocal chords are individual in their formation. This does not of course mean that a person phonating

11 At the present stage in our investigation we have not yet given attention to the differences in the opening time of the glottis in low as opposed to high tones.

at one and the same frequency will always have a glottogram with the same characteristics. A considerable role will evidently be played by the subject's overall condition.

In our opinion, an adequate amount of material has not yet been registered by this method to allow us to express all the factors on which the formation of the glottogram depends, such as, for instance, the factors which appear when there are changes in pitch and intensity of the phonated sound. Also, so far as we know, Fabre's electrical glottography has still not been applied to the recording of the whole consonantal and vocalic system of a language, and even less so to that of representative sound combinations of that language. Nevertheless we may assume that it is exactly this glottographic record which could be very appropriate for recording the dynamics of the process of phonation, which proceeds in time.

As an illustration, we would like to mention some other observations resulting from the analysis of (previously obtained) glottographic records of nonsense words and continuous speech. (Czech language material was used for the most part).

In the initial phonational position, the resistance is higher than in the medial position, since the beginning of an utterance is a transition from the state 'without phonation', having high resistance, to the course of phonation. The final phonation again has a high resistance level — higher than that of the medial position (the course of phonation moving towards the position without phonation). In absolute values, the resistance is not the same for same sounds but depends on its location in the time framework of the dynamic progress of the given utterance.

On the records made to date we have been able to observe, in the framework of the amplitudinal range of the glottogram, various levels which are characteristic for the individual categories of speech sounds. This means not merely the differentiation of voiced and voiceless consonants, but also finer distinctions within these main categories. The various categories of speech sounds manifested themselves on our glottographic records in accordance with the common criterion of their physiological production. We find here levels representing the 'neutral area' of the chords (the term used by Flanagan) without phonation, the phonation of vowels and liquids (these two levels are scarcely distinct in the majority of cases), of voiced occlusives, voiced fricatives, unvoiced occlusives, and unvoiced fricatives. Once more, their interrelations do not appear in absolute but in relative values, i.e., in that they are somehow distinguished from their environs, and these changes are moreover incorporated into the hierarchically (from the point of view of phonation) higher overall process of phonation. In other words, for instance, the phonation represented in an absolute value by a lower degree of resistance may have, as its relative value, the function of high resistance in the medial position of the utterance whole. We might then consider a theory of various levels of the dynamic progression of phonation. The 'speech-sound levels' with differential functions of meaning overlap with the 'phonation level', i.e., they are realized not only against the background, but within the framework of the overall progression of the phonation. The dynamics of speech production is,

from the point of view of phonation, the result of these mutually corresponding relations.

From the linguistic point of view it is perhaps worth pointing out that finer distinctions can become apparent on the basis of phonation than at the level of speech-sound categories. From this point of view we were particularly interested in changes on the glottographic records in the degree of resistance (in the changes of the current) in the case of voiceless stops.

Proceeding empirically from the interpretation of the glottograms, together with the corresponding optical records of the movements of the vocal chords, we may conclude that the varying degree of resistance appearing on the glottograph curve with voiceless stops corresponds to the varying distance between the vocal chords. These variations of what are evidently very specific movements of the vocal chords, variations whose realization has a certain but probably limited tolerance, may take place only within the framework of their movements, which are proper to voiceless stops. In nonsense VCV groups containing a voiceless stop in a Czech context the degree of openness of the vocal chords increases from bilabials through alveolars to velars (Ondráčková 1968). It seems that the same does not hold for Danish tenues, which are of course aspirated (Fischer-Jørgensen *et al.* 1966, Frøkjaer-Jensen *et al.* 1971). This varying degree of openness of the vocal chords during the phonation of voiceless stops in Czech material may perhaps be attributable to the influence of the balancing out of sub-glottal and supra-glottal pressure, as well as the place of the oral closure during phonation with the vocal fold area wide open. The action of intraoral and pharyngeal relations will be two-way (Lafon 1961, Lubker and Parris 1970, Fischer-Jørgensen 1970). Of the three factors on which, according to Sawashima (1968a) maximum glottal area depends in the articulation of voiceless consonants, it is 'mode of articulation' which would be applied in this case.

As far as the glottis being found to be open during voiceless stops is concerned, our discovery is in agreement with the results of experiments carried out using different language material, e.g., with those of Fischer-Jørgensen (1954), who used endoscopy to examine the openness of the glottis during the occlusive phase of Danish *p* and its slow closure during aspiration. It is also in agreement with experiments by Slis and Damsté (1967), Vencov (1968), Sawashima *et al.* (1970) and Rigault (1970).

From the experiments we have carried out so far, it seems that even when the variable factor of the experiment belonged to the supra-segmental level of language events (e.g., the differentiation of stressed and unstressed syllables containing the same voiceless occlusives), it was reflected on the glottographic records by an increase or decrease in the degree of resistance of voiceless stops precisely in accordance with their position in stressed or unstressed syllables.[12]

Properties characteristic for the speech-sound categories of voiced and voiceless occlusives, expressed by the amount of electric current, may become more intensive

[12] This correspondence between perceived degrees of stress and changes in the laryngeal area might fit the motor theory of the perception of intonation (Lieberman 1967).

in stressed as opposed to unstressed position and vice versa (in relative values of course). The glottograms have shown that with stressed voiceless stops there is greater resistance than with the same consonants in unstressed position, and on the contrary with stressed voiced stops the resistance is lower as against the same consonants in their unstressed position (Fant *et al.* 1966, Sawashima 1968b, Lisker *et al.* 1969).

It is not our intention to draw any conclusion with general validity from what we have established. We have merely tried to point out the tendencies which the material indicates. In conclusion I would like to summarize some of these tendencies again.

Recording by electrical glottography is one of the most appropriate methods for registering the dynamics of the process of phonation under natural experimental conditions.

From records made by electrical glottography it will be possible to determine the average duration of one period of a vibration of the vocal chords, the average duration of closure and opening within one period, and the average quotient of the duration of the period to the duration of the closure.

The degree of resistance characteristic for certain categories of speech sounds (from the point of view of their production) appears in relative values which respect the speech-sound environment. The value of this resistance depends on the location of speech-sound combinations in the time-frame of the dynamic progression of the given utterance segment.

Voiceless occlusives (p, t, k) produce, in a Czech context, different degrees of resistance, which usually increases in stressed positions.

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DISCUSSION

LIEBERMAN, P. (Storrs, Conn.)

Dr. Ondráčková's results using the technique of electrical glottography represent a significant refinement on the results and the interpretations of earlier studies based on the original Fabre apparatus. As Dr. Ondráčková notes, the output of the electrical glottograph may reflect factors other than the area of the glottal opening or the distance between the vocal cords. If one thinks of the vocal cords forming a variable impedance in series with the electrical contacts of the glottograph, then it is apparent that the current through the circuit will be a direct function of the surface area of the vocal cords that is in contact. It thus would

be reasonable to find that the electrical resistance registered by the glottograph would decrease for phonation in the chest register where the cross-sectional area of the vocal cords tends to increase. The situation is further complicated by the fact that the vocal cords are not equivalent to low resistance electrical contacts. Their electrical properties may be influenced by their relative 'wetness' and by the pressure that they exert on each other as they collide. It would be reasonable to find that the resistance of the vocal cords decreased as they were pressed together. This might indeed account for the time delay between the optical record of vocal cord closure and the glottograph output that Dr. Ondráčková has noted. This is not to state that the technique of electrical glottography is inappropriate for measurements of glottal activity, but that newer, more direct techniques like direct observation by means of a flexible fiberoptic bundle are preferable in many situations.

The results that Dr. Ondráčková and her associates have obtained by the technique of electrical glottography are nonetheless interesting. The higher electrical resistance that occurs with unvoiced stops in stressed versus unstressed position is consistent with the vocal cords being passively pushed farther apart by the higher intralaryngeal air pressure. The lower resistance that accompanies stressed voiced stops might perhaps reflect a greater adducting force on the vocal cords that might be a consequence of either the increased Bernouilli force that accompanies higher air velocities or a synergetic laryngeal adjustment. It is evident that direct observation of the larynx by means of a flexible fiberoptic bundle might resolve this question.

SOVIJÄRVI (Helsinki)

I would first like to congratulate Dr. Ondráčková, who has told us about many interesting results of her experiments.

I agree with her that "for phonetic purposes use must be made of such recording methods as permit both undisturbed phonation and articulation in the course of continuous speech". From the purely theoretical point of view all methods and devices reported are, of course, necessary for investigating the activity of the vocal chords. On the other hand there is no doubt that some of these methods do have a more or less disturbing influence on the NATURALNESS of the speaking and singing voice. When the test subject is speaking after surface anaesthesia of his nasal cavity and epipharynx, for instance, during the fiberscopic experiments we probably cannot always guarantee the trustworthiness of the records obtained, at least from the point of view of the typical INDIVIDUAL laryngeal adjustments of the subjects to be investigated.

For practical diagnostic purposes during clinical voice training or therapy the requirements of naturalness are met by the methods of electrical glottography and proper applications of acoustic filtering. In this connection I may refer to my laryngo-oscilloscopic band-pass filtering method reported already in 1954. This method has been developed mainly for practice.

With a contact microphone placed on the neck in the larynx area the use of band-pass filter of 2-4 kc/s in conjunction with an oscilloscope or an oscillograph makes it possible to observe (1) the vibrational periods of a voice sustained at a constant frequency level and (2) the registered ones of running speech. I have chosen the frequency area of the filter concerned because it corresponds to the resonance peak *F*4 which is essentially dependent on the acoustic influence of the larynx tube *(vestibulum laryngis)*. (Sovijärvi 1938 and Fant 1960).

The types of the oscillation form of the filtered periods in question correspond in the following way to the suitable air-tightness and non-tightness of glottal vibrations: (1) when each period consists of only one narrow and symmetrical oscillation group which corresponds to the opening phase of about 2-2,5 msec., the voice is dense without any perceivable leaky qualities, (2) when each period has a broader and often asymmetrical oscillation group, the voice is soft, and (3) when the vibrational periods have two or more dissimilar oscillation groups, the voice is disordered, which may, for instance, be caused by an asymmetric position or displacement of laryngeal structures or hyoid bone.

During the last years, I have been interested in the problem of the qualitative differences due to the changes of the vocal chord thickness during singing voice and so in 1968, I started to record X-ray motion pictures taken in the frontal view by means of an X-ray filter specially constructed for the laryngeal area. The speed of the films was 200 frames per sec. Synchronous sound records and frontal cineradiography may detect additional details which have hitherto been sparsely explored. In this connection I want to agree with the following opinion of Dr. Lafon: "La forme des impulsions correspond au spectre de la voix, donc à son timbre".

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FOURCIN (London)

Roach, Donovan and I (in press) have made a synchronised stroboscopic study of the relation between the visually observed behaviour of the vocal folds and the output of our laryngograph. We have found that there is a good inverse correlation between the area function derived from our stroboscopic photographs and the positive-closing laryngograph waveform.

REFERENCE

Fourcin, A.J., R. Donovan, and P. Roach
in press, *Folia Phoniatrica*.

ONDRÁČKOVÁ

Certainly, relative 'wetness' is indeed a factor of which due account should be taken. Our experience has shown that it does not change so abruptly as to make it impossible to compare the relative relations between the various degrees of resistance over a period of time.

On the basis of our earlier experience with electrical glottography we can confirm Prof. Lieberman's assumption that "...once the vocal cords when closing have made contact at some point there will follow a further rapid resistance decrease because of the contact progressing horizontally and vertically, thus offering an increased area of conductance for the glottograph current" (Fant, Ondráčková, Lindqvist, and Sonesson 1966).

The use of electrical glottography is not intended as a universal method for the study of the activity of the vocal cords in all situations, but I do think that the two methods will continue to be used concurrently. Moreover I would mention again here, as I have already said in my paper, what I consider to be the considerably advantageous property of electrical glottography, namely that its application does not call for the introduction of any item at all into the cavities of the vocal tract.

I consider that Prof. Lieberman's statement as to the increase in intralaryngeal air pressure with the phonation of voiceless occlusives, as well as his explanation of the reasons for the higher resistance of stressed voiceless occlusives as against those unstressed, supports my opinion that an increase or decrease in resistance might, at the level of speech production, be one of the indications of voiceless occlusive consonants in stressed and unstressed positions, respectively.

The use of the fiberscope might well contribute to our knowledge of this problem, though I still maintain that a two-dimensional record of the movement of the vocal cords is inadequate in this case.

I also thank Prof. A. Sovijärvi for his comments on my paper and for his suggestions on further methods which will also doubtless contribute towards the solution of the problem of the "activity of the vocal cords".

Dr. Fourcin's communication is very interesting. I thank him for drawing attention to his new publication dealing with the relation between synchronous stroboscope recording and recording by laryngograph. I greatly look forward to the actual publication of the work of Fourcin *et al.*

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