Electrical glottography

Fant, G. and Ondráckova, J. and
Lindqvist-Gauffin, J. and Sonesson, B.

journal: STL-QPSR
volume: 7
number: 4
year: 1966
pages: 015-021

II. SPEECH PRODUCTION AND ANALYSIS

A. ELECTRICAL GLOTTOGRAPHY

G. Fant, J. Ondráčková *, J. Lindqvist, and B. Sonesson

Abstract

We have tested an improved version of the Fabre electrical glottograph with respect to its potentialities in voice research. Registered waveforms are given a physiological interpretation supported by a resistance calibration and synchronous comparisons with the Sonesson optical glottogram and glottal flow derived by inverse filtering. A prolonged time constant enables the study of more slowly varying changes in the mean resistance during phonation pauses and stop gaps. We have found the electrical glottograph to be easy to work with, reasonably stable, and a valuable complement to other instruments for voice research. One characteristic feature of the electrical glottogram is that it provides a very distinct trace of the instant when the vocal cords make contact in the transition from open to closed phase.

1. The Fabre glottograph **

Our study was concerned with a glottograph of the Fabre type (Fabre 1957) belonging to the Laboratory of Phonetics in Prague and there modified by S. Hlaváč. The principle of the Fabre glottograph is that the movements of the vocal folds are picked up as an electrical resistance change between two electrodes placed on each side of the thyroid cartilage. The electrodes are fed by a high frequency current of 0.2-0.5 Mc frequency, as seen in the block diagram of Fig.II-A-1. The electrodes have an effective area of about 2 cm^2 each and have a narrow elliptical shape. This is an improvement minimizing the effects of gross movements up and down of the whole larynx.

---

* Laboratory of Phonetics, Institute of Czech Languages (Director: Doc. F. Daneš), Czechoslovak Akademy of Sciences, Letenská 4, Prague 1. Guest at the Dept. of Speech Communication, KTH, Oct. 11 - Nov. 19, 1966.

Earlier work on Czech male and female subjects were reviewed in Leningrad (Ondráčková 1966). Stimulating discussions on this material with P. Janota is acknowledged. Comparison of glottographic curves with synchronous recordings of vocal cord movements by means of high motion pictures and laryngoscopy is in progress in the Lab. of Phonetics, Prague, in cooperation with Prof. M. Romportl.

** The glottograph was presented to the Lab. of Phonetics in Prague by R. Husson.

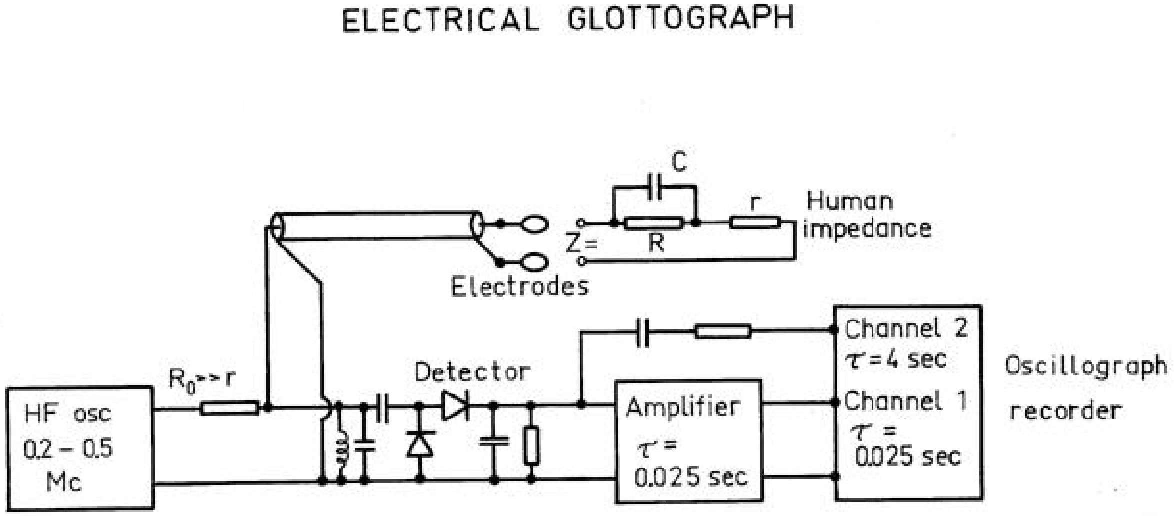

Fig. II-A-1. **Block diagram of the modified Fabre glottograph.**

Another improvement made by Hlaváč is that the order between detection and amplification is reversed, in the original design an amplifier preceding the detector. The amplification after detection introduced by Hlaváč proved to be more stable. The high-pass stages of the amplifier were designed to remove superimposed variations of the DC-level whilst essentially retaining the waveshape within a glottal period. In our experiments in Stockholm we added an extra output bypassing the built-in amplifier. This output had a time constant of 4 sec which is appreciably larger than the 0.025 sec of the amplifier.

The equivalent circuit of the human subject as sensed from the electrodes contains an electrode-skin contact resistance with a capacitance in parallel followed by the transfer resistance which is modulated by the movements of the vocal folds and all laryngeal structures. The contact impedance can be made small compared with the true object of measurements by introducing a sufficiently high carrier frequency. Thin male subjects are ideal in the sense that the relative modulating effect of the vocal cords is large. With more heavily built subjects there is a certain loss of sensitivity due to the shunting effect of fat tissues covering the front of the thyroid cartilage. In such cases a microphonic effect may be noted in the form of a weak formant ripple superimposed on the waveform. The microphonic effect probably derives from a vibratory modulation in the electrode-to-skin impedance which is then no longer small compared with the useful glottal modulation.

Fig. II-A-2(A) shows the signal response of the Fabre glottogram when a relay opens and disconnects a large resistance in parallel with the electrodes. This temporary resistance increase is associated with a deflection of the glottogram curve upwards. The direct, 4 sec-time constant, output of the glottograph displays a rather clean rectangular response, whereas the built-in amplifier curve shows a waveform distortion typical of the 0.025 sec-time constant. As seen from Fig. II-A-2(B) this distortion is not serious in studies of stationary phonation, providing the duration of the pitch cycle is not excessively large. These pictures were taken in Stockholm. Figs. II-A-2(C) and (D), taken in Prague, show glottograms with synchronous oscillogram of the speech wave in the vowels [i] and [o] and in the syllables [to] and [do].

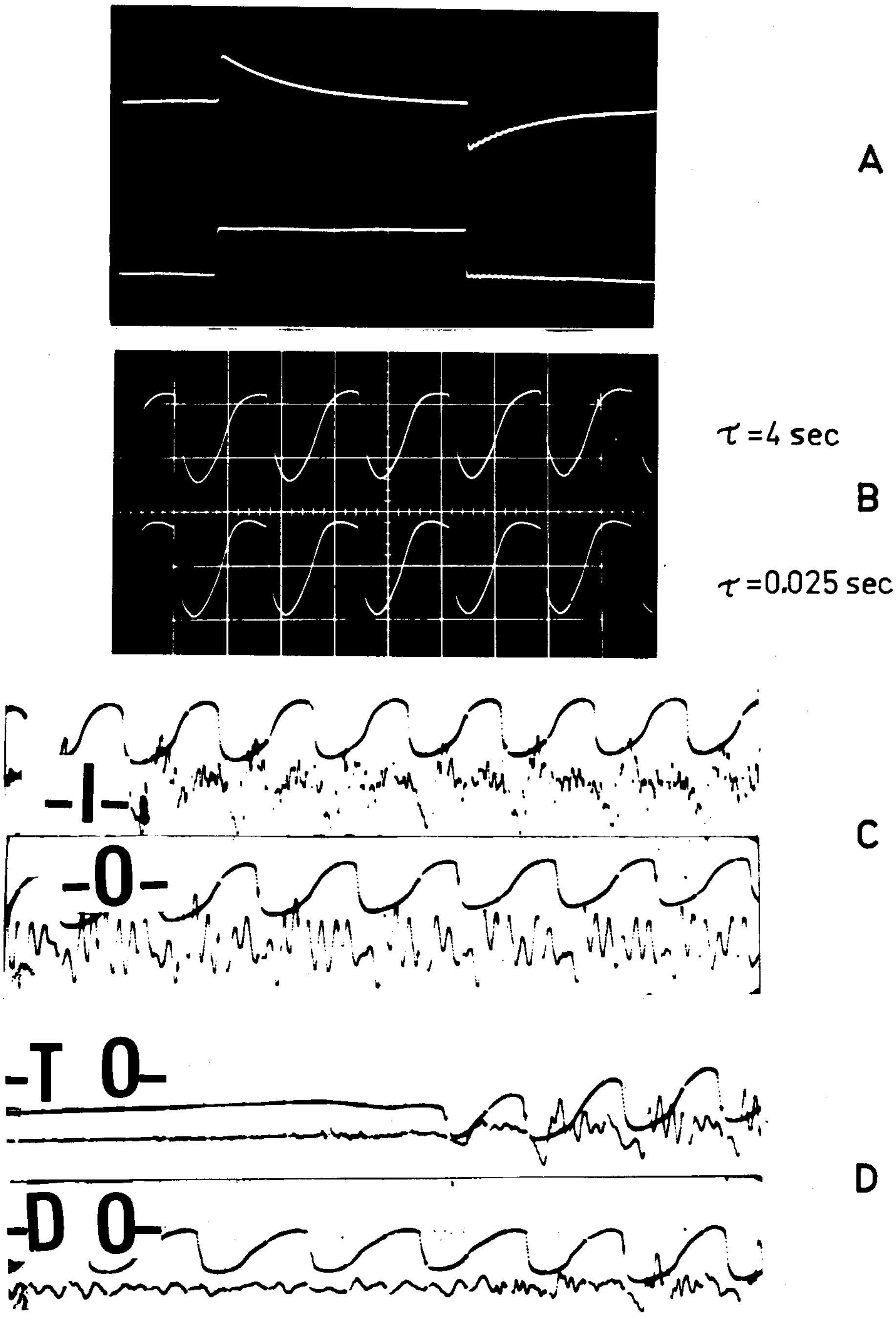

Fig. II-A-2. (A) Response of the glottograph to a rectangularly shaped resistance increase. The direct output with a long time constant preserves the waveform.

(B) Typical glottogram, male subject, long time constant above, short time constant below synchronously recorded.

(C) Electrical glottogram and oscillogram of the vowels [i] and [o].

(D) The same of the syllables [to] and [do].

At the first glance it would be tempting to correlate the rather level upper part of the curve with vocal cord closure and the more symmetrical downwards deflected peak as the maximum opening. This was the interpretation given by Fabre (1957) in this original work and quoted by Husson (1960). The resistance calibration of Fig. II-A-2(A), on the other hand, indicates increasing resistance, i.e., increasing glottal opening upwards. This is the true interpretation as also noted by Ohala (1966) and implicit in the later presentation of Husson (1962).

Once the vocal cords have opened in their full length a further separation does not affect the resistance much since the glottograph current is forced to seek pathways posterior and anterior to the cords. Thus the flat top of the cycle. On the other hand, 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. The following phase from maximum closure to opening is generally more gradual at a low voice pitch. This is to be expected in view of the axial component of the vocal cord movement which during the closed period displaces the area of contact upwards whilst this area presumably is decreasing. One can often identify a point of contact break as indicated by a sudden change of the slope of the glottogram curve. This effect is especially apparent in Fig. II-A-4(C).

The outstanding feature of the Fabre glottogram is the extremely rapid resistance fall when the cords reach contact in the closing phase. This is within the major region of excitation, the F1 component of the oscillogram reaching its maximum value shortly before or after, see Fig. II-A-2(C). This is a wellknown tendency from inverse filter experiments as demonstrated by Miller (1959), Holmes (1963), and Lindqvist (1964).

However, the apparent starting point within the glottal cycle varies with the particular speaker, voice mode, and formant under observation as illustrated by the data of Lindqvist (1964). From a more strict point of view the excitation of a formant is nonuniformly distributed over the whole glottal cycle. This effect together with a variation of the damping factor (bandwidth) accounts for frequent departures from a simple exponential shape of the formant oscillation envelope.

Electrical, optical, and acoustical glottogram

The Sonesson (1960) photo-electrical glottography provides a measure of the cross-sectional area at the level of maximum narrowing in the glottis. To a first order of approximation this area as a function of time is proportional to the flow of air through the glottis expressed in cm^3, as theoretically predicted by van den Berg et al (1957). It is also known that inverse filtering of the current from a pressure microphone with extended low frequency response provides a measure of this glottal flow. An experimental study of Fant and Sonesson (1962) has verified the approximate similarity in curve shape between the optical (photo-electrical) and the acoustical inverse filter glottogram.

We now had an opportunity to compare these two methods with the Fabre glottogram. The relation of the optical glottogram to that of the Fabre method was that to be expected in view of the previous interpretation. Figs. II-A-3(A) and (B) of a male voice phonating at a pitch of F_0 = 100 and 63 c/s respectively, show an approximate synchrony between the main discontinuity of the Fabre glottogram and the end of the light pulse. In the F_0 = 100 c/s sample there is also to be seen a correspondence in time between the discontinuity of the opening branch of the Fabre glottogram and the beginning of glottal light pulse.

The electrical glottogram on the top of Fig. II-A-3(C) (subject JL, F_0 = 120 c/s) has the typical flat top and the abrupt fall. In order to bring out the synchrony with the acoustic flow in the lower curve we have corrected for a 1 msec latency in the inverse filter, as indicated by the displacement in time scales. We can now observe that at the instant in time when the electrical glottogram in the ascending opening phase has reached the saturation flat level, the glottal pulse flow has already reached one-half of its peak value. This should be the instant when the glottal slit has reached a state of maximal length while the cords continue to separate. At the instant when the electrical glottogram signals the first contact of the cords the air pulse is almost but not quite terminated. Fig. II-A-3(D) finally exemplifies the electrical glottogram in relation to the acoustic flow for a third subject (OK) phonating at a pitch of F_0 = 140 c/s. The general picture is the same.

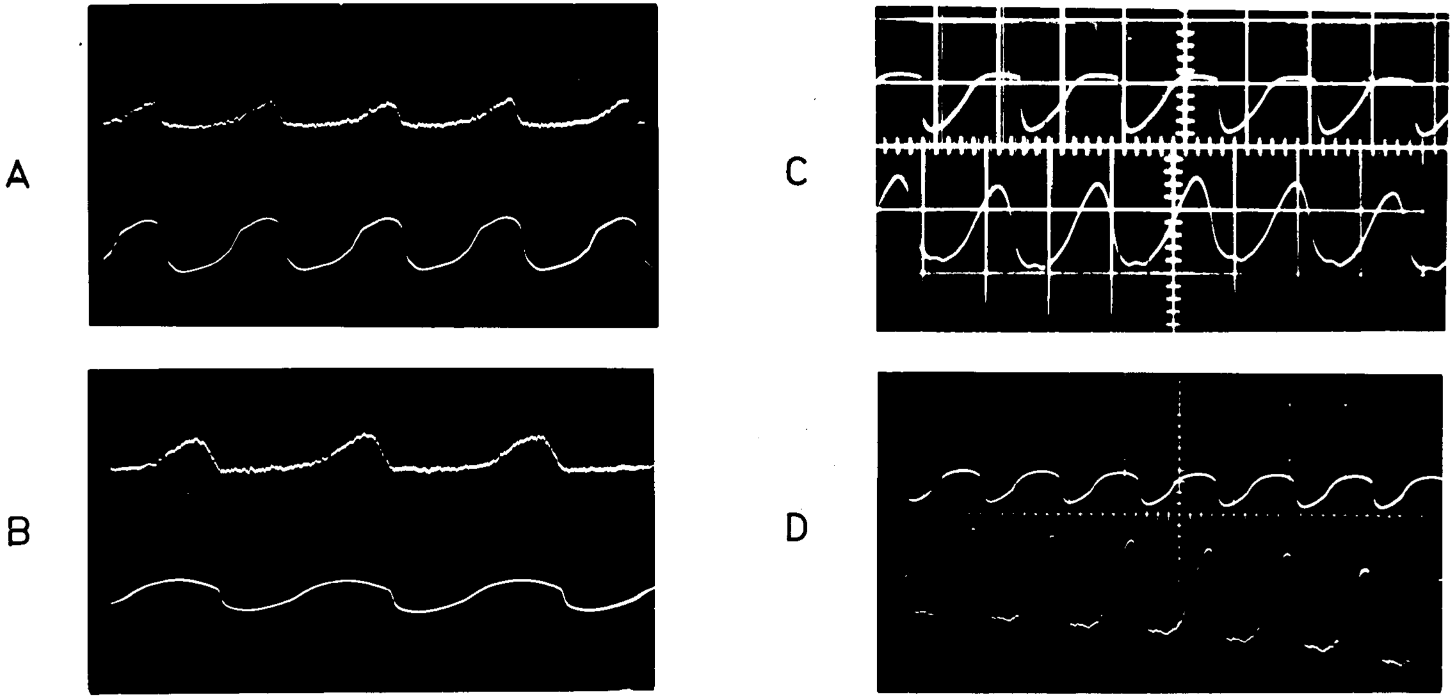

Fig. II-A-3. (A, B): Synchronous recordings of optical (above) and electrical glottogram (below), speaker (GF).

(C, D): Electrical (above) and inverse filter glottal flow (below), subjects (JL) and (OK).

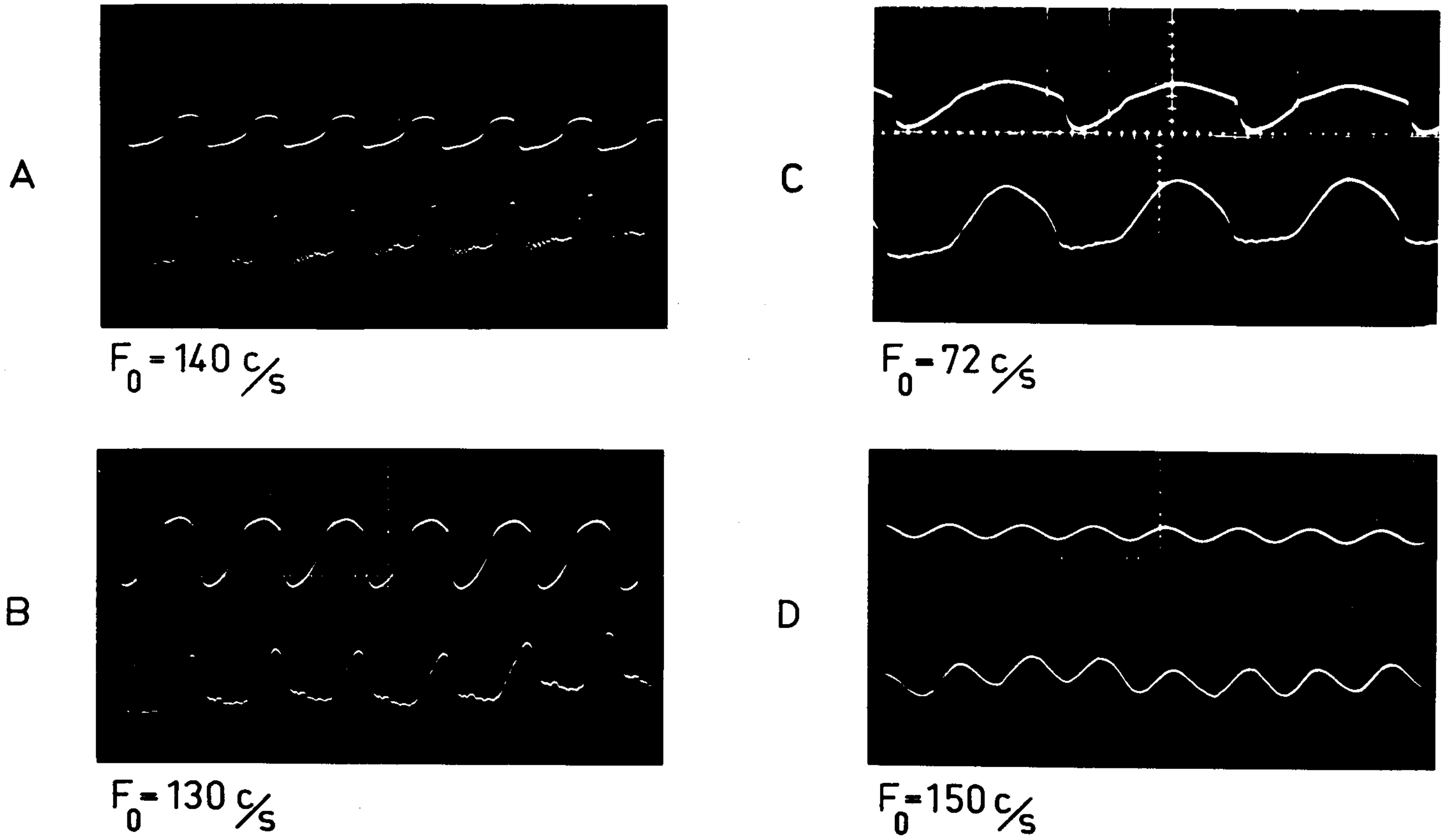

Fig. II-A-4. Subject (JS) phonating at:
(A) high voice effort, $F_0 = 140$ c/s
(B) medium voice effort, $F_0 = 130$ c/s
(C) medium voice effort at very low pitch, $F_0 = 72$ c/s
(D) very low voice effort, breathy voice, $F_0 = 150$ c/s
In each pair electrical glottogram above and inverse filter volume flow below.

Fig. II-A-4 illustrates the effect of pitch and voice intensity on the electrical and acoustical glottogram. The particular subject (JS) has a trained voice. At high voice effort and F_0 = 140 c/s (A), the ratio of open phase to total period length is 1:2.4. In (B), medium voice effort, F_0 = 130 c/s, the opening quotient is 1:2.0. In (D), extremely low "breathy" voice effort and $F_0 \approx$ 150 c/s, both the electrical and acoustical glottograms are rather sinusoidal as could be expected from a presumed state of small variations around a constant open cord configuration. In (C) finally, we have an interesting example of very low pitch, F_0 = 72 c/s,and rather low intensity, subjectively sensed as medium voice effort. Here we have corrected for the latency in the inverse filter. The synchrony between the discontinuities in the electrical glottogram and the beginning and the end of the acoustical flow pulse is here perfect. This would imply a vibratory mode in which the vocal cords open and close in their full length retaining a parallel orientation. The acoustic flow and the electrical resistance curve both show a rather symmetrical shape. The usual appearence of the acoustical flow pulse is that the time spent in the descending path is shorter than that of the ascending path. However, in Fig. II-A-4(C)the very last part of the closing phase is more abrupt than in the beginning of the opening phase, as is generally found.

The mean resistance as a measure of laryngeal adjustment

Fig. II-A-5(A) is a Fabre glottograph recording of a subject closing his glottis without phonation and half a second later opening the glottis. The bottom trace is the direct output with time constant 4 sec whilst the upper trace shows the distortion introduced by the built-in amplifier marking off a downward short pulse in the beginning of the closing movement and marking a positive pulse in the opening movement. In Fig. II-A-5(B) there is displayed with the same compressed time scale the oscillogram (somewhat reduced base response) of "sɛja mɑ́:men Ijɛn" and the direct output of the Fabre glottograph below. Well ahead of the phonation the resistant keeps falling by a magnitude greater than the amplitude of periodic excursions within the voiced portion. To what extent this is a result of overall changes in the spatial distribution of muscle mass and to what extent it reflects the successive closing of the arythenoids is hard to say.

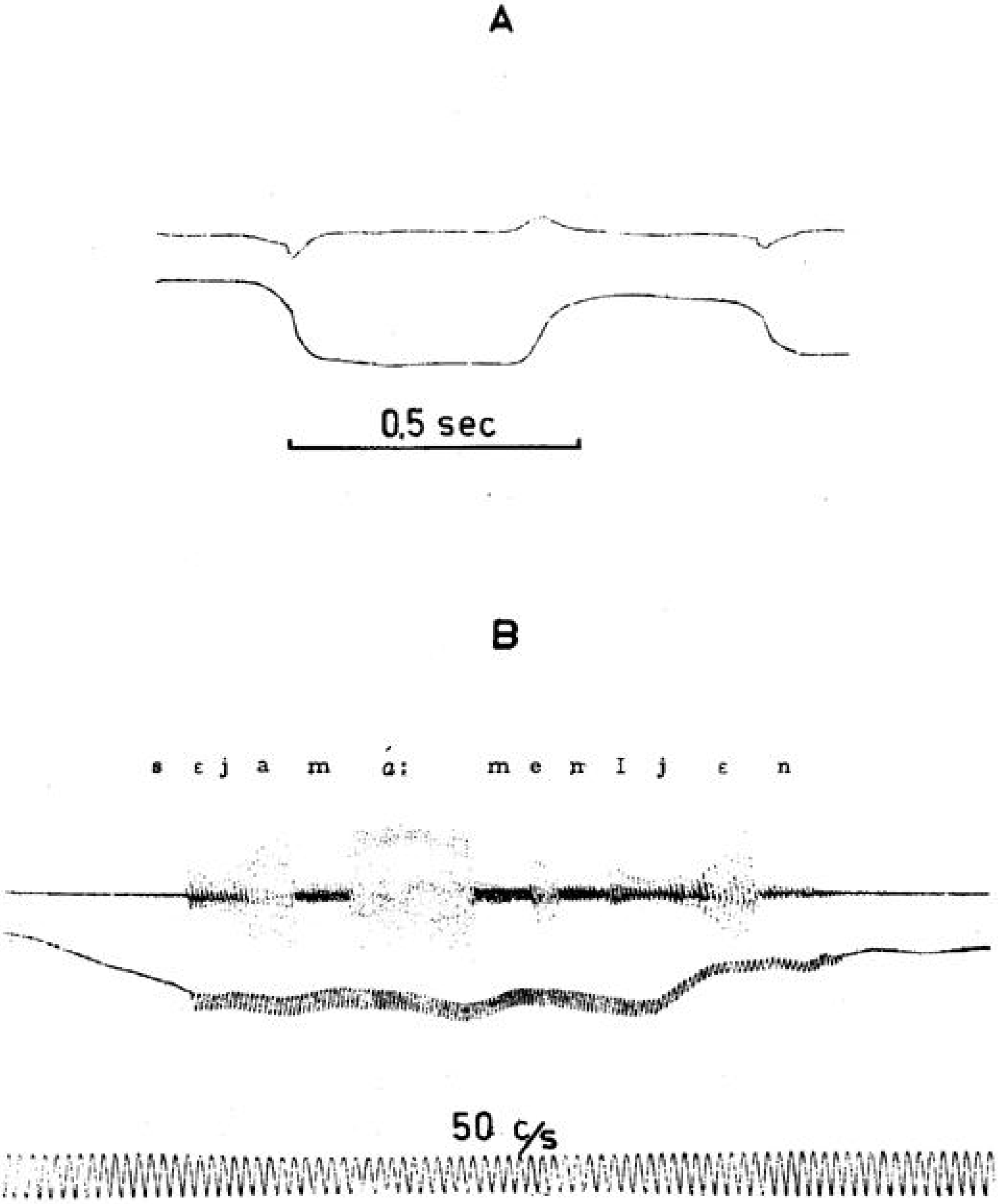

Fig. II-A-5. The effect of glottal articulation. (A) Voluntary closing-opening-closing of the glottis with short time constant registration above, long time constant below. (B) Oscillogram and electrical glottogram of a sentence containing the accent 1 nonsense word [mά:men] within a carrier phrase.

During voicing the mean value of the resistance retains a rather low value except at the end where it increases. The superimposed resistance ripple starts with a downward excursion and returns to the value before oscillation and is then clamped to this slowly varying base line.

In Fig. II-A-6(A) we see the typical excursion of the base line upward during the voiced occlusion of /b/ whilst the voicing ripple successively decays in amplitude. In less stressed articulations of voiced stops the glottograph oscillations retain rather constant amplitude during the voiced occlusion (Fig. II-A-2(D), /do/). In the unvoiced stop gap of /k/, Fig. II-A-6(B), there is a similar but more pronounced increase of the resistance signifying a corresponding opening movement. The extent of this, however, never reaches the value of rest before the sentence but it is clearly dependent on the intonation pattern. This agrees with the observations of Ventzov (1966) and suggests a new possible application of the electrical glottograph.

Fig. II-A-6(D) finally shows that a glottal stop inserted to function as a boundary marker between two morphemes, one ending with a vowel and the other starting with a vowel, is articulated differently. The resistance retains a value even lower than in the preceding and following voiced segments. This is natural in view of the cords being tightly pressed together.

Preliminary studies of the glottogram mean resistance as a correlate of the distinctions between stressed and unstressed syllables and as a factor influenced by the Swedish word accent 1 (acute) and accent 2 (grave) have been undertaken but these are not conclusive enough to deserve a detailed discussion. There is some indication that a stressed vowel has a lower resistance than an unstressed vowel but this is not quite consistent and it may be that the resistance is a better correlate of sentence stress. Accent 1 vowels tend to have lower resistance than accent 2 vowels whereas the resistance in the stop gap of an aspirated unvoiced stop preceding the vowel has a greater resistance in accent 1 than in accent 2. Voiceless stops have a higher resistance in stressed syllables than in unstressed syllables. Thus we have an instance of the principle that the contrast between a consonant and a following vowel is larger in stressed than in unstressed syllables. A larger contrast between the first vowel and a preceding consonant is also found in accent 1 compared with accent 2, as stated above.

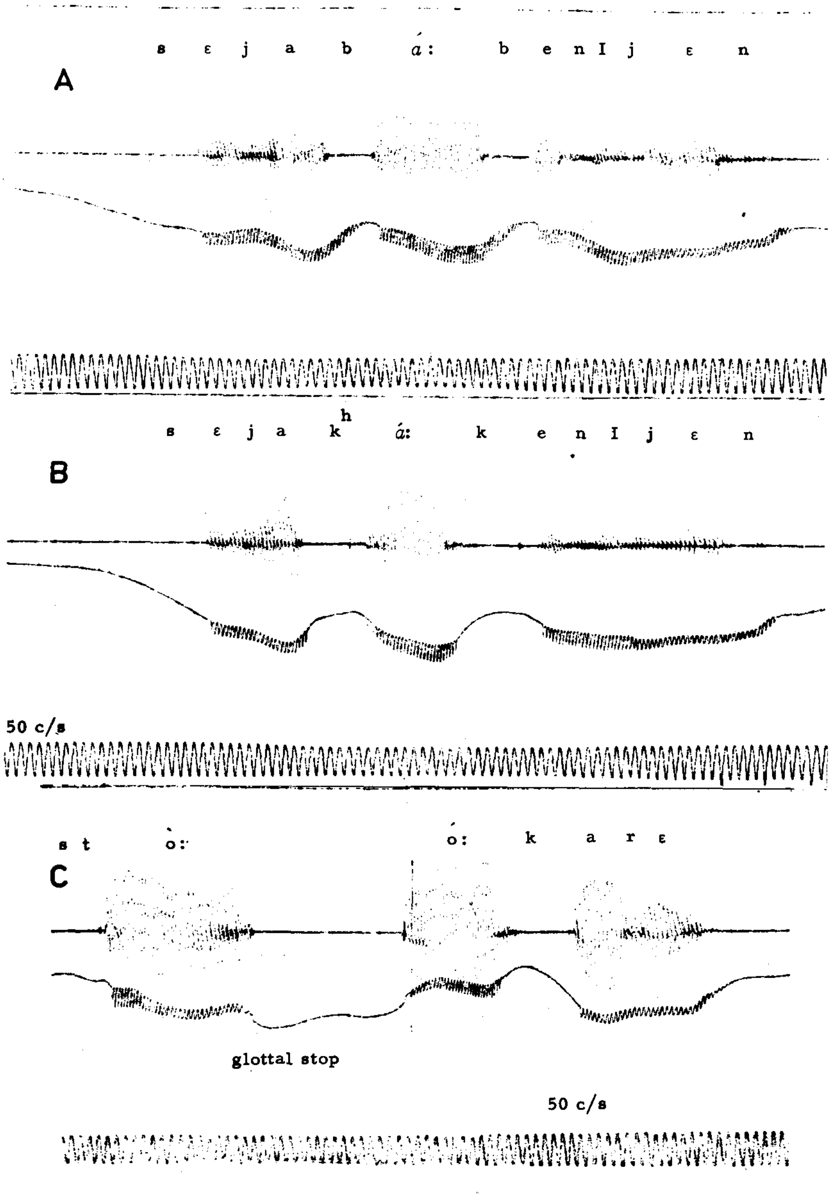

Fig. II-A-6. (A) and (B) illustrating the accent 1 nonsense words [bɑ́:ben] and [kɑ́:ken] within a carrier phrase.
(C) glottal stop marking a word boundary shows up as an extreme low resistance in the electrical glottogram. The Mingograph channel displaying the output of the electrical glottograph lags the speech oscillogram trace by 15 *msec* as indicated by the vertical line. This instrumental factor affects (A), (B), and (C) as well as Fig. II-A-5 (B).

Conclusion

The Fabre glottograph, when adjusted to have along time constant, is a valuable instrument for indirect studies of the voice mechanism as well as of laryngeal articulations. It is recommended as a supplement to inverse filtering or optical glottography. The typical feature of an extremely well developed discontinuity in the closing phase could be made use of in speech analysis as a reference for time domain voice frequency analysis.

References:

van den Berg, Jw., Zantema, J.T., and Doornenbal, Jr., P.: "On the Air Resistance and the Bernoulli Effect of the Human Larynx", J.Acoust.Soc.Am. 29 (1957), pp. 626-631.

Fabre, Ph.: "Un procédé électrique percutané d'inscription de l'accolement glottique au cours de la phonation: glottographie de haute fréquence", primary results presented in Bull. Acad. Nat. Méd. (1957), pp. 66-69.

Fant, G.: "A New Anti-Resonance Circuit for Inverse Filtering", STL-QPSR 4/1961, pp. 1-6.

Fant, G. and Sonesson, B.: "Indirect Studies of Glottal Cycles by Synchronous Inverse Filtering and Photo-Electrical Glottography", STL-QPSR 4/1962, pp. 1-3.

Hlaváč, S.: "Vysokofrekvenční glotografická metoda vyšetřování pohybu hlasivek", Slaboproudý obzor (to be printed).

Holmes, J.N.: "An Investigation of the Volume Velocity Waveform at the Larynx During Speech by Means of an Inverse Filter", paper B4 in Proc. of Speech Communication Seminar, Vol. I (Stockholm 1963).

Husson, R.: La voix chantée (Paris 1960).

Husson, R.: Physiologie de la phonation (Paris 1962).

Husson, R.: "Étude théorique et expérimentale du fonctionnement phonatoire de la sirène glottique", Thesis 1965.

Lindqvist, J.: "Inverse Filtering Equipment", STL-QPSR 1/1963, p. 13.

Lindqvist, J.: "Inverse Filtering. Instrumentation and Techniques", STL-QPSR 4/1964, pp. 1-4.

Lindqvist, J.: "Studies of the Voice Source by Means of Inverse Filtering", STL-QPSR 2/1965, pp. 8-13.

Miller, R.L.: "Nature of the Vocal Cord Wave", J.Acoust.Soc.Am. 31 (1959), pp. 667-677.

Ohala, J.: "A New Photo-Electric Glottograph", Working Papers in Phonetics IV, Univ. of California, Los Angeles (1966), pp. 40-52.

Ondráčková, J.: "Glottographical Research in Czech Sound Groups", to be printed in the Proc. of the XVIII Int.Congr. of Psychology, Moscow-Leningrad 1966.

Sonesson, B.: On the Anatomy and Vibratory Pattern of the Human Vocal Folds, Acta Oto-Laryngologica, Suppl. 156 (Lund 1960).

Ventzov, A.V.: "A Mechanism for Production of Voiced and Voiceless Intervocalic Consonants", to be printed in the Proc. of the XVIII Int.Congr. of Psychology, Moscow-Leningrad 1966.