A PHOTO-ELECTRIC GLOTTOGRAPH

Børge Frøkjær-Jensen

In the past year a photo-electric glottograph was built in the Institute of Phonetics by the present writer.

Different types of glottographs.

The first glottograph was constructed by Dr Sonesson, Sweden (1), (2). This photo-electric equipment is destined for observations of the larynx vibrations, but it is not possible to use it in connected speech because of interference from the plastic rod which is inserted through the mouth and placed in the pharynx. One can mainly pronounce or sing long vowels like [ɛ:] and [œ:].

The Fabre glottograph (3), (4), and (5), which measures the electric impedance in the larynx by means of a pair of electrodes placed in contact with the skin on both sides of the larynx, is considered to be very good for recording glottis movements in connected speech. But it is doubtful whether it is exclusively glottis movements that are recorded. Contractions of the pharynx and raising and lowering of the larynx obviously influence the result (6).

In the last few years a good deal of work has been made in different laboratories to develop the glottograph. Some experiments have been done at the Haskins Laboratories. The light source was inserted through the mouth via a fibre optics bundle, and the photo transducer that picked up the light passing through the glottis was placed in contact with the skin just below the larynx (7). Under these conditions some difficulties arose when the subject made velopharyngeal closures and when the cartilages of the larynx were moving up and down.

A better solution is apparently to place the light source below the glottis (as Sonesson did) and to pick up the light variations by means of a small photo transducer inserted through the nose into the pharynx. This has been done by Malécot whose glottograph (called GLOTLUX) was primarily intended for investigations of the fortis/lenis problem (8).

The same principles have been employed by John Ohala (9). He has tried to fix the photo transducer in the pharynx by mounting it 7 cm from the lower end in a transparent plastic tube (4 mm in diameter). The lower end of this tube was fixed by swallowing it down in the oesophagus.

Slis and Damsté describe a glottograph (1o) with fibre optics inserted through the nose. They are able to move the flat end of the optics by means of a nylon thread which goes through the protecting tube and through a hole in the tube outside of the nose.

Sawashima, Hirose, and Fujimura have made some experiments with photography of the glottis by means of a flexible fibre optics cable inserted through the nasal passage, too (11). Camera and light source are looking at the glottis through the same fibre optics cable containing both light guide and image guide. The optical cable is pushed in position behind the epiglottis. - It is now possible to connect a fibre optics cable to a video camera for making tape recordings or moving pictures of the glottis (as far as we know this has not yet been done).

Our glottograph.

So far, our experiments with the glottograph are based on the most common principle, i.e. an external light source and a light sensitive cell pushed down through the nasal passage and placed behind the epiglottis in the pharynx.

The light source consists of a 5oo watts projector lamp with blower. The light is led to the skin through a 6o cm long acryl rod with a diameter of 4o mm. This acryl rod makes it more comfortable for the subject because of the greater distance between the subject's face and the hot light house of the projector. Only a few per cent of the light is lost in the transmission rod which is mounted in the lense holder instead of the front lenses (objectives) of the projector.

In order to avoid the 5o cps ripple of the light, which will interfere very strongly with the oscillations from the vocal cords, the current for the projector lamp is rectified and smoothed. After a normal bridge rectifier and an LC smoothing filter about 2oo volts are left for the lamp, i.e. the lamp consumes an effect of about 4oo watts.

Our mains supply of 22o volts AC is not very stable. When the mains supply varies, it causes variations in the light level. The supply varies over a range of up to 25 volts. We intend, therefore, to stabilize the mains supply with a 22o/22o volts stabilizer, and connect the bridge rectifier to that stabilized voltage. However, this had not been done when we made the illustrations for this paper, as we had not got the stabilizer yet.

In the first experiments, which are described in this article, the light sensitive transducer in the pharynx was a photo transistor (Texas Instruments type LS4oo) (9). This photo transistor is very small (diameter 2 mm) and has a shape which makes it very well suited for mounting in a polyethylene tube with an internal diameter of 2 mm and an external diameter of 3 mm. Thus mounted in the end of the small tube it goes quite easily down into the pharynx. If the subject has very sensitive mucous membranes and strong reflexes, it can be necessary to give a little amount of local anaesthesia, but this is not normally needed (it has not been necessary to do so for making any of the illustrations in this paper). The distance from the nostrils to the lense of the photo transistor is for a normal subject 18o cm tall between 13 and 16 cm (9). Therefore we have placed a little mark on the polyethylene tube at a distance of 13 cm from the photo transistor. The photo transistor must be fixed by means of glue in the tube in order to avoid that saliva percolates into the tube thereby causing partial short cut between the terminals.

The photo transistor is connected through a shielded cable to an amplifier, which is mounted near the subject's face on the acryl rod extending from the projector. In this way the distance between the light sensitive cell and the amplifier is the smallest possible, which reduces the possibility of picking up hum (and our local broacast station) which would disturb the glottogram curves.

The amplifier itself is based on an integrated circuit, "Fairchild" type µA 7o2 C. This integrated circuit gives sufficient amplification for driving an oscilloscope or an ink writer (mingograph).

However, we have supplied the photo transistor amplifier with an output stage 2N 3o54 (RCA). In this way the amplifier delivers an output power sufficient for driving nearly all the different recorders on the market.

When we have got some experience through the practical work with the glottograph, we shall be able to determine whether or not some filtering of the signal is necessary. Possibly an HP-filter could stabilize the zero line when making analyses of the larynx oscillation.

Technical specifications of the glottograph.

If the photo transistor is placed in total darkness the input voltage of the amplifier is only 0.7 μV. If the photo transistor is placed in position over a closed glottis which is illuminated from below, the input voltage is 3.7 μV. A fully open glottis causes an input voltage of 6 mV, whereas the input level only varies up to 3 mV under normal conditions of phonation (subject BFJ).

The maximum output from the amplifier is 3 volts/500 mA which is obtained with an input voltage of 1o mV (input impedance 2000 ohms). During this measurement the output load resistance has been 6 ohms, which is the minimum permissible load resistance.

In the normal working range: 0 - 3 mV input voltage which corresponds to 0 - 1.6 volts/0-200 mA output, the amplification is linear within ± 2 per cent. The power gain is 81 dB (voltage gain 56 dB and current gain 1o6 dB).

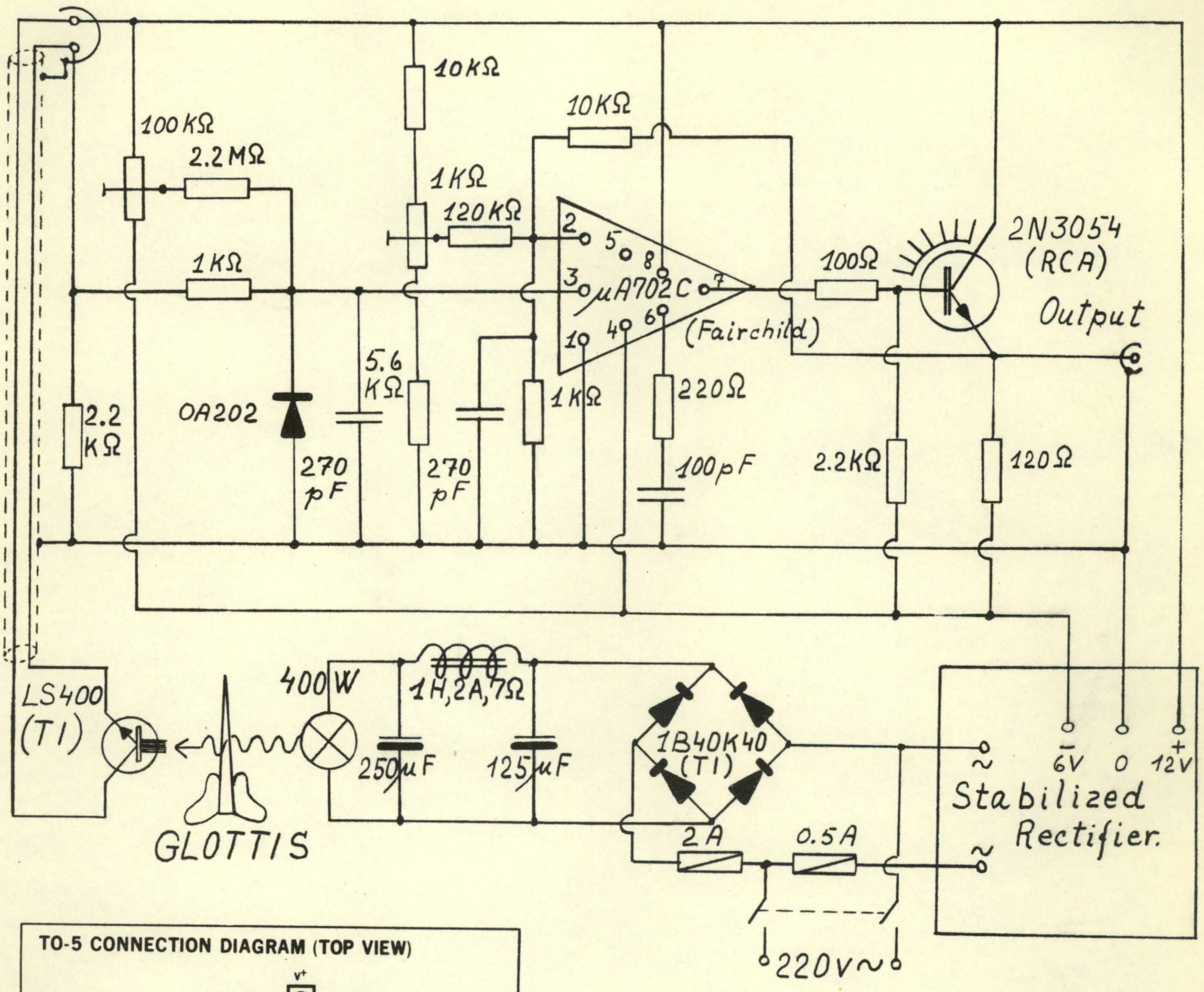
The frequency range has been tested by means of a Philips stroboscope type 91o3. The light pulses and the output pulses of the glottograph have been measured with a Tektronix scope type 5o2A. Calculations show that the photo transistor with amplifier has a rise time of 10 μs and a fall time better than 50 μs, i.e. the glottograph has a frequency range from DC up to at least 20,000 cps.

Picking up the light from the glottis:

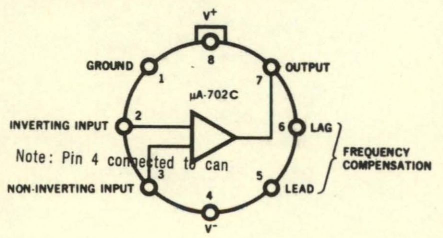
As yet, our experience with the glottograph is limited to a few subjects. Only some of the subjects (all phoneticians at the Institute) were able to fix the photo transducer in such a way that glottograms were produced on the oscilloscope screen. The subjects accomplished this by looking at the screen while moving the transducer up and down with open glottis until a maximum deflection was obtained on the screen.

It is, however, difficult to fix this position of the transducer for most subjects. The articulatory movements disturb it, especially movements of the soft palate and movements of the epiglottis. We have tried to fix the transducer by mounting it midway

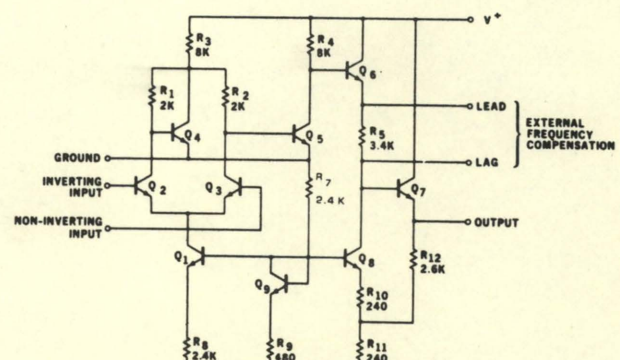
AMPLIFIER FOR GLOTTOGRAPH



TO-5 CONNECTION DIAGRAM (TOP VIEW)



SCHEMATIC DIAGRAM OF THE μA-702C



in the polyethylene tube, which then was swallowed down into the oesophagus (9). However, after trying myself for several days to produce glottograms in that way I made sure that this was not the best method. The photo transducer was placed too far back in the pharynx.

Now we want to test different types and shapes of photo transistors and photo diodes. The type LS400 which has hitherto been used has a light sensitive angle of only 15^{o}, which is probably too little when the transducer is moved by the articulations.

After making the illustrations for this paper I have succeeded in removing the convex lense which formed the front part of the photo transistor house. As a result of this it is now much easier to pick up the light, and the position of the photo transistor in the pharynx is not so critical now as before.

Different ways of fixing the transducer and shaping the polyethylene tube, e.g. by fixing a steel spring inside the tube and moving it into position by means of a nylon thread (lo), will be tried too.

Results:

The two main purposes we had in mind when building the glottograph were: (I) Investigations of changes in the voice spectrum at high voice effort, and changes in voice quality in different registers and at different pitch levels in singing. Some investigations of these problems have been started by the present writer (12). (II) Investigations of the position and movements of the vocal cords in Danish stop consonants as part of the comprehensive studies of stop consonants started some years ago by Eli Fischer-Jørgensen (13), (14).

The photos shown on the following pages present some preliminary results. The photos are all made from the storage screen of a Tektronix oscilloscope type 564. The same vertical sensivity has been used for all the photos, whereas different time settings have been used for the horizontal sweep time.

An opening movement of the glottis is recorded as a raising of the glottogram curve. Unfortunately, it is not possible to show a zero line indicating the curve position for the closed glottis. Even if the glottis is closed more or less light may penetrate through the vocal cords and the mucous membrane.

Comparison between low and high voice effort in chest register

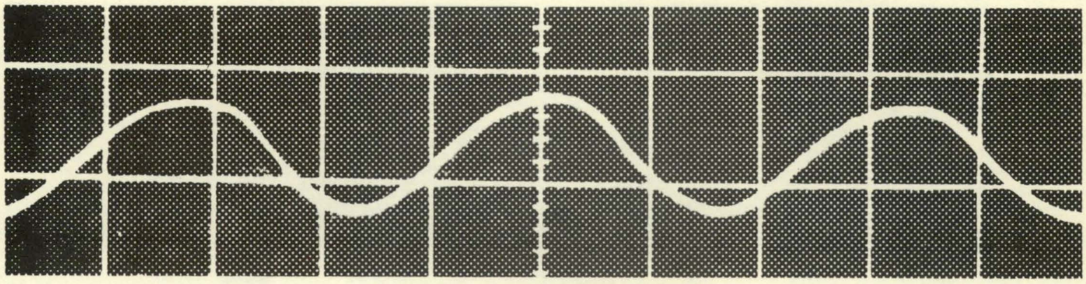


Fig. 1

Glottogram of low voice effort at F_o = 12o cps in chest register. (Vowel [i:] , subject JR).

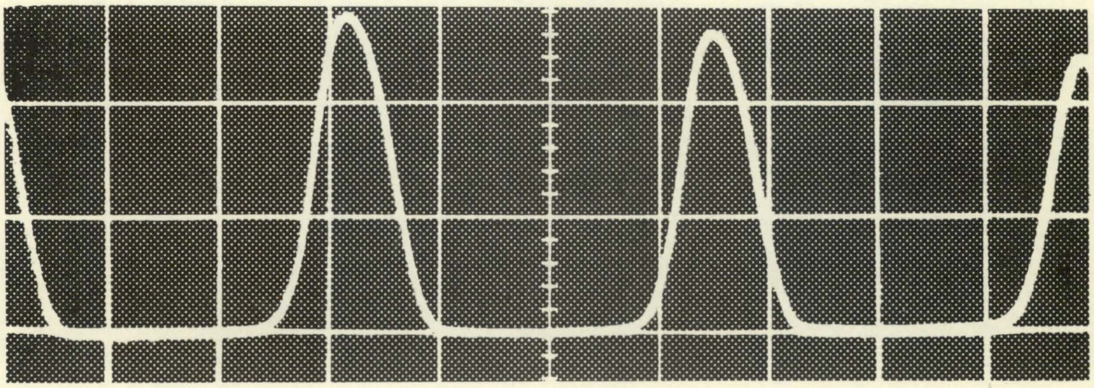


Fig. 2

Glottogram of high voice effort at F_o = 120 cps in chest register. Notice the long closure phase in the vowel spoken with high voice effort. (Vowel [i:] , subject JR).
For further explanations of the difference on the acoustic level between low voice effort (Fig. 1) and high voice effort (Fig. 2), see reference (12).

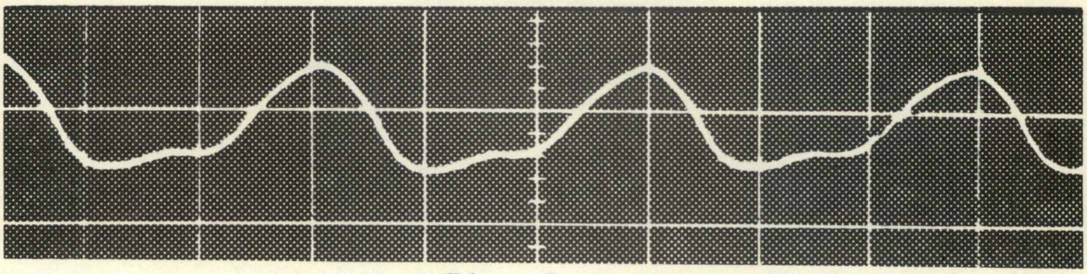


Fig. 3

Glottogram of high voice effort at F_o = 110 cps in chest register.
The subject has deliberately reinforced the 2. harmonic. This physiological waveform with the strong 2. harmonic may be explained by means of the upward travelling wave in the mucous membrane of the vocal cords (15). (Vowel [ɛ:] , subject JR).

Comparison between low and high voice effort in chest register and in head register

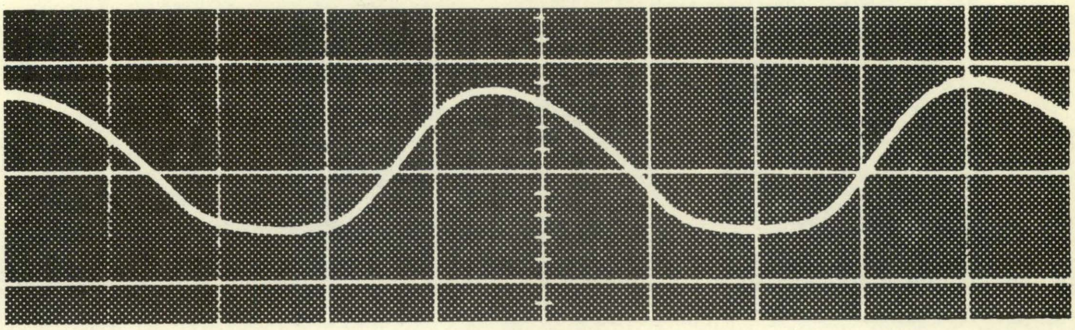


Fig. 4

Glottogram of low voice effort at F_o = 120 cps in chest register. (Vowel [ε:], subject BFJ). Compare Fig. 1, subject JR.

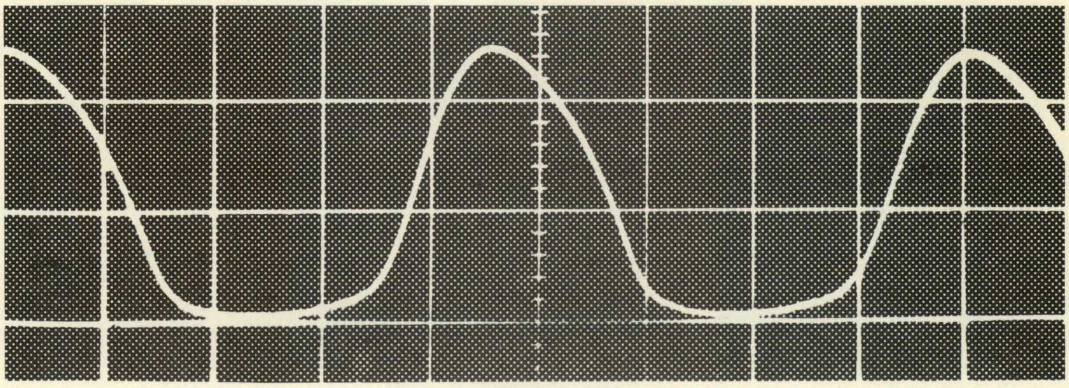


Fig. 5

Glottogram of high voice effort at F_o = 120 cps in chest register. (Vowel [ε:], subject BFJ). Compare Fig. 2, subject JR.

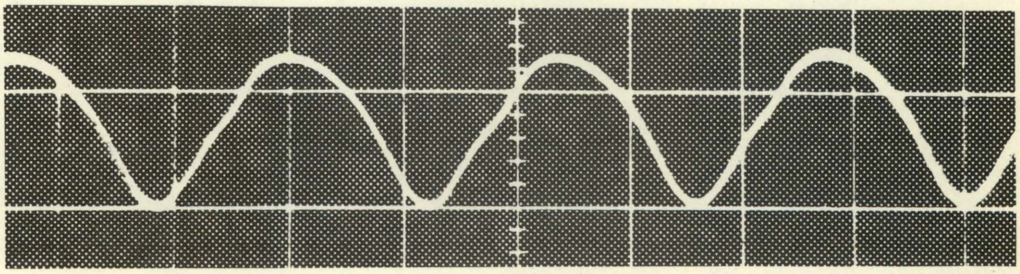


Fig. 6

Glottogram of low voice effort at F_o = 400 cps in head register. Notice that the closure phase, if it is at all present, is very short. (Consonant [m:], subject BFJ).

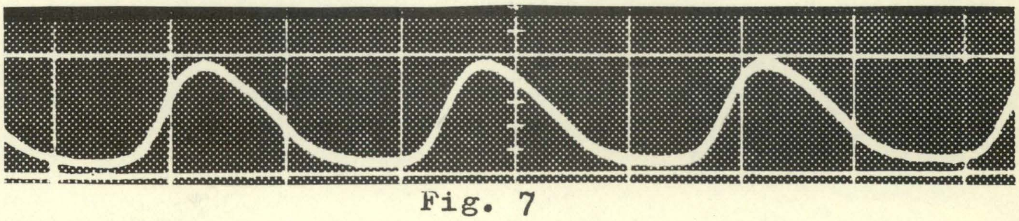


Fig. 7

Glottogram of high voice effort at F_o = 400 cps in head register. Notice that the closure phase is much longer than in Fig. 6, and that the slope is steeper in the opening than in the closing movement. (Consonant [m:], subject BFJ).

Comparison between head register and chest register at the same fundamental frequency F_o = 225 cps

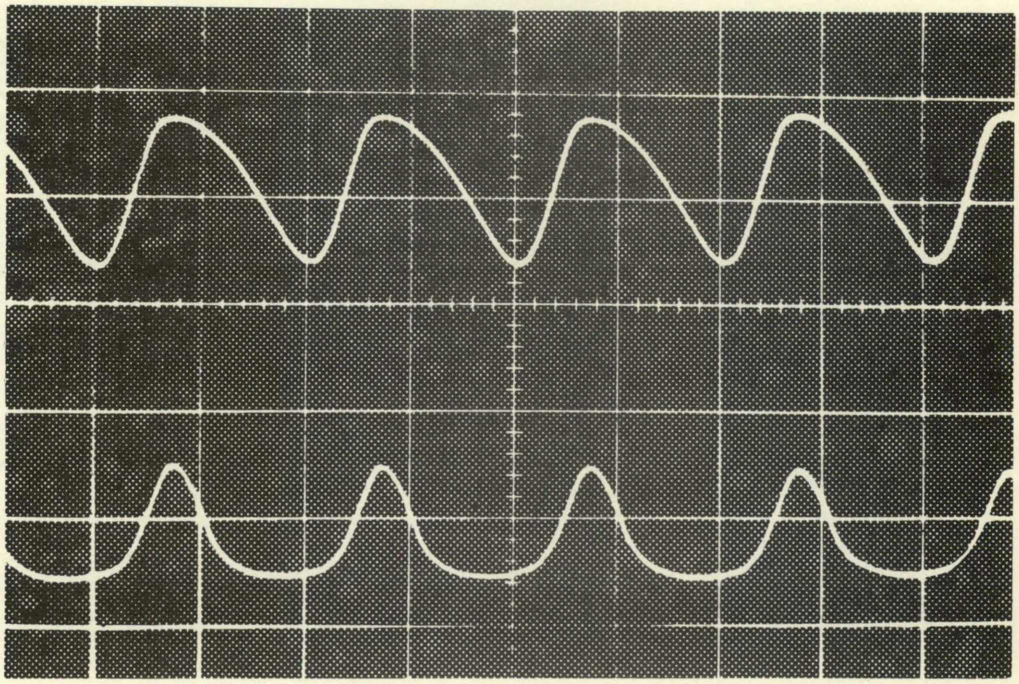


Fig. 8

Both glottograms illustrate medium voice effort. Notice the longer closing phase in the lower curve (chest register) compared to the upper curve (head register). This is a typical difference. (Vowel [i:], subject BFJ).

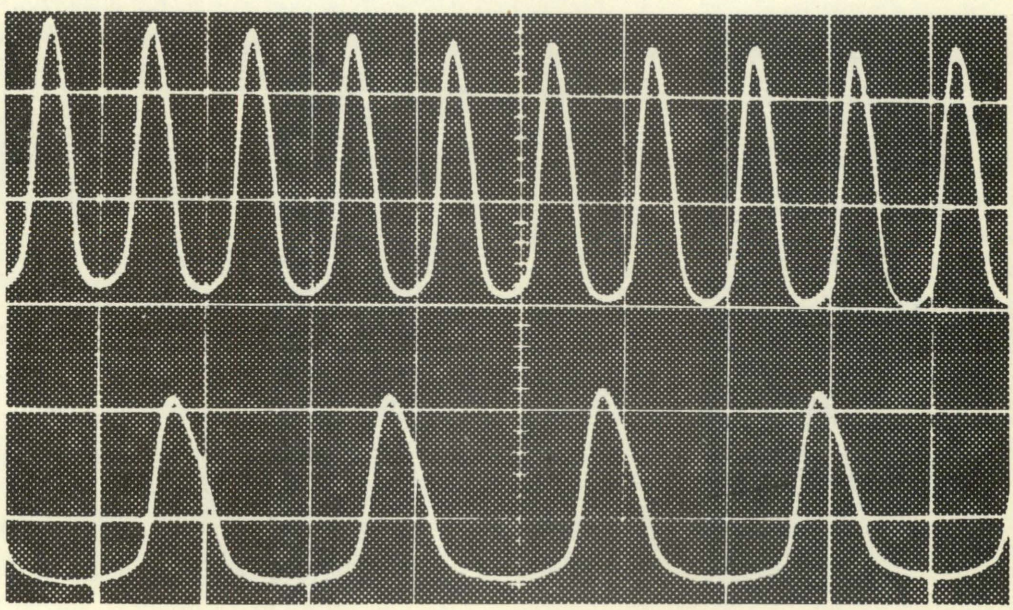


Fig. 9

Upper curve: Fundamental frequency 200 cps.
Lower curve: Fundamental frequency 100 cps.
High voice effort in chest register. (Vowel [ε:], song, subject BFJ).

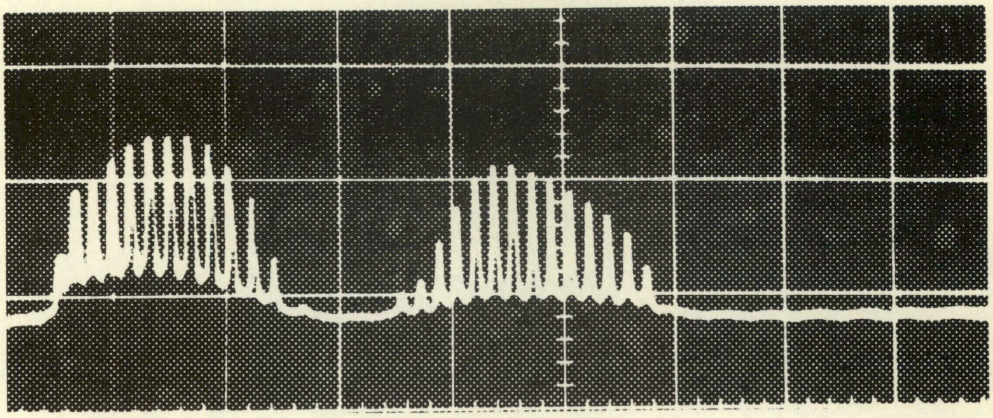


Fig. 10

Glottal attack in the word [ʔaʔa] 'a - a' (baby talk) (subject BFJ).
Compare this glottal attack with the examples of the Danish "stød" in Figs. 12 and 13.

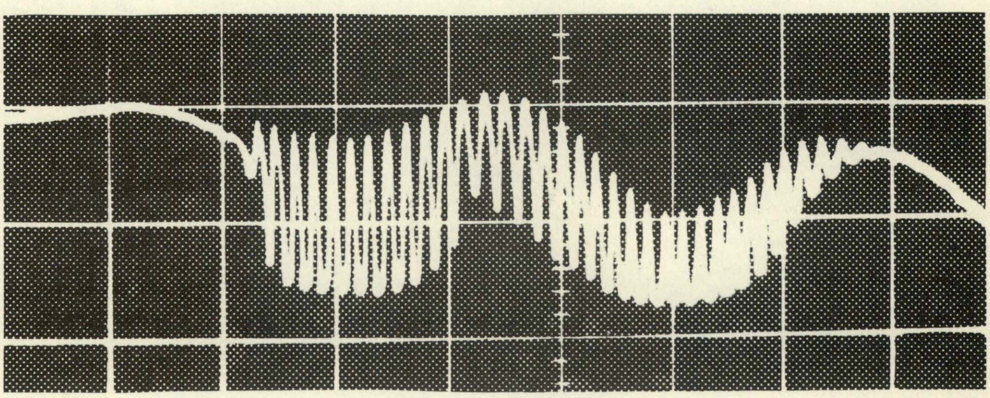


Fig. 11

Unvoiced and voiced [h] in the word [haɦah] , 'ha-ha' (expression of surprise) (subject BFJ).

Notice in these two glottograms (Figs. 10 and 11) the difference between a final vowel ending with a glottal closure and a final vowel ending with an aspiration.

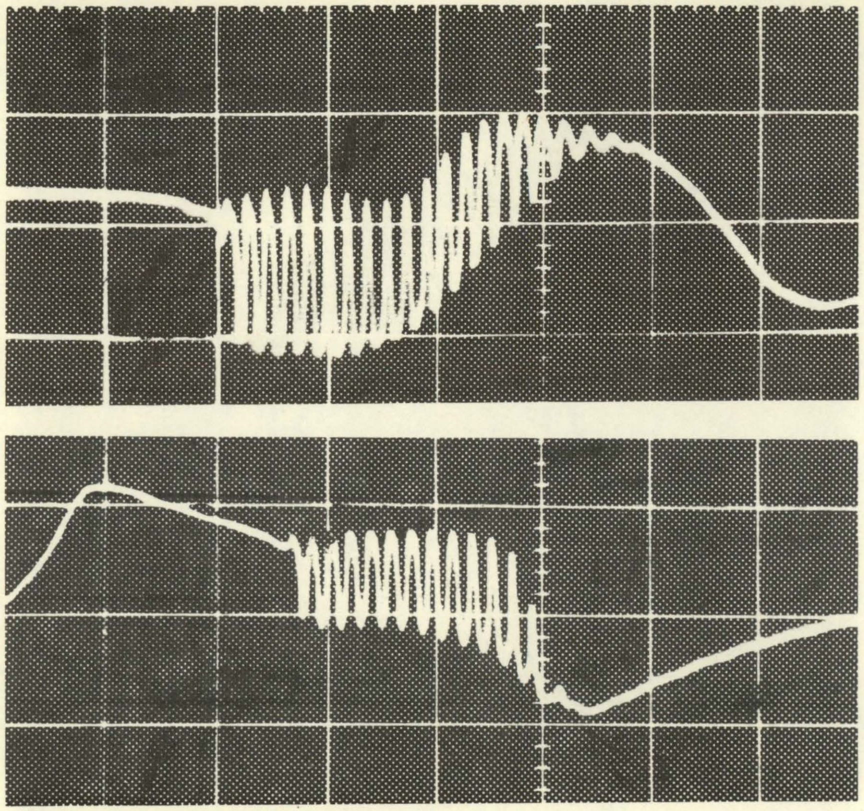


Fig. 12

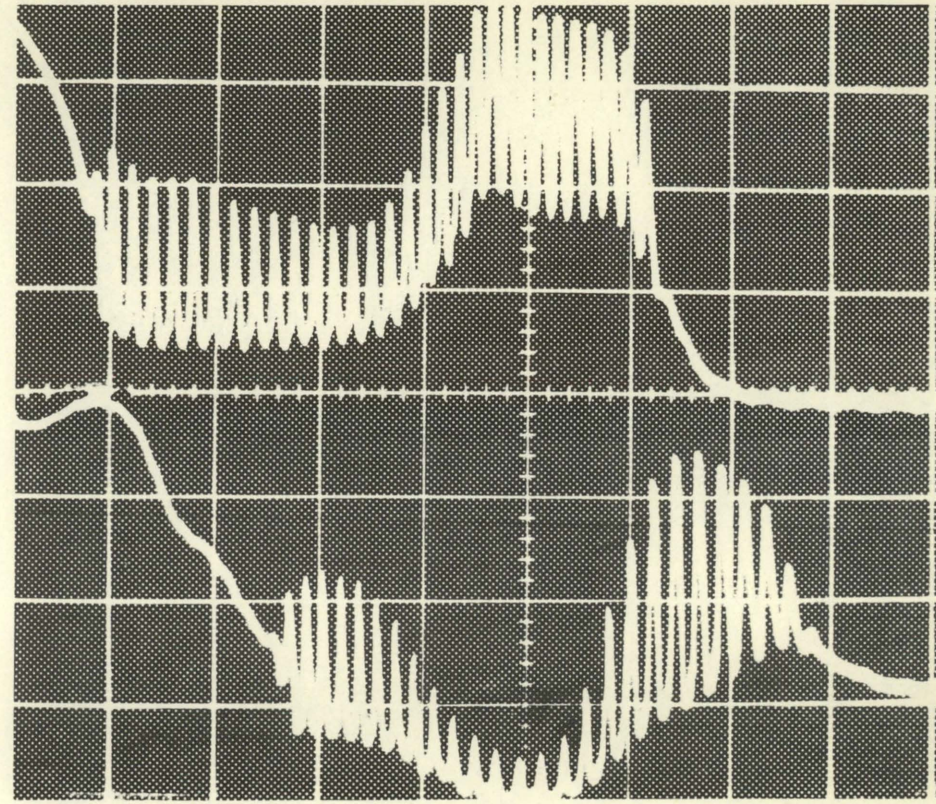


Fig. 13

Danish "Stød"

One-syllable minimal pair and two-syllable minimal pair illustrating the "stød" in Danish.

Upper curve: [hun] hun 'she' — Upper curve: [hu:ən] huen 'the cap'

Lower curve: [hunʔ] hund 'dog' — Lower curve: [huʔən] huen 'the inclination'

(The "stød" is not a glottal closure in standard Danish (16), but possibly in the Jutland dialect (17). The lack of a zero line in the glottograms makes it impossible to determine whether or not the glottis is closed in the "stød"-phase. Subject BFJ is talking standard Danish with a slight Jutland dialect substratum.)

The Danish p t k

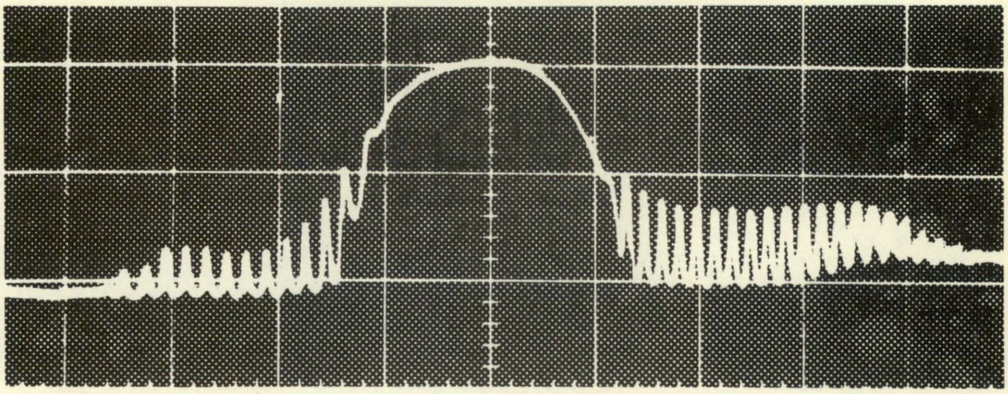


Fig. 14

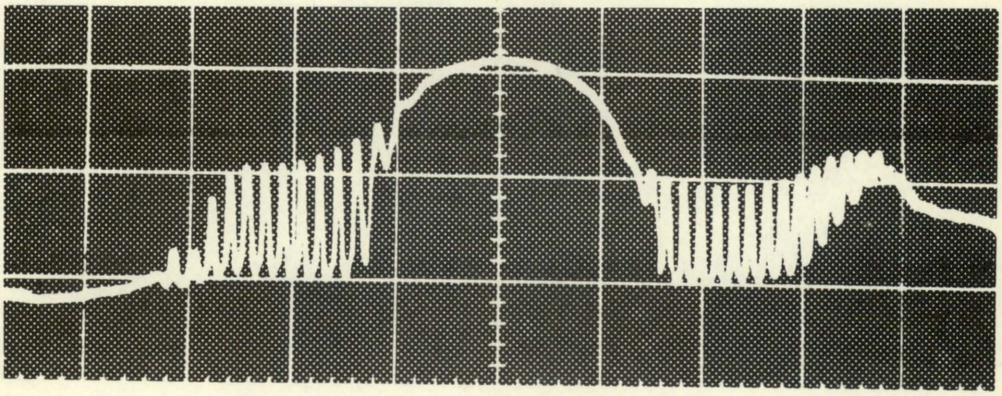


Fig. 15

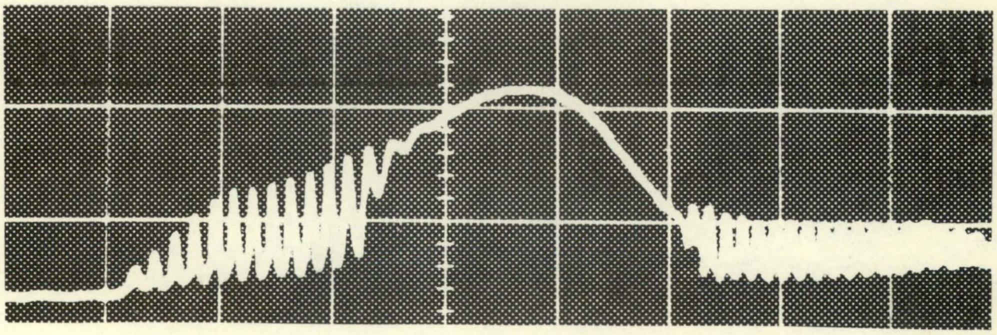


Fig. 16

Glottograms of the Danish tenues ptk in the words [ɛpɛ], [ɛtɛ], and [ɛkɛ] show in all cases a fully open glottis (as observed earlier in an endoscopic examination by Eli Fischer-Jørgensen (14)). The vocal cords do not vibrate during the closure. In our last report (3) we published some curves of the same stops made with the FABRE GLOTTOGRAPH. These curves, too, show an open glottis during the closure phase of the articulation of Danish ptk. - The main difference between the tenues ptk and the mediae bdg in Danish is one of aspiration. Tenues are aspirated and mediae are not. (Subject BFJ.)

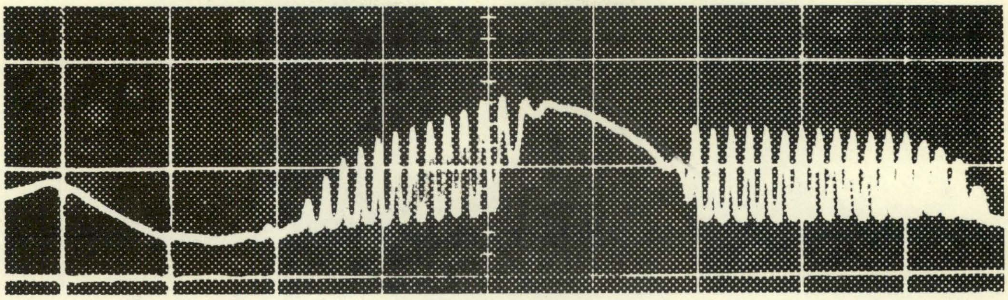


Fig. 17

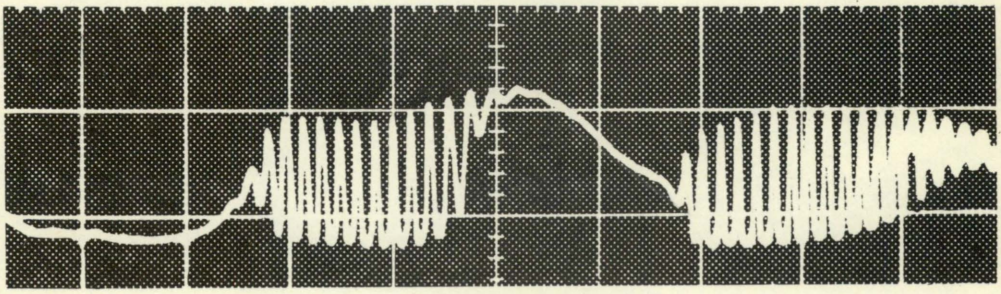


Fig. 18

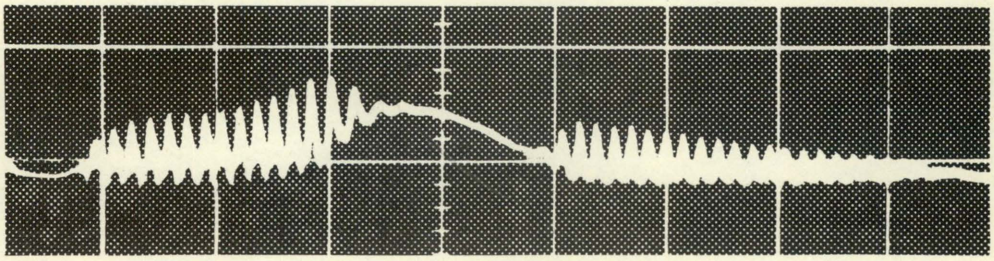


Fig. 19

Fig. 17 [εbε], Fig. 18 [εdε], and Fig. 19 [εgε] may be compared with Figs. 14, 15, and 16. (Subject BFJ.)

At first we observe that the glottis is on the whole more closed in the mediae than in the tenues, which confirms our visual observations in the endoscope. Secondly, the glottis is most open in the beginning of bdg when the air pressure is being built up in the pharyngeal and oral cavities. Then the glottis gradually closes in order to avoid aspiration after the explosion. As the glottis is nearly closed during the explosion the vocal cords will start to vibrate immediately after the explosion.

(This may be confirmed with more subjects by means of simultaneous recordings of glottogram, oscillogram, subglottal air pressure, and pharyngeal air pressure.)

Future tasks.

We hope that it will later be possible to make simultaneous recordings of the subglottal pressure, the pharyngeal pressure, the air flow, and the glottogram. Such combinations of physiological parameters would be extremely useful for investigations of the stop mechanism and of whisper. For research on changes in the voice spectrum at high voice effort and for research on register shift and changes in pitch levels in singing it is also necessary to know how the primary voice spectrum changes. As for the relations between the glottal area curve recorded with the glottograph and the primary voice source, see references (18), (19), and (2o).

Finally we may employ the waveform observed as voice source input for our synthesizer when imitating a special voice quality.

Acknowledgement:

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