(ARIPUC 12, 1978)

THE GLOTTAL GESTURE IN SOME DANISH CONSONANTS - PRELIMINARY OBSERVATIONS

Birgit Hutters[1]

1. Introduction

In the present paper some preliminary fiberoptic and glottographic observations of various Danish obstruents will be presented. Furthermore, some of our preliminary EMG[2] results will be mentioned. But it should be emphasized that the results are very preliminary, and thus the present account may deviate somewhat from the results as they will appear in the final report.

2. Procedure

Photo-electric glottograms of various obstruents in stressed, intervocalic position were made with the fiberscope positioned in the pharynx, serving as light source, and a photo-transducer placed on the frontal part of the neck. In addition to the light source function the fiberscope has a controlling function: during the glottographic recording a still-picture of the larynx is taken during each test sound, making it possible to control the stability of the light and the larynx. This stability is very important for the reliability of the glottographic recordings.

---

1) Institute of Phonetics, University of Copenhagen.

2) The EMG project at the Institute of Phonetics is part of a larger framework titled: "The glottal behaviour in Danish consonants, stress, and stød". Fiberoptic and glottographic investigations are also included in this main project.

Furthermore, the still furnishes immediate information about the state of the glottis and the surrounding structures at the moment of exposure. A synchronizing pulse is recorded in order to synchronize the still and the glottogram. Moreover, a microphone signal is recorded. Fig. 1 illustrates the curves used for segmentation and extraction of parameters, and the still of the glottis, taken in the exemplified test sound, is displayed as well. The obstruents mentioned in this paper are p t k b d g f s said in the frame sentence "De ville sige [- i(:) $(^{l}_{n})$ə]" (they would say ...), i.e. the segment preceding and following the test sound is [i] ("sige" is pronounced [si:]). All the test words are meaningful Danish words. So far, only one subject (Hu) has been closely investigated, but a cursory inspection of other subjects has been performed as well. The dialect of the subject treated here is Advanced Standard Copenhagen Danish.

3. Extraction of parameters

The acoustic and glottographic signals are segmented as seen in fig. 1:

The acoustic signal

V_1: onset of the preceding vowel

V_2: offset of the following vowel

C_1: onset of the consonant

C_2: offset of the consonant

E: explosion of the stop.

The glottographic signal

G_1: onset of the glottal gesture[1]

G_2: offset of the glottal gesture[1]

---

1) It should be noted that both the definition of the parameter called the opening-closing gesture of the glottis, and the identification of this parameter in the glottograms cause problems, which will be treated in a later report.

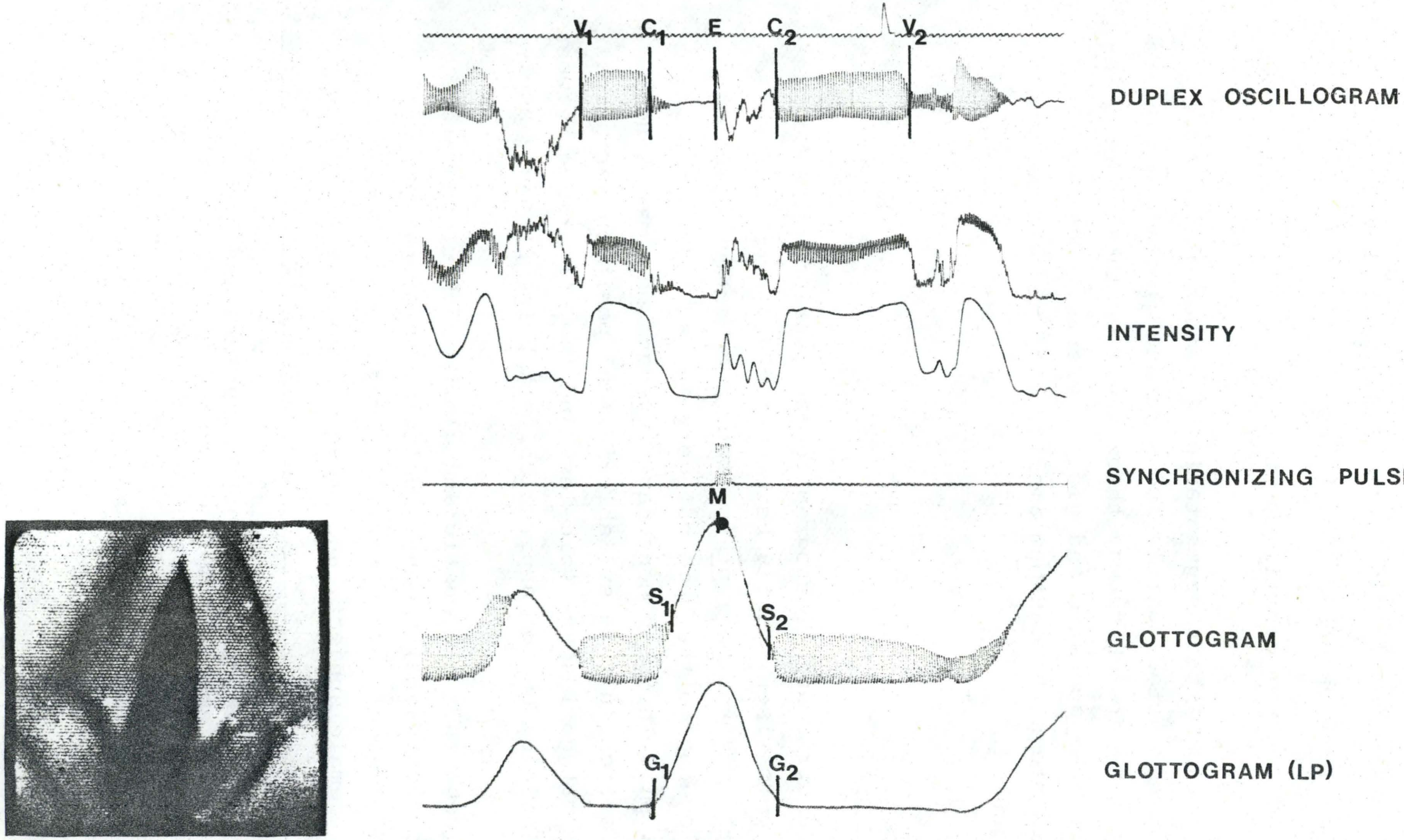

Figure 1

The curves used for delimitation of segments and extraction of parameters, and a still of the glottis, taken at the moment indicated by the filled circle on the glottogram.

S_1: offset of the vocal fold vibrations

S_2: onset of the vocal fold vibrations

M: moment of maximum glottis aperture.

On the basis of this segmentation a number of temporal parameters can be extracted, partly acoustic and glottal parameters, and partly parameters which may throw light on the temporal relationship between acoustic and glottal events. Besides the temporal parameters the maximum amplitude of the glottograms has been measured.[1]

4. Observations

The fiberoptic and glottographic observations will be presented as a comparison, partly between two different categories of obstruents (ptk vs. bdg; pt vs. fs), and partly between obstruents belonging to the same category (p vs. t vs. k; b vs. d vs. g; f vs. s). The stop consonants ptk and bdg are phonologically distinct only in syllable-initial position (principal rule). Both categories are voiceless and the difference between them is essentially one of aspiration, ptk being strongly aspirated.

Fig. 2 depicts the acoustic and glottographic parameters of the eight obstruents, shown with inclusion of the preceding vowel i. Each set of parameters is averaged over 10 measurements of one female subject, and presented in a stylized form.

---

1) It is well known that the relations between the amplitude of the glottogram and the glottis aperture are very complicated. These problems have been discussed in some detail in Hutters (1976) and will be treated again in a later report.

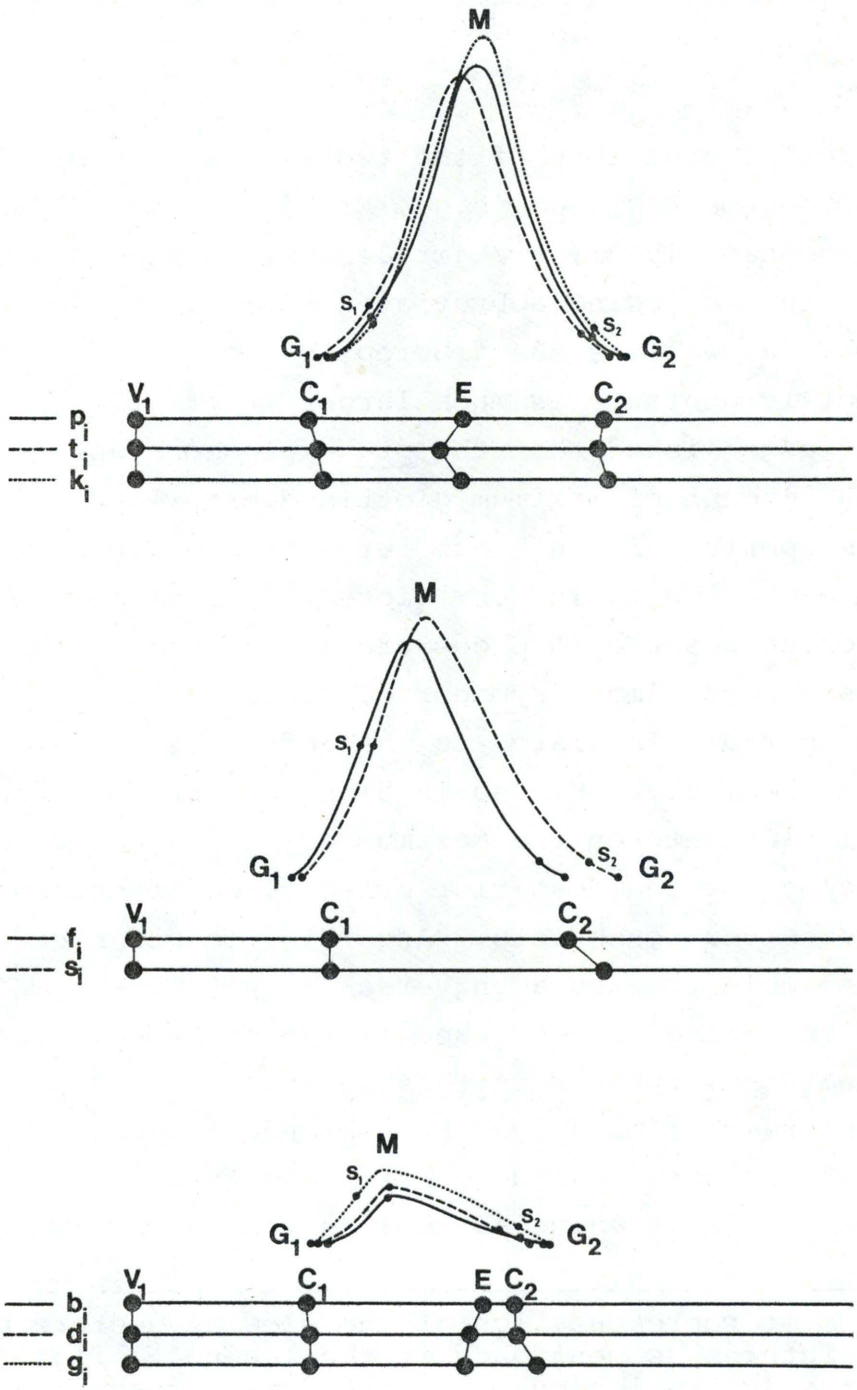

Figure 2

A stylized presentation of the acoustic and glottographic parameters of p t k b d g f s including the preceding vowel i, averaged over 10 measurements of one female subject. Line-up point is the onset of the preceding vowel.

Figs. 3 and 4 illustrate raw curves and stills of p and b (see the legend to figs. 3 and 4 for further explanation).[1]

4.1 ptk vs. bdg

The glottal behaviour of the two sets of stops is already rather well documented (see, e.g., Frøkjær-Jensen (1967, 1968), Fischer-Jørgensen (1968), Frøkjær-Jensen, Ludvigsen and Rischel (1971) - in the following abbreviated F-L-R). The present glottographic as well as the fiberoptic recordings confirm that maximum glottis aperture is much larger in ptk than in bdg. It has been established that the ptk explosion falls rather close to the moment of maximum glottis aperture, whereas in bdg the maximum aperture is much earlier than the moment of explosion. In bdg the explosion falls very close to the offset of the glottal opening-closing gesture (O-C gesture). As seen in the figures, the ptk gesture is almost symmetric, whereas in bdg the moment of maximum aperture is biased to the left.

Hirose (see, e.g., Hirose 1975) has shown that there is a high correlation between the maximum glottis aperture and the EMG peak value for the posterior cricoarytenoid muscle (PCA) in Japanese voiceless consonants. According to our recordings, this may not hold true as a universal rule. With some of our subjects - including the one used in the fiberoptic and glottographic recordings treated in this paper - the PCA values are of the same order of magnitude in ptk and in bdg, in spite of the big difference in maximum glottis aperture. The insufficiency of PCA activity (peak value as well as timing) as an indication

---

1) The form of representation of the glottal gesture based on still pictures as mentioned in the legend to figs. 3 and 4 is used for illustration only. This form of representation implies that the timing of the acoustic events is invariant across the tokens. No attempt has been made to meet this requirement, however. An investigation of the information given by representations based on still pictures and on moving pictures, respectively, and of the reliability of these two methods, is planned - and in part in progress - at the Institute.

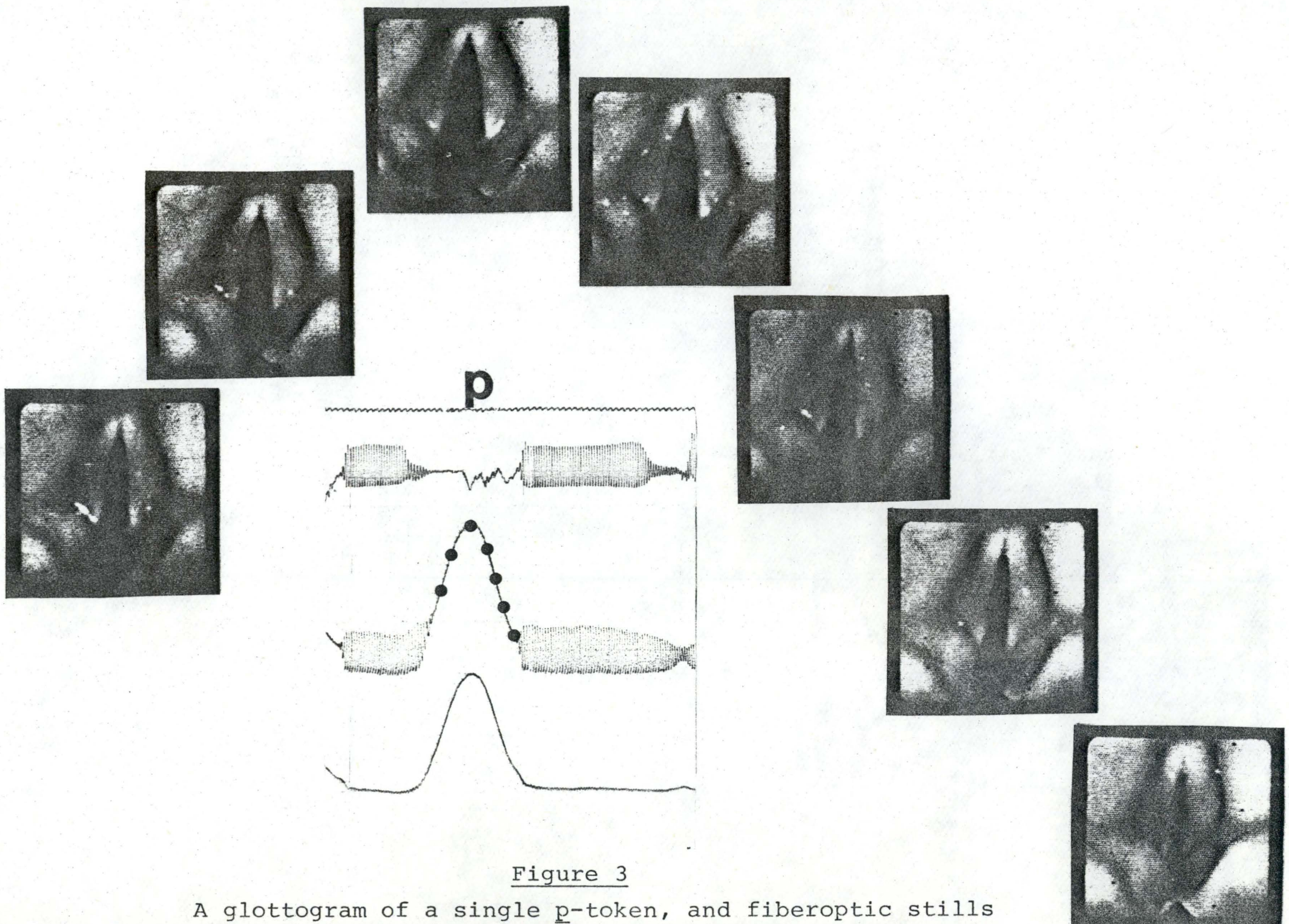

Figure 3

A glottogram of a single p-token, and fiberoptic stills of p taken at different moments during the opening-closing gesture of the glottis, as indicated by the filled circles (the stills originate from seven different renderings of the same sound).

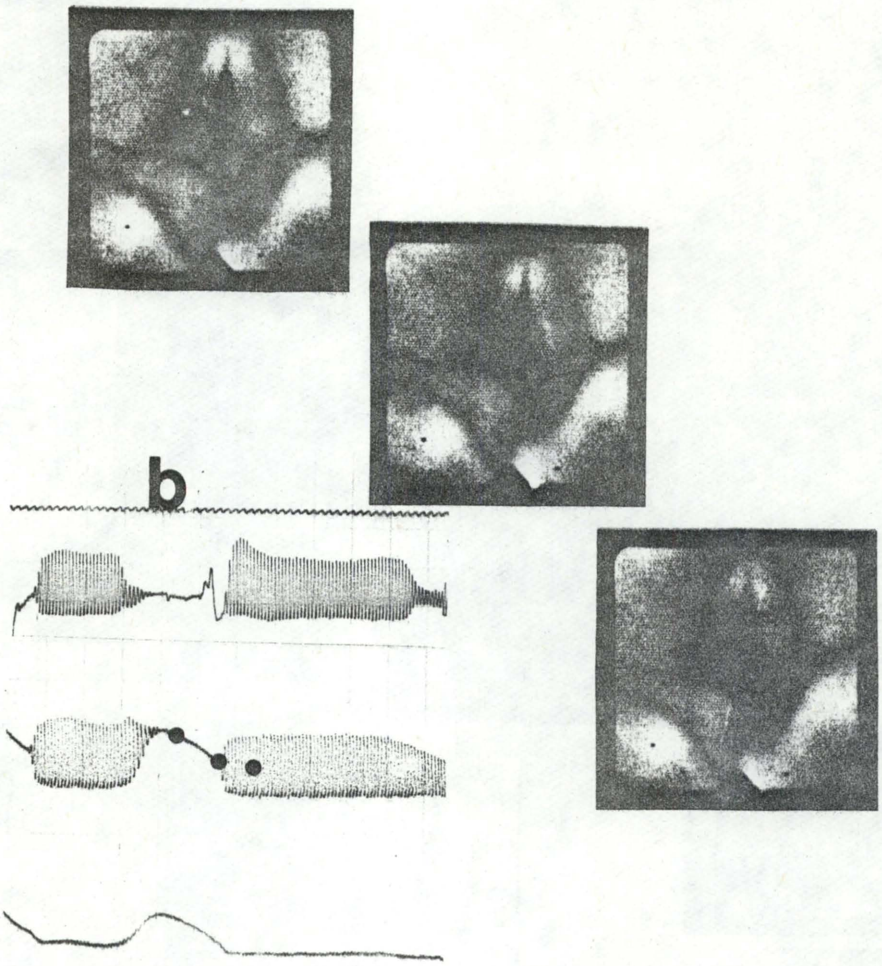

Figure 4

A glottogram of a single b-token, and fiberoptic stills of b taken at different moments during the opening-closing gesture of the glottis, as indicated by the filled circles (the stills originate from three different renderings of the same sound).

of the muscular activity underlying the actual articulatory realization is demonstrated very clearly by the EMG recordings of (voiced) v and l, which often show clear PCA activity, whereas the fiberoptic and glottographic recordings do not reveal a corresponding opening of the glottis.

4.2 pt vs. fs

Comparing the onset of the glottal O-C gesture to the acoustic onset of the consonant, it appears from my data that the onset of the O-C gesture lies earlier in the case of fricatives than in the case of stops. By measuring the distance from the onset of the preceding vowel to the onset of the O-C gesture I find this distance to be longer for stops than for fricatives, i.e. there seems to be a difference of timing of the glottal gesture. In most of our subjects a corresponding difference is seen in the EMG recordings.

So far the present recordings reveal that the maximum glottis aperture is smaller in fs than in pt, which is in agreement with F-L-R. The EMG recordings seem to show a corresponding difference between fs and pt if not just the PCA activity but also the activity of the interarytenoid muscle is taken into account.

As mentioned above, the glottal O-C gesture is almost symmetric in the aspirated stops; in the fricatives, however, the moment of maximum glottis aperture is biased slightly to the left.

Finally, I shall make some observations concerning the duration of voicing. In the fricatives the vibrations of the vocal folds continue rather far into the opening gesture, whereas in the stops the vibrations cease quickly after the onset of the glottal opening, due to the supraglottal closure. This difference in the duration of voicing is also observed, among others, by F-L-R. Moreover, they found the reverse relationship for the onset of the vibrations. In the fricatives the vibrations did not occur again until the adduction of the vocal folds was almost completed, whereas in the aspirated stops they started well in advance of the completion of the adduction. In the material presented here, however, this difference in onset time of the vocal fold vibrations between stops and fricatives does not appear. This discrepancy is probably due to a different quality of the following vowel. In the material presented in this paper the following vowel is i, whereas in the material of F-L-R the following vowel is a vowel of e or ε quality. In another part of my material the following vowel is a vowel of a quality, and here the vibrations of the vocal folds do indeed reoccur early in the adduction phase of the glottal O-C gesture for stops but not for fricatives, thus confirming the observation made by F-L-R. Such differences in the offset and onset of vocal fold vibrations are due to different aerodynamic conditions, and consequently, not only the consonant is decisive but also the surrounding sounds. Furthermore, the anatomy of the speech organs - i.e. the size of the larynx and the supraglottal cavities - may be of importance for the voicing conditions.

4.3 p vs. t vs. k

The aspirated stops ptk differ in more respects than just place of articulation. As early as 1954, Eli Fischer-Jørgensen showed that the duration of "aspiration" (affrication plus aspiration) is shortest in p, longer in k, and longest in t. This has been confirmed in a number of subsequent investigations and is confirmed also by my data, although the difference between p and k does not seem to be significant in this material (Hu). The difference in the duration of "aspiration" is correlated to affrication: the more the consonant is affricated, the longer is the duration of "aspiration". It is worth mentioning that the duration of the supraglottal closure - at least in the subject treated here - shows the opposite relationship, i.e. the p closure is longest, the t closure shortest. In fig. 2 it is seen that the p explosion lies closer to the maximum glottis aperture than does the t explosion, the k explosion lying between p and t. But the differences in distance between the explosion and the moment of maximum aperture of the glottis is not caused solely by differences in closure duration but also by differences in the timing of the moment of maximum glottis aperture.

In several investigations of the glottal behaviour in stops it has been observed that there seems to be a correlation between maximum glottis aperture and place of articulation. The more the place of articulation is retracted, the larger is the maximum glottis aperture (see, e.g., Fischer-Jørgensen 1968, Ondráčková 1970, Sawashima 1974, Pétursson 1976). This seems to be partly confirmed by my glottographic and fiberoptic recordings. The difference between p and k seems clear, whereas the maximum aperture in t varies considerably.

4.4 b vs. d vs. g

Some minor differences are also observed between b, d, and g. As pointed out by Eli Fischer-Jørgensen (1954, 1968), the duration from the moment of explosion to the onset of the following vowel is longer in g than in b and d, due to the affrication of g. My data shows, furthermore, that the duration of the open phase is longer in d than in b, due to the affrication observed in the younger generation's pronunciation of d.[1] The difference in the degree of affrication is correlated to a difference in the timing of the explosion in relation to the offset of the glottal O-C gesture.

Concerning the maximum glottis aperture, the relationships are similar to those found in ptk, in that we find the smallest aperture in b and the largest aperture in g.

4.5 f vs. s

It is obvious that the duration of f is shorter than that of s, and a corresponding difference is seen in the duration of the glottal O-C gesture.

Concerning maximum glottis aperture, it is seen that the aperture of s is larger than that of f.

---

1) It has to be recalled that the following vowel is i, which creates optimum conditions for affrication.

5. Final remarks concerning the control of the glottis

Although the observations of glottal behaviour (and its relation to supraglottal events) in various Danish consonants presented here are rather random and very preliminary, I might venture some more general remarks concerning the glottal behaviour and some assumptions about its underlying control mechanisms.

F-L-R put forward the interesting hypothesis that the opening-closing gesture in Danish ptk is due to neural commands, whereas the gesture in bdg may be a consequence of the aerodynamic conditions. The two gestures are called active and passive, respectively. This hypothesis was later rejected as a consequence of EMG recordings showing PCA activity in ptk as well as in bdg (see Fischer-Jørgensen, Hirose 1974). However, it is conceivable that the PCA activity observed in bdg has nothing whatsoever to do with the preplanned motor control of these stops,[1] but is rather caused by some peripheral reflex mechanism, elicited by the change in, say, the intraoral pressure, and having no special function in speech. The stills of the glottis in bdg show that the PCA activity influences only to a very limited degree the distance between the vocal processes and, furthermore, the maximum glottis aperture is not between the processes but in the middle of the ligamental part of the vocal folds as in the case of vocal fold vibrations.

Many years ago, it was realized that the offset of voicing in Danish bdg is solely a matter of the aerodynamic conditions (Fischer-Jørgensen 1963), and the same explanation may be advanced concerning the opening-closing movement in these consonants. If it is true that glottal behaviour in Danish bdg is primarily a consequence of the aerodynamic conditions and that the observed PCA activity is elicited by some reflex mechanism, then this glottal behaviour should appear also in the

---

1) Any discussion in such terms must be taken with reservations since it is a fundamental problem whether the preplanned motor control involved in speech production is of a totally different nature than generally assumed.

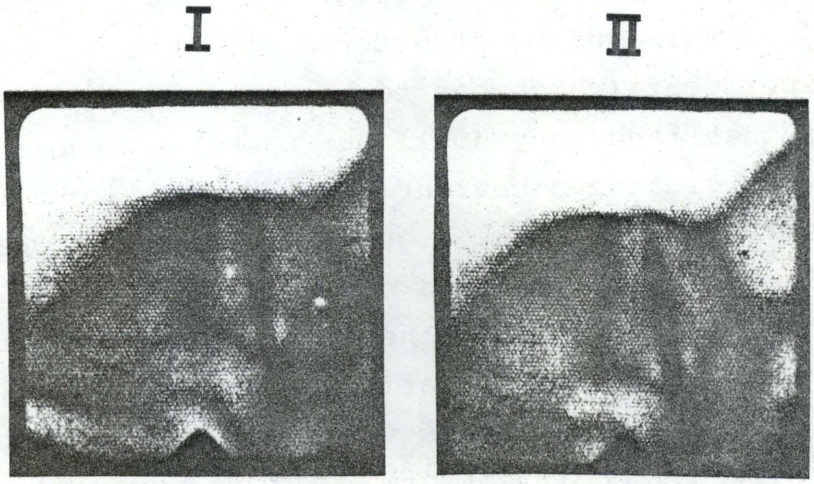

Figure 5

Fiberoptic stills of the larynx taken during [b̥] (I) and during an externally implemented closure (II). See the text for further explanation.

case of an externally implemented closure which can be obtained in the following way: the subject is phonating a sustained i vowel into an airtight mask with a small aperture. When the subject's phonation is momentarily interrupted, at unexpected points in time, by closing the external orifice of the mask, the aerodynamic conditions are changed in a fashion similar to that of Danish bdg. In fig. 5 are shown two stills of the glottis in these two conditions, and it is clear that the state of the glottis and the surrounding structures are very much alike. This primitive experiment (which has to be elaborated and supplemented by EMG recordings) and many small but probably stable differences observed in the glottal behaviour in consonant production may indicate, as far as I see it, a causal relation between the motor control of the laryngeal muscles and some sort of reflex mechanism, elicited by the conditions in other parts of the speech apparatus.

If the suggested interpretation of the PCA activity in Danish bdg is confirmed, the hypothesis ventured by F-L-R can be maintained in a slightly modified form. But in any case, we have to realize that motor behaviour of the speech organs is centrally as well as peripherally controlled with a complex interplay between the two control mechanisms, which ought to influence the interpretation of our experiments and our speech production models.

References

Fischer-Jørgensen, E. 1963: "Beobachtungen über den Zusammenhang zwischen Stimmhaftigkeit und interoralem Luftdruck", Zs.f.Ph. 16, p. 19-36

Fischer-Jørgensen, E. 1968: "Voicing, tenseness and aspiration in stop consonants", ARIPUC 3, p. 63-114

Fischer-Jørgensen, E. and H. Hirose 1974: "A preliminary electromyographic study of labial and laryngeal muscles in Danish consonant production", Haskins SR-39/40, p. 231-254

Frøkjær-Jensen, B. 1967: "A photo-electric glottograph", ARIPUC 2, p. 5-19

Frøkjær-Jensen, B. 1968: "Comparison between a Fabre glottograph and a photo-electric glottograph", ARIPUC 3, p. 9-16

Frøkjær-Jensen, B., C. Ludvigsen and J. Rischel 1971: "A glottographic study of some Danish consonants", F&S, Akademisk Forlag, p. 123-140 (ARIPUC 7, 1973, p. 269-295)

Hirose, H. 1975: "The posterior cricoarytenoid as a speech muscle", Ann. Bull. Univ. Tokyo, Logopedics-Phoniatrics 9, p. 47-66

Hutters, B. 1976: "Problems in the use of the photoelectric glottograph", ARIPUC 10, p. 275-312

Ondráčková, J. 1972: "Vocal-chord activity", Folia Ph. 24, p. 405-419

Pétursson, M. 1976: "Aspiration et activité glottale", Phonetica 33, p. 169-198

Sawashima, M. and S. Niimi 1974: "Laryngeal condition in articulation of Japanese voiceless consonants", Ann. Bull. Univ. Tokyo, Logopedics-Phoniatrics 8, p. 13-17