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LARYNGEAL ADJUSTMENTS IN DANISH VOICELESS OBSTRUENT PRODUCTION

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1. Introduction

The two series of Danish stops, /ptk/ and /bdg/, are both voiceless; the former is discriminated from the latter by strong aspiration. These two series are distinctive only in initial position. In medial and final positions only [b̥d̥g̥] appear, although a careful pronunciation with aspiration is possible word-finally if a pause follows.

It is well-known that after /s/ a voiceless unaspirated stop appears in Danish as well as in other Germanic languages. If we take up the sequence of /s/ followed by a labial stop, Danish offers us the following six possibilities (although the last two are not distinctive):

[s # pʰ s # b̥ # sb̥ -sb̥- sb̥ # spʰ#]

The aim of this study was to compare the laryngeal adjustments in Danish voiceless obstruent production. First single consonants, and then consonant sequences, which were all treated as phonetic phenomena, will be dealt with. Laryngeal adjustments for two types of voiceless stops have already been studied in such languages as Korean (Kagaya 1974), Hindi (Kagaya and Hirose 1976), Mandarin (Iwata and Hirose 1976) and Fukienese (Iwata et al. 1979). As for voiceless obstruent sequences we have recent reports about Swedish (Löfqvist and Yoshioka 1980), English (Yoshioka et al. 1981), Icelandic (Löfqvist and Yoshioka 1981) and Dutch (Yoshioka et al. 1982). This study will add some data from another Germanic language, Danish, to these.

Studies on Danish consonants include an electromyographic one by Fischer-Jørgensen and Hirose (1974), a glottographic one by Frøkjaer-Jensen et al. (1971), as well as a summarized report by Hirose et al. (1977). In order to improve on second of these, fiberoptic filming was adopted together with photo-electric glottography in our present study. Further, medial and final consonants were also treated, as the third paper above was limited to initial position consonants.

2. Experimental and test utterances

Using a fiberscope, a film of the larynx during speech was taken at a rate of 50 frames/sec. The obtained film was analyzed with the help of a film analyzer, and the distance between the vocal processes was measured frame by frame as an indication of the glottal width. The temporal change in glottal width was graphed and examined in reference to the audio signals.

Then, the illumination light of a fiberscope, which had been inserted through the nose, served as the light source for the photo-electric glottography. Glottograms were recorded with a phototransducer placed on the neck. Glottography grasps the glottal opening-closing movement in terms of the amount of light passing through the glottis, and the light is changed into electric signals with the help of a photo-

transducer. The output signals are certainly affected by the position of the light source in relation to the glottis, but the waveforms of glottograms and the glottal width curves obtained by fiberscope are known to have a high correlation with each other.

3. Subjects and test utterances

Two native speakers of Danish (one female, EFJ; one male, FB) served as subjects. The fiberoptic filming of EFJ was done in 1976. The fiberoptic and glottographic experiment with FB was carried out in October, 1982.

EFJ first read words beginning with various consonants ([Ci:lə]) in a frame sentence [de:], meaning 'it is . . . ,' and then the three sentence including the sequences /s#p/ /s#b/ /#sb/ i.e. 'Kan Lis pile? Kan Lis bile? Kan vi spile?' They were read four times each.

FB's test utterances were prepared so that they might contain isolated examples of /p/ /b/ /s/ and their combinations. The following served as the frame sentences:

Kan I (Ib, Lis) . . . ? meaning 'Can you (Ib, Lis) . . . ?'

Table 1 shows FB's test utterances. Each was read four times for the fiberoptic filming and then three times for the glottography.

Table 1

Subj.: FB

Kan I pile ?	/#p/	Kan Lis pile ?	/s#p/
Kan I bile ?	/#b/	Kan Lis bile ?	/s#b/
Kan I sile ?	/#s/	Kan Lis sile ?	/s#s/
Kan I spile ?	/#sb/	Kan Lis spile ?	/s#sb/
Kan Ib ile ?	/b#/	Kan I gispe ?	/#g/ /-sb-/
Kan Ib pile ?	/b#p/	Kan I gipse ?	/#g/ /-bs-/
Kan Ib bile ?	/b#b/	Kan I pippe ?	/pibə/
Kan Ib sile ?	/b#s/	Kan I pibe ?	/pi : bə/
Kan Ib spile ?	/b#sb/	Det er Ibs isse.	/bs#/ /-s-/
Kan Lis ile ?	/s#/	Gisp ikke !	/sb#/ /-g-/

4. Results

In the present paper the results obtained from the fiberoptic investigation alone will be reported.

The figures show the typical contours of temporal change in terms of glottal width. The abscissa represents the frame numbers, one frame corresponding to 20 msec; and the ordinate corresponds to the apparent glottal width along an arbitrary scale. ↓ indicates the voice offset of the preceding vowel; R the oral release of the articulatory closure; and ↑ the voice onset of the following vowel.

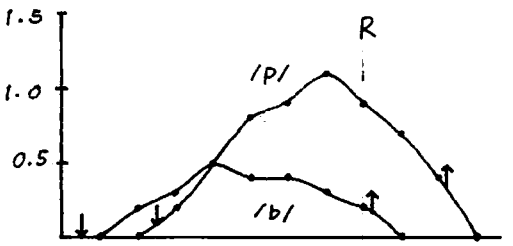
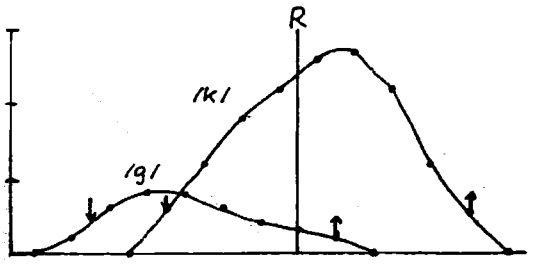


Fig. 1 */p/ and /b/ EFJ*



/k/ and /g/ EFJ

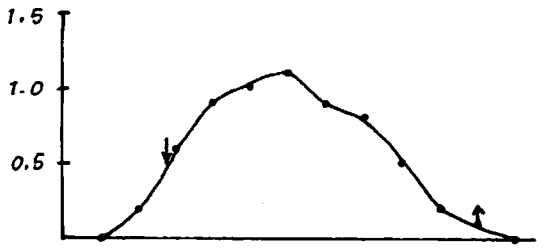


Fig. 2 */s/ EFJ*

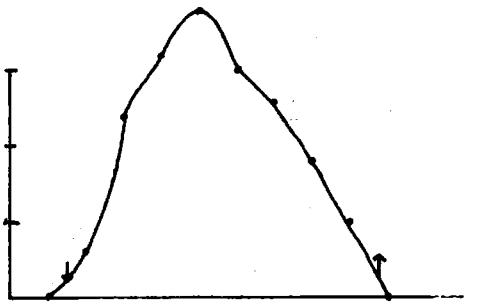


Fig. 3 */s/ FB*

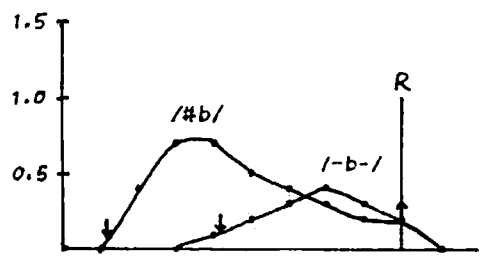


Fig. 4 *initial /b/ and medial /b/ FB*

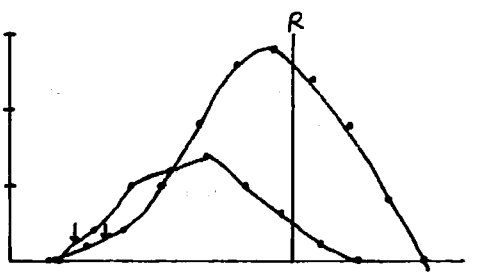


Fig. 5 *various final /b/s FB*

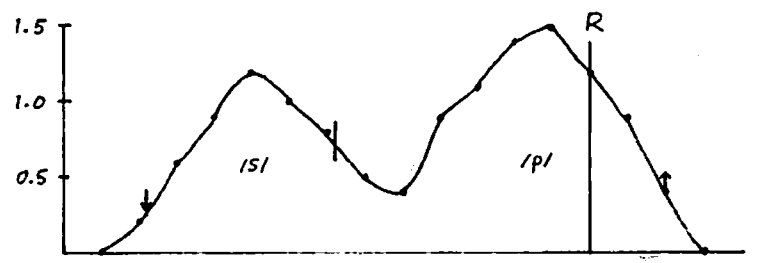


Fig. 6 */s#p/ FB*

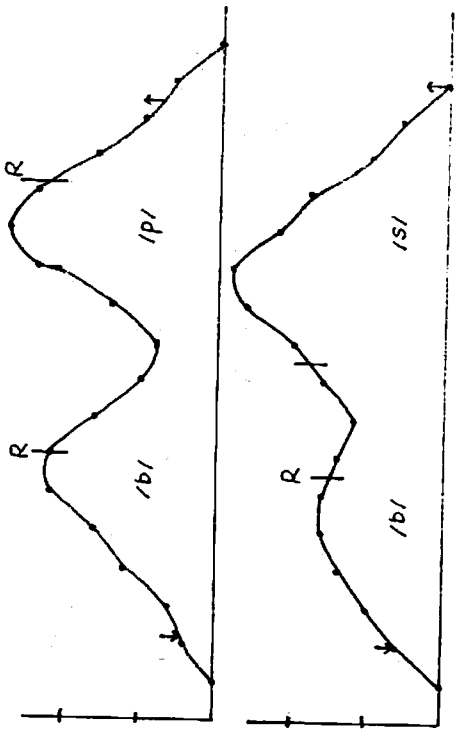


Fig. 8 */b#p/ and /b#s/ FB*

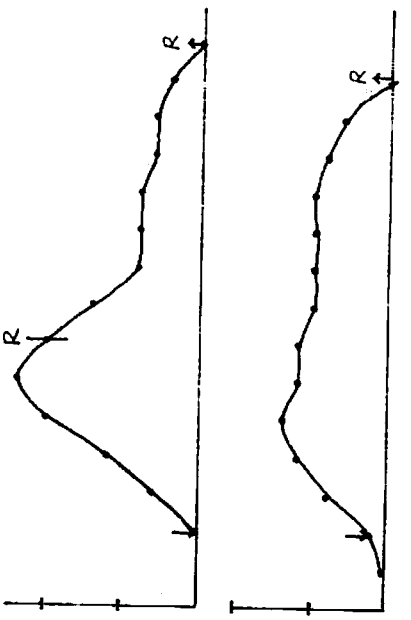


Fig. 9 */b#b/ FB*

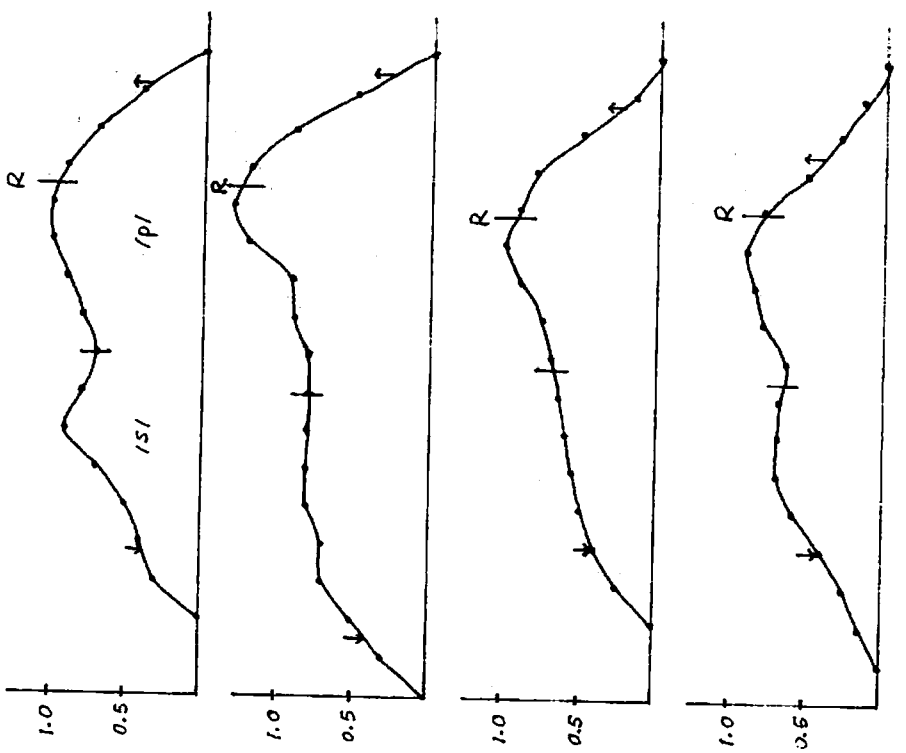


Fig. 7 */s#p/ EFJ*

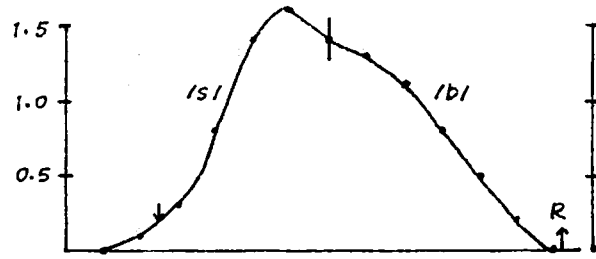
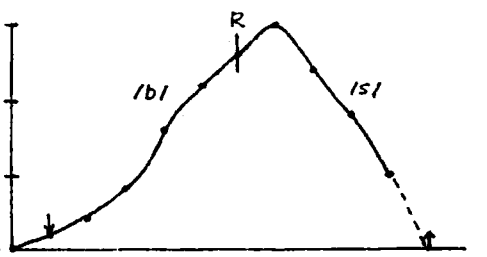


Fig. 10 */-sb-/ FB*



/-bs-/ FB

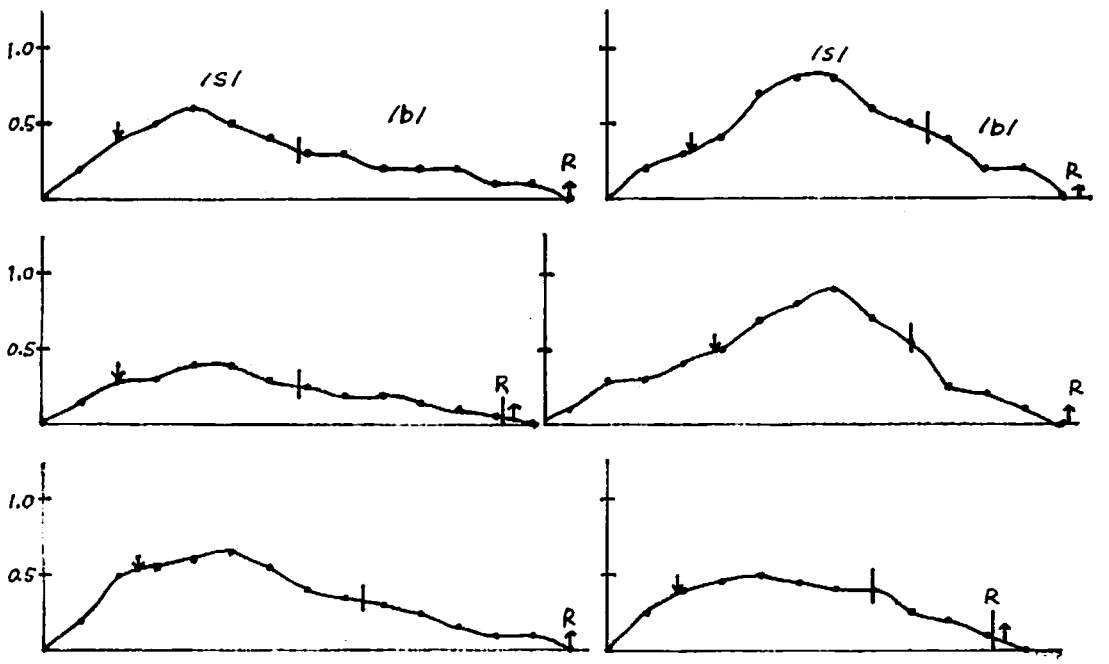


Fig. 11 */s#b/ EFJ*

/#sb/ EFJ

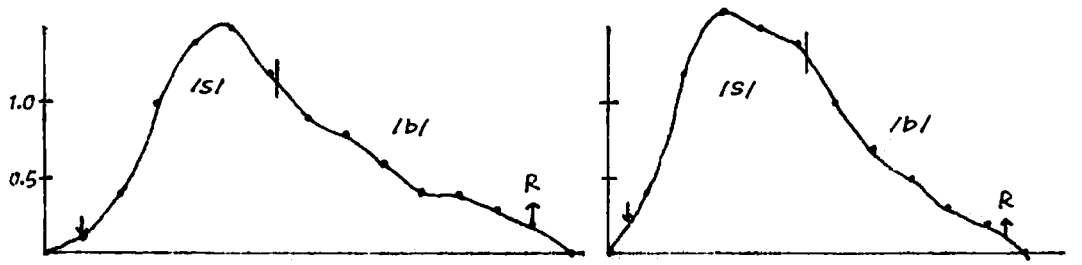


Fig. 12 */s#b/ FB*

/#sb/ FB

Part I. Single consonants

4.1 Initial consonants

In EFJ, /ptk/ showed much greater glottal openings than /bdg/ (Fig. 1). The timing of the oral release differed greatly. In /ptk/ the release occurred near the maximum glottal opening, while in /bdg/ it was just before the voice onset of the following vowel. The open glottis period was a little longer in /ptk/ than in /bdg/, but the closure was retained longer in /bdg/.

In the /f/ and /s/ of EFJ (Fig. 2), it was observed that the glottis tended to start opening already during the preceding vowel. The /p/ and /b/ of FB showed similar glottal openings to those of EFJ, but the tendency for /s/ noted in EFJ was not observed in FB (Fig. 3).

4.2 Medial and final consonants

Medial /b/ /g/ (Fig. 4) were short in the open glottis period and diminished in glottal opening considerably, as compared with initial /b/ /g/. In the utterances pippe /pib / and pibe /pi:b /, the laryngeal adjustments of medial /b/ were neither affected by the length of the preceding vowel nor by the orthography.

In word-final position the laryngeal adjustment for /b#/ was not uniform. /b#/ showed variation in glottal opening and the timing of release, sometimes resembling initial /p/, sometimes initial /b/ (Fig. 5). In all of the six utterances, the explosion occurred, but it was a weak one, with one exception, which was accompanied by aspiration.

The fricative /s/ in medial and final positions diminished also in the open glottis period and glottal opening, but the opening was always above a certain degree and showed a distinct peak.

Part II. Consonant sequences

4.3 /s#p/

It was observed that the temporal change in glottal width showed two peaks corresponding to /s/ and /p/, respectively, where the peak for /p/ was the larger. This two-"peakedness" was distinct in FB (Fig. 6), while in EFJ both a one-peaked shape and a two-peaked shape appeared (Fig. 7). Common to both subjects was the fact that the the opening reached during /p/ was always the maximum. As for the timing of the release of /p/, no difference was observed between single /p/ and /p/ in a sequence.

4.4 /b#s/ /b#p/ /b#b/

/b#/ in the sequences was either with or without explosion. As for the glottal opening, /b#/ resembled word-initial /b/, while the timing of its explosion was near the maximum opening as for /p/.

In the sequences /b#s/ /b#p/, where the final stop was followed by an initial /s/ or /p/, the glottal width curve was two-peaked (Fig. 8). Of these two peaks the one for the initial consonant was the larger. In most examples of the two-peaked shape the final stop was with explosion, but there was one case which showed a two-

peakedness in spite of no explosion.

In the sequence /b#b/, a final stop and an unaspirated stop with a word boundary intervening, the glottal opening followed the one peak pattern for the final /b#/. One of the examples showed no explosion and was pronounced as a kind of geminate (Fig. 9).

4.5 Sequences of /s/ and /b/

The sequences of /s/ and /b/, /s#b/ /#sb/ /-sb-/ and /-bs-/ /bs#/, all formed a one-peaked shape with the maximum opening during /s/. If we compare FB's two kinds of sequences with /s/ in medial and final position, that is to say those with /s/ preceding (/-sb-/ and /-sb#/) and those with /b/ preceding (/-bs-/ and /-bs#/), the former type reached the maximum opening earlier (Fig. 10).

In the /s#b/ and /#sb/ of EFJ the relative length of /s/ and /b/ was reversed and it was always the consonant after a word boundary that was the longer, i.e. /b/ in the former and /s/ in the latter (Fig. 11). As for the same sequences by FB, /b/ was the longer in /s#b/ while in /#sb/ the two consonants were nearly of the same length (Fig. 12). Regardless of the difference in relative length, the sequences of both subjects followed a one-peaked pattern with the peak for /s/. Therefore, it seems that no difference was observed between /s#b/ and /#sb/ in terms of laryngeal adjustments.

5. Comments

Part I. Single consonants

5.1 Initial consonants

In our results /p/ showed a maximum glottal opening 2.5 or three times as wide as /b/. The oral release of /p/ occurred just after the maximum glottal opening was attained, while in /b/ it was almost at the same time as the voice onset of the preceding vowel. The open glottis period was a little longer in /p/ than in /b/, but the closure was retained longer in /b/.

Frøkjaer-Jensen et al. (1971) gives the relation in size of glottis aperture between /p/ and /b/ for the three subjects. Two of their values are similar to those for EFJ and FB. In their study they tended to observe a release for /p/ rather before the peak. In our results, however, it was rather after the peak, although in /t/ and /k/, which have a fairly long VOT, the release occurred normally before the maximum opening was attained.

Of languages in which two types of voiceless stops are discriminated, such as Hindi (Kagaya and Hirose 1975). Mandarin (Iwata and Hirose 1976) and Fukienese (Iwata et al. 1979), the following can be mentioned. The relative size of the glottal opening for aspirates and inaspirates in Danish resembles Hindi, while Mandarin and Fukienese inaspirates show a less noticeable glottal opening. The closure duration of aspirates is shorter than that of inaspirates in all four languages mentioned above, but the difference is greatest in Hindi and Danish comes second. The open glottis period is longer in aspirates than in inaspirates and the difference is distinct in all of the languages except Danish.

5.2 Medial and final consonants

In Danish only one series /bdg/ appears medially. In this position both the closure duration and the glottal opening diminish greatly. Danish differs from (e.g.) Swedish, in which the closure duration of stops is longer in medial position than in initial position (Löfkvist 1976). and the glottal opening does not diminish so much medially (Lindqvist 1972).

Final stops appear differently in various languages. For example, the Dutch /p/, a voiceless inaspirate, "is generally produced with a negligibly small opening gesture of the glottis, particularly when it is followed by a word-initial vowel," and in this position glottalization occurs (Yoshioka et al. 1982). In Fukienese stops an activity of the false vocal folds is observed (Iwata et al. 1979). The three series of Korean stops are neutralized and become implosives. In the sense that there is no opposition word-finally, neutralization occurs also in Danish. But in the case of Danish, the laryngeal adjustments are more varied.

We observed that the laryngeal adjustment of medial /b/ was not affected by the orthography. As for final stops, however, the orthography was not taken into consideration in our present experiment. Whether the orthographic difference (p or b) has no relevance here as well to laryngeal adjustments should be examined in the future.

Part II. Consonant sequences

5.3 /s#p/

According to Pétursson (1977), in laryngeal adjustments for /s/ followed by an aspirated stop three patterns were found in Icelandic. They are two-peakedness with each peak corresponding to /s/ and /p/, respectively; two-peakedness with each peak corresponding to /s/ and /p/, respectively; one-peakedness with the maximum opening during /s/; and one-peakedness with the maximum opening during /p/. The first was the most frequent pattern. From our results with Danish the tendency toward two-peakedness can also be observed. In the two-peaked pattern the peak for /p/ was the larger of the two and in EFJ's one peaked utterance the maximum opening was reached during /p/—these facts seem to indicate that what is important is to attain the maximum opening during /p/, irrespective of the number of peaks.

Frøkjaer-Jensen et al. (1971) tried to explain the glottal opening of consonant sequences in terms of a summation of the glottal width for each consonant. As reasons for this they mentioned the following: The timing relation of the peak and explosion differed between single consonants and consonant sequences; and a glottal opening greater than that for single /p/ or /s/ was sometimes observed in consonant sequences. In our results, however, even when consonant sequences followed the one-peaked pattern, the maximum glottal opening and the timing of explosion showed no difference from those of single consonants. Therefore, their summation hypothesis does not apply to our results. If the hypothesis that "on the velocity of glottal opening and closing there is an upper and lower limit" (Yoshioka et al. 1981) is correct, an opening which exceeds that for single /p/ or /s/ will hardly be realized.

Frøkjaer-Jensen et al. (1971) suggest the possibility that laryngeal adjustments in consonant sequences vary according to speech tempo or style of speaking. However Pétursson (1977) observed all the above-mentioned patterns irrespective of speech tempo. If we turn to our results, FB always formed a two-peaked shape and it was also FB who showed the longer consonant durations. But considering that even EFJ's rather slower pronunciation of the same sample did not form a two-peaked shape, individual variation could have been the main cause rather than the speed of pronunciation. As our number of samples is very small, we cannot say much, but it can well be expected that individual variation, speech tempo, and style of speaking all affect laryngeal adjustment.

5.4 /b=s/ /b#p/ /b#b/

In our results /b#p/ formed a two-peaked shape and /b#b/ was realized as a curve with one peak during the final /b#/.

About laryngeal adjustments for /b#p/ and /b#b/, Frøkjaer-Jensen et al. (1971) state that "/b#p/ gradually assumes a two-peaked shape in slow pronunciation." They even noticed slight tendencies toward two-peakedness in the sequence /b#b/ in very emphatic speech. They were then regarding the glottal opening for /#b/ as a passive gesture caused by aerodynamic conditions, so they did not relate the slight two-peakedness of /b#b/ to the active opening gesture. But later electromyographic study corroborated a myographic activity for /#b/ (Fischer-Jørgensen and Hirose 1974). That is to say, the observed tendencies would rather indicate this activity.

In FB, when /b#/ was followed by stops of the same place of articulation, i.e. /p/ or /b/, an explosion occurred at the word boundary in all of the samples but one, although FB was likely to pronounce clearly.

5.5 Sequence of /s/ and /b/

All the sequences of /s/ followed or preceded by the voiceless inaspirate /b/ formed a curve with the maximum opening during /s/. This agrees with results for other Germanic languages.

That no particular difference was observed between the patterns of the laryngeal adjustment for /s#b/ and /#sb/ corresponds to the Danes' claims that s#b and #sp sound almost alike irrespective of the orthography.

It is a phenomenon common to Germanic languages that stops following /s/ have no aspiration in such consonant clusters as sp- st- sk- in word-initial position. In English, Swedish etc. where /ptk/ are voiceless aspirates and /bdg/ are voiced, it seems adequate to say that a stop after /s/ loses its aspiration. This explanation applies to Danish, too. On the other hand, it is also possible to regard clusters such as /sb/ /sd/ /sg/ without reference to the orthography, for Danish is possessed of voiceless unaspirated stops in its system. Although the same phenomenon occurs as in other Germanic languages, Danish makes it possible to interpret the clusters in two ways, owing to its phonological system.

When we compared FB's two kinds of sequences, i.e. sequences with /s/ preceding and those with /b/ preceding, the former reached the maximum opening earlier than the latter. This result corresponds to those obtained in other Germanic lan-

guages, showing that /s/ is faster than /b/ in terms of the velocity of the opening movement of the glottis.

In EFJ's fricative /s/ there was a tendency toward the glottis' beginning to open while the vocal folds were still vibrating for the preceding vowel. This was clearly observed also in her /#sb/ and contrasted with FB's /#sb/, which opened rather abruptly for the /s/. If the medial sequences /-sb-/ /-bs-/ had been examined in EFJ, we would possibly have obtained results different from those of FB. So far we cannot decide yet whether such a tendency as was found in EFJ can be observed also in English or Swedish or if it exists only in Danish.

6. Concluding remarks

In the present study, Danish stops and consonant sequences were investigated by use of a fiberscope. Two series of voiceless stops were laryngeally adjusted so that they differed greatly in the degree of glottal opening as well as in the timing of the oral release, as is the case in other languages which discriminate two voiceless types. Medially, the pattern of the laryngeal adjustment for stops was simplified and word-finally it was varied without distinctive function. As for consonant sequences, one of the subjects showed a laryngeal adjustment similar to that observed in other Germanic languages, e.g. two-peakedness in /s#p/, one-peakedness in /#sb/, and /s/ showing a rapid opening gesture. In the other subject, the tendency toward two-peakedness in /s#p/ was not so distinct, and her /s/, in isolation as well as in sequences, showed some different adjustments. That is, the glottal opening started earlier.

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