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THE INFLUENCE OF ASPIRATION ON THE FUNDAMENTAL FREQUENCY OF THE FOLLOWING VOWEL IN DANISH: SOME PRELIMINARY OBSERVATIONS

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Abstract: Some preliminary observations are reported which seem to indicate that the fundamental frequency of a stressed vowel is higher after an aspirated than after an unaspirated stop consonant, and that the difference is not restricted to the beginning of the vowel but is also found at the middle and frequently all through the vowel.

1. Introduction

It is well known that the fundamental frequency of a vowel is higher after a voiceless than after a voiced stop consonant, other things being equal (see e.g. Di Cristo and Chafkouloff 1977, Fischer-Jørgensen 1968, House and Fairbanks 1953, Johansson 1976, Löfqvist 1975, Lehiste and Peterson 1961, Lea 1973, Mohr 1971). This tendency is most marked at the onset of the vowel, but the difference has been found to persist even at the end of the vowel (e.g. Löfqvist 1975, Hombert 1976).

The effect of aspiration on the fundamental frequency of the following vowel seems to be less well established. For Danish, where the only distinction between ptk and bdg is one of aspiration (both series being voiceless), Fischer-Jørgensen (1968) found no difference in Fo at the onset of the following vowel. Jeel (1975), on the other hand, found a difference at that point of measurement, which was statistically significant. Jeel also measured Fo at the point of minimum Fo in the vowel and at the end of the vowel (it is not explicitly stated where the minimum point is located, but it seems to be in the middle third of long vowels (cp. section 2.3 below) and somewhat earlier in short vowels). At these points of measurement there was a tendency for Fo to be higher after aspirated than after unaspirated stop, but the difference was significant in neither case. Nor do data from other languages having an aspirated-unaspirated opposition such as Thai (Gandour 1974), Korean (Han and Weitzman 1970, Kagaya 1974) or Hindi (Kagaya and Hirose 1975) show any consistent trend for the effect of aspiration on the Fo of the following vowel.

Hombert and Ladefoged (1977) have employed a cross-language approach in an attempt to clarify the matter. On the basis of their comparison of Fo contours after French and English *p*, *t*, and *k*, they conclude (p. 34) that "it is clear from these data that there is not a direct correlation between the duration of the aspiration after a voiceless consonant and the onset fundamental frequency of the following vowel since English and French voiceless consonants have very similar perturbatory effects on the Fo of the following vowel". Things become less clear, however, if one compares their data on English *ptk* and *bdg*, the latter being referred to (p. 34) as "voiceless unaspirated or "voiced"". It turns out, then, that Fo at the onset of the vowel is considerably higher after *ptk* than after *bdg* (about 20 Hz and 60 Hz for the male and female subject, respectively), and that the difference, although decreasing, still persists after 12 voice periods.

The aim of the present paper is to report in a very preliminary form some observations concerning the influence of aspiration on the fundamental frequency of the following vowel in Danish. The questions to be considered below are the following: 1) Do aspirated and unaspirated stops influence Fo of the following vowel differently? 2) How far into the vowel does the difference, if any, persist? 3) Do stressed and unstressed vowels behave differently with respect to the influence of aspiration on the Fo of the following vowel?

2. Method

2.1 Material

The material to be considered here consisted of the vowels [i], [ɑ], [u] occurring in nonsense words of the type /pV'pV:pV/ ([b̥ʰV'b̥ʰV:b̥ʰV]) and /bV'bV:bV/ ([b̥V'b̥V:b̥V]), the vowels being identical in the three syllables. The test words were embedded in the carrier sentence "stavelserne i .... forkortes" ('The syllables of .... are shortened'). Each test word occurred five times in a randomized list.

2.2 Recordings and speakers

The recordings took place in an anechoic chamber by means of professional recording equipment. Two female subjects (BH and JG) and three male subjects (JB, SH, and NR (the author)) acted as speakers. They were all phoneticians, and all speakers of Advanced Standard Copenhagen Danish (see Basbøll 1968). Each subject read the list twice, so that ten tokens of each test word were obtained.

2.3 Data processing

The recordings of three of the subjects (JG, JB, and NR) were processed by the Multiple Channel Processing system which is implemented on the Institute's PDP/8 minicomputer. The MCP system (which is described in some detail in Holtse and Stellinger 1976) samples and averages slowly varying analog signals (in this case the output from hardware fundamental frequency and intensity meters) at a rate of 200 samples per second within selected time windows of 1250 ms. Up to seven channels may be sampled simultaneously. The line-up points used in the averaging process were the onset of the vowels in the CV'CV:CV test words. These points were determined from intensity tracings. Since only one line-up point can be specified in each channel for the averaging, the signal from the Fo meter was sampled in parallel in three channels, the first channel being averaged around the onset of the first (pretonic) vowel, the second channel around the onset of the second (long stressed) vowel, and the third channel around the onset of the third (posttonic) vowel. The output from the intensity meter was sampled in the fourth channel. The averaged curves were displayed on a graphic terminal screen. Figs. 1 to 18 show photographs of the screen. The average curves in the figures represent 10 tokens of each test word, i.e. both readings of the word list.

The MCP tracings were supplemented by a set of measurements of the fundamental frequency at the point of minimum Fo in the long stressed vowel. This set included data from all five subjects.

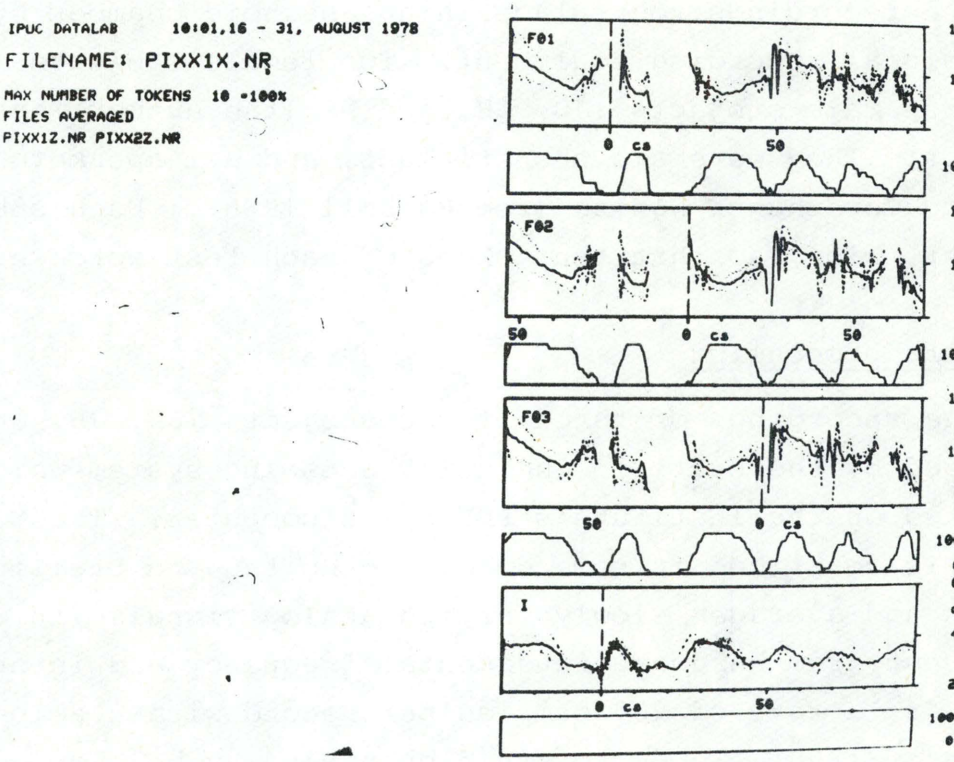

Figure 1

Average curves of the testword pi'pi:pi spoken by subject NR. The upper three channels (FØ1, FØ2, and FØ3) contain F_o tracings averaged with the onset of the fist, second, and third vowel of the testword, respectively, as line-up points (see section 2.3). The fourth channel contains the intensity averaged around the onset of the first vowel. The unbroken curves indicate the average, and the dotted lines on either side indicate the average plus and minus one standard deviation. The vertical broken lines at o cs on the time axis indicate the line-up points. Immediately below each channel the number of measurements (expressed as the percentage of the maximum number) included in the averaging of that channel is shown as a function of time. (For F_o channels any measurement lower than 60 Hz is excluded from the averaging.)

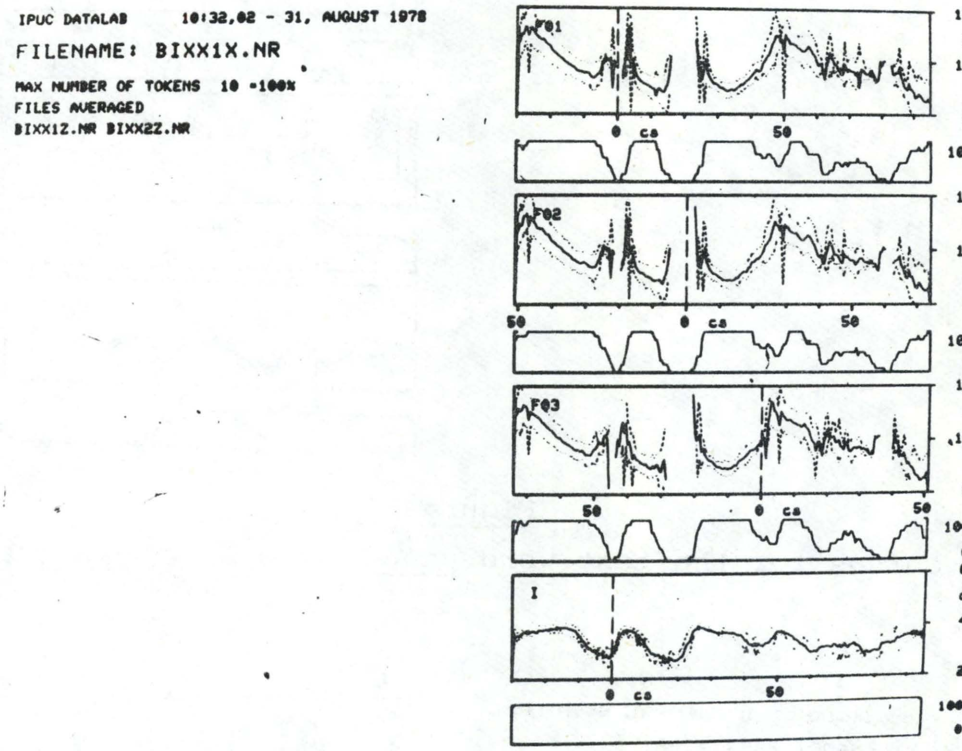

Figure 2

Average curves for the test word bi'bi:bi spoken by subject NR.

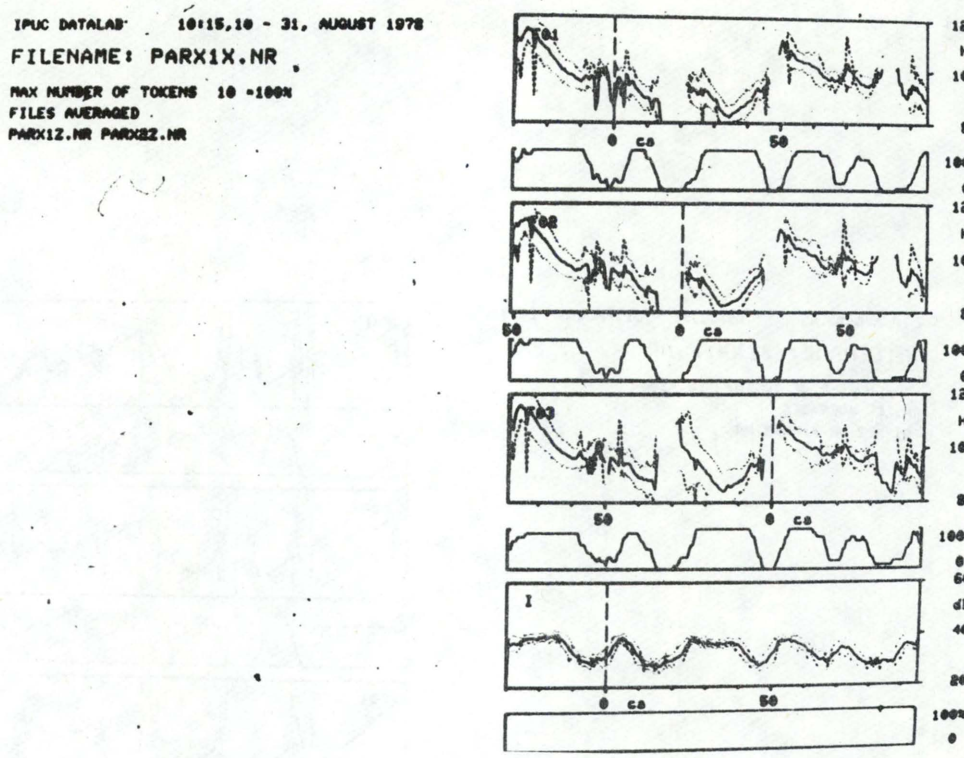

Figure 3

Average curves for the test word pa'pa:pa spoken by subject NR.

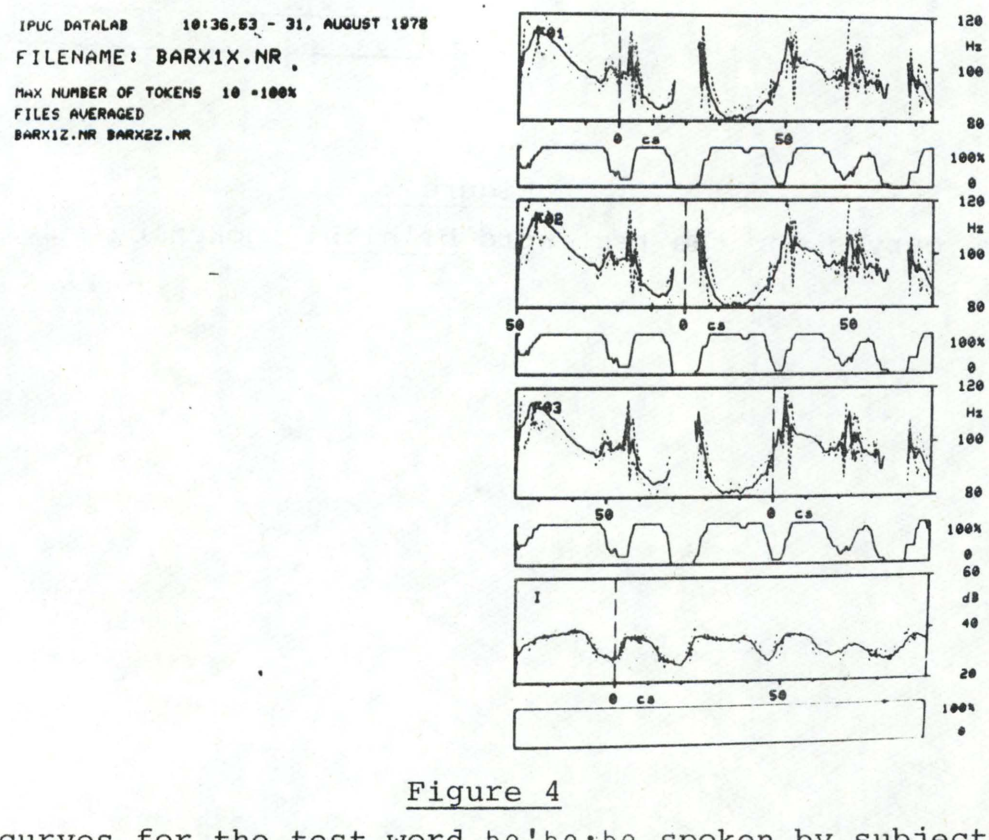

Figure 4

Average curves for the test word ba'ba:ba spoken by subject NR.

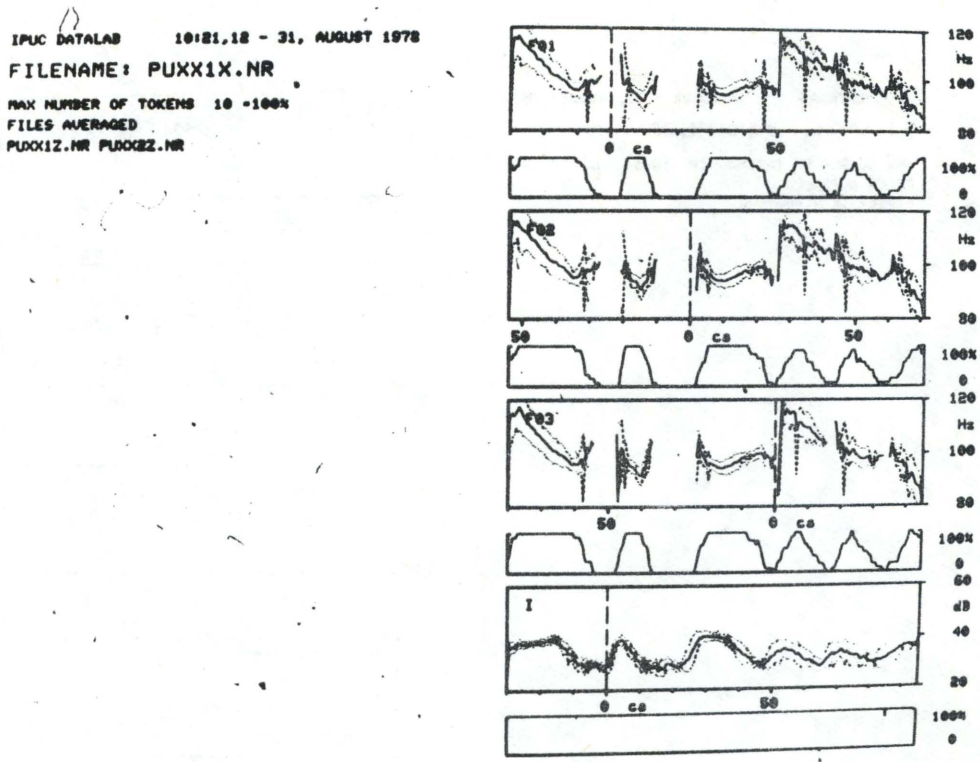

Figure 5

Average curves for the test word pu'pu:pu spoken by subject NR.

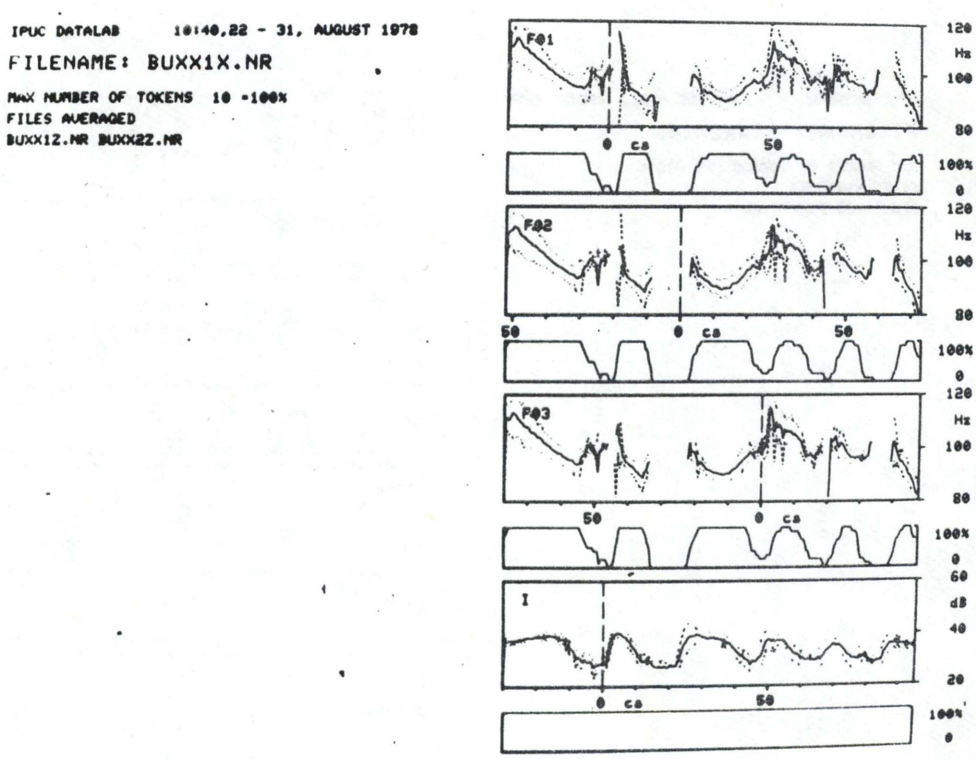

Figure 6

Average curves for the test word bu'bu:bu spoken by subject NR.

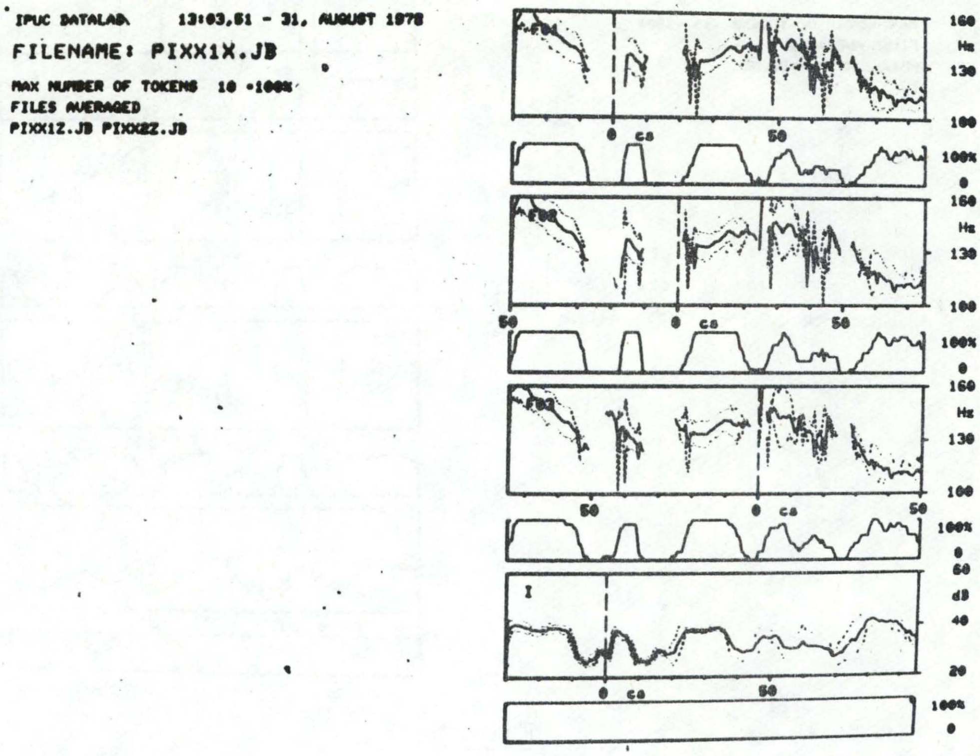

Figure 7

Average curves for the test word pi'pi:pi spoken by subject JB.

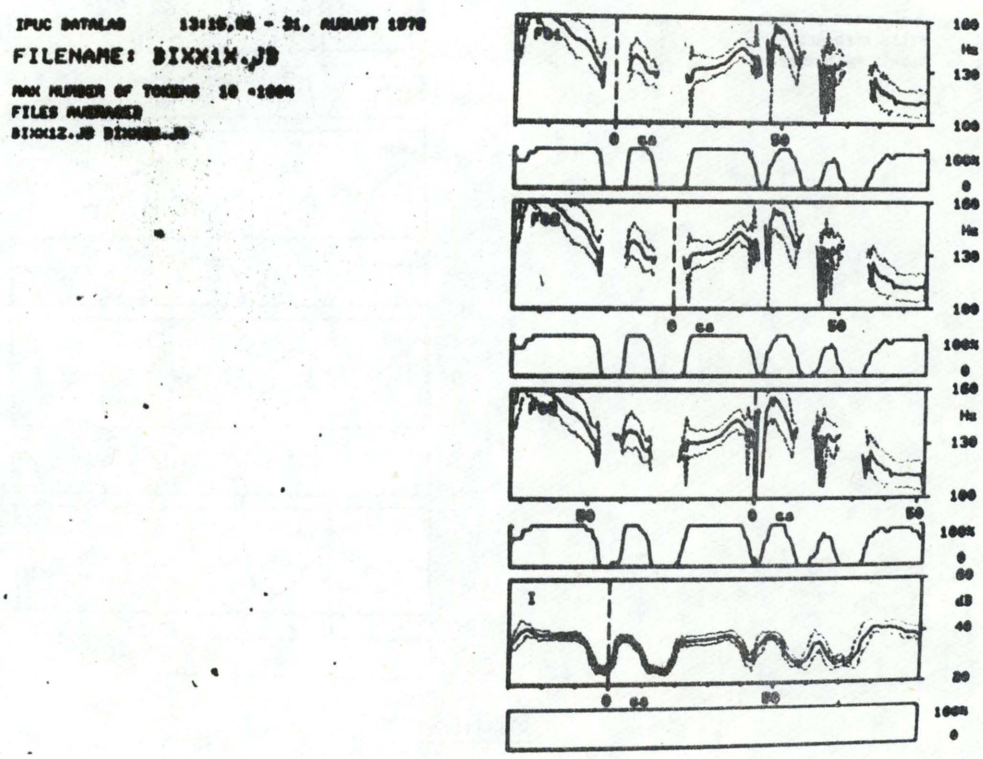

Figure 8

Average curves for the test word bi'bi:bi spoken by subject JB.

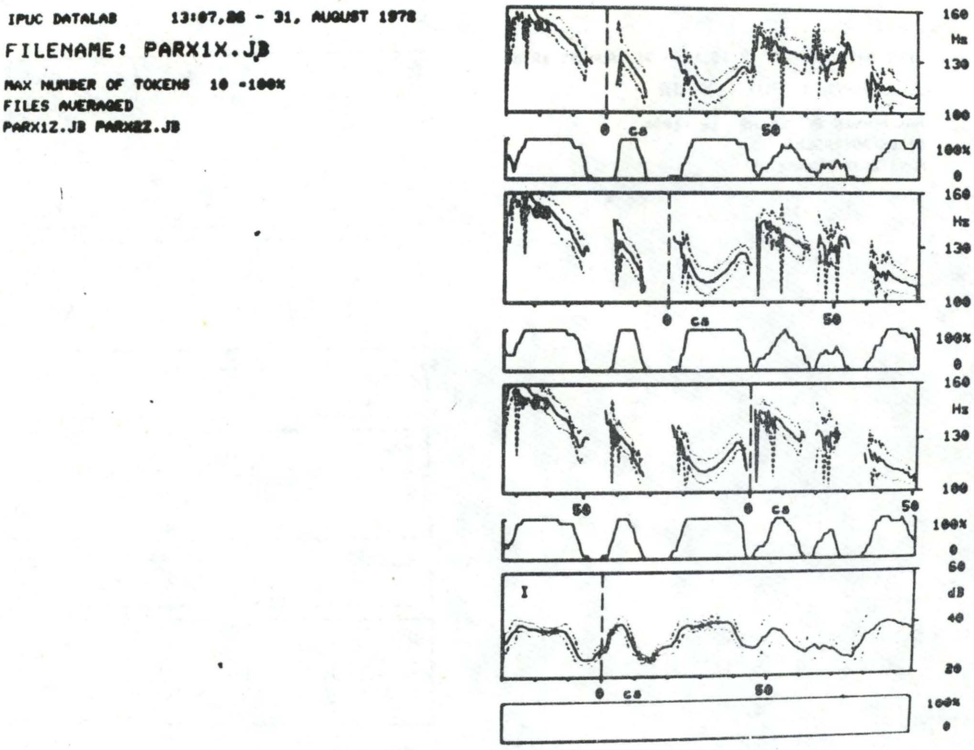

Figure 9

Average curves for the test word pa'pa:pa spoken by subject JB.

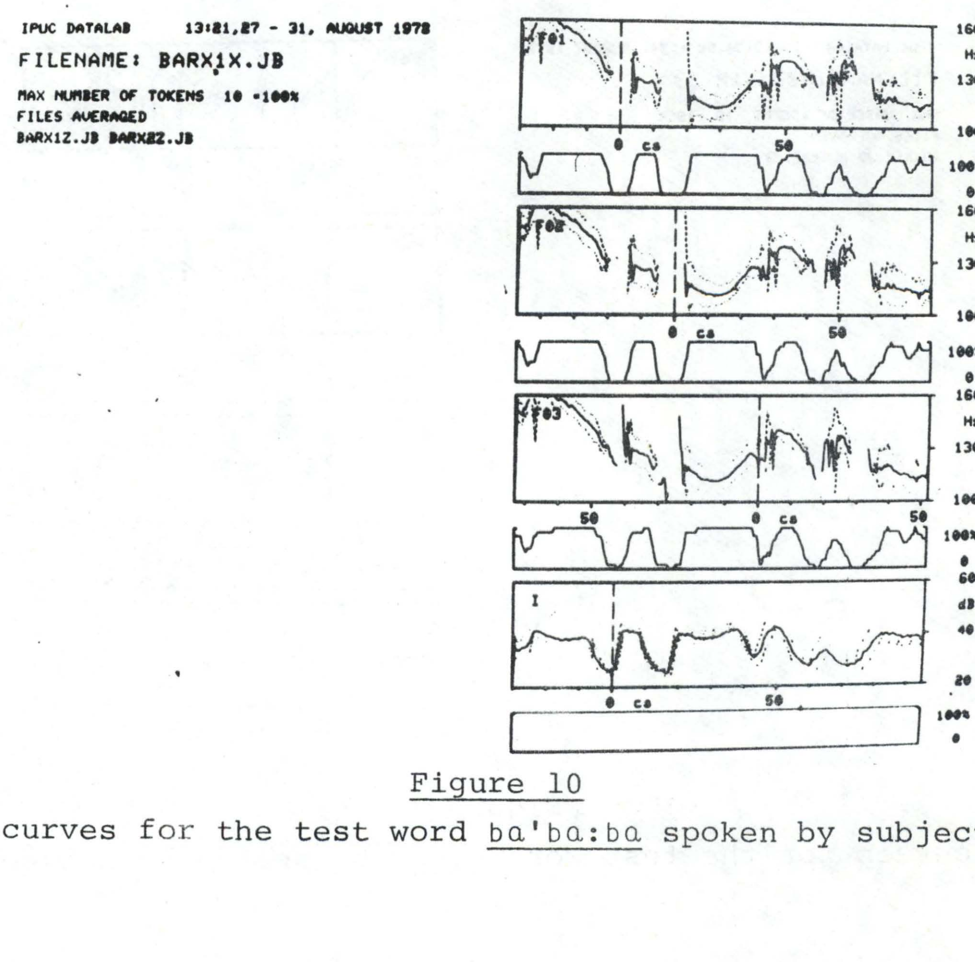

Figure 10

Average curves for the test word ba'ba:ba spoken by subject JB.

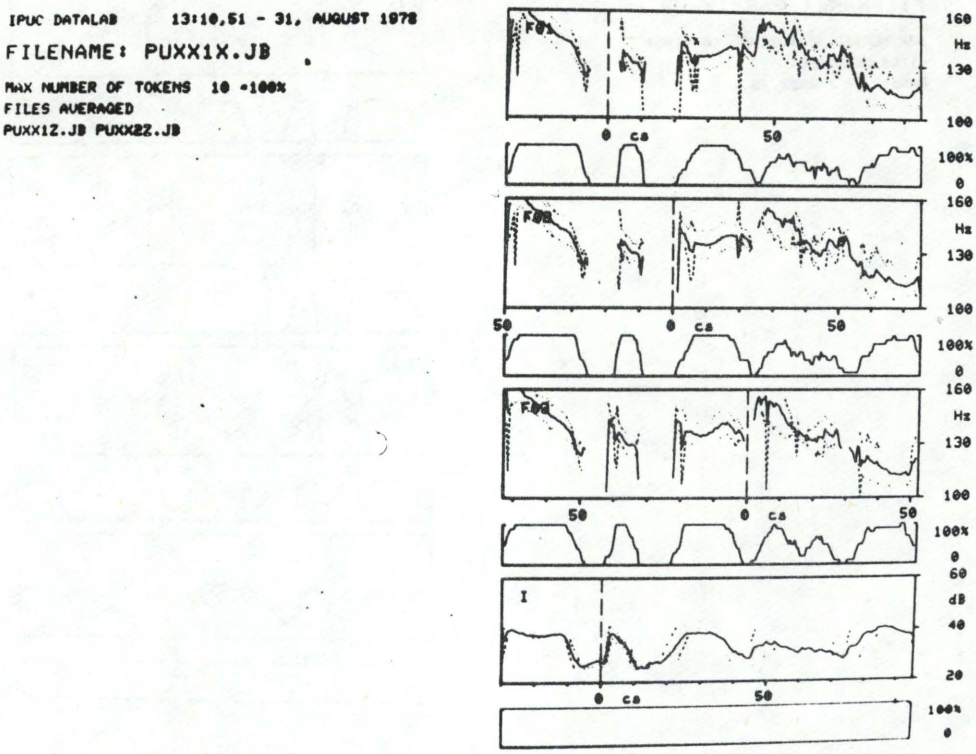

Figure 11

Average curves for the test word pu'pu:pu spoken by subject JB.

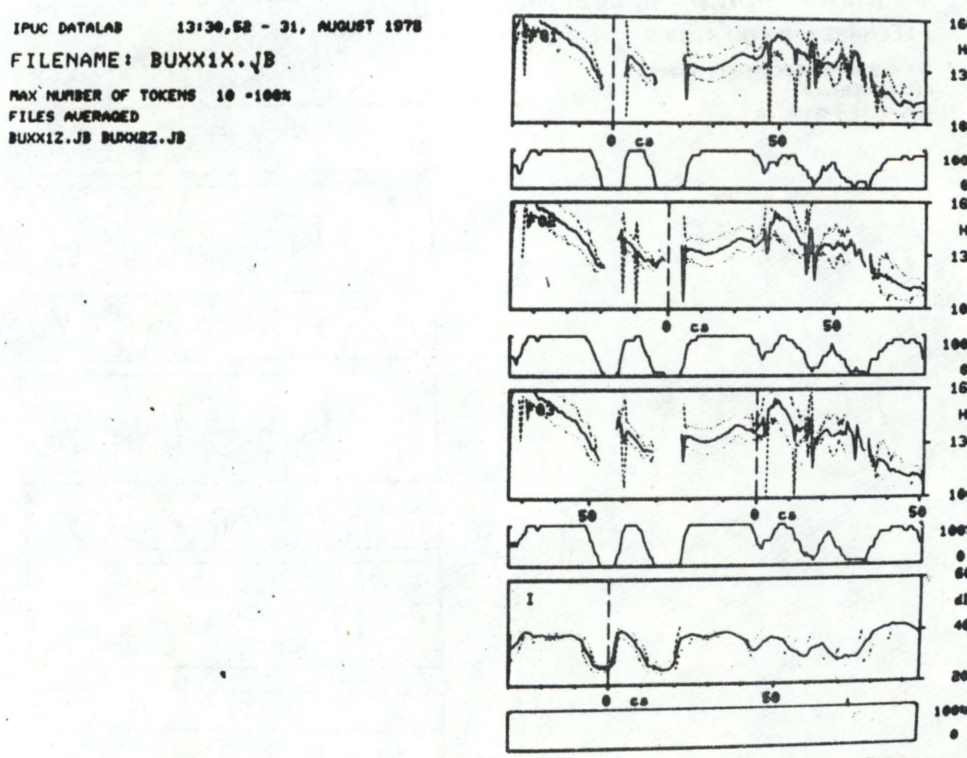

Figure 12

Average curves for the test word bu'bu:bu spoken by subject JB.

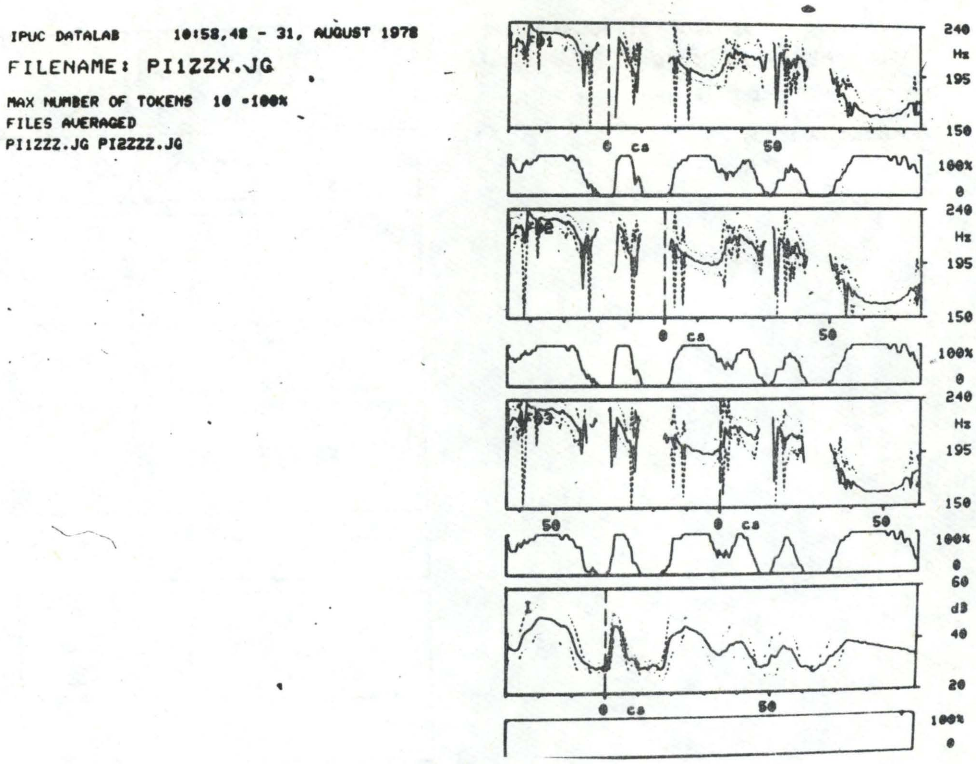

Figure 13

Average curves for the test word pi'pi:pi spoken by subject JG.

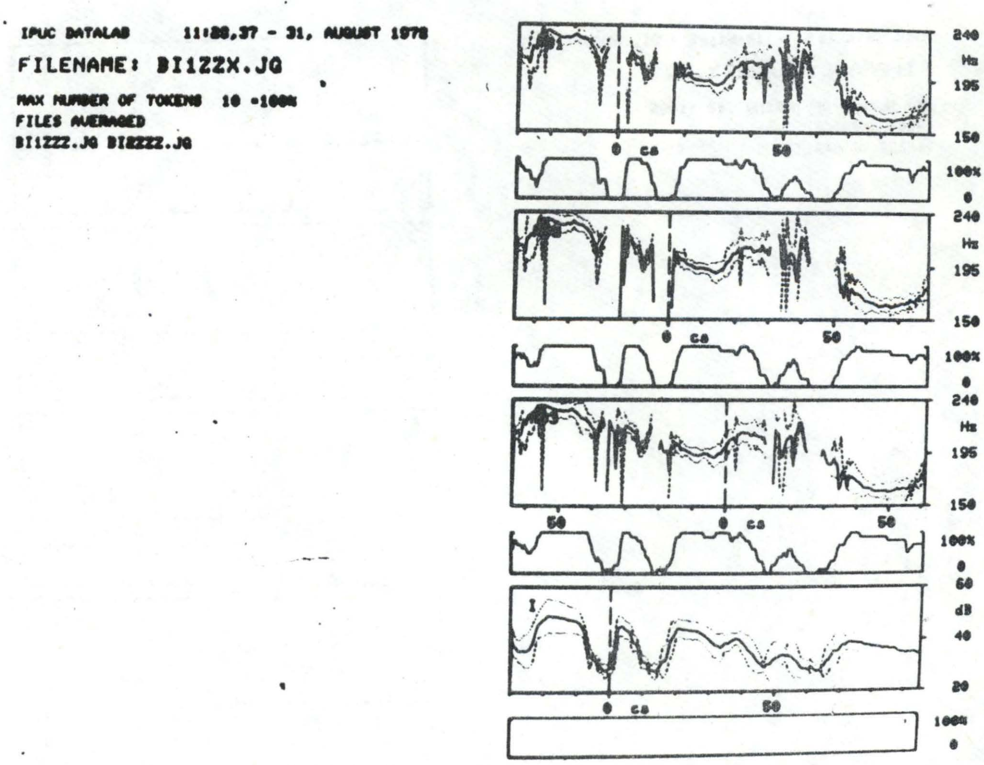

Figure 14

Average curves for the test word bi'bi:bi spoken by subject JG.

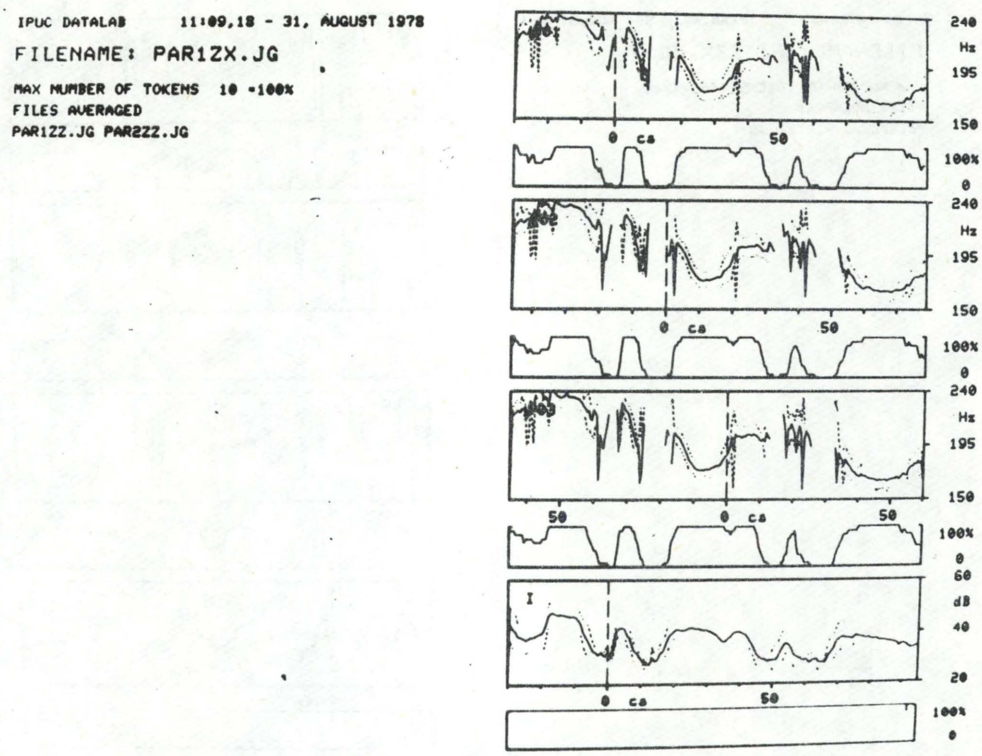

Figure 15
Average curves for the test word pɑ'pɑ:pɑ spoken by subject JG.

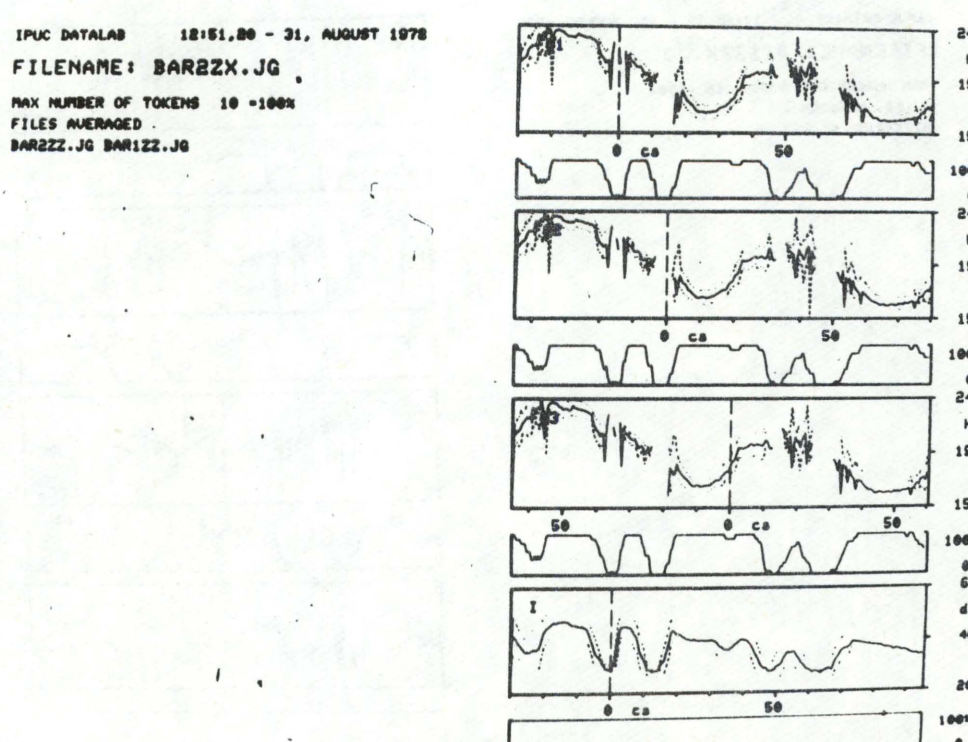

Figure 16
Average curves for the test word bɑ'bɑ:bɑ spoken by subject JG.

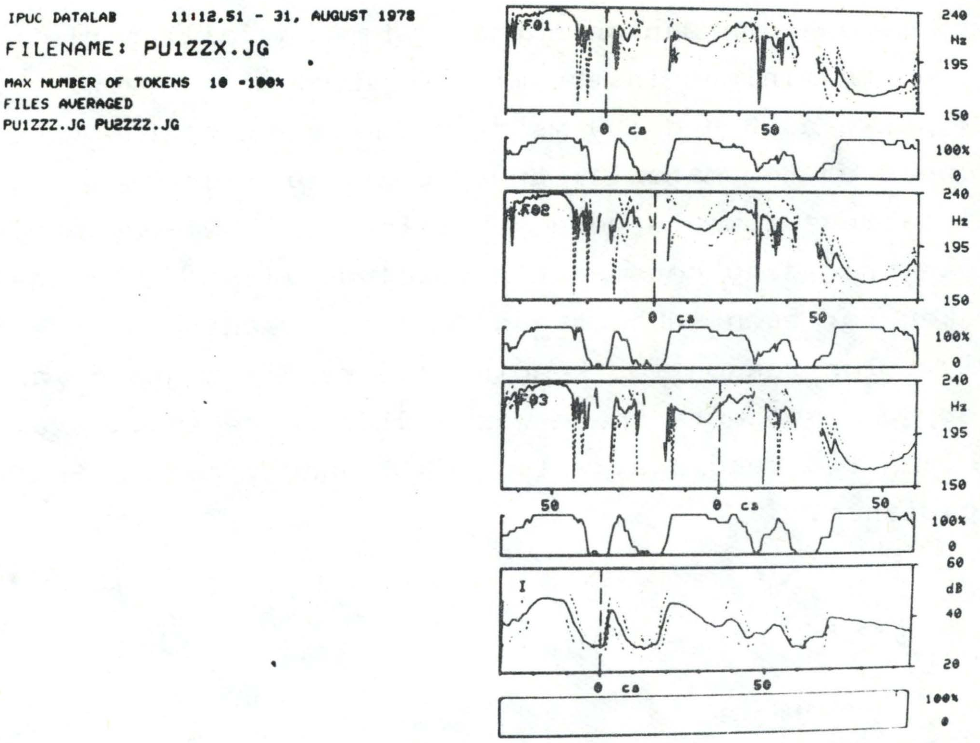

Figure 17

Average curves for the test word pu'pu:pu spoken by subject JG.

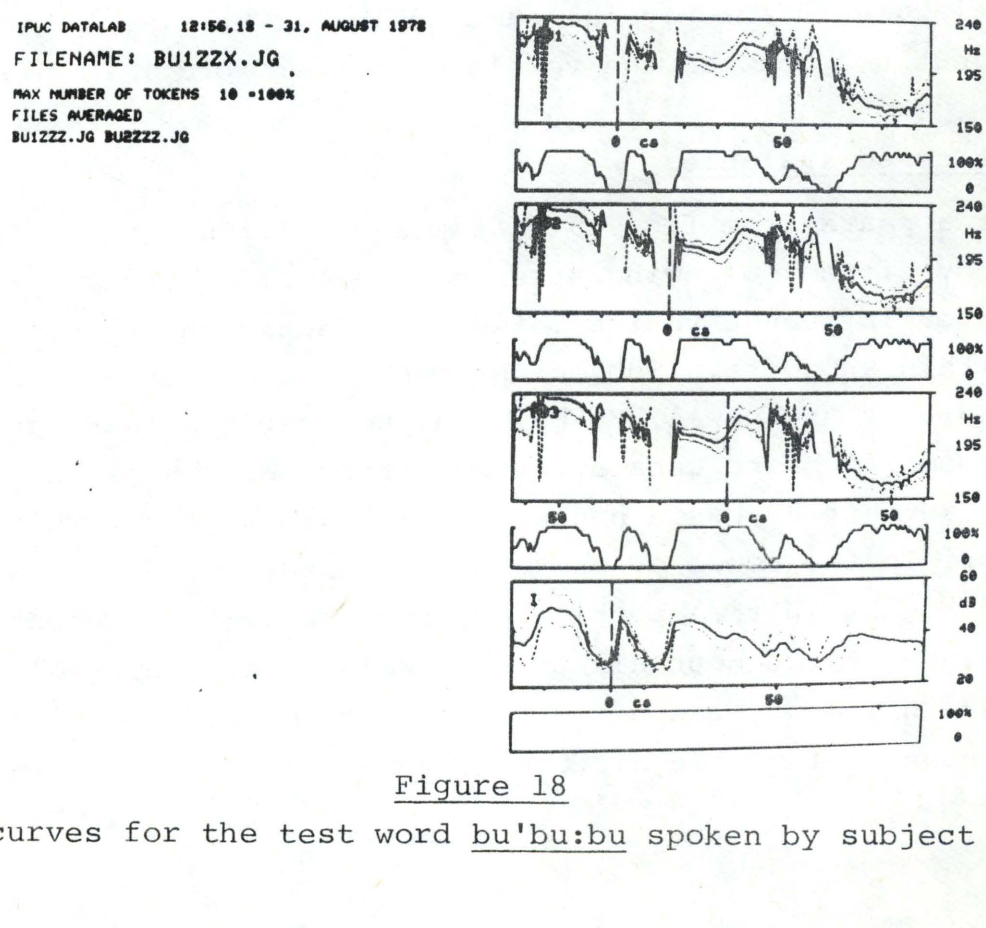

Figure 18

Average curves for the test word bu'bu:bu spoken by subject JG.

As mentioned in section 1 above, the stressed vowels of Advanced Standard Copenhagen Danish normally have a falling-rising Fo movement with its minimum in the middle third of the vowel, i.e. roughly between 50 and 150 ms from the onset of the vowel in the long vowels of the material under consideration here.

These measurements were submitted to a two-way analysis of variance (preceding consonant x vowel quality). The analysis was undertaken for each subject and for each reading of the list separately. The reason for keeping the readings apart was the fact that for some subjects there was a difference in general Fo level between the two readings, which would unduly add to the within group variance.

3. Results

In fig. 19 averaged Fo curves are shown for p- and b-words superimposed upon one another in order to facilitate comparison. The curves are drawings made on the basis of photographs of the graphic terminal screen (similar to those displayed in figs. 1 to 18), enlarged to exactly the same scale. (The time axis is correct within but not between the vowels of a test word.)

3.1 Stressed syllables

It appears from fig. 19 that p and b influence the fundamental frequency of the following stressed vowel differently. But the pattern of influence varies between subjects, and to some extent also within subjects. Subject NR has the clearest difference in the middle of the vowel, Fo being higher after p than after b. There seems to be no consistent difference at the beginning of the vowel. Subject JB has a higher Fo all through the vowels i and u after p. In the vowel ɑ, on the other hand, the difference is limited to the initial portion of the vowel. For subject JG, Fo is higher throughout all three vowels i, ɑ, and u following p, although in i and ɑ the difference grows smaller toward the end of the vowel. In u the difference remains constant during the vowel.

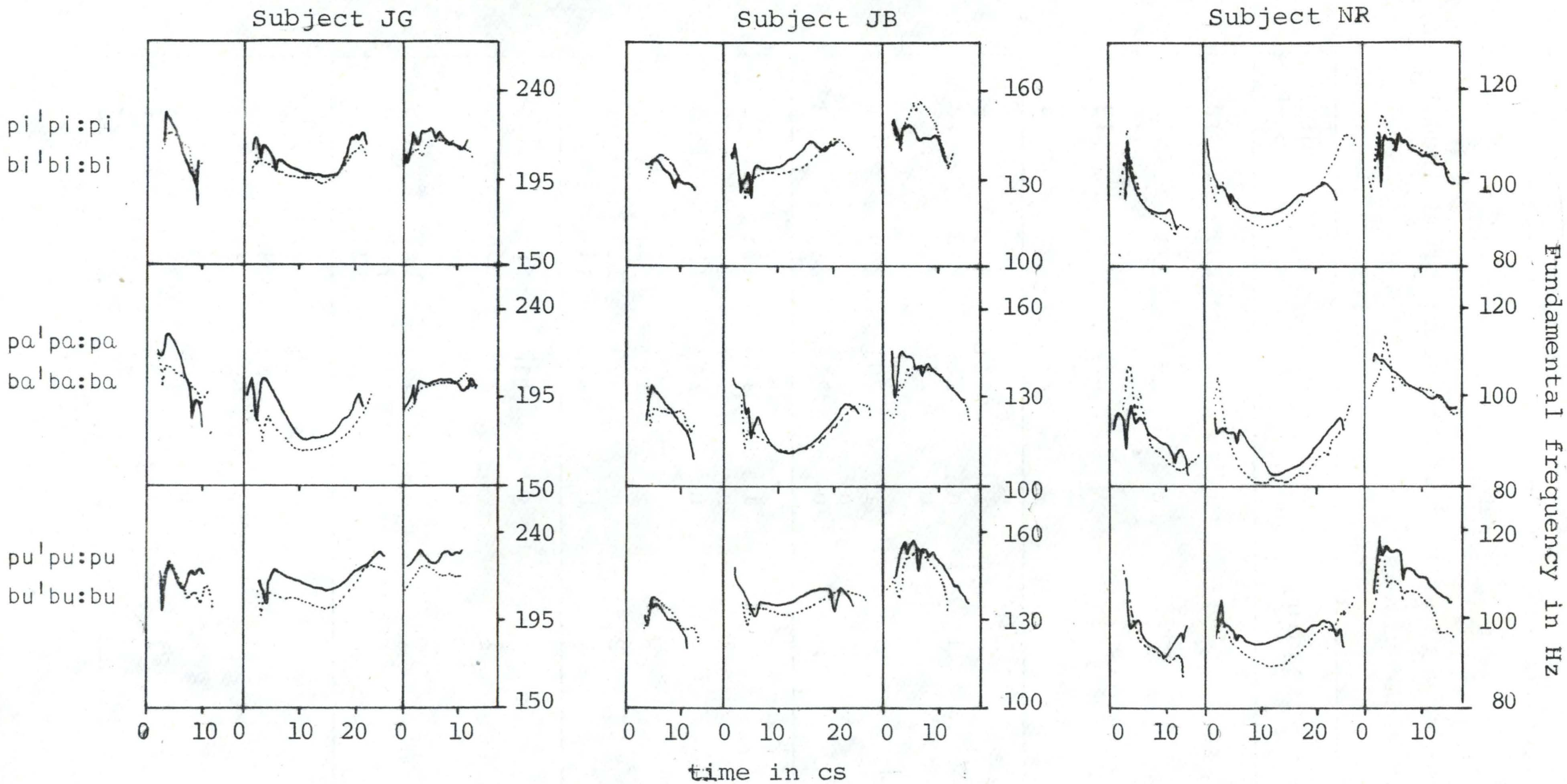

Figure 19

Average curves for p-words (unbroken lines) and b-words (dotted lines) superimposed upon one another (for further explanation, see text).

Table 1

Averages of F_o measured at the point of minimum F_o in long stressed vowels.

subject	reading	vowel qual.	p_	b_	diff. p_-b_
BH	1	i	219	209	10
		ɑ	188	185	3
		u	225	221	4
	2	i	212	199	13
		ɑ	175	172	3
		u	213	209	4
JG	1	i	211	205	6
		ɑ	186	178	8
		u	230	217	13
	2	i	201	200	1
		ɑ	177	172	5
		u	214	211	3
JB	1	i	140	138	2
		ɑ	117	117	0
		u	144	139	5
	2	i	143	140	3
		ɑ	120	119	1
		u	145	141	4
SH	1	i	126	119	7
		ɑ	111	108	3
		u	126	121	5
	2	i	126	121	5
		ɑ	111	111	0
		u	127	122	5
NR	1	i	93	91	2
		ɑ	83	82	1
		u	95	92	3
	2	i	95	92	3
		ɑ	87	83	4
		u	97	92	5

The results of the measurements of fundamental frequency at the minimum points of the stressed vowels are summarized in tables 1 and 2. Table 1 contains the means for the vowels i, ɑ, and u after p and b. It appears that the differences are quite small, varying from 0 to 13 Hz with an average of 4.4 Hz, but as can be seen from table 2, the effect of the preceding consonant was in all cases significant at the 5 per cent level or better. (There was also a highly significant effect of vowel quality.) The interaction between preceding consonant and vowel quality was in no cases significant ($p > 0.5$).

Table 2

Levels of significance obtained for the effect of preceding consonant on the Fo measured at the point of minimum Fo in long stressed vowels.

	BH	JG	JB	SH	NR
reading 1	$p<0.01$	$p<0.01$	$p<0.05$	$p<0.01$	$p<0.01$
reading 2	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.01$	$p<0.01$

3.2 Unstressed syllables

From fig. 19 it appears that no consistent pattern of influence of the preceding consonant can be found in the fundamental frequency of the unstressed vowels, whether pretonic or posttonic. There are indeed cases in which Fo is higher after p than after b, but cases of no difference are equally frequent, and there are a few examples of the opposite relation. The pattern of influence of the preceding consonant seems not to be affected by the position of the unstressed syllable, i.e. whether it is pre- or posttonic.

From the curves in figs. 1 to 18, displaying the number of measurements as a function of time, it appears as if b in posttonic syllables may sometimes be voiced (or rather that the energy during the closure has been high enough to trigger the Fo meter). For the subjects NR and JB, however, this apparent voicing may be due to differences between tokens in the position in time of the line-up point in relation to offset and onset of voicing in the surrounding vowels. Taken token by token the posttonic stops were very rarely voiced with these subjects. For subject JG, on the other hand, it is evident that her posttonic stops, both b and p, are voiced in the majority of cases. This can also be seen from the Fo curves in the figures, which show an almost continuous movement during the entire tonic and posttonic part of the words in b-words as well as in p-words. One explanation for the very frequent voicing of JG's stops is probably her high speaking rate; her distance in time between the onset of the first vowel and the onset of the third vowel in the test words is about 35 cs on an average. The corresponding distances for NR and JB are 50 and 45 cs, respectively. An inspection of intensity tracings and spectrograms of the test words uttered by JB revealed a tendency for the voicing to be slightly weaker in p than in b. Before the vowel i p was followed by a phase of voiced aspiration, before u and ɑ such aspiration could be seen in a few cases only.

Neither b nor p were voiced in pretonic syllables for any of the subjects.

4. Discussion

Although the material under consideration is rather limited the main results seem to be quite clear, namely that the fundamental frequency of a vowel in a stressed syllable is higher after a voiceless aspirated than after a voiceless unaspirated stop, and that the difference is not restricted to the initial portion of the vowel, but is found also in the middle and in a great number of cases all through the vowel.

These results seem to be somewhat in disagreement with what would be predicted from current hypotheses dealing with the effect of aspiration on the fundamental frequency of the following vowel.

It has been suggested that the high Fo after an aspirated stop could be explained by the high rate of airflow upon release of the stop (e.g. Ohala 1973). It is true that the glottis aperture is far larger in Danish aspirated stops than in unaspirated stops (Frøkjær-Jensen, Ludvigsen,and Rischel 1971, Hutters 1978), and also that the airflow is higher (Fischer-Jørgensen 1968). This could explain a higher Fo at the onset of the vowel following an aspirated stop, but not the persistence of the difference between the effects of the aspirated-unaspirated distinction as far into the vowel as is found in the present data.

Hombert, Ohala, and Ewan (1976) and Ohala (1978) suggest that the voiced-voiceless opposition affects the vertical tension of the vocal cords both within the consonant and in the following vowel. Under the assumption that the vertical tension of the vocal cords is reflected by the height of the larynx they employ larynx height data measured by means of the "thyroumbrometer" (Ewan and Krones 1974) in support of the hypothesis. Ewan and Krones investigated the vertical movement of the larynx in vowel-stop-vowel sequences in English, French, Thai and Hindi. They found the larynx to be significantly higher in unvoiced stops than in voiced stops, and - what is interesting from the point of view of the present investigation - they found that in Thai and Hindi the distinction between voiceless aspirated and voiceless unaspirated was not accompanied by significant differences in larynx height, neither in the stop nor in the vowel following it. According to the vertical tension hypothesis, then, no difference should be expected between aspirated and unaspirated voiceless stops with regard to their influence on the Fo of the following vowel. This is in agreement with the Thai data of Gandour (1974) and the Hindi data of Kagaya and Hirose (1975), but not with the data on Danish reported above. Unfortunately Ewan and Krones (1974) do not accompany their larynx height data with simultaneous Fo tracings.

Another "tension hypothesis" has been advanced by Halle and Stevens (1971), who suggest that the vocal cords should be stiffer, i.e. have a greater longitudinal tension, in aspirated than in unaspirated stops. This would predict the higher Fo after aspirated stops actually found in the present material. On the other hand, EMG data on the behaviour of laryngeal muscles, among them the vocalis, in Danish stops reported by Fischer-Jørgensen and Hirose (1974) do not indicate that the vocal cords should be any stiffer in <u>ptk</u> than in <u>bdg</u> in Danish.

The results for the unstressed syllables are much less consistent than the results for the stressed ones, and the conclusion to be tentatively drawn is that the fundamental frequency of unstressed vowels is not affected by a difference in aspiration of the preceding stop consonant. This is not very surprising, since the aspiration of stops in unstressed syllables is considerably shorter than in stressed syllables. It is also in line with fiberscopic observations reported by Birgit Hutters (personal communication) that the difference in glottal gesture between p and b in unstressed syllables is far smaller than in stressed syllables, the gesture of p being more similar to that of b.

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