AN INVESTIGATION OF THE FUNDAMENTAL FREQUENCY OF VOWELS AFTER VARIOUS DANISH CONSONANTS, IN PARTICULAR STOP CONSONANTS

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Abstract:

In the experiment reported, it is investigated how the fundamental frequency of the vowels starts after various Danish consonants. The main result of the experiment is that the vowel starts at a lower frequency after Danish bdg than after ptk.

1. Introduction

Investigations of languages with voiced bdg and voiceless ptk have shown that the fundamental frequency of the following vowel is lower after bdg than after ptk.

House and Fairbanks (1953) investigated the fundamental frequency of American vowels preceded and followed by the same consonant. They found that the average fundamental frequency of the vowels was decreasing, according to the surrounding consonants, in the order ptk > fs > bdg > vzmn. The mean difference between vowels, preceded and followed by bdg and ptk, was 6 Hz. However, they did not know whether it was the preceding or the following consonant that exerted the greatest influence on the vowels. Data from ten male subjects formed the material investigated.

Lehiste and Peterson (1961) investigated the fundamental frequency of American vowels in various consonant surroundings. They measured the maximum fundamental frequency and found that a preceding consonant influences the average fundamental frequency of the following vowel, which is decreasing in the order ptk > fsh bdgl > mn > v. The average difference between the fundamental frequency of vowels after bdg and ptk was 12 Hz. The following consonant had no influence on the vowel. Only one American male subject was used in this investigation.

Kim (1965) found that in Korean, vowels following the weakly aspirated voiceless stops start a little lower than vowels following the unaspirated voiceless and the strongly aspirated voiceless stops. The weakly aspirated voiceless stops of Korean are lenes, whereas the other two categories are fortes.

Slis and Cohen (1969) investigated the fundamental frequency of Dutch vowels after voiced and voiceless consonants. They found that vowels after voiced consonants have a maximum which, on an average, is 6 Hz lower than that of vowels after voiceless consonants.

Fischer-Jørgensen (1972) investigated French stop consonants between vowels. The fundamental frequency of the following vowel was measured for one of the subjects. The vowel started on a lower frequency after <u>bdg</u> than after <u>ptk</u> in 75 out of 78 pairs. The average difference was 27 Hz.

In his investigation of Swedish tonal accents Öhman found that the fundamental frequency initially in the stressed vowel was highest after the voiceless stop <u>k</u>, lowest after the voiced consonants <u>g</u>, <u>j</u>, and <u>v</u>, and intermediate after the voiceless fricatives <u>f</u> and c.

Haycock and Haggard (1970) found that vowels start on a higher fundamental frequency after <u>ptk</u> than after <u>bdg</u>. The difference was 5-6 Hz.

In an experiment with synthetic syllables Haggard et al. (1970) made the following observation: if a syllable is ambiguously perceived as beginning with <u>p</u> or <u>b</u> when the following vowel has level pitch, then a change of the pitch so that it starts at a higher frequency suffices to make the subjects perceive the consonant as voiceless. If, on the contrary, the starting-point is lowered (in relation to the originally level pitch), the consonant is heard as voiced. 12 English subjects took part in the perceptual test.

Fujimura (1971) carried out an experiment with synthetic syllables and found that the frequency at the start of the following vowel is important for the perception of the stop consonants as voiced or voiceless. 10 American and 3 Japanese subjects were asked to judge a synthetic syllable with various voice onset times as either [kε] or [gε]. The shift from g to k occurred at a somewhat longer voice onset time for the American subjects when the starting fundamental frequency of the vowel was low and rising from 70 to 100 Hz, than when the vowel started at 100 Hz and exhibited no rise. One of the Japanese subjects was totally reluctant to change the answer from g to k when the fundamental frequency of the vowel started at a low level.

Halle and Stevens (1971) want to explain the connection between type of consonant and vowel pitch in terms of common features. They argue that - according to studies of the mechanism of vocal cord vibrations - the factors conditioning higher versus lower fundamental frequency include stiffening and slackening of the vocal cords. Halle and Stevens give voiceless ptk the features [-slack vocal cords, +stiff vocal cords] and voiced bdg the features [+slack vocal cords, -stiff vocal cords]. Danish voiceless ptk will get the features [-slack vocal cords, +stiff vocal cords] and Danish voiceless bdg the features[-slack vocal cords, -stiff vocal cords].

2. The present investigation

All investigations mentioned above, except the one on Korean, concern languages with voiced bdg and voiceless ptk. In the experiment reported in the present paper it was investigated how the fundamental frequency of the vowel starts after Danish stop consonants. These stops are all voiceless, the main difference between ptk and bdg being one of aspiration.

2.1. Material

The material consisted of the following words: *pane [p^{h}a:nə], bane [ba:nə], pande [p^{h}anə], bande [banə], tale [t^{h}a:lə], dale [da:lə],tande [t^{h}anə], danne [danə], kane [k^{h}a:nə], gane [ga:nə], kande [k^{h}anə], and *ganne [ganə]. Moreover, the following words were included for comparison: fane [fa:nə], *fanne [fanə], *sane [sa:nə], sande [sanə], hale [ha:lə], Hanne [hanə], mane [ma:nə], malle [malə], *nale [na:lə], nalle [nalə], vane [va:nə], valle [valə], *lane [la:nə], and lande [lanə].[1] All the test words were said in the carrier sentence (sig ordet - igen: 'say the word - again'). The tested consonants are all in initial stressed position.

2.2. Subjects and recording

The sentences were read in random order by 3 female subjects: EC, EH, and VJ and 3 male subjects: LG, JJ, and BM. All the subjects are students of phonetics and speak Standard Danish. They all have strongly aspirated ptk and furthermore strongly affricated t, and all have a low pitch on the stressed syllables gliding to a higher tone in the unstressed syllables. 4 of the subjects: EC, EH, JJ, and VJ read the whole material. BM read the sentences with stop consonants and with fs. LG only read the sentences with stop consonants. All the subjects read the material 6 times each. Thus the material consists of 792 words, of which 432 have a stop consonant initially. The recordings took place in the studio of the Institute of Phonetics. A professional Lyrec tape-recorder was used. The speed of the tape was 7½"/sec.

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1) Words marked by means of an asterisk are possible but non-existent Danish words.

2.3. Registration

The signal from the tape recorder (the same as used for recording) passed a pitch-meter and an intensity meter. By means of a mingograph 4 curves were obtained:

a. a duplex oscillogram.

b. a logarithmic intensity curve, high-pass filtered at 500 Hz and with an integration time of 2.5 msec.

c. a linear, unfiltered intensity curve with an integration time of 10 msec.

d. a pitch curve.

2.4. Measurements

The fundamental frequency was measured in Hz at 7 points in each sentence. Fig. 1 shows where these points were measured on the pitch curve. The measured points are:

1. the minimum at the end of the carrier phrase ('ordet').
2. the start of the initial consonant in the test word.
3. the minimum of the initial consonant.
4. the start of the voiced aspiration (only p and k).
5. the start of the stressed vowel in the test word.
6. the minimum of the stressed vowel.
7. the end of the stressed vowel.

Moreover, the distance from the start of the stressed vowel to the minimum of the fundamental frequency in that vowel was measured.

The results of the measurements for each subject are separated in the comparison. The female voices are measured with an accuracy of about 5 Hz and the male voices with an accuracy of about 2 Hz. No difference can be found between the start of the long and the short vowels, nor between the minima of these vowels.

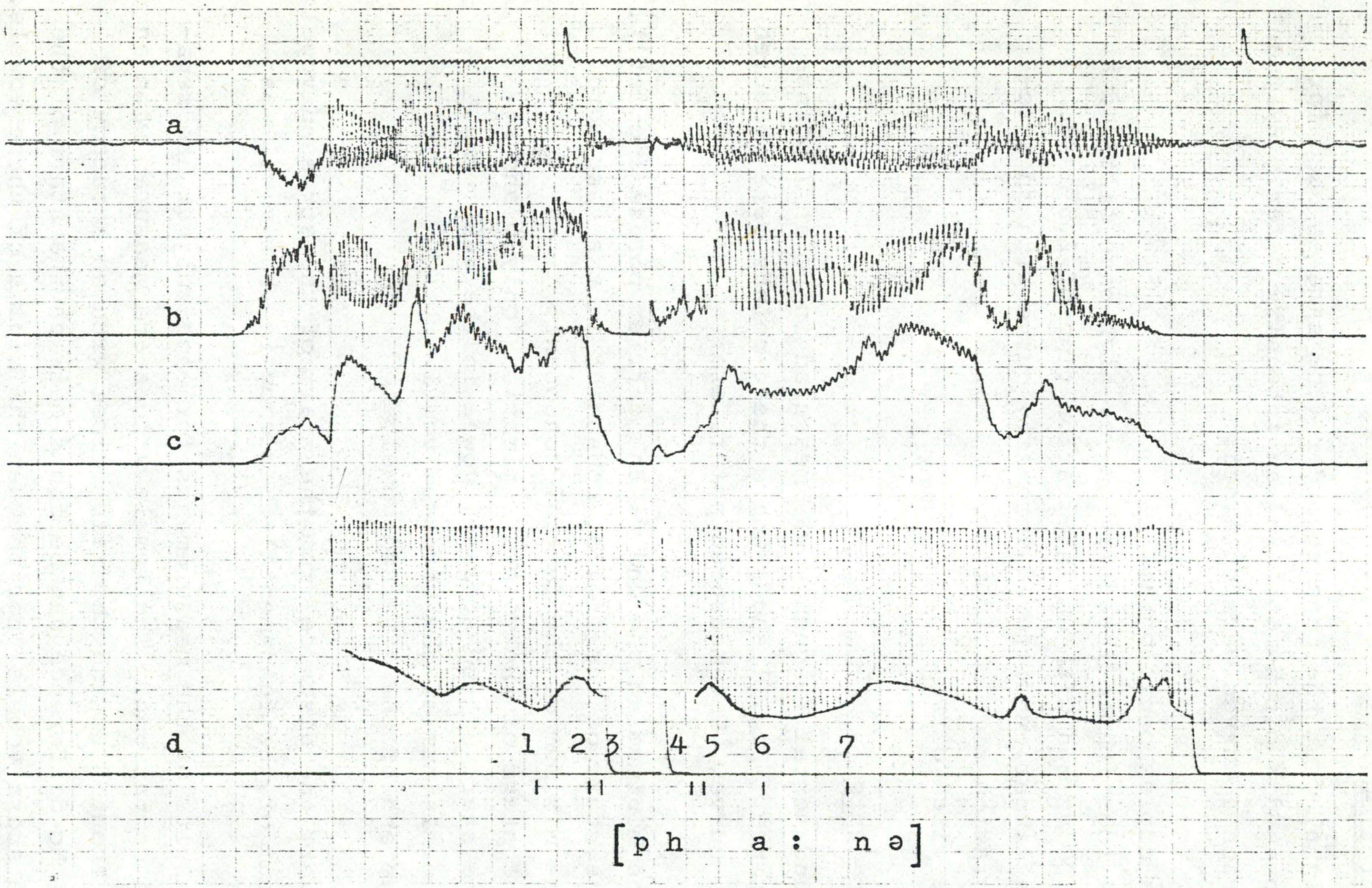

Figure 1

Mingogram of [pʰa:nə]. Subject LG. The numbers refer to the measured points on the pitch curve.

For that reason, the long and the short vowels are not separated, except for the frequency at the end of the vowel, which exhibits a significantly higher value in long vowels than in short vowels. A t-test was used to investigate at which level of significance (99.9, 99, or 95%) the difference between word-pairs such as 'pane - bane' could be said to differ from zero. Some of the consonants have been combined, so that there are 7 groups in all: ptk, bdg, fs, h, mn, v, and l. The first and second group each comprises 36 examples, the third and fifth group 24 examples, and the fourth, sixth and seventh group 12 examples for each subject. Two of the subjects: EC and EH have fully voiced h, JJ has voiceless h, and VJ has partly voiced or voiceless h.

3. Results of the measurements

3.1. Fundamental frequency of the minimum at the end of the carrier phrase

No difference was found.

3.2. Fundamental frequency at the start of the initial consonant of the test word

None of the subjects has any difference between the start of ptk and bdg. BM has no difference between the start of stop consonants and fs. EC has decreasing frequency at the start of the consonants in the order ptkbdgfs > h > mnvl. For EH the order is ptkbdg > fs > h > mn > l > v, for JJ ptkbdg > mn > fshvl, and for VJ ptkbdg > smnl > hf > v.

3.3. Fundamental frequency at the minimum of the initial consonant in the test word

The voiceless consonants are often slightly voiced at the beginning. The minimum was measured where the voiced oscillations stop, but as these oscillations are of different duration, the value of this measure is dubious. Besides, in nasals the pitch curve falls from the beginning of the consonant to the start of the following vowel. A comparison of the minima is therefore meaningless.

3.4. Fundamental frequency at the start of the voiced aspiration

The last part of the aspiration is voiced after most p's and some k's. The voiced aspiration can be separated from the vowel by means of the weak intensity of the oscillations which is followed by a rather sudden increase of intensity coinciding with a change of the direction of the pitch curve from rising to falling. The spectral energy of these weak oscillations is concentrated at a very low frequency. JJ has no voiced aspiration. In the case of the other subjects (except VJ), the voiced aspiration starts at a clearly higher frequency than the vowel after bdg. VJ has no difference between the start of a voiced aspiration and the start of the vowel after bdg.

3.5. Fundamental frequency at the start of the stressed vowel in the test word

All the subjects have a lower start of the vowel after bdg than after ptk. Three of the four subjects who read the test words containing voiced consonants (m, n, l, v), have a lower start of the vowel after voiced than after voiceless consonants (except JJ who has hardly any difference). Figs 2-7 contain histograms of the fundamental frequency at the start of the vowel

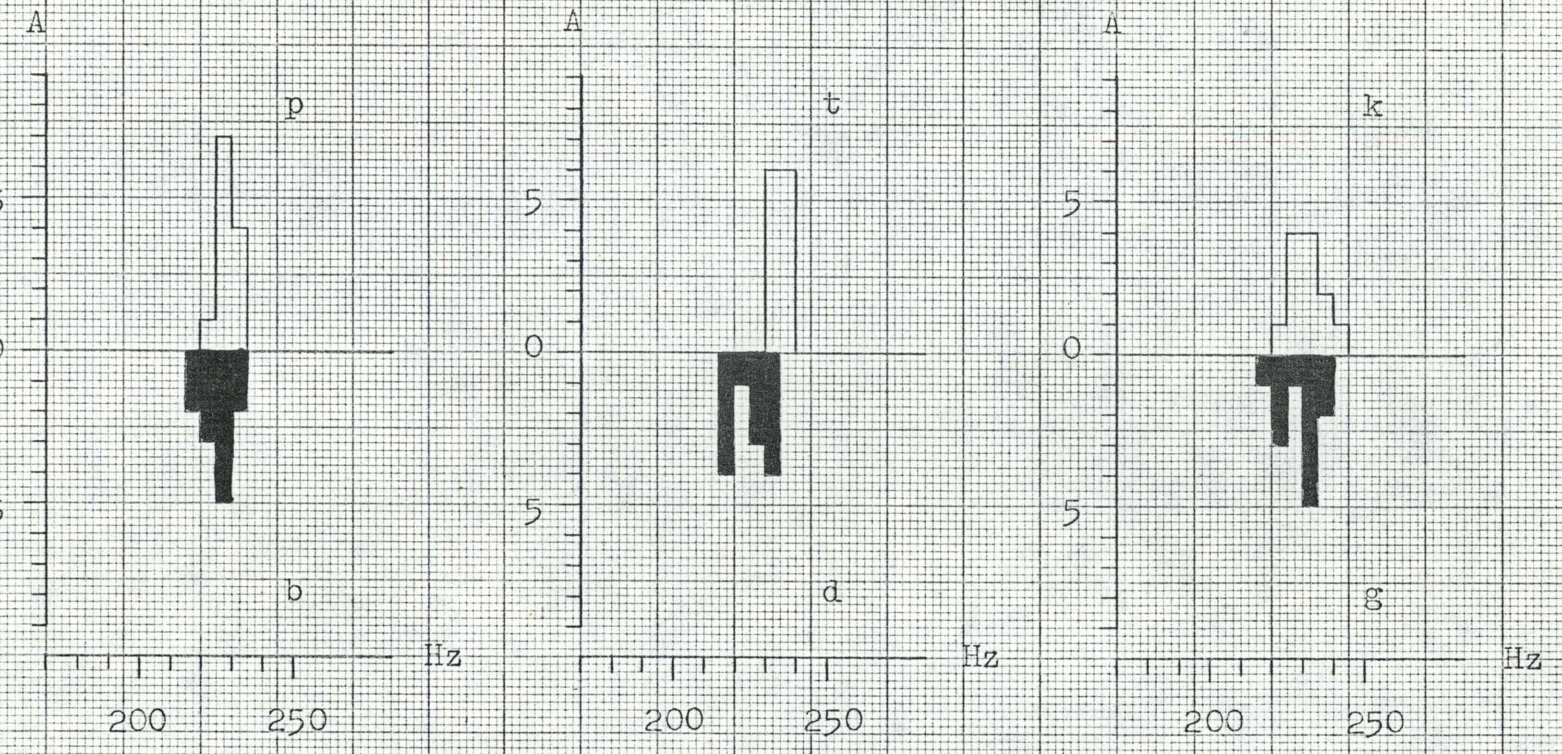

Figure 2. Fundamental frequency at the start of the vowel after <u>ptk</u> and <u>bdg</u>. (Subject VJ).

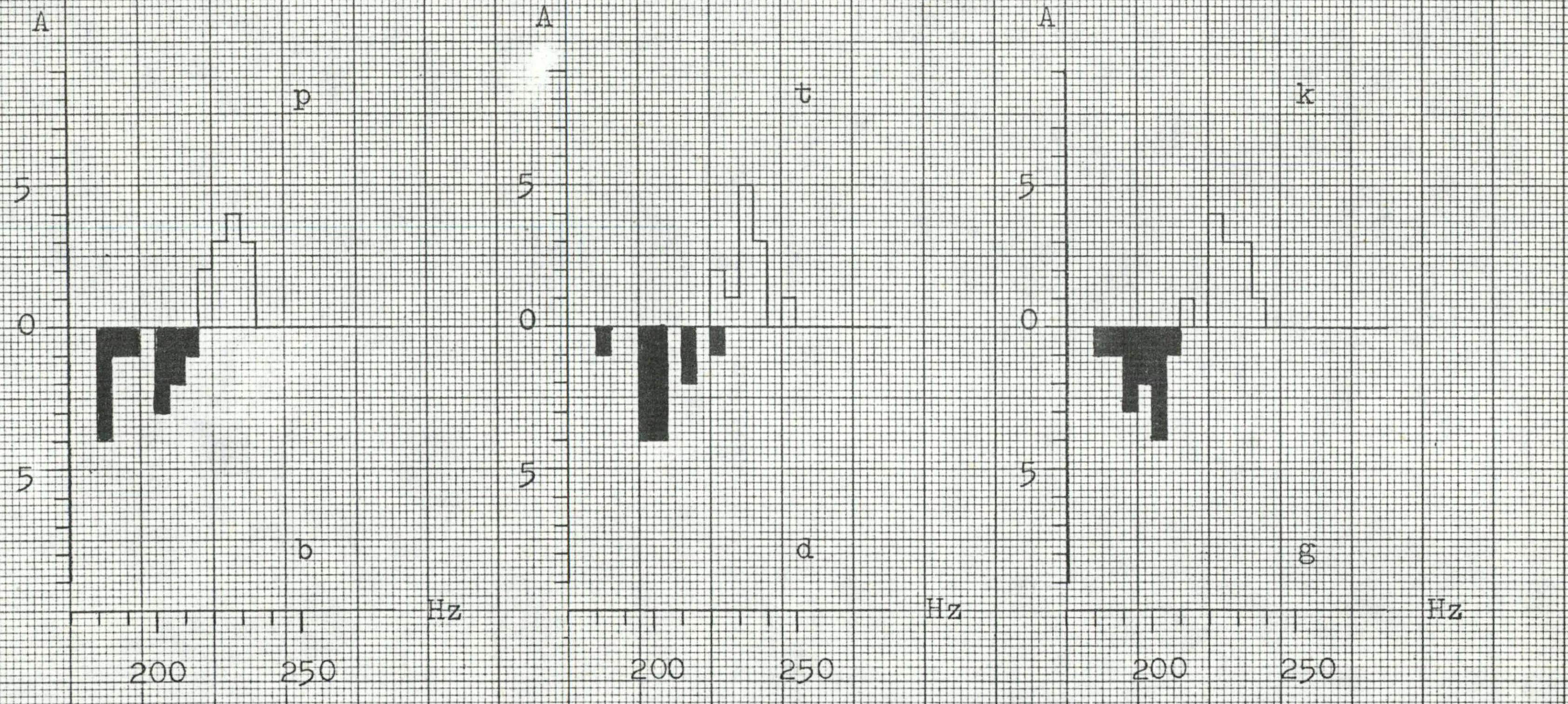

Figure 3. Fundamental frequency at the start of the vowel after <u>ptk</u> and <u>bdg</u>. (Subject EC).

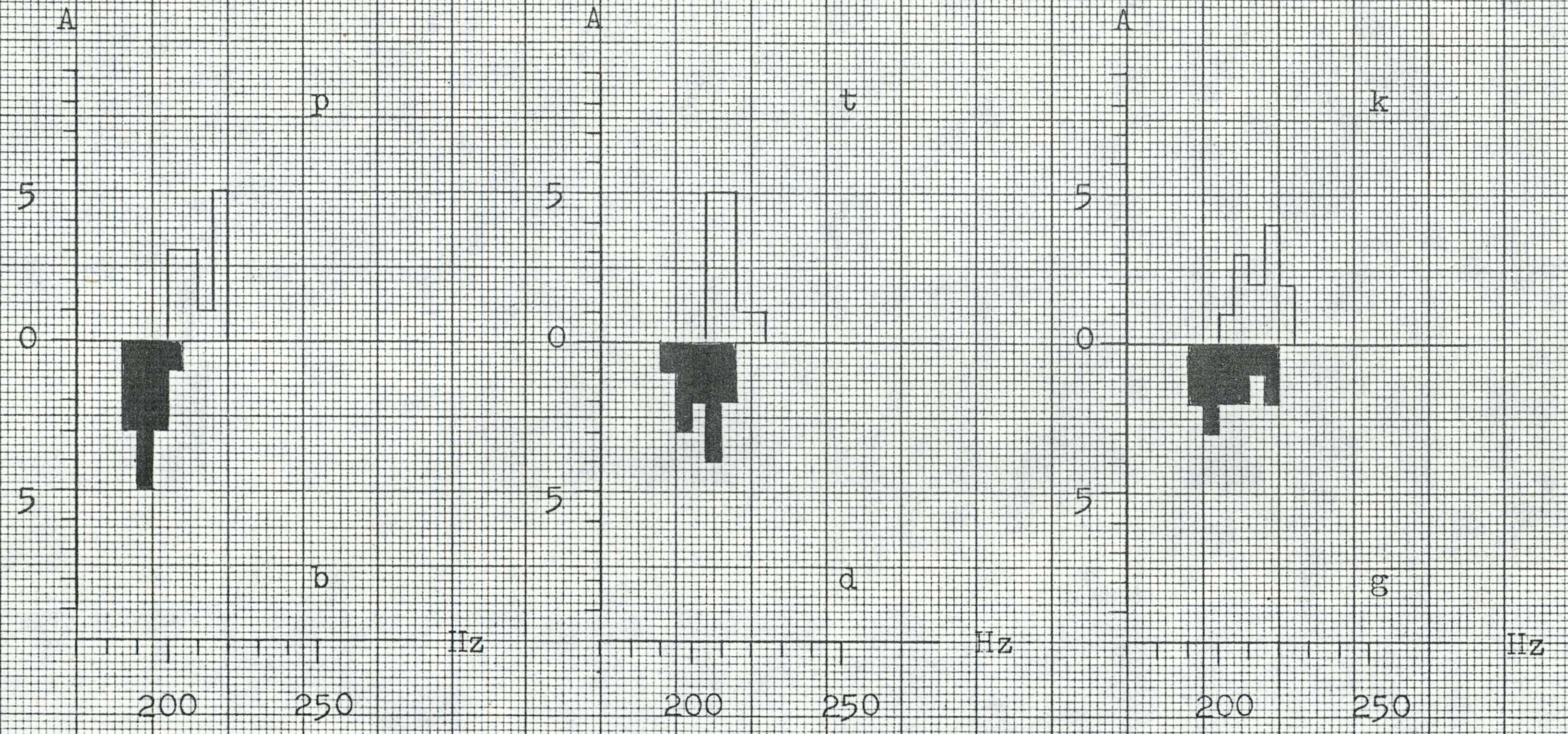

Figure 4. Fundamental frequency at the start of the vowel after ptk and bdg. (Subject EH).

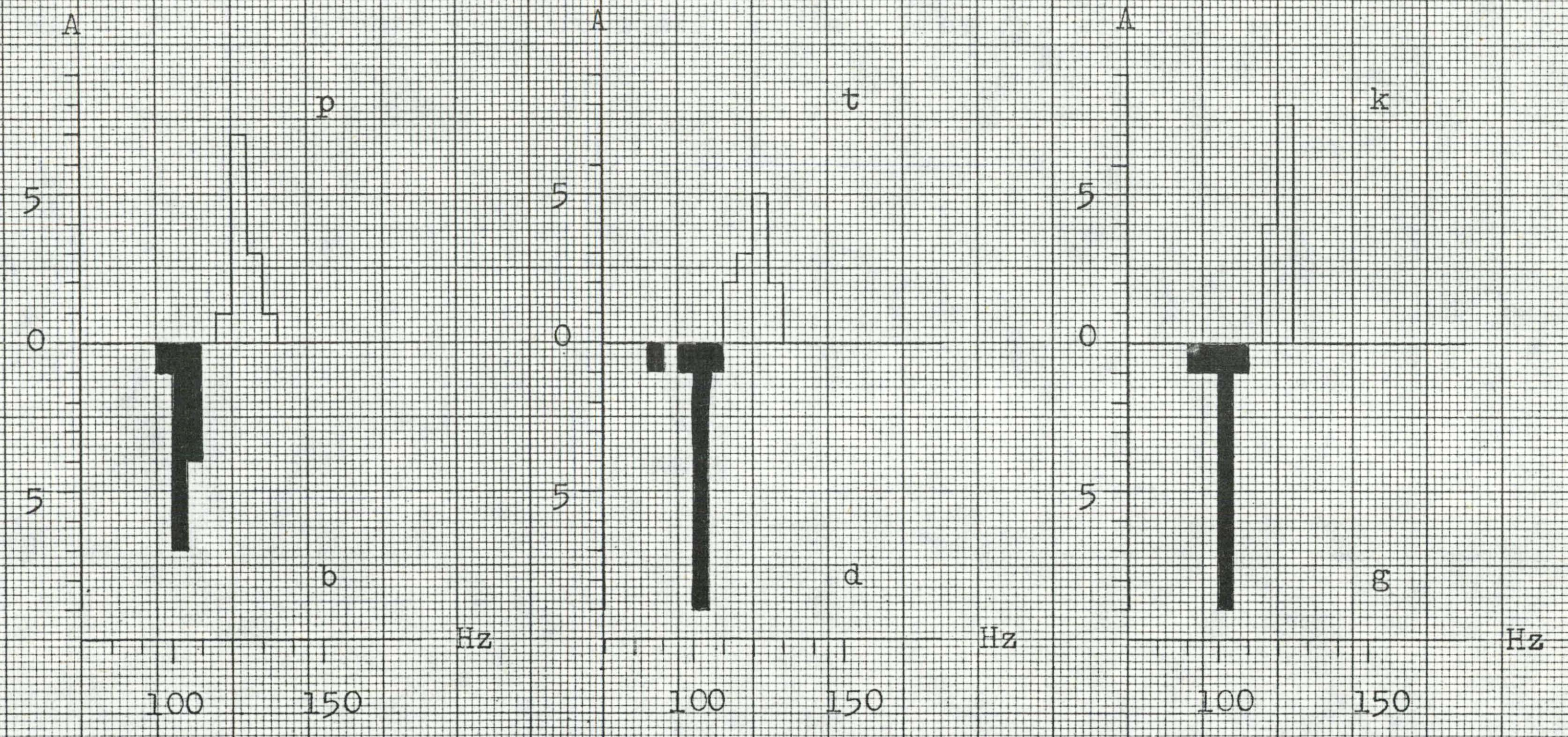

Figure 5. Fundamental frequency at the start of the vowel after ptk and bdg. (Subject LG).

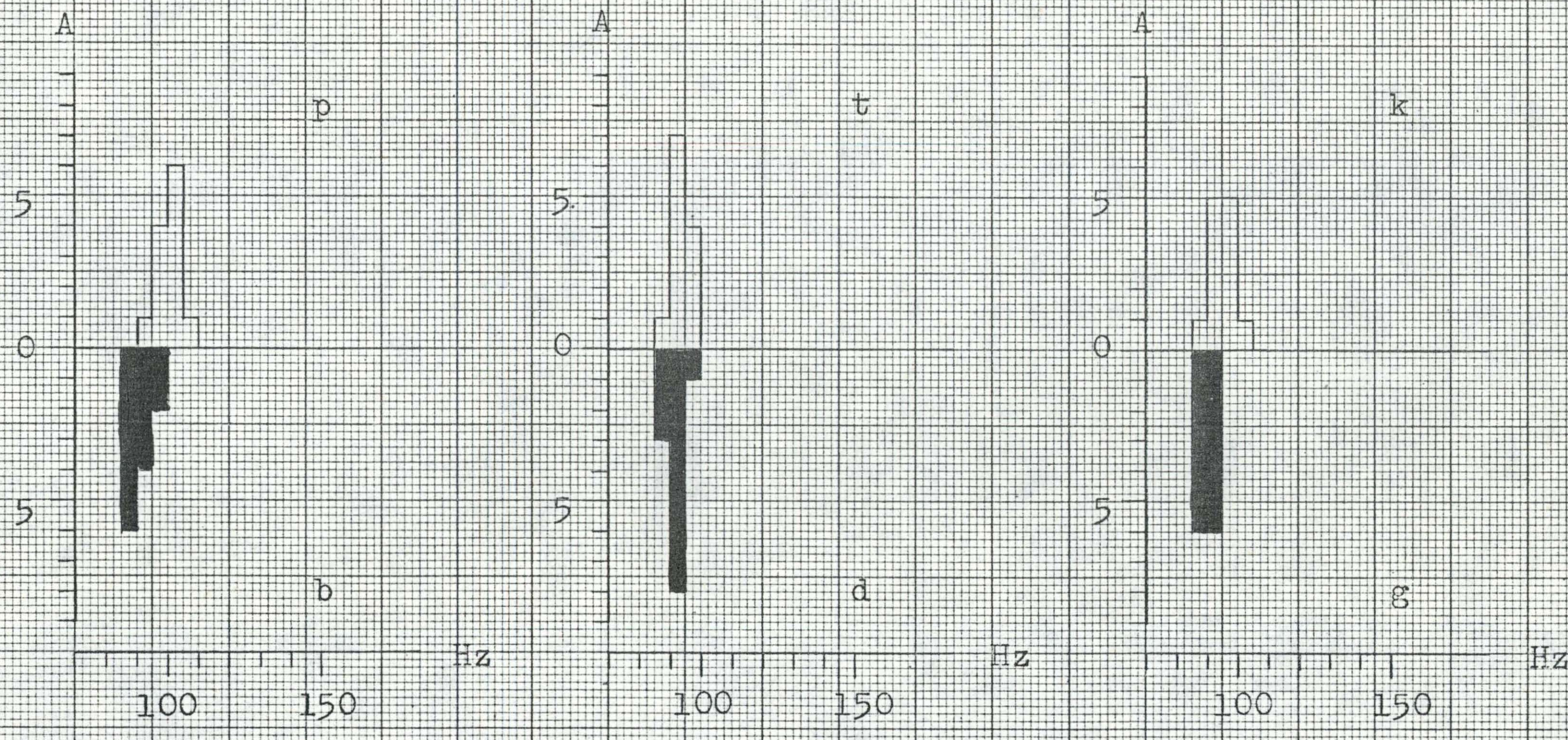

Figure 6. Fundamental frequency at the start of the vowel after <u>ptk</u> and <u>bdg</u>. (Subject BM).

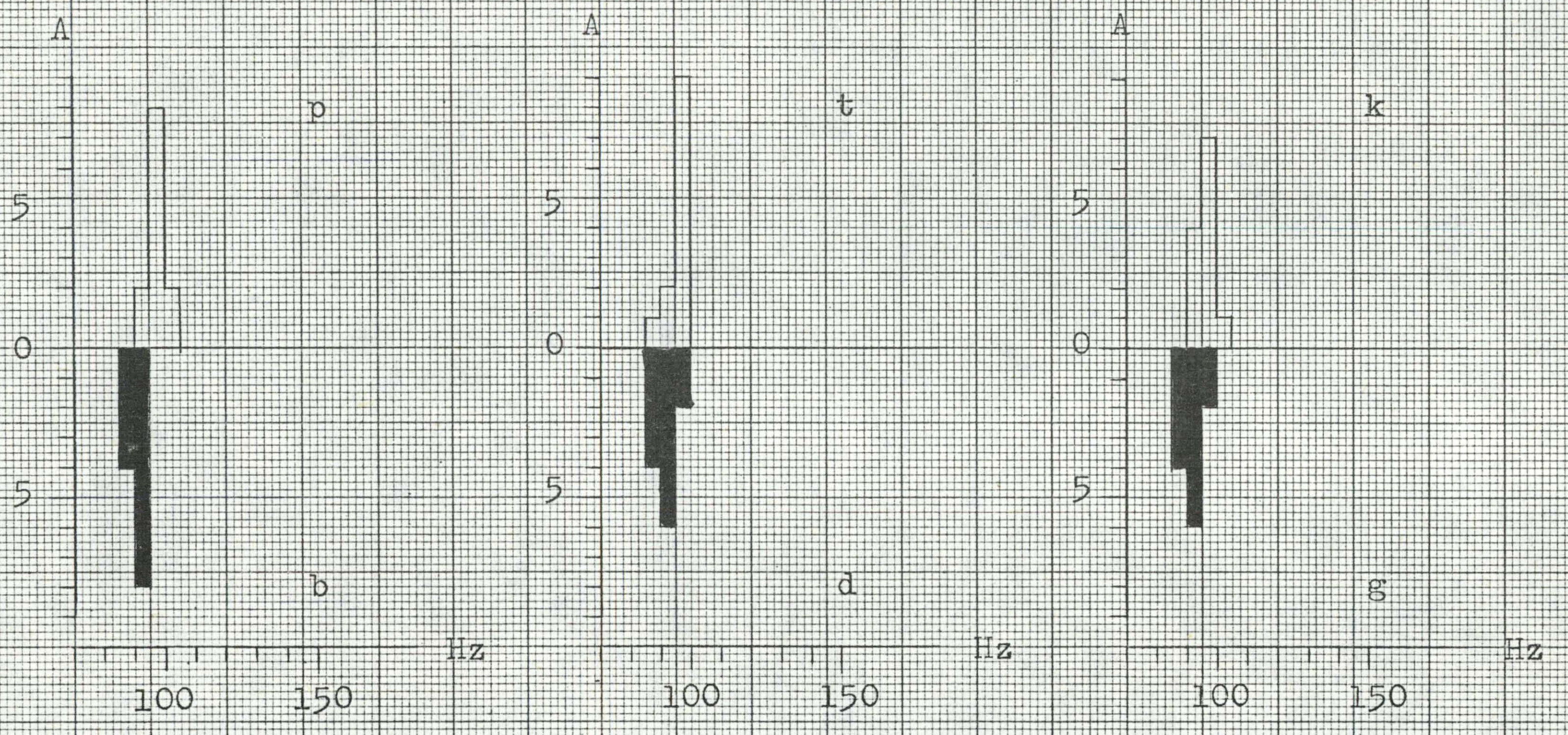

Figure 7. Fundamental frequency at the start of the vowel after <u>ptk</u> and <u>bdg</u>. (Subject JJ).

after the different stop consonants, and figs 8 and 9 show the mean fundamental frequency at the start of the vowel after all the consonants. The differences between the average fundamental frequencies at the start of the vowel can be seen in table I, and table II shows whether these differences are significant, and on which level.

3.6. Fundamental frequency of the minima in the stressed vowel

The differences between the minima in the vowels following different consonants are less pronounced than the differences between the start of the vowels. For none of the subjects are the differences significant.

3.7. Fundamental frequency at the end of the stressed vowel

The long vowels end on a higher F_0 than the short vowels for all subjects. The difference in fundamental frequency between different consonant types is nearly equalized at the end of both the long and the short vowels. There is, however, a tendency for all subjects to retain a small difference, so that the fundamental frequency of both the long and the short vowels is decreasing according to the preceding consonants in the order ptkh > bdgfs > mnvl.

3.8. Distance from the start of the stressed vowel to the frequency minimum in the vowel

The measurement of the distance from the start of the vowel to the minimum in the vowel is a problematic matter, because the mid part of the vowel has a rather flat F_0 curve and it is difficult to decide where the minimum is. But the tendency is that the minimum is reached later in the long vowels than in the short

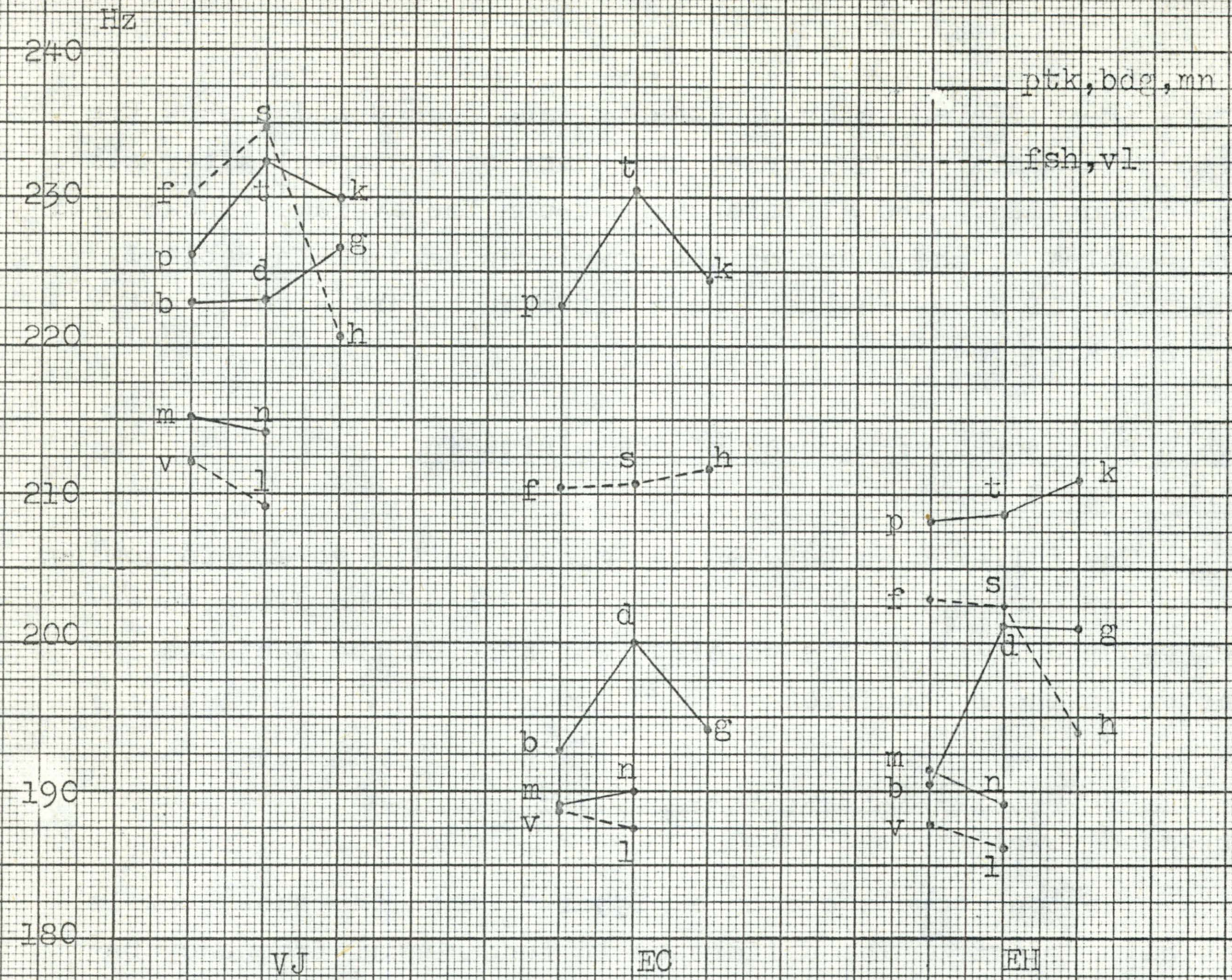

Figure 8. Fundamental frequency at the start of the vowel after various consonants. Female subjects.

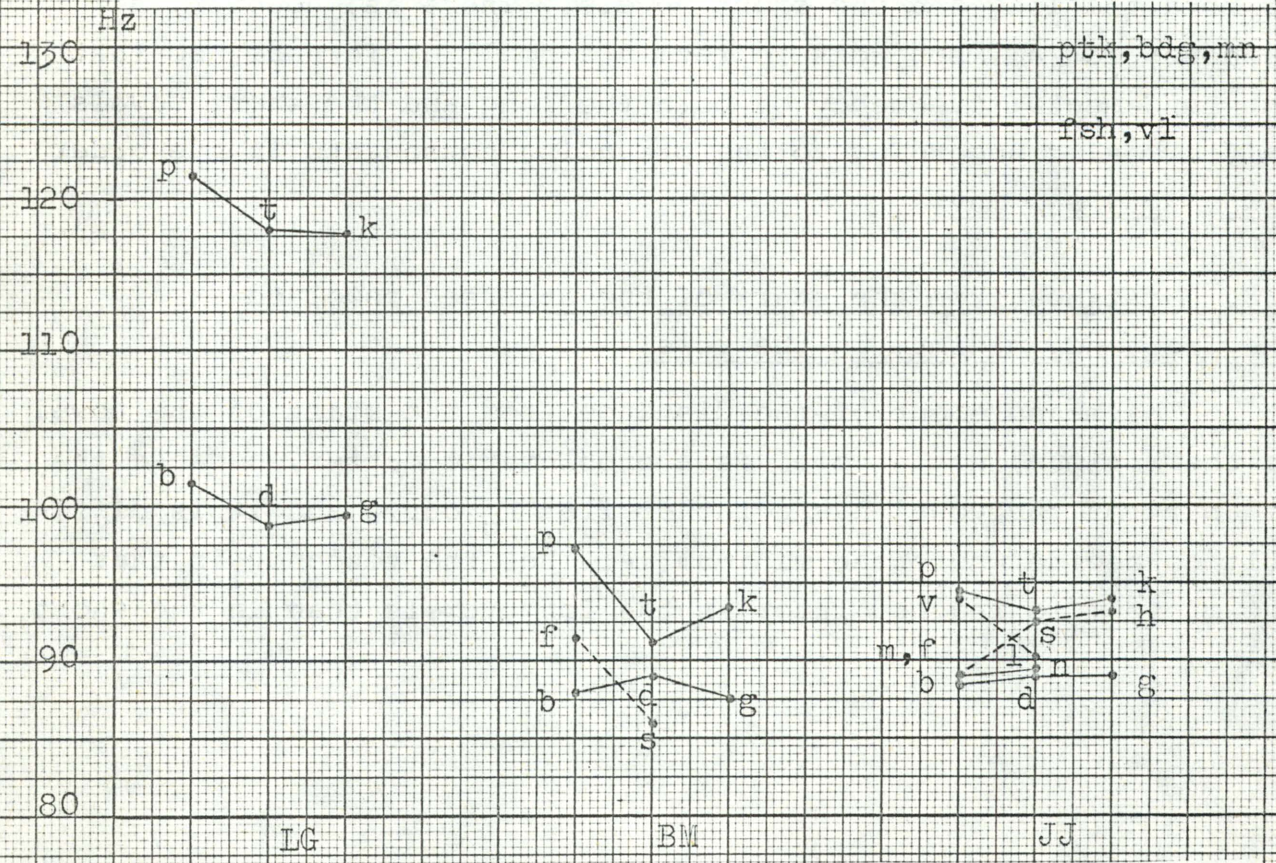

Figure 9. Fundamental frequency at the start of the vowel after various consonants. Male subjects.

TABLE I

Differences between the average frequency values (in Hz) at the start of vowels after various consonants

	VJ	EC	EH	LG	BM	JJ
p	226.3	222.8	208.2	121.5	97.2	94.6
b	223.1	192.8	190.5	101.5	88.1	88.5
diff.	3.2	30.0	17.7	20.0	9.1	6.1
t	232.5	230.6	208.9	118.0	91.0	93.3
d	223.2	200.0	201.4	98.7	89.1	88.9
diff.	9.3	30.6	7.5	19.3	1.9	4.4
k	229.9	224.4	211.1	117.7	93.4	94.1
g	226.8	194.2	201.1	99.4	87.4	89.0
diff.	3.1	30.2	10.0	18.3	6.0	5.1
p	226.3	222.8	208.2		97.2	94.6
f	230.2	210.5	202.9		91.4	88.8
diff.	-3.9	12.3	5.3		5.8	5.8
t	232.5	230.6	208.9		91.0	93.3
s	234.7	210.8	202.4		86.1	92.4
diff.	-2.2	19.8	6.5		4.9	0.9
k	229.9	224.4	211.1			94.1
h	220.8	211.8	194.0			93.2
diff.	9.1	12.6	17.1			0.9
b	223.1	192.8	190.5			88.5
m	215.2	189.2	191.6			89.0
diff.	7.9	3.6	-1.1			-0.5
d	223.2	200.0	201.4			88.9
n	214.2	190.0	189.2			89.5
diff.	9.0	10.0	12.2			-0.6
b	223.1	192.8	190.5			88.5
v	212.2	188.8	187.7			94.2
diff.	10.9	4.0	2.8			-5.7
d	223.2	200.0	201.4			88.9
l	209.2	187.5	186.3			90.3
diff.	14.0	12.5	15.1			-1.4

TABLE II

The table shows whether the difference between averages of the frequency at the start of vowels after various consonants is significant and on which level

	VJ	EC	EH	LG	BM	JJ	
ptk	+ >	+++ >	+++ >	+++ >	+ >	+ >	bdg
pt	<	+++ >	>		++ >	>	fs
k	+++ >	+++ >	+++ >			>	h
bd	+++ >	>	>			<	mn
b	+++ >	>	>			<	v
d	+++ >	+++ >	+++ >			<	l

> means that the fundamental frequency at the start of the vowel is higher after the consonants listed in the left-hand column than after those listed in the right-hand column; < means that it is lower. + indicates the 95% significance level, ++ 99%, and +++ 99.9%.

vowels. Besides, there is a tendency that the distance to the minimum is decreasing according to the preceding consonants in the order ptkh > bdgfs > mnvl, but there are individual deviations from this tendency.

4. Conclusion

The difference between the fundamental frequencies of vowels after bdg and ptk is often explained as a distinction between voiced and voiceless consonants, and the investigation reported here does show that the vowel tends to start at a low frequency after the voiced consonants, viz. m, n, l, v. But there is also a difference between the fundamental frequencies of vowels after Danish bdg and ptk. This cannot be explained as a voiced-voiceless distinction, since both Danish bdg and ptk are voiceless. - According to Halle-Stevens [ptk] should have stiffer vocal cords than [bdg]. This issue cannot be settled on the basis of the present investigation.

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