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VARIATION IN INHERENT Fo LEVEL DIFFERENCES BETWEEN VOWELS AS A FUNCTION OF POSITION IN THE UTTERANCE AND IN THE STRESS GROUP

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Abstract: The inherent Fo level differences in the vowels u and ɑ were examined in a material which made it possible to vary the position of the vowels in the utterance, keeping their position in the stress group constant, and vice versa. The main finding was that the inherent Fo level differences were statistically significant in both stressed and unstressed syllables throughout the material, but in stressed vowels the differences were larger than in the unstressed ones. The effect of position in the utterance and stress group can be summarized as follows: In vowels in stressed position the differences tend to decrease through the utterance, in vowels in first posttonic position they (surprisingly) increase, and in second posttonic position they do not seem to vary systematically with the position in the utterance. Apart from the differences being larger in stressed than in unstressed syllables, there seems to be no effect in the unstressed vowels from their position in the stress group.

1. Introduction

The course of fundamental frequency in non-tonal languages such as Danish may be described as the superposition of three simultaneous main components (apart from emotional factors): 1) a sentence component, which conveys information about the utterance as a whole (is it declarative, interrogative, continuative?), 2) a stress group component, and 3) a segmental component, which is specified by the segments of the utterance.

The sentence and stress group components are mainly language specific (an analysis of these components in Advanced Standard Copenhagen Danish is reported in Thorsen, 1978 and 1979a). The segmentally determined Fo variation, on the other hand, is assumed to be universal[1] and to be a consequence of physiological, aerodynamic and (possibly) acoustical factors in the production of speech (see, e.g., Ohala (1978) and Reinholt Petersen (1978)).

One of the segmental factors influencing fundamental frequency is vowel height. There seems to be a universal tendency for Fo to be higher in high vowels than in low vowels, other things being equal. This phenomenon, which has been termed inherent Fo, intrinsic Fo, vowel specific Fo, has been shown to exist in a number of languages, e.g. English (Peterson and Barney, 1952, Lehiste and Peterson, 1961), French (Di Cristo and Chafcouloff, 1977), German (Neweklowsky, 1975), Swedish (Löfqvist, 1975), Danish (Reinholt Petersen, 1978), Yoruba (Hombert, 1976), and other West African languages (Ladefoged, 1964). (A summary of the literature is given in Hirst, Di Cristo and Nishinuma, 1979.)

The majority of these experiments, however, employed stressed vowels in words embedded in short carrier phrases, and have thus investigated a rather limited subset of the contexts where inherent Fo level differences may play a role in speech.

Reinholt Petersen (1978) used a test material which permitted inherent Fo to be considered in both stressed and unstressed syllables. In that material, vowels were inserted in nonsense words of the structure CV'CV:CV in the carrier phrase "Stavelserne i _____ forkortes" ('The syllables of _____ are shortened'). For technical reasons no measurements were made of Fo in the unstressed vowels, but tracings of the Fo curves showed a clear tendency towards smaller differences between i/u vs. ɑ in unstressed than in stressed vowels.

The purpose of the experiments reported below was to investigate the inherent Fo level variation under more varied conditions. The questions to be considered were the following: Do we find significant Fo level variation in unstressed as well as in stressed syllables, and can the magnitude of the variation be shown to be

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1) This applies to non-tonal languages. In Yoruba, a tonal language, Hombert (1976) has found a tendency to actively minimize the effect of preceding consonants on Fo in vowels.

related to (a) position in the utterance, and (b) position in the stress group (the stress group being defined as a stressed syllable plus the following unstressed syllables up to the next stressed one, irrespective of intervening word or morpheme boundaries, or to the end of the utterance)?

The focusing upon the stress group as a frame of reference in the investigation was due to the fact that the stress group seems to be a basic unit in the description of intonation in Advanced Standard Copenhagen Danish (cf. Thorsen, 1978) and also in the description of variation of vowel duration (Peter Holtse, personal communication).

2. Method

2.1 Material

The test vowels chosen were u and ɑ, embedded in nonsense words of the type mVmVmV, because these vowels have been shown (Reinholt Petersen, 1978) to have the largest inherent Fo differences, and m should have a negligible influence on Fo of the vowels.

The test words appeared in three different versions, viz. with the stress on the first, second, and third syllable, respectively, and each version was placed initially, medially, and finally in a carrier sentence. Thus, the material consisted of the following 18 test sentences:[1]

1 I 'mumumu muteres em'erne
2 I mu'mumu muteres em'erne (In ___ the m's are mutated)
3 I mumu'mu muteres em'erne

4 Em'erne i 'mumumu muteres
5 Em'erne i mu'mumu muteres (The m's in ___ are mutated)
6 Em'erne i mumu'mu muteres

7 Em'erne muteres i 'mumumu
8 Em'erne muteres i mu'mumu (The m's are mutated in ___)
9 Em'erne muteres i mumu'mu

10 I 'marmarmar markeres em'erne
11 I mar'marmar markeres em'erne (In ___ the m's are marked)
12 I marmar'mar markeres em'erne

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1) Note that the orthographic sequence ar is pronounced [ɑ].

13 Em'erne i 'marmarmar markeres
14 Em'erne i mar'marmar markeres (The m's in __ are marked)
15 Em'erne i marmar'mar markeres
16 Em'erne markeres i 'marmarmar
17 Em'erne markeres i mar'marmar (The m's are marked in _)
18 Em'erne markeres i marmar'mar

The relevant syllables are underlined. Note that the word immediately following the testword varies with the testword: muteres after u-words and markeres after ɑ-words. This made it possible to include the first syllable of these words in the test material and thus expand it without having extremely long nonsense words. On the other hand, the segmental structure of these syllables was different from that of the nonsense words, and - what might possibly be more serious - they differed among themselves: u was followed by t and ɑ by k.

It was not clear to what extent the different segmental conditions in the material might be expected to affect the fundamental frequency of the vowels and particularly the Fo difference between u and ɑ in the first syllables of muteres and markeres in comparison with the Fo differences in the nonsense words. From Johansson (1976) it appears that voiceless stops give rise to a higher Fo in the preceding vowel than do nasal consonants (Johansson does not specify the point of measurement in the vowel). On the other hand, Lehiste and Peterson (1961) and Jeel (1975) found no such effect. To my knowledge, an interaction between vowel height and following consonant, particularly with regard to its place of articulation, that would influence the magnitude of the inherent differences between vowels, has never been attested.

In an attempt to clarify these matters under conditions comparable to those of the present investigation, a small, supplementary experiment was conducted, the details of which are given in Appendix I. In that experiment no significant effect on Fo in u and ɑ from the following consonant (m, t, k) could be shown. Nor was there any significant interaction between t and k and preceding u and ɑ. On this basis it was considered justified to include the first syllable of the words muteres and markeres in the test material.

2.2 Recordings, subjects

The 18 test sentences were combined with 9 distractor sentences in 10 different random orders in a reading list. The list was read once by each subject. The recordings took place in a sound treated room at the Institute, using a Sennheiser MD21 microphone and a REVOX A77 tape recorder. The subjects were instructed to read the sentences with a neutral, declarative intonation and to use a speaking rate natural to them. There were four speakers: three female (ER, SI, and KM) and one male (NR, the author), all phoneticians and all speakers of Advanced Standard Copenhagen Danish.

2.3 Registrations and measurements

The apparatus used for registration was a REVOX A77 tape recorder, an intensity meter, and a fundamental frequency extractor (both F-J Electronics), and a Mingograph (Elema 800). The following acoustic registrations were made: duplex oscillogram, linear HiFi intensity curve (integration time 2.5 ms), logarithmic HP-filtered (500 Hz) intensity curve (integration time 5 ms), fundamental frequency curve.

The duplex oscillogram and the intensity curves were used for segmentation. The accuracy of segmentation was ±0.5 cs. With regard to the Fo measurements, it proved impossible to establish a point of measurement which was defined on the basis of the Fo curve itself (e.g. Fo minimum or Fo maximum) and which could be used consistently throughout the material. Therefore, Fo was measured at the middle of the test vowels. This point has the advantage of being easily determined from the duplex oscillogram and intensity curves, and it is appropriate in the sense that the midpoint Fo measure yields a reasonably accurate description of the Fo movement in the testwords. This is illustrated in fig. 1, where actual Fo curves are compared with curves interpolated between the midpoint Fo values. The maximum difference between the curves is about 3 Hz for subject NR and 7 Hz for subject KM, i.e. about 3 per cent. A few samples had to be dismissed for various reasons, but altogether 2537 Fo measurements were obtained out of 2640 possible (4 subjects x 10 repetitions x (12 sentences x 4 vowels + 6 sentences x 3 vowels)).

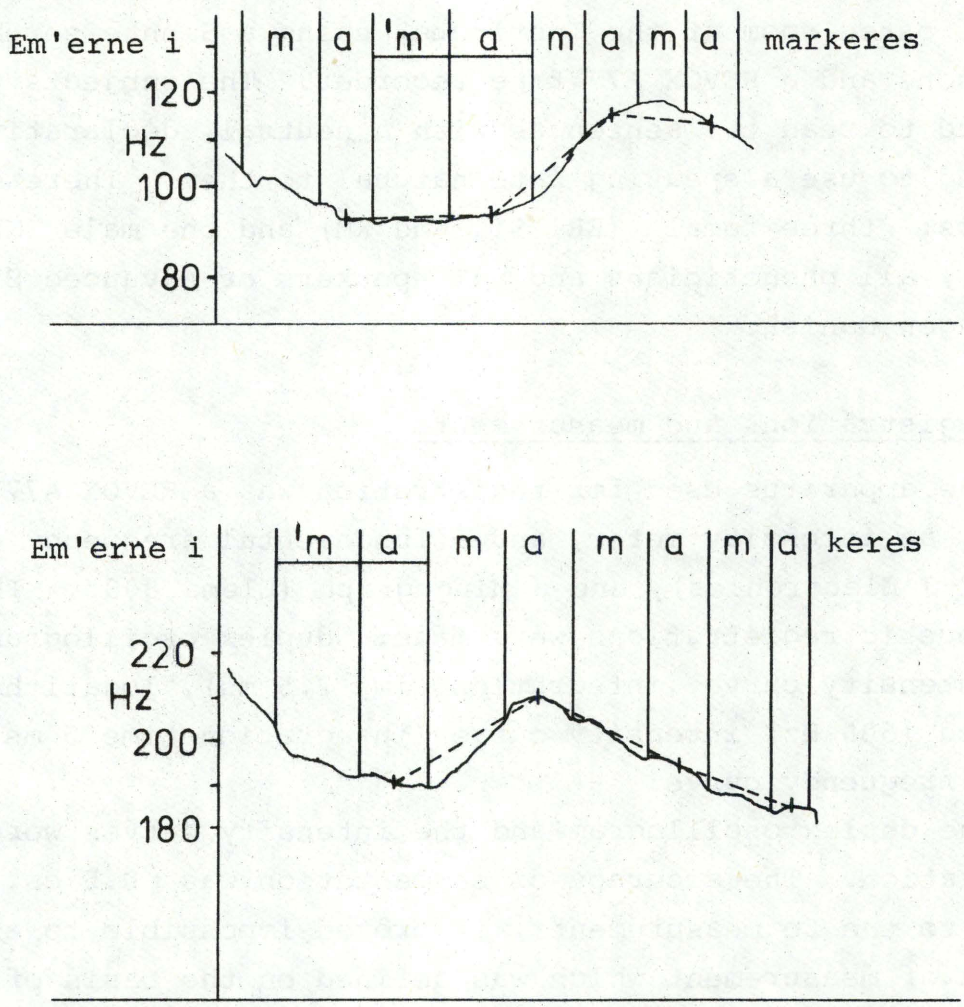

Figure 1

Examples of actual Fo curves (full lines) and curves interpolated between the Fo values measured at the middle of the vowels (broken line). The short vertical lines in the curves indicate the points of measurement. Subject NR (top) and subject KM (bottom).

3. Results

Mean fundamental frequencies and standard deviations for all vowels in the test material are tabulated for the four speakers in tables 1 to 4, and the means are shown graphically in figs. 2 to 5. Furthermore, the means obtained for each subject were converted into a relative measure, viz. the deviation in semitones from that subject's stressed ɑ in sentence 10 (i.e. the ɑ-sentence in which the test word occurs in initial position and is stressed on the first syllable). Fig. 6 shows the means over all subjects expressed in semitones.

It appears that the Fo measures obtained in the present experiment are in good agreement with what should be expected from Thorsen's (1978) model for the Fo course in declarative sentences in Advanced Standard Copenhagen Danish (part of Thorsen's model is shown in fig. 7). Furthermore, it is clear that the magnitude of the Fo variation determined by the stress groups decreases through the utterance, also when expressed in semitones, i.e. the decrease of the absolute variation through the utterance as shown in figs. 2 to 5 does not correspond to a constant relative variation (see also Thorsen, 1979b).

3.1 Inherent Fo variation

Tables 5 to 8 enumerate the mean Fo differences between u and ɑ. The statistical significance of the differences was tested by a series of t-tests. The levels of significance achieved are given in the tables.

In stressed syllables the differences between u and ɑ were significant at a very high level ($p < 0.001$) in all cases except one, namely in utterance final position for subject NR; here the difference was significant at the 1 per cent level.

In unstressed syllables the differences were slightly less clear, but still a level of significance of 5 per cent or better was achieved in 85 out of 96 cases (i.e. 24 unstressed vowels x 4 speakers). The fundamental frequency of ɑ was in no case higher than that of u.

From tables 5 to 8 and figs. 2 to 5 it appears that the magnitude of the differences between the Fo of u and ɑ is correlated

Table 1

Means and standard deviations (in Hz), arranged in accordance with the structure of the material (see the list in section 2.1 above). The stress groups are delimited by vertical lines. Subject ER.

	utterance position 1	2	3	4	5	6	7	8	9	10
u	i	296.8 11.09	369.7 17.62	310.8 14.63	285.6 14.75	te	res	em'	er	ne
ɑ	i	248.9 20.78	351.8 19.59	277.4 20.71	252.3 14.41	ke	res	em'	er	ne
u	i	249.7 10.63	269.6 16.81	338.5 12.42	284.3 16.15	te	res	em'	er	ne
ɑ	i	228.3 10.70	237.2 14.06	323.8 24.36	271.5 9.66	ke	res	em'	er	ne
u	i	254.5 12.42	244.6 17.32	309.6 15.41	327.1 18.00	te	res	em'	er	ne
ɑ	i	231.6 9.58	222.0 8.79	252.0 15.10	303.7 26.22	ke	res	em'	er	ne
u	em'	er	ne	i	267.8 15.51	313.2 19.14	272.5 10.78	267.2 14.26	te	res
ɑ	em'	er	ne	i	225.1 4.48	284.2 12.45	237.3 11.97	230.3 8.90	ke	res
u	em'	er	ne	i	260.8 11.51	269.3 14.38	313.3 12.60	278.4 14.67	te	res
ɑ	em'	er	ne	i	240.1 19.72	215.3 8.78	277.7 12.75	254.0 12.90	ke	res
u	em'	er	ne	i	262.0 11.17	245.3 9.33	282.4 19.35	300.7 17.81	te	res
ɑ	em'	er	ne	i	244.1 13.76	224.2 12.08	238.9 13.85	281.0 9.85	ke	res
u	em'	er	ne	mu	te	res	i	222.3 12.32	240.1 13.06	207.8 7.40
ɑ	em'	er	ne	mar	ke	res	i	194.7 9.11	217.7 7.45	193.1 4.14
u	em'	er	ne	mu	te	res	i	246.5 16.86	214.4 6.54	222.0 9.67
ɑ	em'	er	ne	mar	ke	res	i	229.7 18.74	187.4 5.72	205.3 8.34
u	em'	er	ne	mu	te	res	i	241.8 13.15	226.0 15.19	211.1 7.42
ɑ	em'	er	ne	mar	ke	res	i	229.0 13.03	216.2 13.75	184.5 6.00

Table 2

Means and standard deviations (in Hz), arranged in accordance with the structure of the material (see the list in section 2.1 above). The stress groups are delimited by vertical lines. Subject SI.

	utterance position 1	2	3	4	5	6	7	8	9	lo
u	i	285.o lo.72	326.4 13.88	282.1 12.6o	259.8 9.4o	te	res	em'	er	ne
ɑ	i	242.8 7.27	3o3.3 lo.14	27o.3 7.87	251.5 6.11	ke	res	em'	er	ne
u	i	26o.6 14.35	28o.7 17.62	322.1 16.34	289.1 14.65	te	res	em'	er	ne
ɑ	i	239.7 6.95	241.6 8.92	3o3.1 14.39	286.3 8.54	ke	res	em'	er	ne
u	i	256.6 8.14	250.8 lo.56	284.3 lo.ol	3o8.8 15.3o	te	res	em'	er	ne
ɑ	i	245.o 8.29	238.3 7.23	257.4 12.65	298.3 12.62	ke	res	em'	er	ne
u	em'	er	ne	i	262.8 11.77	288.9 12.79	262.8 7.69	249.8 8.66	te	res
ɑ	em'	er	ne	i	223.o lo.19	274.4 18.55	253.9 11.63	24o.9 8.41	ke	res
u	em'	er	ne	i	253.4 5.17	247.o 5.o6	276.9 6.97	266.2 6.1o	te	res
ɑ	em'	er	ne	i	243.o 6.27	217.8 6.49	257.9 8.49	259.o lo.49	ke	res
u	em'	er	ne	i	264.3 6.11	25o.9 3.45	261.6 6.46	28o.9 7.ol	te	res
ɑ	em'	er	ne	i	246.5 3.34	234.o 5.ol	235.3 4.76	272.3 9.64	ke	res
u	em'	er	ne	mu	te	res	i	242.7 12.o4	264.1 18.o3	232.8 9.o4
ɑ	em'	er	ne	mar	ke	res	i	211.4 7.92	242.8 12.74	227.3 8.44
u	em'	er	ne	mu	te	res	i	254.4 12.47	228.9 14.54	235.7 15.o7
ɑ	em'	er	ne	mar	ke	res	i	248.1 11.39	2o5.9 7.oo	226.7 7.21
u	em'	er	ne	mu	te	res	i	263.1 6.1o	249.5 7.43	224.3 8.65
ɑ	em'	er	ne	mar	ke	res	i	245.2 4.49	233.9 7.19	2o3.6 6.5o

Table 3

Means and standard deviations (in Hz), arranged in accordance with the structure of the material (see the list in section 2.1 above). The stress groups are delimited by vertical lines. Subject KM.

	utterance position									
	1	2	3	4	5	6	7	8	9	lo
u	i	198.6 8.3o	23o.8 9.19	2o6.7 5.56	191.7 6.17	te	res	em'	er	ne
a	i	182.o 6.57	223.8 9.75	198.8 5.83	185.o 3.81	ke	res	em'	er	ne
u	i	187.5 5.13	196.8 6.12	228.o 7.67	2o4.5 4.77	te	res	em'	er	ne
a	i	175.3 4.22	176.1 3.96	216.4 8.54	2o1.o 6.94	ke	res	em'	er	ne
u	i	182.4 4.86	176.9 5.16	199.6 3.92	214.6 9.13	te	res	em'	er	ne
a	i	171.6 4.93	169.1 3.63	183.o 7.16	2o8.7 8.98	ke	res	em'	er	ne
u	em'	er	ne	i	188.6 4.72	212.o 6.oo	193.3 5.62	182.5 2.17	te	res
a	em'	er	ne	i	173.o 4.78	2oo.3 4.47	185.4 6.47	177.8 4.73	ke	res
u	em'	er	ne	i	187.7 5.33	186.5 6.22	2o9.1 6.4o	193.4 7.24	te	res
a	em'	er	ne	i	178.2 6.25	166.9 5.32	197.3 1o.23	184.6 6.8o	ke	res
u	em'	er	ne	i	184.9 4.31	178.o 4.35	192.4 6.33	2o4.3 4.4o	te	res
a	em'	er	ne	i	172.7 4.o8	167.7 4.o8	176.6 5.58	199.o 6.41	ke	res
u	em'	er	ne	mu	te	res	i	179.2 5.o5	185.9 4.26	179.o 6.6o
a	em'	er	ne	mar	ke	res	i	165.o 4.67	175.2 6.53	172.1 5.4o
u	em'	er	ne	mu	te	res	i	184.o 7.45	172.o 3.16	187.6 4.24
a	em'	er	ne	mar	ke	res	i	173.4 5.78	157.8 2.70	17o.3 4.81
u	em'	er	ne	mu	te	res	i	18o.6 3.57	171.7 3.83	172.5 4.84
a	em'	er	ne	mar	ke	res	i	172.5 4.22	163.o 4.o2	162.3 3.62

Table 4

Means and standard deviations (in Hz), arranged in accordance with the structure of the material (see the list in section 2.1 above). The stress groups are delimited by vertical lines. Subject NR.

utterance position

	1	2	3	4	5	6	7	8	9	lo
u	i	lol.o 2.45	124.7 3.27	118.o 3.92	lo8.9 3.38	te	res	em'	er	ne
ɑ	i	87.5 2.68	117.3 4.22	llo.5 3.69	95.8 2.1o	ke	res	em'	er	ne
u	i	91.8 2.39	99.9 3.45	123.5 4.45	113.3 2.54	te	res	em'	er	ne
ɑ	i	85.4 3.27	87.6 2.17	117.o 4.83	lo9.1 4.o4	ke	res	em'	er	ne
u	i	93.o 1.63	92.o 1.7o	lo3.5 2.92	125.4 4.ol	te	res	em'	er	ne
ɑ	i	87.1 3.35	86.2 2.57	93.4 2.76	121.o 4.4o	ke	res	em'	er	ne
u	em'	er	ne	i	loo.o 2.87	117.2 5.57	111.8 4.57	lo4.9 3.45	te	res
ɑ	em'	er	ne	i	86.8 1.o3	lo9.8 7.o8	lo5.o 4.32	95.o 4.88	ke	res
u	em'	er	ne	i	95.6 3.13	99.3 2.55	117.1 4.46	llo.2 2.68	te	res
ɑ	em'	er	ne	i	89.8 1.23	87.3 1.64	llo.o 3.27	lo7.1 3.67	ke	res
u	em'	er	ne	i	98.1 2.88	94.7 2.63	lo2.5 4.4o	119.3 5.5o	te	res
ɑ	em'	er	ne	i	89.o 2.62	84.7 3.oo	9o.9 2.42	llo.9 3.67	ke	res
u	em'	er	ne	mu	te	res	i	89.3 3.27	9o.7 2.45	91.4 4.43
ɑ	em'	er	ne	mar	ke	res	i	82.9 2.28	82.8 1.93	85.3 1.34
u	em'	er	ne	mu	te	res	i	97.1 5.9o	89.3 2.65	88.o 2.65
ɑ	em'	er	ne	mar	ke	res	i	88.4 6.oo	78.6 4.25	8o.o 2.33
u	em'	er	ne	mu	te	res	i	97.2 3.26	94.3 2.83	86.2 3.26
ɑ	em'	er	ne	mar	ke	res	i	91.5 4.79	9o.1 2.69	8o.6 5.2o

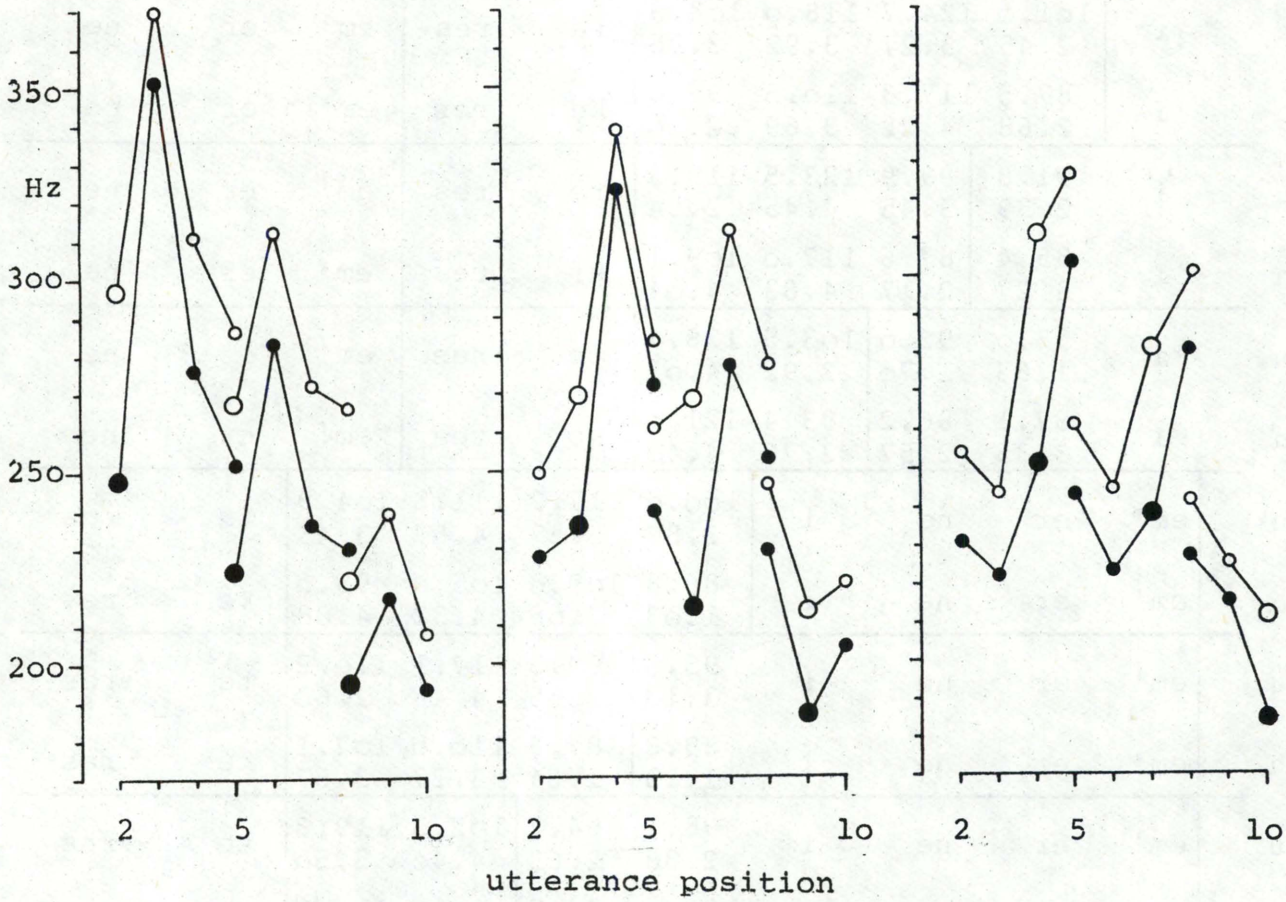

Figure 2

Mean fundamental frequencies (in Hz) in the test words. The data-points belonging to the same word are connected by straight lines. The left, middle, and right graphs display words with the stress on the first, second, and third syllables, respectively. Large circles represent stressed and small circles unstressed syllables. u is indicated by open and ɑ by filled circles. Subject ER.

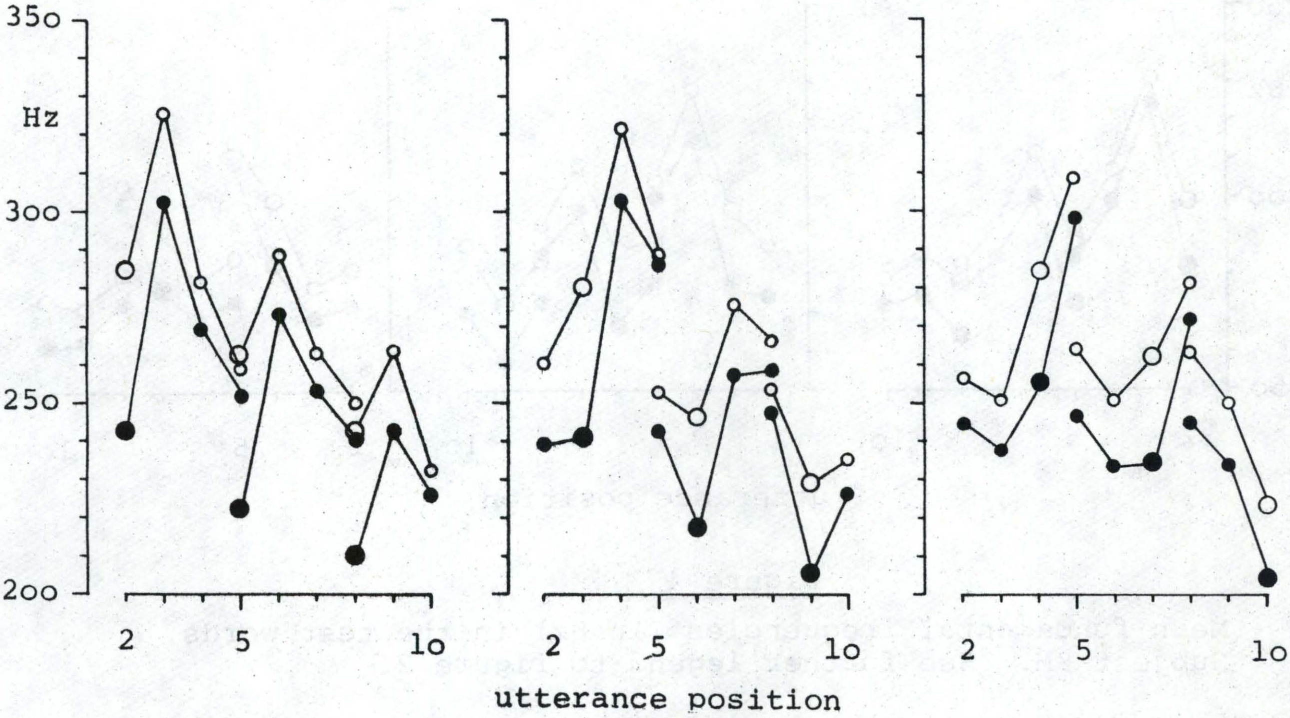

Figure 3

Mean fundamental frequencies (in Hz) in the test words. Subject SI. See further legend to figure 2.

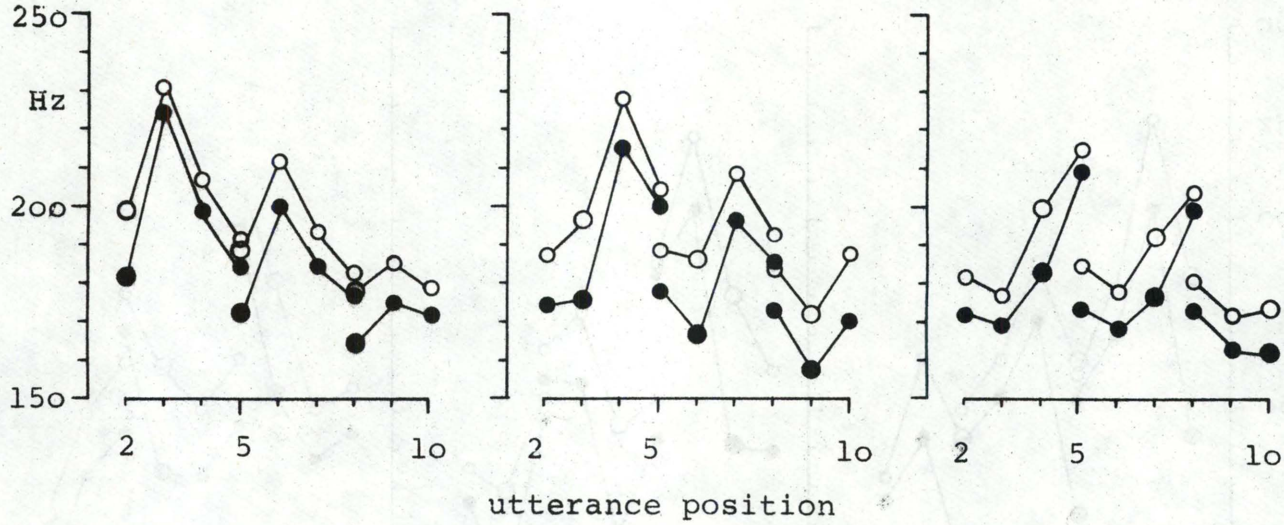

Figure 4

Mean fundamental frequencies (in Hz) in the test words. Subject KM. See further legend to figure 2.

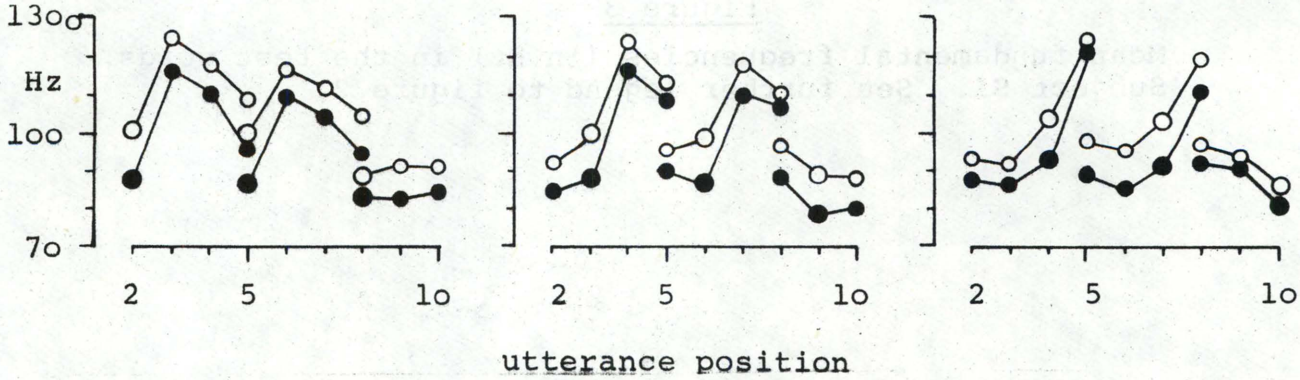

Figure 5

Mean fundamental frequencies (in Hz) in the test words. Subject NR. See further legend to figure 2.

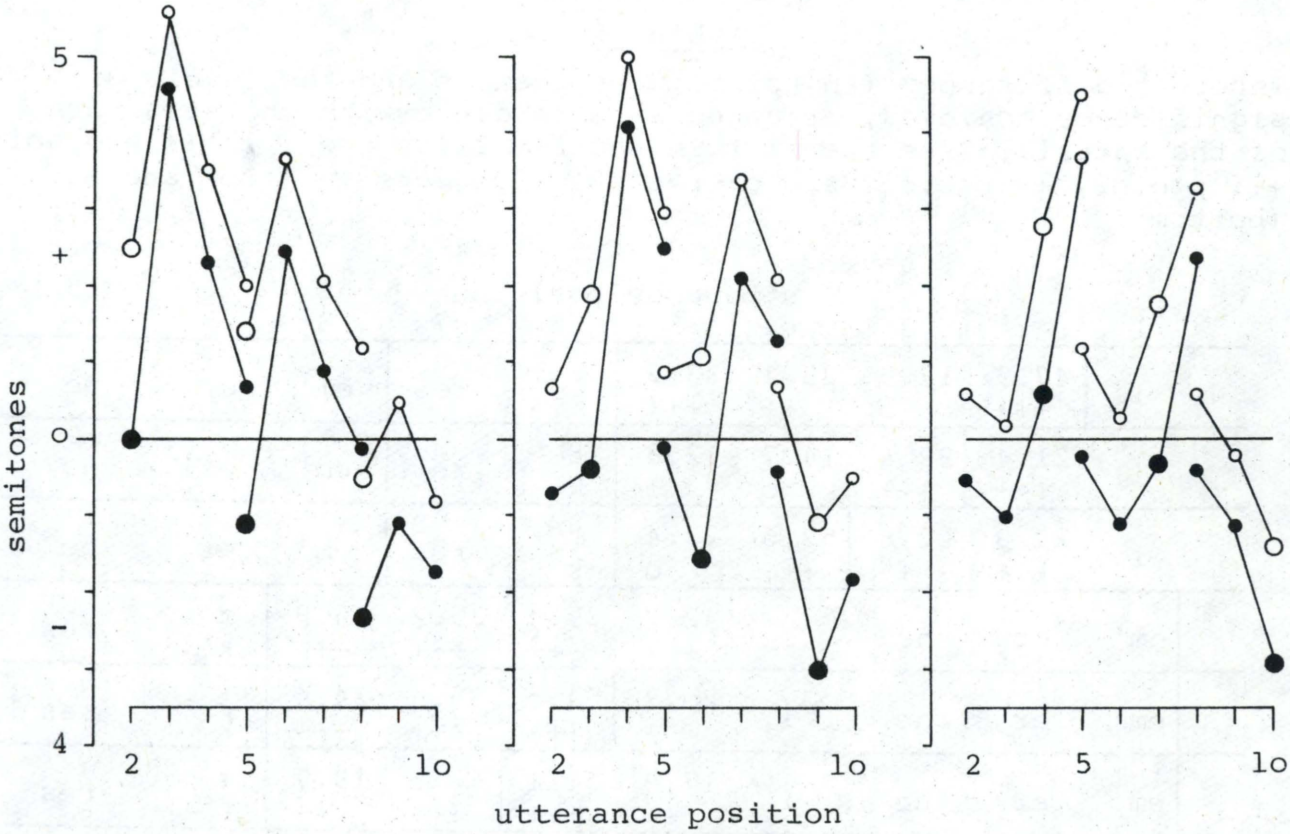

Figure 6

Mean Fo (in semitones) in the test words. All subjects pooled. See further legend to figure 2.

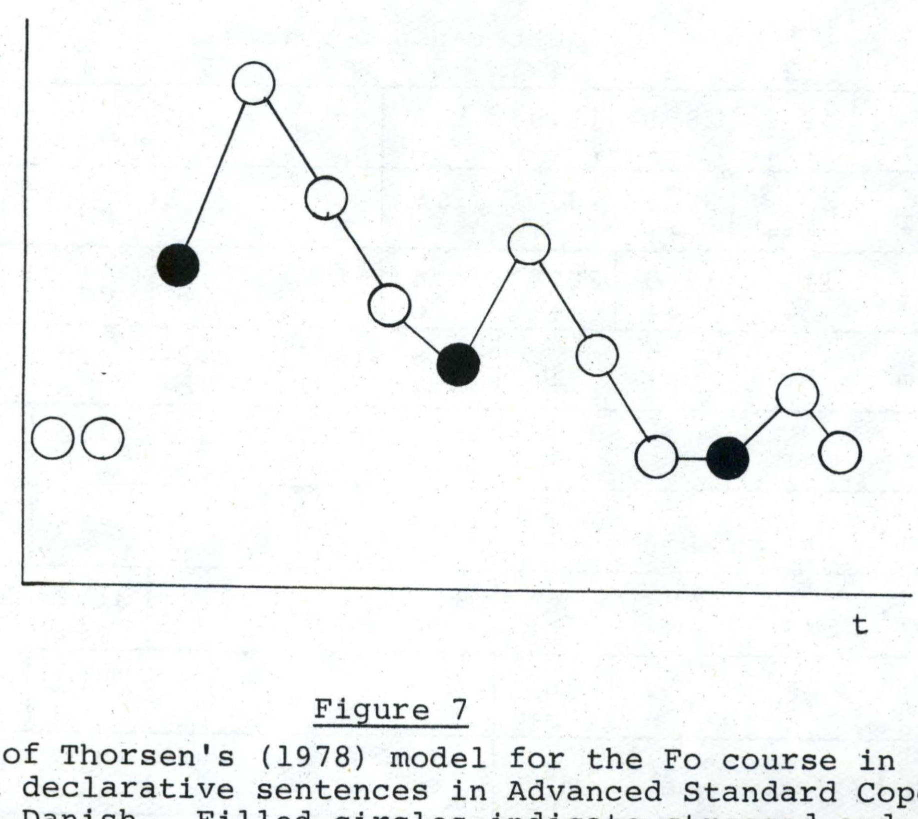

Figure 7

Part of Thorsen's (1978) model for the Fo course in short declarative sentences in Advanced Standard Copenhagen Danish. Filled circles indicate stressed and open circles indicate unstressed syllables.

Tables 5-6

Inherent differences (in Hz) between u and ɑ and the levels of significance achieved, arranged in accordance with the structure of the material (see the list in section 2.1 above). +++: p<o.ool, ++: p<o.ol, +: p<o.o5, and o: p>o.o5. Subjects ER (top) and SI (bottom).

utterance position

1	2	3	4	5	6	7	8	9	lo
i	47.9 +++	17.9 o	33.3 ++	33.2 +++	$^{t}_{k}e$	res	em'	er	ne
i	21.4 +++	32.4 +++	14.7 o	12.8 +	$^{t}_{k}e$	res	em'	er	ne
i	22.9 +++	22.6 ++	57.6 +++	23.4 o	$^{t}_{k}e$	res	em'	er	ne
em'	er	ne	i	42.7 +++	29.o ++	35.2 +++	36.9 +++	$^{t}_{k}e$	res
em'	er	ne	i	2o.7 +	54.o +++	35.6 +++	24.4 +++	$^{t}_{k}e$	res
em'	er	ne	i	17.9 ++	21.1 +++	43.5 +++	19.7 ++	$^{t}_{k}e$	res
em'	er	ne	m^{u}_{ar}	$^{t}_{k}e$	res	i	27.6 +++	22.4 +++	14.7 +++
em'	er	ne	m^{u}_{ar}	$^{t}_{k}e$	res	i	16.8 +	27.o +++	16.7 +++
em'	er	ne	m^{u}_{ar}	$^{t}_{k}e$	res	i	12.8 +	9.8 o	26.6 +++

utterance position

1	2	3	4	5	6	7	8	9	lo
i	42.2 +++	23.1 +++	11.8 +	8.3 +	$^{t}_{k}e$	res	em'	er	ne
i	2o.8 +++	39.1 +++	19.o +	2.8 +++	$^{t}_{k}e$	res	em'	er	ne
i	11.6 ++	12.5 ++	26.9 +++	1o.4 o	$^{t}_{k}e$	res	em'	er	ne
em'	er	ne	i	39.8 +++	14.5 o	8.9 o	8.9 +	$^{t}_{k}e$	res
em'	er	ne	i	1o.4 +++	29.2 +++	19.o +++	7.2 o	$^{t}_{k}e$	res
em'	er	ne	i	17.8 +++	16.9 +++	26.3 +++	8.6 +	$^{t}_{k}e$	res
em'	er	ne	m^{u}_{ar}	$^{t}_{k}e$	res	i	31.2 +++	21.3 +	5.4 o
em'	er	ne	m^{u}_{ar}	$^{t}_{k}e$	res	i	6.3 o	23.o +++	9.o o
em'	er	ne	m^{u}_{ar}	$^{t}_{k}e$	res	i	17.9 +++	15.6 +++	2o.7 +++

Tables 7-8

Inherent differences (in Hz) between u and ɑ and the levels of significance achieved, arranged in accordance with the structure of the material (see the list in section 2.1 above). +++: p<o.ool, ++: p<o.ol, +: p<o.o5, and o: p>o.o5. Subjects KM (top) and NR (bottom).

utterance position									
1	2	3	4	5	6	7	8	9	lo
i	16.6 +++	7.o o	7.9 ++	6.7 +	$^{t}_{k}$e	res	em'	er	ne
i	12.2 +++	2o.7 +++	11.6 ++	3.5 o	$^{t}_{k}$e	res	em'	er	ne
i	lo.8 +++	7.8 ++	16.6 +++	5.9 o	$^{t}_{k}$e	res	em'	er	ne
em'	er	ne	i	15.6 +++	11.7 +++	7.9 ++	4.7 +	$^{t}_{k}$e	res
em'	er	ne	i	9.5 ++	19.6 +++	11.8 ++	8.8 +	$^{t}_{k}$e	res
em'	er	ne	i	12.2 +++	lo.3 +++	15.8 +++	5.3 +	$^{t}_{k}$e	res
em'	er	ne	m^{u}_{ar}	$^{t}_{k}$e	res	i	14.2 +++	lo.7 +++	6.9 +
em'	er	ne	m^{u}_{ar}	$^{t}_{k}$e	res	i	lo.6 +	14.2 +++	17.3 +++
em'	er	ne	m^{u}_{ar}	$^{t}_{k}$e	res	i	8.1 +++	7.9 +++	lo.2 +++

utterance position									
1	2	3	4	5	6	7	8	9	lo
i	13.5 +++	7.4 +++	7.5 +++	13.1 +++	$^{t}_{k}$e	res	em'	er	ne
i	6.4 +++	12.3 +++	6.5 ++	4.2 +	$^{t}_{k}$e	res	em'	er	ne
i	5.9 +++	5.8 +++	lo.1 +++	4.4 +	$^{t}_{k}$e	res	em'	er	ne
em'	er	ne	i	13.2 +++	7.4 +	6.8 ++	9.9 +++	$^{t}_{k}$e	res
em'	er	ne	i	5.8 +++	12.o +++	7.1 +++	3.1 o	$^{t}_{k}$e	res
em'	er	ne	i	9.1 +++	lo.o +++	11.6 +++	8.4 +++	$^{t}_{k}$e	res
em'	er	ne	m^{u}_{ar}	$^{t}_{k}$e	res	i	6.4 +++	7.9 +++	6.1 +++
em'	er	ne	m^{u}_{ar}	$^{t}_{k}$e	res	i	8.7 ++	lo.8 +++	8.o +++
em'	er	ne	m^{u}_{ar}	$^{t}_{k}$e	res	i	5.7 ++	4.2 ++	5.6 ++

with the over-all Fo level of the speaker. Therefore, the absolute differences were converted into relative ones, so the difference between a given u and corresponding ɑ was expressed in semitones relative to the ɑ. Note, however, that subject ER's inherent differences are somewhat larger than those of SI, although the two speakers have approximately same over-all Fo levels. In this connection it is also worth noticing that the range of Fo deflection in the stress group and intonation contour is larger with ER than with SI. This is interesting, since it could be indicative of a tendency towards agreement between suprasegmental and segmental factors with regard to the magnitude of the Fo variation they give rise to.

3.1.1 Inherent Fo differences in relation to position in the utterance

The material was structured in such a manner that the Fo differences between u and ɑ could be examined in different positions in the utterance while position in the stress group was kept constant. This is illustrated in table 9 which also shows the part of the material considered in the present section.

In fig. 8 the inherent Fo differences, expressed in semitones, are plotted as a function of the position in the utterance in stressed, first posttonic, and second posttonic syllables, respectively. (The third, fourth, and fifth posttonic syllables were left out, because they occurred only in few and unevenly distributed positions in the utterance - cf. table 9). The straight lines in fig. 8 are regression lines fitted to the data points of all speakers pooled using the least squares method.

In the stressed vowels there is a statistically significant negative correlation between the inherent differences (expressed in semitones) and the position in the utterance. The slope of the regression line is -0.09 and the correlation coefficient -0.367 ($p < 0.05$, N=36).

In vowels in the first posttonic syllable the opposite tendency seems to apply, i.e. there is a positive correlation between the differences and the position in the utterance. The slope of the regression line is +0.072 and the correlation coefficient 0.406 ($p < 0.02$, N=32).

Table 9

Schematic description of the test material. The columns correspond to the utterance positions, and each of the rows represent two sentences with identical stress patterns (one u- and one ɑ-sentence). The testwords are underlined, and the stress patterns are given by numerals, 0 being the stressed syllable, 1 the first posttonic, 2 the second posttonic, etc. The syllables considered in the present section are enclosed in rectangles.

Word No.	Utterance position									
	1	2	3	4	5	6	7	8	9	10
1 - 10	-	0	1	2	3	0	1	0	1	2
2 - 11	-	-	0	1	2	0	1	0	1	2
3 - 12	-	-	-	0	1	0	1	0	1	2
4 - 13	0	1	2	3	0	1	2	3	0	1
5 - 14	0	1	2	3	4	0	1	2	0	1
6 - 15	0	1	2	3	4	5	0	1	0	1
7 - 16	0	1	2	3	0	1	2	0	1	2
8 - 17	0	1	2	3	0	1	2	3	0	1
9 - 18	0	1	2	3	0	1	2	3	4	0

In vowels in the second posttonic position the inherent Fo differences are also increasing through the utterance, although to a much lesser degree than in the first posttonic position. The slope of the regression line is +0.004 and the correlation could not be shown to be statistically significant, $r = 0.015$ ($p > 0.05$, $N=20$).

Thus, it seems reasonable to conclude that in stressed position the inherent Fo differences decrease slightly through the utterance, in first posttonic syllables they increase slightly, and in the second posttonic position they are constant (constant in the sense that the variation cannot be accounted for by the position in the utterance).

3.1.2 Inherent Fo differences in relation to position in the stress group

The structure of the material made it possible to examine the inherent Fo differences in different positions in the stress

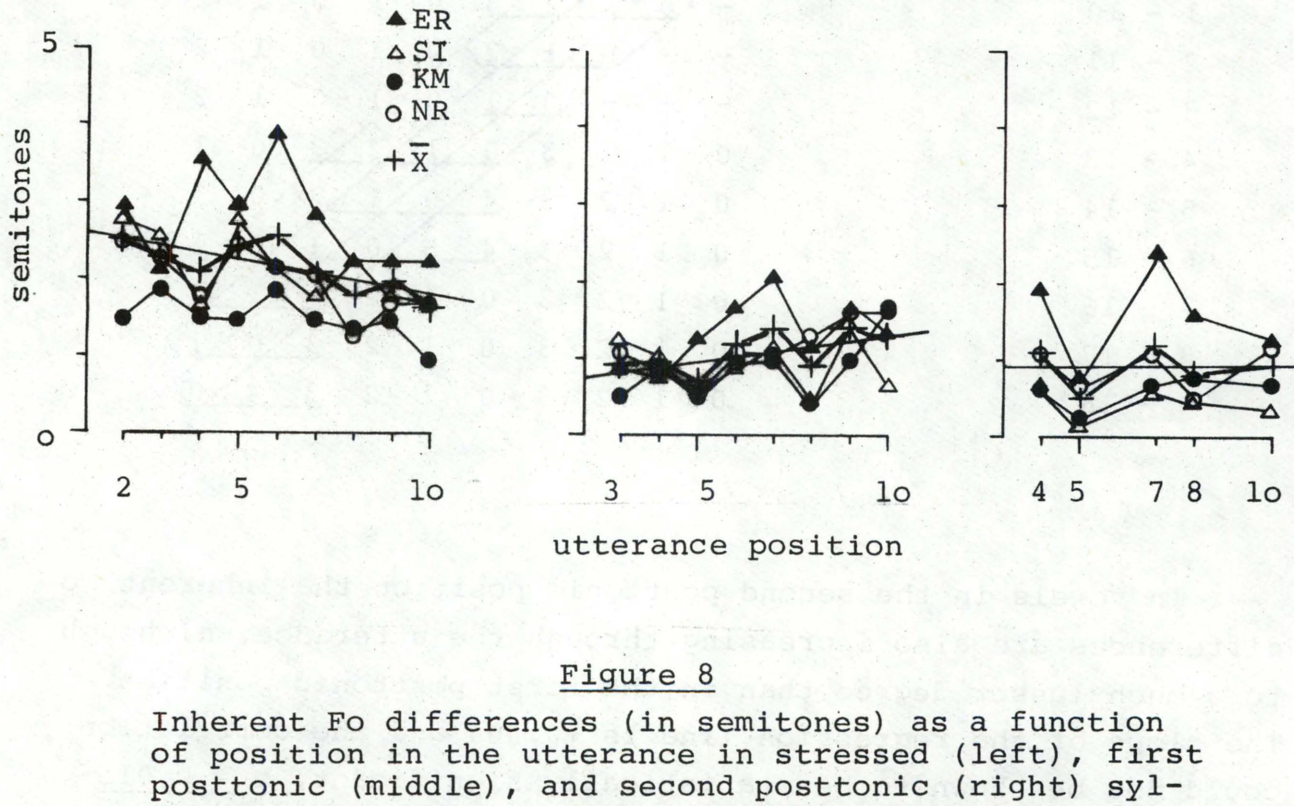

Figure 8

Inherent Fo differences (in semitones) as a function of position in the utterance in stressed (left), first posttonic (middle), and second posttonic (right) syllables. The straight lines are regression lines fitted to the data points of all subjects pooled.

group, keeping the position in the utterance constant. This is shown in table 10 from which it can also be seen that the number of different stress group positions represented in each utterance position differs between utterance positions; in utterance position 4, for example, stress group positions 0, 1, and 2 (i.e. stressed syllable and the first and second posttonic syllables) are represented, while e.g. in position 5 in the utterance the stress group positions 0 through 4 are represented.

Table 10

Schematic description of the test material. The columns correspond to the utterance positions, and each of the rows represents two sentences with identical stress patterns (one u- and one ɑ-sentence). The testwords are underlined, and the stress patterns are given by numerals, 0 being the stressed syllable, 1 the first posttonic, 2 the second posttonic, etc. The syllables considered in the present section are enclosed in rectangles.

Word No.	Utterance position									
	1	2	3	4	5	6	7	8	9	10
1 - 10	-	0	1	2	3	0	1	0	1	2
2 - 11	-	-	0	1	2	0	1	0	1	2
3 - 12	-	-	-	0	1	0	1	0	1	2
4 - 13	0	1	2	3	0	1	2	3	0	1
5 - 14	0	1	2	3	4	0	1	2	0	1
6 - 15	0	1	2	3	4	5	0	1	0	1
7 - 16	0	1	2	3	0	1	2	0	1	2
8 - 17	0	1	2	3	0	1	2	3	0	1
9 - 18	0	1	2	3	0	1	2	3	4	0

In fig. 9 the relative inherent Fo differences are plotted as a function of their position in the stress group in each of the utterance positions examined. Although the variation between subjects is considerable, the general tendency (although not entirely consistent) seems to be that the differences are reduced as a function of the position in the stress group up to and including the second posttonic position. From that point the differences seem to increase, as judged from the utterance positions

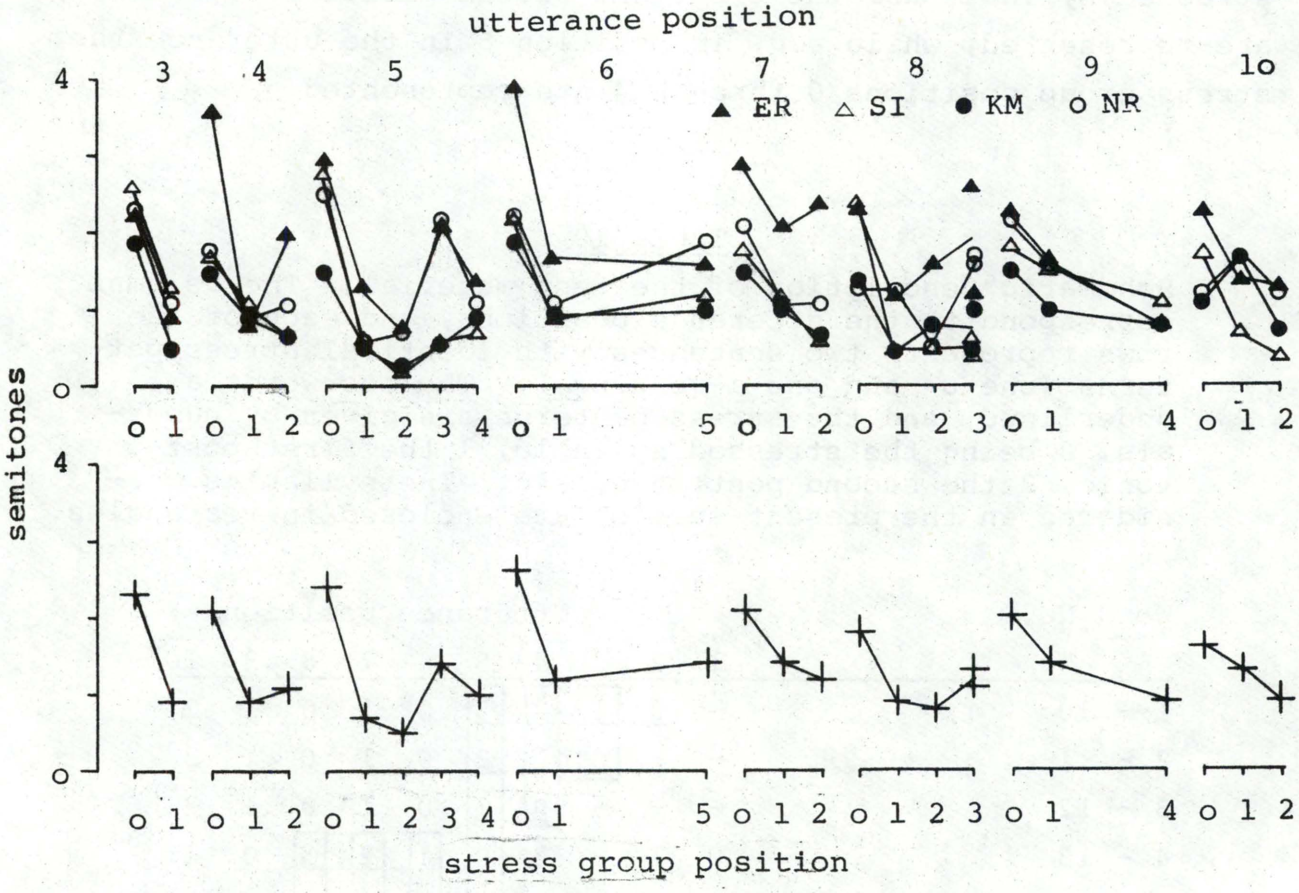

Figure 9

Inherent Fo (in semitones) as a function of the position in the stress group in utterance position 3 through 10. Position o in the stress group indicates the stressed syllable, and 1 through 5 indicate the first through fifth posttonic syllables. The upper graph shows the data for the individual subjects, and the lower shows the averages over all subjects. Note that the third posttonic syllable in utterance position 8 is represented by two data points. This is due to the fact that this syllable occurred twice under equivalent conditions (see table 10). In the graphs the lines connecting the data points end at the mean of the two data points.

in which the stress group positions later than the second posttonic position are represented (viz. positions 5, 6, 8, and 9 in the utterance).

It must be kept in mind, however, that the effect of the stress group position is to some extent blurred by the influence from position in the utterance. Fig. 9 shows that the difference in inherent Fo between the stressed syllable and the first posttonic syllable is reduced through the utterance, and that the relation between those syllables and the others is also changed through the utterance (cf. section 3.1.1 above).

In an attempt to normalize for the utterance position effect the mean inherent differences (fig. 9, lower graph) in stress group positions 0 and 1 were converted to deviations from the regression lines describing the utterance position effect (cf. section 3.1.1 and fig. 8). The data of stress group positions 2, 3, 4, and 5 were not normalized, since the utterance position effect was assumed to be negligible in stress group position 2 and, supposedly, this was also the case in positions 3, 4, and 5. In order to obtain the correct relations between the stressed syllable and the first posttonic one, and between those syllables and the remaining ones, the difference in the middle of the utterance (i.e. in the imaginary position 5.5) computed from the regression lines was added to the deviation found in the stressed and first posttonic syllables. The normalized inherent differences in each stress group position were then averaged over all utterance positions. The normalized and averaged differences are plotted in fig. 10. The tendency towards decreasing/increasing inherent Fo differences through the stress group is also apparent in the normalized data, but it must be pointed out that the increase is represented by the data points corresponding to the third and the fifth posttonic syllables, which have been determined under the assumption of constant inherent differences through the utterance (cf. section 3.1.1 above). Furthermore, the fifth posttonic syllable occurs only once in the material, namely in position 6 in the utterance. In view of this, it may perhaps be too rash to maintain that the inherent Fo differences show a decreasing/increasing tendency through the stress group. On the contrary, it may not be unreasonable to suggest that in the unstressed syllables the magnitude of the inherent Fo differences is constant through the stress group.

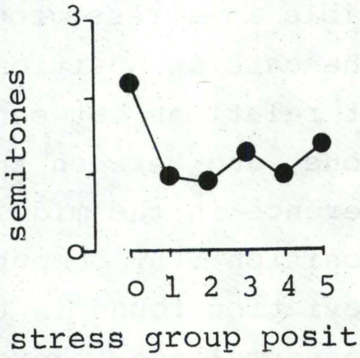

Figure 10
Normalized and averaged inherent differences (in semitones) plotted as a function of position in the stress group.

4. Discussion

As regards the fundamental frequency contributions from the sentence- and stress group components, the results obtained in the present experiment are in good agreement with those of previous investigations of the intonation of Advanced Standard Copenhagen Danish (Thorsen, 1978).

The specific purpose of the experiment reported above was to examine the effect upon the inherent Fo differences in vowels of suprasegmental factors such as stress conditions (stress vs. nonstress), and position of the vowels in the utterance and the stress group in declarative sentences. The result which emerges most clearly is that the inherent Fo differences between u and ɑ are greater in stressed than in unstressed vowels, but also that under both conditions of stress the differences are statistically significant regardless of the position in utterance or stress group. The differences found in stressed vowels in the present material correspond reasonably well with those found in Reinholt Petersen (1978) and, further, the tendency reported in that paper towards larger inherent differences in stressed than in unstressed vowels is also in agreement with the present findings.

With respect to the influence from position in utterance and stress group on the magnitude of the inherent Fo differences, the results seem less clear. Obviously, the two factors cannot be regarded as mutually independent, a fact which makes the description of the inherent Fo differences rather complex. What particularly contributes to the complexity is the behaviour of the first posttonic syllable, in which the differences tend to increase through the utterance. If that syllable had shown a behaviour similar to that of the remaining unstressed syllables, the following description might have been suggested: In stressed syllables the inherent differences between u and ɑ decrease through the utterance (from about 2.5 to about 1.75 semitones), and in unstressed syllables the differences between the two vowels remain constant at approximately 1 semitone in all utterance- and stress group positions.

One explanation for the deviant behaviour of the first posttonic syllable may be related to the fact - which is characteristic for that syllable and distinguishes it from all others - that in a stress group it constitutes the peak Fo and the termination of the very steep Fo rise starting at the Fo minimum located in or immediately before the preceding stressed syllable. In fig. 11 the extent of the Fo rise in a and u words is plotted as a function of the position in the utterance of the stressed syllable. It is seen that the rise is greater in a than in u; and along with the general reduction of the rise as a function of the position in the utterance, the difference between a and u with respect to the extent of the rise is also decreasing through the utterance, so that the extent of the rise is almost the same in the two vowels at the end of the utterance.

Thus, the increasing inherent Fo differences observed in the first posttonic syllable might be explained in the following way: At the beginning of the utterance, where Fo is high and the extent of the rise from the stressed syllable to the first posttonic syllable is large, it is more difficult for u than for a to reach the intended Fo of the first posttonic syllable. At the end of the utterance, where Fo is lower and the extent of the rise smaller, the two vowels differ less in their ability to reach the intended level in the first posttonic syllable.

Whether this explanation is physiologically acceptable will not be discussed in detail here, but if the Fo differences between high and low vowels can be accounted for by a higher degree of tension in the laryngeal tissues in high vowels than in low vowels as a consequence of the tongue pull in high vowels (whether translated into a horizontal tension in the vocal cords as suggested by Ladefoged (1964) and Lehiste (1970), or into a vertical tension as suggested by Ohala (1978)), then it might not be unreasonable to assume that the higher degree of tension in u can reduce the effect of the forces responsible for the Fo rise from stressed to first posttonic syllable, and further, that this impeding effect is more pronounced at the beginning of the utterance than at the end of it.

It must be emphasized that the results presented in the present paper are based on declarative sentences, in which the sentence component contributes to a falling fundamental frequency through the utterance. It will be of interest to see whether the tendencies towards decreasing inherent differences in stressed syllable and increasing differences in first posttonic syl-

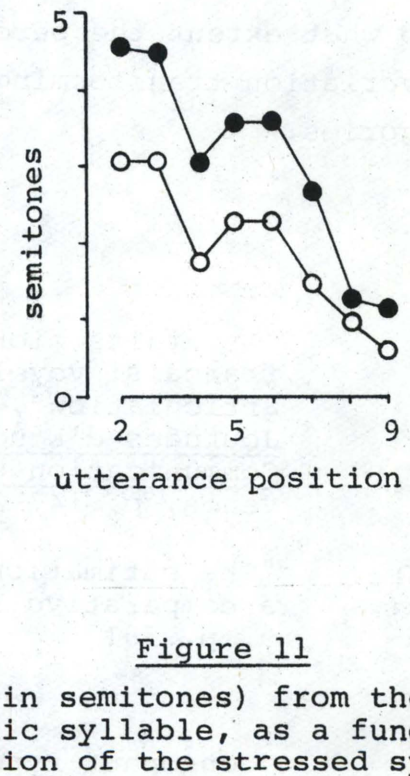

Figure 11

The Fo rise (in semitones) from the stressed to the first posttonic syllable, as a function of the utterance position of the stressed syllable.

lable through the utterance will also be apparent in interrogative sentences (or more correctly: syntactically unmarked questions), which are characterized by a "flat" sentence component at a relatively high Fo level, i.e. whether they can be ascribed to a "position in the utterance" effect (i.e. early/late), or a "position on the intonation contour" effect (i.e. high/low). Data obtained from such sentences might also contribute to the discussion of the physiological explanation attempted above.

For future work on the topic dealt with in the present paper two lines of research suggest themselves: one concentrating upon the physiological causes of the inherent Fo variation, taking into account the findings of the present experiment; the other turning upon the perceptual role of the inherent Fo variation, or, more specifically, to what extent the perceptual process employs knowledge of that variation transforming the acoustic signal into linguistic categories.

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APPENDIX

AN INVESTIGATION OF THE EFFECT OF CERTAIN CONSONANTS ON THE FUNDAMENTAL FREQUENCY IN PRECEDING UNSTRESSED VOWELS

1. Method

The vowels u and ɑ were combined with each of the consonants t, k, and m in words and carrier sentences similar to those employed in the main experiment. The following sentences:

Em'erne i mu'mumu muteres
Em'erne i mu'mumu mukeres
Em'erne i mu'mumu mumeres

Em'erne i mar'marmar marteres
Em'erne i mar'marmar markeres
Em'erne i mar'marmar marmeres

were arranged together with 2 distractor sentences in 10 different random orders in a list, which was read by one subject (NR, the author) under conditions identical to those of the main experiment. The following acoustic registrations were made: duplex oscillogram, two intensity curves, and Fo curve. The fundamental frequency was measured at the middle of the unstressed vowels in the test syllables (underlined in the list above).

2. Results

The means of the Fo measures were:

	t	k	m
u	116.3	116.6	115.7
ɑ	112.1	111.3	111.8

The data were submitted to a two-way analysis of variance (2 vowels x 3 consonants) which showed a significant effect of vowel quality ($F = 37.646$, $p < 0.01$), no effect of the following consonant ($F = 0.126$, $p > 0.05$), and no significant interaction ($F = 0.346$, $p > 0.05$).

In view of the structure of the material used in the main experiment, the point of interest was whether there was any interaction between the vowels and the two consonants k and t. Therefore the data were submitted to another two-way analysis of variance, in which only t and k were included. Thus, any interaction could be ascribed to them alone. The results of this analysis did not deviate essentially from the first one, and, specifically, the interaction could not be shown to be statistically significant ($F = 0.442$, $p > 0.05$).