THE DANISH LONG VOWELS. *)

Børge Frøkjær-Jensen

This paper presents part of an analysis of the Danish long vowels in stressed position which was made in 1959/6o. The paper summarizes an earlier article in Danish (1).

The investigation took place at the phonetics laboratory of Dr. Svend Smith at the Institute of Speech Disorders in Hellerup, where the Sona-Graph of the Institute of Linguistics and Phonetics was placed at that time.

25 subjects were recorded: lo male speakers, 9 female speakers, and 6 children. In order to avoid mispronunciations, all the recordings were played back twice to the speakers, after which I also carefully have controlled the recordings myself. Because of the small number of subjects it was considered important to choose speakers without speech defects and with a pronunciation which by most Danish speakers would be estimated as correct and good Danish.

The linguistic material:

The following long vowel phonemes occur in Danish: /i̯:/ - /e:/ - /ɛ:/ - /a:/ - /y:/ - /ø:/ - /œ:/ - /u:/ - /o:/ - /ɔ:/. All these phonemes were analysed in stressed position in the most common Danish word type, the bisyllabic structure: 'CV-Cə. It was considered preferable to use words beginning with /h/ in order to avoid influence in the beginning of the vowel from the preceeding consonant or word. Thus all the vowels occur under the same test conditions, i. e. /h/ + long stressed vowel + unstressed syllable with ə. Unfortunately it is not possible to find a series of words with commutation between all the Danish long vowel phonemes.

The vowel [ɑ:] which is a combinatory variant of the /a:/-phoneme before and after /r/ was included in the analysis.

The following series of words were chosen for the analysis:

hine	[hi:nə]	hyre	[hy:ʁə]	hule	[hu:lə]
hede	[he:ðə]	høre	[hø:ʁə]	hove	[ho:və]
hæve	[hɛ:və]	høne	[hœ:nə]	håne	[hɔ:nə]
have	[ha:və]	harve	[hɑ:və]		

*) Part of a thesis for the cand.art.-degree. (See also p. 47.)

The Danish long narrow vowels are not influenced by /r/, therefore the vowels in the examples "hyre" and "høre" do not represent particular variants as for the /a:/-phoneme.

4oo words were recorded on the tape recorder, and the long stressed vowels from these words were analysed on the spectrum analyser ("Sona-Graph") to determine the formant frequencies.

The formant frequencies:

On the basis of 1o subjects I have found the following average formant frequencies for male speakers:

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	233	277	356	512	685	24o	3o5	38o	254	348	413
F_2	2123	2o87	1968	1741	1139	1846	1628	1552	72o	75o	866
F_3	3oo9	2713	248o	2282	2458	2o37	2o13	2o31	2121	226o	2193
F_4	3327	3388	337o	3416	345o	3172	3151	3151	3247	3116	3172

(Average of the vowel formant frequencies in Danish for male speakers).

It is often very difficult to determine the formant positions of F_3 and F_4 from spectrograms of the back vowels /u:/, /o:/, and /ɔ:/ because of the very weak energy in the upper part of the spectrum, and very often the upper formants do not appear at all. In the formant frequency chart F_3 and F_4 of /u:/ are thus based upon 4 subjects only.

In an article by Dr. Svend Smith (2) the formant frequencies of the Danish vowel sounds are given for the first time. The findings of Dr. Smith were based upon direct listening to the formants by ear and controlled with the aid of a Siemens Tonfrequenz Spektrometer.

I have found that these formant frequencies are in rather good accordance with the frequencies from my investigations and corresponding analyses made by Eli Fischer-Jørgensen. The differences are small, but they are nevertheless clear. Dr. Smith has explained that the reason may be traces of Hellerup dialectal pronunciation in his speech. This is probably true of the rounded back vowels. If, however, we examine more closely the relations between the formant frequencies of Dr. Svend Smith and my subjects, we may observe that

(1) F_1 is higher in all vowels spoken by Dr. Smith,

(2) F_2 is lower in the front vowels, and

(3) F_2 is higher in the back vowels.

This is an interesting result, because it must mean that Dr. Smith during his pronunciation kept an intensity level in the phonation which was higher than the intensity level of normal speech.

(For further explanations: see the **next article in this report:** "Changes in formant frequencies and formant levels at high voice effort").

The analysis has given the following formant frequencies for female speakers and for children's voices:

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	278	345	413	572	808	247	346	413	290	371	432
F_2	2587	2555	2415	2145	1327	2041	1850	1817	797	778	968
F_3	3397	3161	2984	2898	2885	2383	2317	2537	-	(2660)	(2612)
F_4	4014	4082	4132	4118	3856	3685	3685	3656	(3755)	3749	3757

(Average of the vowel formant frequencies in Danish for female speakers).

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	304	407	479	553	985	281	413	478	305	413	461
F_2	2921	2571	2575	2347	1479	2181	1873	1831	794	875	981
F_3	3522	3287	3291	3043	2721	2605	2599	2682	(3155)	(3600)	(3160)
F_4	4427	4383	4339	4314	3997	3863	3932	4018	(3900)	(3915)	3933

(Average of the vowel formant frequencies in Danish for children's voices).

The last table of the vowel formant frequencies for children's voices is not statistically relevant because the material was too inhomogeneous. The table is only based upon 4 boys and 2 girls from 9-13 years old.

Accuracy:

The formant frequencies are subject to some uncertainty. It is not possible to read the spectrograms with an accuracy of more than ± 15 c/s. Furthermore the frequency response of the Sona-Graph may cause some shift in formant frequency if it is not quite flat. All analyses in this investigation were made with the "high-shaping" frequency response of the Sona-Graph. This means that all first formant frequencies probably are o - 25 c/s lower in real speech than the analyses state. Taking the accuracy of reading into consideration I suppose, without having done any experiments on the uncertainty, that the real frequencies of the first formant are o - 3o c/s lower than the charts indicate, and that the uncertainty for the other formant frequencies is in the order of ± 15 c/s. *)

Difference between male and female formants:

The cavities of the female vocal tract is smaller than the cavities of the male vocal tract. That means: the female formants must be higher than the corresponding male formants. Gunnar Fant has pointed out (3) that the female formants are on an average 17 % higher than the male formants, and the investigations of Chiba and Kajiyama (4) show that the female vocal tract is 15 % shorter than the male vocal tract.

On the basis of my material I have calculated the average difference in percentage between the female and the male formant frequencies and found it to be 16.1 %. Similarly, we find an average difference between the men's and the children's formant frequencies of 24.9 %. The greatest differences appear between the formant frequencies of the unrounded front vowels, and the smallest differences appear between the unrounded back vowels(5).

The phoneme areas:

Vowel diagram no. 1 shows the phoneme areas for standard Danish based on recordings from lo male subjects. F_1 and F_2 are plotted into the co-ordinate system along the vertical and the horizontal axis, respectively. Envelopes have been drawn around the different phonemes and the variant [ɑ:] . You find lo dots

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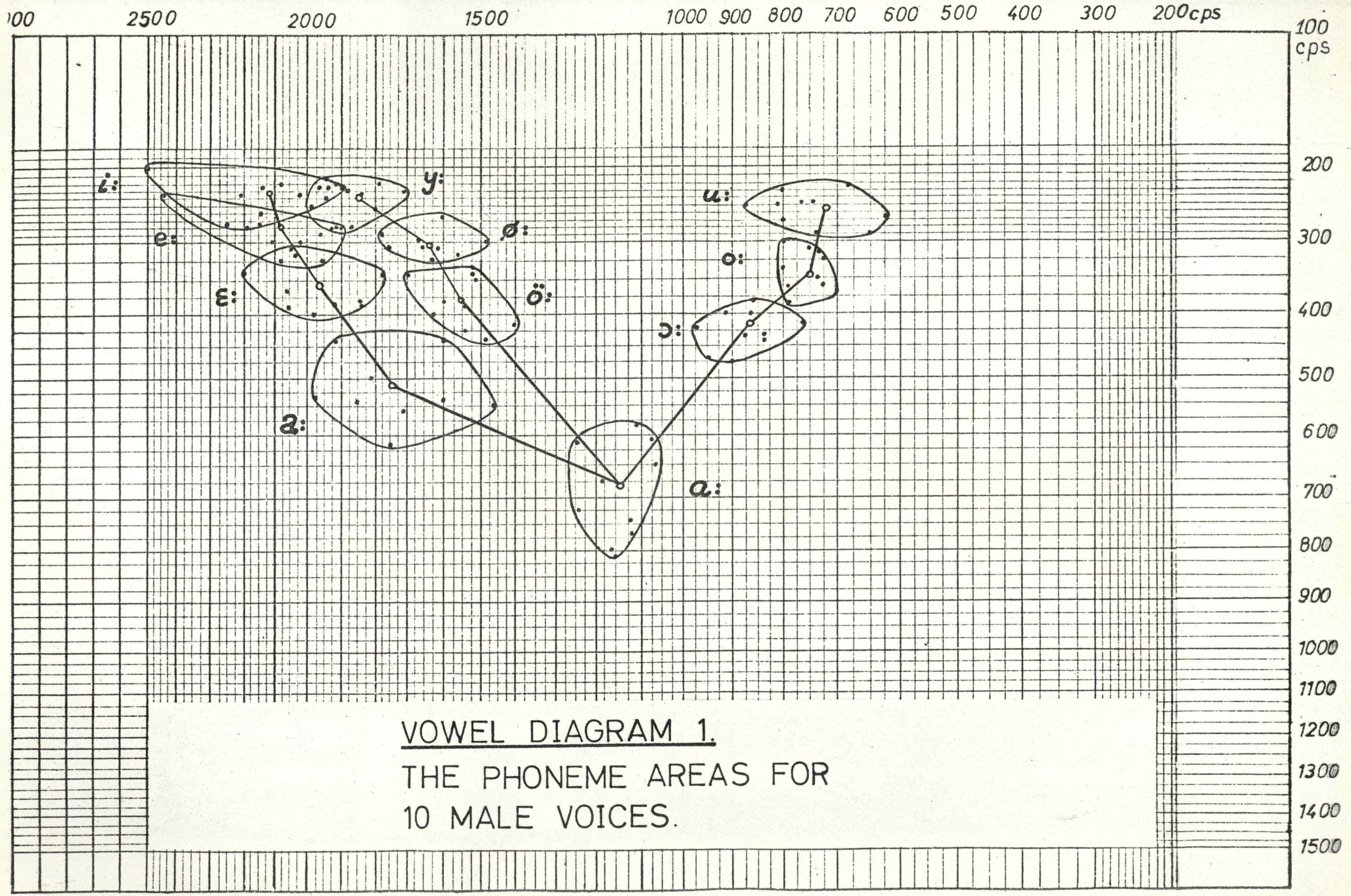
*) A presentation of the sources of error by sound spectrography based upon analysis of synthetic vowels is made by B. Lindblom (6).



VOWEL DIAGRAM 1.

THE PHONEME AREAS FOR
10 MALE VOICES.

in each envelope, one dot from each of the 1o recordings of the subjects.

For each phoneme envelope I have calculated the mathematical average frequencies for F_1 and F_2 and plotted these averages into the phoneme envelopes. All the average phonemes have been connected by lines. In this way we get a vowel triangle which is very similar to the well-known vowel triangle based on articulatory and auditory principles.

The mel-scale has been used in all the vowel diagrams in order to give a depiction which corresponds better to the auditory aspects of speech than does the linear frequency scale.

We observe that the phoneme areas are badly defined because of the overlapping between /i:/, /e:/, and /y:/, and further between /e:/ and /ɛ:/. That means that we find F_1/F_2 combinations in Danish which may be perceived e.g. either as /i:/ or as /e:/.

It is not certain that we still have overlappings between the areas if we take the formant intensity levels in account, or if we consider F_3 and F_4, but unfortunately it is very complicated to depict all these parameters in a two-dimensional vowel chart.

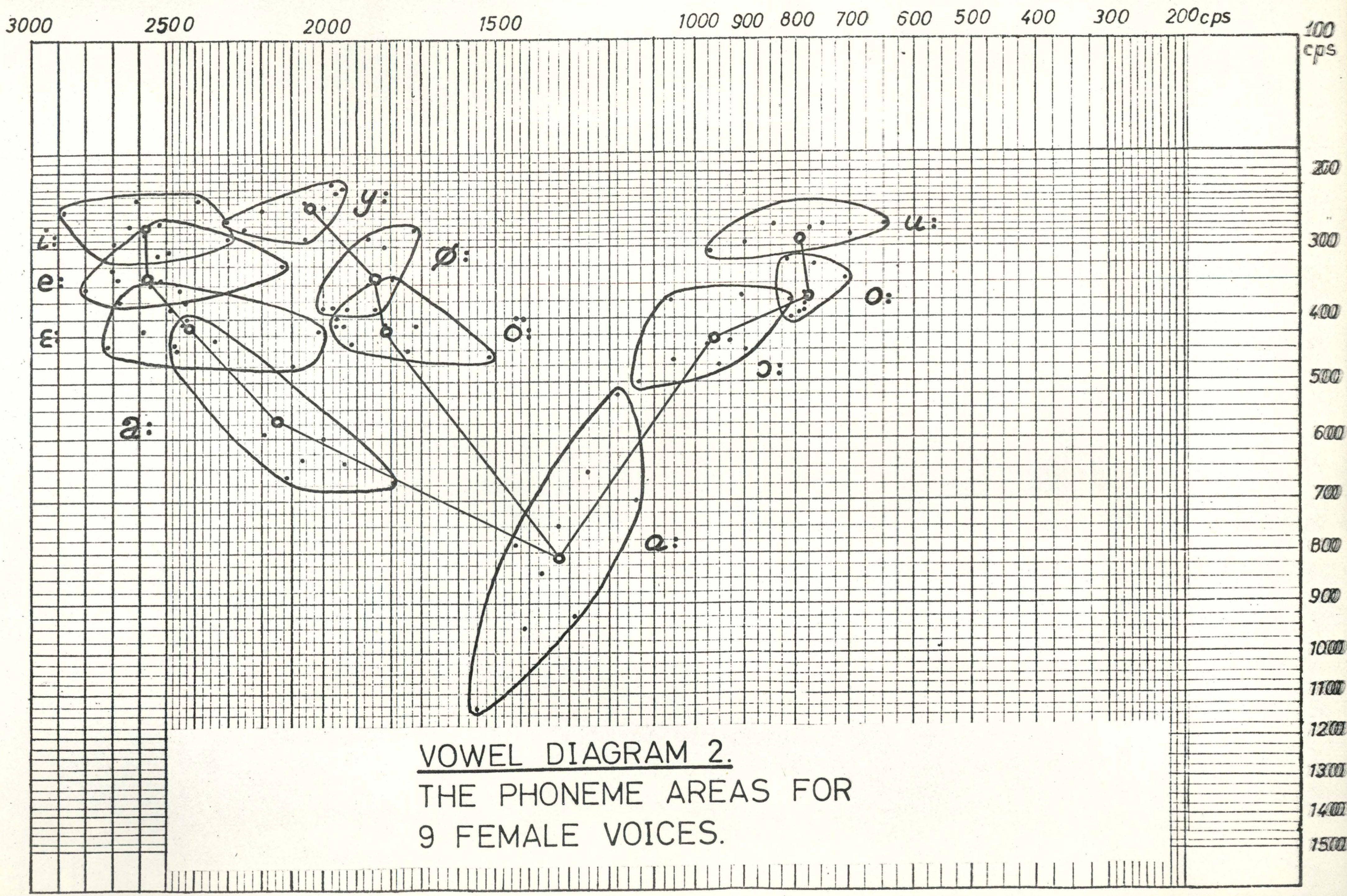
It is interesting to notice that the subject who has the best distinction between the phonemes, is a professional speaker at the Danish Radio.

Vowel diagram no. 2 shows the same phoneme areas for 9 female speakers. Notice here the great variability of the /a: - ɑ:/ phoneme in Danish.

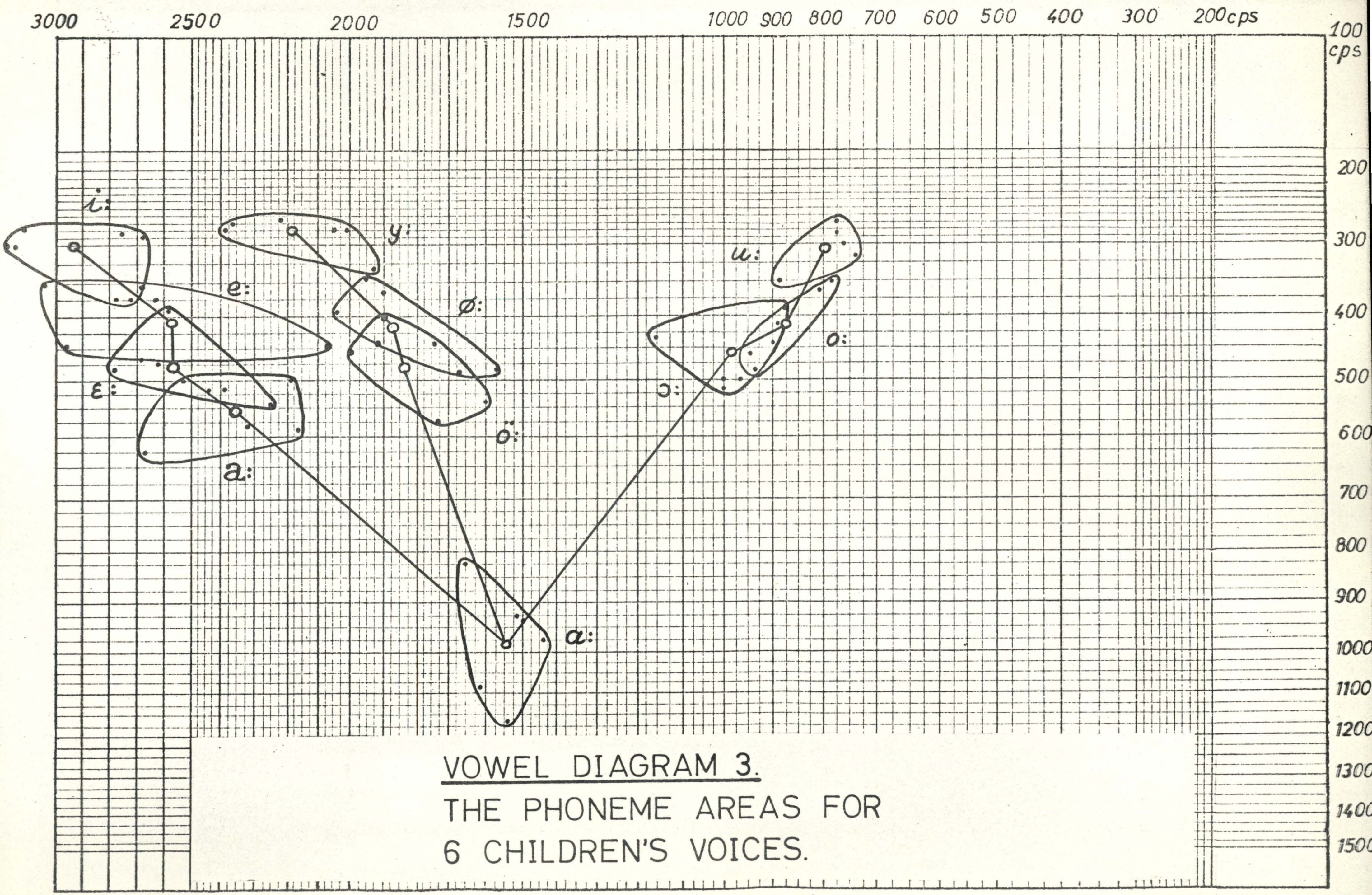
Vowel diagram no. 3 depicts the phoneme areas for 6 children's voices.

In vowel diagram no. 4 the phoneme areas of the male and female speakers are combined. It is interesting to see that the male and female front vowels are almost separated in this vowel diagram. For the back vowels the merging is more marked, but still we observe that the female speakers have a higher F_2 than do the male speakers.

If the children's phoneme areas had been plotted into the same vowel diagram (no. 4) you could observe a total separation between the corresponding phonemes of men and children.

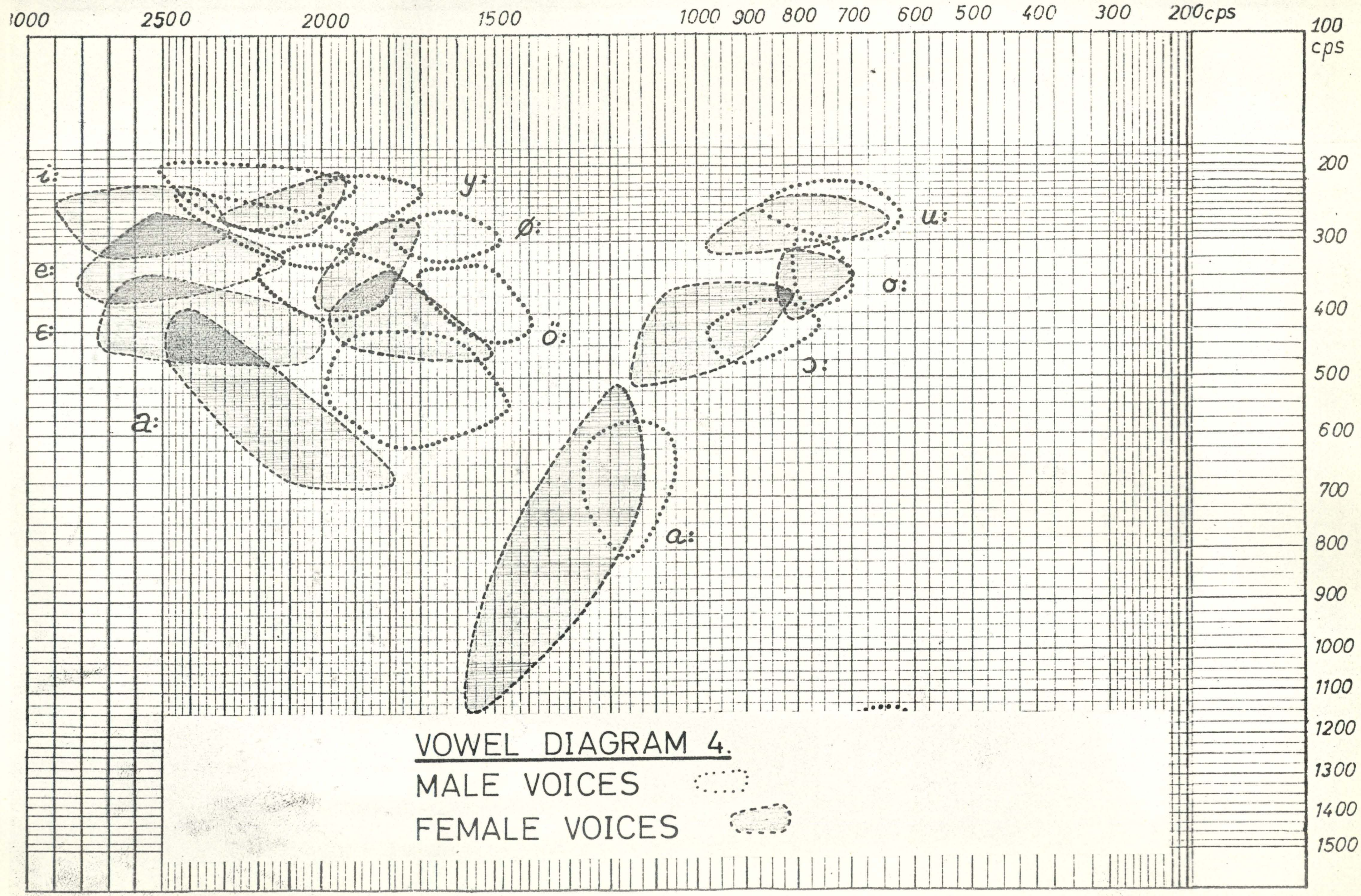


VOWEL DIAGRAM 2.
THE PHONEME AREAS FOR
9 FEMALE VOICES.



VOWEL DIAGRAM 3.

THE PHONEME AREAS FOR 6 CHILDREN'S VOICES.


VOWEL DIAGRAM 4.
MALE VOICES
FEMALE VOICES
3000
2500
2000
1500
1000
900
800
700
600
500
400
300
200cps
100 cps
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
i:
e:
ɛ:
a:
y:
ø:
ö:
u:
o:
ɔ:
ɑ:

The phoneme areas for one speaker:

One subject has spoken the eleven bisyllabic words with long stressed vowels lo times over a period of one year. The results are given in vowel diagram no. 5 based on the following average formant frequencies:

	/i:/	/e:/	/ɛ:/	/a:/	/ɑ:/	/y:/	/ø:/	/œ:/	/u:/	/o:/	/ɔ:/
F_1	274	32o	423	557	757	263	356	466	295	39o	5o2
F_2	2187	2112	2o68	188o	1139	1898	1599	1572	768	732	88o
F_3	2988	2755	26o4	2449	2641	2144	21o3	2184	2156	255o	2483
F_4	339o	3367	33o7	333o	353o	3547	2962	31o8	3o93	3o61	3o13

(Average of the vowel formant frequencies for 10 recordings spoken by one speaker).

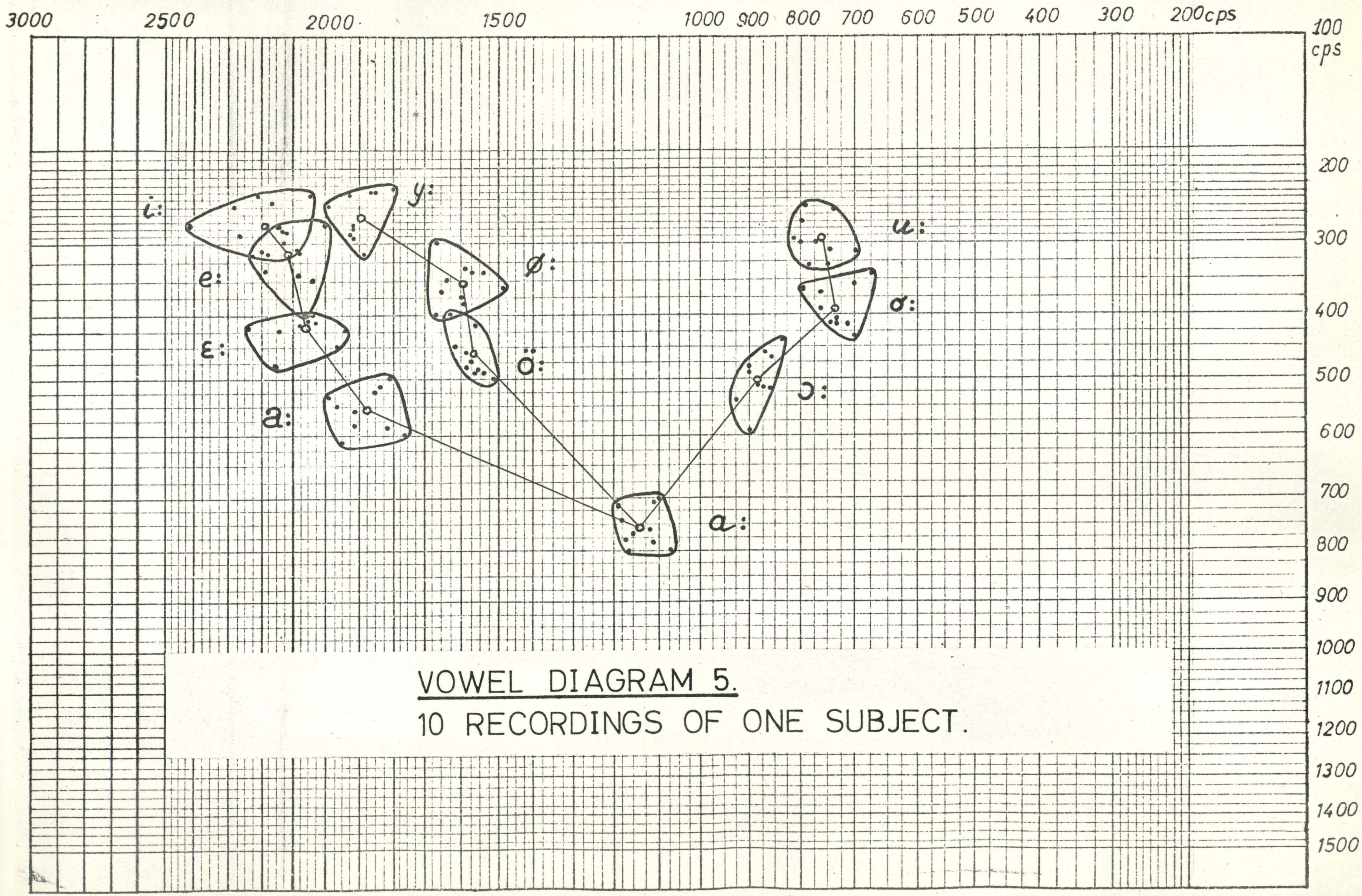
The lo recordings were, furthermore, spoken with different intensity levels. They therefore tell us a good deal about the variability in vowel articulation of the human voice. We may see that the phoneme areas are rather small (the variations in intensity level and the long time intervals between the recordings being taken in account). Overlapping of any importance only occurs between the phoneme envelopes of /i:/ and /e:/. If F_3 were taken in consideration (in a sort of three-dimensional pattern) the overlapping areas would be diminished because F_3 of /i:/ is spread out in the frequency range 3165-2665 c/s, and F_3 of /e:/ is spread out in the range 292o-264o c/s, but we still have some overlapping.

Corrections for F_3:

Gunnar Fant (7) has suggested a mathematical formula which combines the effect of F_2 and F_3 into one formant:

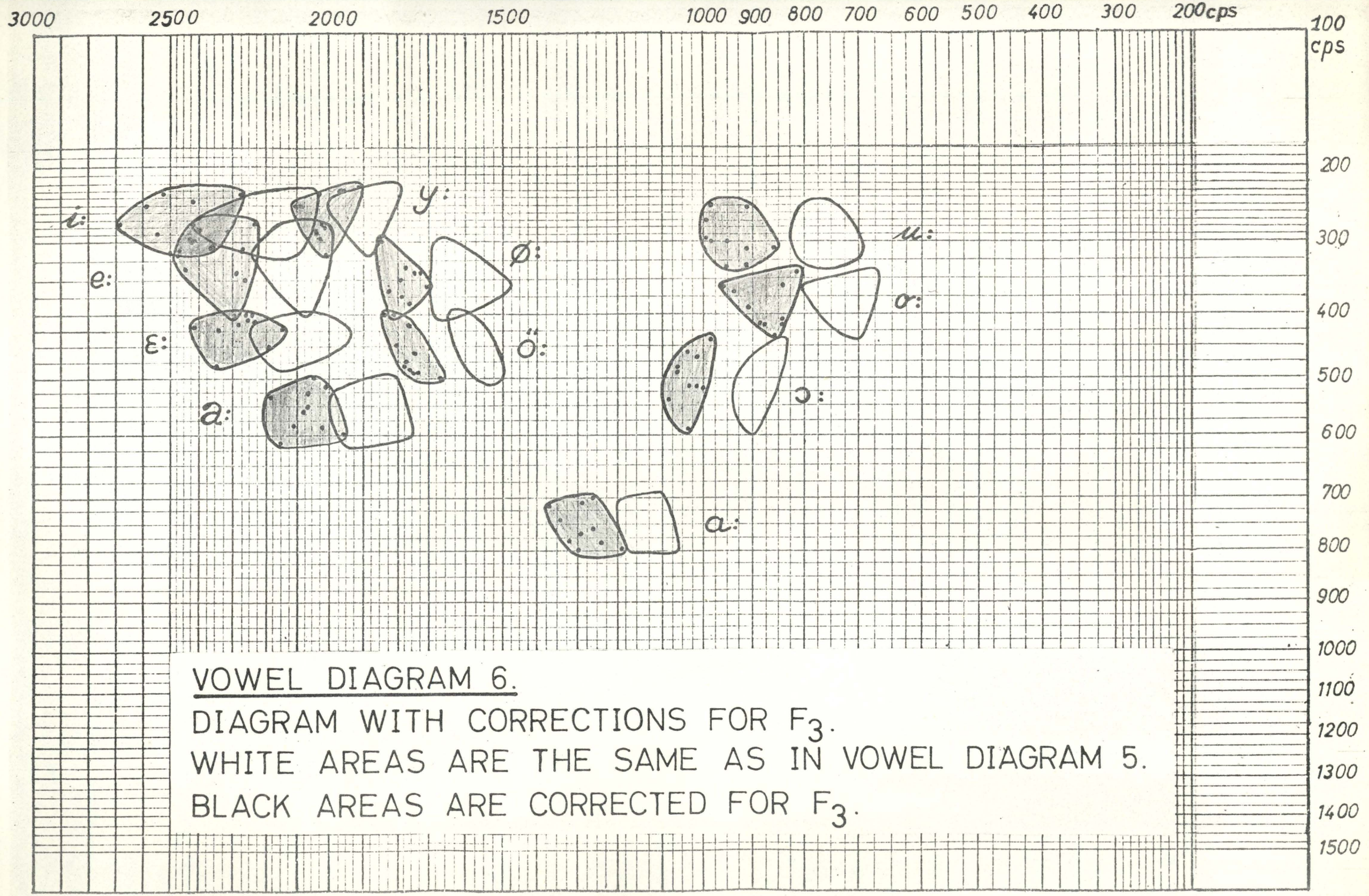
$$F_2' = F_2 + 1/2\,(F_3 - F_2)\,\frac{F_2 - F_1}{F_3 - F_1}$$

The application of this formula probably depends on the vowel system under consideration. The correction of F_2 may perhaps be used with advantage in vowel systems such as the Danish one, which has both rounded and unrounded front vowels. We get



VOWEL DIAGRAM 5.

10 RECORDINGS OF ONE SUBJECT.



VOWEL DIAGRAM 6.

DIAGRAM WITH CORRECTIONS FOR F_3.

WHITE AREAS ARE THE SAME AS IN VOWEL DIAGRAM 5.

BLACK AREAS ARE CORRECTED FOR F_3.

a better differentiation between the phoneme envelopes in the pairs /i:/ - /y:/,/e:/ - /ø:/, and /ɛ:/ - /œ:/ when using this formula.

I have tried to calculate the F_2' formant frequencies from the last vowel diagram, no. 5. These calculations are used in vowel diagram no. 6 which represents the same recordings as diagram no. 5, but in diagram no. 6 both the normal phoneme envelopes and the F_3-corrected envelopes are drawn. We see the differences most clearly between the pairs /i:/ - /y:/ in the two depictions.

It is, however, dubious whether the advantage we obtain by using this correction for F_3 is worth the time we must use for calculations on a large amount of material.

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References:

(1) B. Frøkjær - Jensen, "De Danske Langvokaler", Tale & Stemme 2(1963), pp. 59-75.

(2) Svend Smith, "Analysis of Vowel Sounds by Ear", Archives Néerlandaises de Phonétique Experimentale XX(1947), pp. 78-96.

(3) Gunnar Fant, Acoustic Analysis and Synthesis of Speech with Applications to Swedish (1959).

(4) Chiba and Kajiyama, The Vowel (1941).

(5) Gunnar Fant, "A Note on Vocal Tract Size Factors and Non-Uniform F-Pattern Scalings", Quarterly Progress and Status Report 4(1966), Speech Transmission Lab., RIT, Stockholm, pp. 22-3o.

(6) Björn Lindblom, "Accuracy and Limitations of Sona-Graph Measurements", Proceedings of the IV. International Congress of Phonetic Sciences, Helsinki 1961 (1962), pp. 188-2o2.

(7) Gunnar Fant, Modern Instruments and Methods for Acoustic Studies of Speech (1958).