PERCEPTION OF GERMAN AND DANISH VOWELS WITH SPECIAL REFERENCE TO THE GERMAN LAX VOWELS /I, Y, U/

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1. Introduction

The investigations reported in this paper were carried out at large intervals from 1955 to 1973. They had a double purpose:

(a) The main purpose was to find out how German lax vowels, especially /I, Y, U/, were perceived when heard in isolation. Some phoneticians, e.g. E.A. Meyer (1910 and 1913) and R.M.S. Heffner (1949 p. 97-98), consider these vowels to be more closely related perceptually to [i, y, u] than to [e, ø, o], cp. e.g. Heffner (1949 p. 97): "It is still a fact that [i] [I] [y] and [Y] are to our perception [i]-type vowels rather than [e]-type vowels". Both Meyer and Heffner emphasize that this auditory impression is in contradiction to the results of E.A. Meyer's palatographic and plastographic investigations which showed that North German /I/ and /Y/ have a much lower tongue position than /i:/ and /y:/, and that it may even be lower than that of /e:/ and /ø:/. An explanation which immediately suggests itself is that the auditory impression may be influenced by orthography. This hypothesis might be tested by investigating the perception of isolated vowel segments.

(b) A second purpose was to compare the perception of vowels in words and cut out of words, in which the surrounding consonants affect not only the transitions, but also the formant frequencies of the central part of the vowel. Such cases are found particularly in short lax vowels, e.g. in short front unrounded vowels between labials and short rounded back vowels between alveolars. How, for instance, is the vowel of Dutzend heard in isolation?

2. General characteristics of German lax vowels

It is not the intention to enter here into any detailed discussion of the opposition tense/lax, only to draw attention to a few major points. The discussion has mainly been centered around English vowels. It might be more useful to concentrate on North German, where the distinction is much more clear, and where the lax vowels /I, Y, U, ɛ, ɔ, œ, a/ can be compared to a set of monophthongal tense vowels /i:, y:, u:, e:, ø:, o:, a:/ (/ɛ:/ is often absent in natural North German speech).

2.1. Physiological characteristics

It is obvious that the lax vowels have a relatively lower tongue height than the tense vowels. It is also obvious that they do not simply constitute intermediate steps of vowel height. E.A. Meyer's finding that /I/ and /Y/ may have lower tongue height than /e:/ and /ø:/ has been confirmed by later X-ray photos of German vowels, cp. e.g. the X-ray photos of German /i:, I, e:/ in Russell 1929, Chiba and Kajiyama 1958, and Wängler 1961 (second edition, in the first edition (1958) /e:/ has been reproduced a second time instead of /I/). I have found the same relation in X-ray photos of /y:, ø:, Y/ spoken by a North German subject.

The tongue is, however, not only lower in lax vowels, it is also flattened out so that the tongue root is closer to the pharynx wall. Stewart (1967) has found the difference in pharynx width to be the essential feature in some West African vowel systems, partly based on Ladefoged (1964). Halle-Stevens (1970) have proposed to use the feature "advanced tongue root" also in English and German instead of tense/lax.

The elevation of the tongue in [i:] compared to [I] is considered to be a consequence of drawing the tongue root forward, the tongue being bunched up by this movement. The tension which Sievers (1901 p. 98) could feel in the muscles under the lower jaw (an observation which Hockett has repeated for English, e.g. 1955 p. 31) should thus be due to a contraction of the geniohyoid and mylohyoid muscles involved in advancing the tongue root, and the feature tense/lax could be dispensed with.

It is true that the high tense vowels /i:, y:, u:/ have a more advanced tongue root than the lax vowels /I, Y, U/ in German (and English), and sometimes it is also true of /e:, ø:, o:/ compared to /I, Y, U/; but this might be part of a general difference between tense and lax articulation. The description given by Jakobson and Halle (1956 p. 30) "greater (vs. smaller) deformation of the vocal tract away from its rest position" may still be a better way of formulating the difference. This question could be settled by means of electromyographic recordings of the various muscles involved in vowel articulation. Preliminary investigations of the tongue muscles in English show higher activity in the genioglossus for the tense vowels (McNeilage-Sholes 1964, Hirano-Smith 1967, and Lawrence J. Raphael 1971). Raphael is puzzled by finding more activity in /e:/ than in /I/ in his own pronunciation, but this is not astonishing since the tongue may be lower in /I/ than in /e:/, also in American English (cp. the X-ray photos in McNeilage-Sholes 1964).

German vowels do not seem to have been investigated by means of electromyography. Simple observations of lip and jaw movements give, however, a good deal of information, and such observations could be multiplied and supported by measurements without great difficulties. First, it is quite evident that the lip movement is less pronounced in lax vowels.

Already Sievers (1901 p. 86) drew attention to this fact. /Y/ and /U/ have less rounding than /y:/ and /u:/, and often less than /ø:/ and /o:/ (see, e.g., the lip photos in Wängler 1961), and /I/ has normally less lip spreading than /i:/. Moreover, although /I/ may have lower tongue height than /e:/, it generally seems to have less jaw opening (see Russell 1929, Chiba and Kajiyama 1958 p. 150, and Wängler 1961). These features can certainly not be a consequence of tongue root advancement, but point to a general laxness of the muscles involved in the formation of these vowels compared to tense vowels. Cp. also that Louise Kaiser (1941 p. 186 ff) has found that in Dutch /I/ has lower tongue height, but smaller lip and jaw opening than /e:/.

One more difference between tense and lax vowels which is fairly well established is that lax vowels have a stronger air stream (see E.A. Meyer 1913, Schuhmacher 1970, and EFJ 1969). E.A. Meyer explains this by a looser contact between the vocal cords in lax vowels, and this could be seen as part of the general laxness. Sievers (1901 p. 98 ff) is of the same opinion, Halle-Stevens (1970) have advanced the opposite hypothesis. They assume the vocal cords to close less firmly in tense vowels which should give them a breathy character. This may be true of the so-called tense vowels in West African languages, but sounds astonishing as a characteristic of tense vowels in German.

2.2. Acoustic analysis

Very few acoustic investigations of German vowels have been undertaken. Barczinski-Thienhaus (1935) found relatively more partials in lax vowels, but as these vowels were sung and continued for five minutes, the results are pretty uncertain.

Vierling-Sennheiser (1937) found some amplification of higher partials above 5000 Hz, particularly in /U/.

A detailed acoustic analysis of the vowels of six informants has been undertaken by Hans Peter Jørgensen (1969). The following perceptual investigation is mainly based on his material. Two of his informants were from the Rheinland. They had the first formant of /I, Y, U/ placed in between those of /i:, y:, u:/ and /e:, ø:, o:/. The other four informants were genuine North Germans, the first formants of their lax vowels /I, Y, U/ were either below or at the level of the first formants of /e:, ø:, o:/. As for the higher formants, lax unrounded front vowels had a lower F_2 and F_3 than the corresponding tense vowels, lax rounded front vowels had a lower F_2, but a higher F_3 (evidently because of the smaller amount of lip rounding), and lax back rounded vowels had a higher F_2 than the corresponding tense vowels. On the whole, the lax vowels were found to have a more central position in the F_1-F_2 vowel diagram, which is in complete agreement with what should be expected on the basis of the articulatory differences.

A. Fliflet (1962) has described the acoustic difference between German tense and lax vowels on the basis of visual inspection of spectrograms. He lists six characteristics of lax vowels: (1) centralized formant frequencies, (2) a more equal distribution of energy in the whole frequency domain, (3) less sharp formant contours, (4) less regular structure of formants, (5) longer transitions, (6) a general shimmering ("Unruhe") of the entire spectral picture, for instance more noise components.

These observations are in good agreement with the finding that lax vowels have a stronger air stream and with E.A. Meyer's hypothesis about laxness in the vocal cords; cp. also that Joos 1948 p. 97 states that synthetic vowels with broader formants sound more like American English /I, U/, whereas vowels with narrower formants sound more like German and French /e:, o:/. In support of their (opposite) hypothesis Halle-Stevens (1970) mention that the weakness of the higher formants in [i:] is so pronounced that it cannot be explained sufficiently by the low position of the first formant. Glottographic investigations are needed on this point.

E.A. Meyer supposed that the stronger air stream in lax vowels might give rise to high fricative noise, which might make /I/ sound more like [i:]. This is not very probable, and at any rate it does not explain why /U/ should sound more like [u:].

On the whole the articulatory and acoustic descriptions of tense and lax vowels are in good agreement and give no motivation for assuming that German /I, Y, U/ should be closer to [i:, y:, u:] than to [e:, ø:, o:] from an auditory point of view. If they sound like [i:, y:, u:] to Germans it must be due to other (phonemic and/or orthographic) factors.

3. Perceptual tests[1]

3.1. The material

The material consisted of a number of vowel segments cut out of words. A set of stimuli was prepared in 1955 and used for an identification test and for a small discrimination test. A new set of stimuli was prepared in 1963 and used for identification tests in 1963, 1964, 1969, and 1973.

1) I am grateful to Birgit Hutters, Hans Peter Jørgensen, and Henny Pontoppidan Lauritzen for helping me with measurements and calculations, and to Peter Holtse and Hideo Mase for making the graphs.

3.1.1. The material for the identification test 1955

The material comprised 47 vowel segments from various languages, Danish (7 items), German (33), Dutch (4), and English (3).

The vowels were taken from the following words:
Danish: (Speaker EFJ, female) /ki:lə, he:lə, hɛ:lə, pibə, vebə, nesə, sdødə/.
German: (Speaker ED, male) lieben, Lippen, Ibis, eben, immer, älter, Schluss
(Speaker GR, male) lieben, leben, Lippe, läppisch, Kehle, killen, kühle, Hölle, Hülle, tun, Ton, Tunnel
(Speaker CH, female) Kiele, Kehle, killen, Keller, Biber, Riff, Güte, Goethe, Kütte, Götter, fühlen, bündig.

The words spoken by ED were taken from a record, the words spoken by GR and CH were taken from a tape recording made at the Royal Technical High School in Stockholm for the purpose of investigating close and loose contact.

ED was a speech teacher speaking a clear and distinguished standard German, GR has an obvious Berlin accent. His [I, Y, U] are very low. CH was from Hamburg. Her speech is characterized by very close vowels and a high fundamental. The higher formants of her vowels were very weak.
Dutch: (Speaker Sch., male) tien, dienen, denen, tinnen.
English: (Speaker F.I., Amer. Engl., female) did, pip.
(Speaker B., Brit. Engl., male) soot.

The central part of the vowel (50-90 msec) was cut out so that (practically) no transitions remained. The cut was sharp.

The vowel segments were combined into two test tapes. The vowels from the same speaker were kept together, and the female voices came last, but there was no indication of the start of a new speaker. The vowels of the same speaker were given in random order. Each vowel was repeated three times and a number was said by the present author before each new vowel.

The tape recordings were made on a professional tape recorder, but for the dubbing and listening a semi-professional tape recorder was used, and the listening took place in a class room via loudspeaker. I was therefore not sure that the quality was sufficiently good, and as it turned out that the vowels of Güte and bündig spoken by CH were heard as [u:] and [o:] respectively by the majority of the listeners, I put the material aside.

The mistakes made in these two words may, however, have been due to the unusually weak higher formants of CH. The other results were confirmed by later experiments, and they will therefore be taken into consideration in the section on the results, but they will be mentioned relatively briefly, and no lists of the formant frequencies are given.

3.1.2. The material used for the listening tests 1963-1973

In 1963 a new series of stimuli was prepared. Vowel segments of 60-80 msec duration were cut out of the central part of the sounds as in the preceding experiment. The material comprised whole sets of vowels from one Danish and four German speakers, with the exclusion of the low vowels /a/ and /a:/ for which the difference tense/lax is rather dubious. Moreover there were some extra items, mainly vowels which were strongly influenced by the surroundings. There were 19 Danish and 57 German vowel segments.

All the speakers were male.

The Danish speaker was PD, born 1906, speaking a distinct and relatively old-fashioned Standard Danish. Compared to the mean of eight male speakers (EFJ 1972) he has a relatively low first formant of the high vowels and a relatively low second and third formant of most of the front vowels. The frequencies of the three first formants of his vowels are given in table 1.

The words are given in broad phonetic transcription.

TABLE 1.

Formant frequencies (in Hz) of the Danish vowels used in the identification tests 1963-1973.

Danish speaker PD

	F_1	F_2	F_3		F_1	F_2	F_3
/i:lə/	200	1975	3000	/ilə/	225	1900	2950
/he:lə/	290	2050	2750	/sbelə/	300	1925	2575
/hɛ:lə/	375	1975	2650	/hɛlə/	400	1850	2525
/hy:lə/	210	1825	2050	/hylə/	230	1625	2000
/ø:ðə/	275	1625	1925	/øləð/	290	1550	2025
/hœ:nə/	375	1550	1925	/hœnsə/	450	1475	2275
/ku:bə/	220	775		/kubəl/	270	750	
/ho:bə/	300	650		/sgobə/	500	950	2150
/hɔ:bə/	410	975		/hɔbə/	550	1150	2275

One of the four German speakers, ED, was also employed in 1955. The words used in 1963 were taken from the same record and were partly the same words, in order to obtain a certain control on the results of the old experiment. ED's long vowels are sufficiently long to present a minimal influence from surrounding consonants. Of the short vowels [U] in Schluss was not a very good example of a typical /U/, since it stood between two alveolars.

The other German speakers were the informants of Hans Peter Jørgensen, used for his acoustic analysis of German vowels (1969), and the items were taken from his tape recordings. The speakers were NB (from Schleswig), HT (from Berlin), and HL (from the Ruhr).

The words were chosen so as to present a minimal influence from surrounding consonants. The formant frequencies of these vowels (mainly based on Hans Peter Jørgensen's measurements) are given in table 2.

TABLE 2.

Formant frequencies (in Hz) of the German vowels used in the identification tests 1963-1973.

Speaker ED:

	F_1	F_2	F_3		F_1	F_2	F_3
lieben	275	2300	2950	Distel	300	2125	2750
leben	300	2175	2575	älter	450	1925	2425
müde	275	1825	2125	nützen	375	1575	2400
Flöte	325	1600	2150	öfter	525	1475	2350
suchen	260	600		Schluss	325	950	2700
Ostern	350	750		hoffen	575	1000	2875

Speakers:

	NB			HT			HL		
	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3
hiessen	220	2100	2900	225	2400	3075	275	2025	2700
Esel	300	2075	2525	275	2425	2750	350	1950	2500
hissen	300	1875	2325	325	2125	2750	340	1875	2450
essen	450	1825	2400	500	2025	2600	450	1775	2450
hüten	220	1550	1900	210	1550	2000	280	1650	1975
Höhlen	300	1350	2000	325	1525	1975	320	1500	1950
Hütten	300	1375	1975	320	1575	2125	300	1575	1950
Höllen	450	1325	2175	435	1450	2175	500	1350	1925
hupen	240	720		260	700		300	800	
hoben	340	750		325	700		400	800	
hupfen	340	825	2425	400	850		375	980	
Hopfen	500	950	2400	525	1035	2100	650	1025	2600

Some extra items were added, mainly to show maximal influence from surrounding consonants. The formants of these vowels are given in table 3.

TABLE 3.

Formant frequencies (in Hz) of the extra vowels used in the identification tests 1963 - 1973.

		F_1	F_2	F_3			F_1	F_2	F_3
<u>ED</u>:					<u>NB</u>:				
	Lippen	300	1700	2425		bibbern	300	1700	2350
	Ziege	250	2450	2975		Dutzend	340	960	2400
	Minne	275	2200	2825					
					<u>HL</u>:				
						Dutzend	280	1100	2025
						Dotter	550	1150	2150

The vowel segments were combined into a test tape consisting of five distinct series, one for each speaker. Each vowel was repeated three times with an interval of one second. There was a five second interval between different vowels. Before each new vowel there was a brief tone signal of 300 Hz, which was found to be a pleasant pitch. Before numbers 5, 10, and 15 there were two tone signals. This was done in order to avoid spoken numbers, which might influence the perception of the following vowels.

A small extra test containing the words: <u>hissen</u>, <u>hütten</u>, <u>hupfen</u> spoken by NB, HT and HL, <u>Dutzend</u> and <u>bibbern</u> spoken by NB, <u>Dutzend</u> and <u>Dotter</u> spoken by HL and <u>Lippen</u> spoken by ED was played to the German listeners only.

The dubbing was done on a professional tape recorder (Lyrec) of the same type as the one used for the recording. The listening took place via loudspeaker in a class room with some damping of the walls (Danish listeners) or via earphones (German listeners in Kiel and Köln).

3.1.3. Materials used for the discrimination test 1955

A small number of German vowel segments were used in a discrimination test in 1955. The formant frequencies of these words are given in table 4. The measurements of CH's vowels are not very exact since she has a fundamental above 250 Hz.

TABLE 4.

Formant frequencies (in Hz) of the vowels used in the discrimination test 1955.

ED:	F_1	F_2	F_3	CH:	F_1	F_2	F_3
Ibis	250	2325	3050	fühlen	270	1800	2600
eben	290	2175	2700	Goethe	325	1825	2600
immer	290	2125	2675	Kütte	350	1825	2700
älter	450	1925	2425	Götter	400	1750	2700

GR:			
lieben	225	2336	3300
leben	340	2375	2975
Lippe	375	1775	2625
läppisch	525	1800	2650

The vowels of each speaker were combined in groups for comparison of the type later labelled 4IAX, for example "i-e, i-I", where the listener had to decide which pair, number one or number two, showed the higher degree of similarity between the members. Each double pair was repeated three times, in order to avoid memory effects as far as possible. The distance between double pairs was 1.5 sec., and the interval between different double pairs was 5 seconds. A number was spoken before each new double pair.

3.2. Listeners and instructions for listeners

The listeners taking part in the test in 1955 were 22 (for some stimuli 28) Danish students, attending a course of general phonetics for students of foreign languages.

The test tape made in 1963 was played both to Danish and German listeners. The Danish listeners were (1) two groups of students of foreign languages (24 in each), attending a course of general phonetics in the autumn 1963, (2) two groups of students of Danish (20 and 21), attending a course of Danish phonetics in the autumn 1963, 5 phoneticians and 5 dialectologists who listened individually in January 1964.

The German listeners were groups of phoneticians and students from Bonn, Hamburg, Kiel, and Köln.[1] The test in Bonn took place in 1969. Unfortunately, some high frequency components must have got lost when the test was played back, since many rounded front vowels were heard as rounded back vowels, and some unrounded front vowels were heard as rounded front vowels. That something was wrong also appears from a comparison between two answers to the test made by the same person, in Bonn in 1969 and in Kiel in 1973. In 1969 he had 12 mistakes of the type mentioned, in 1973 one. The material from Bonn was therefore discarded.

In Hamburg the test also took place in 1969. 19 listeners, mostly speech therapists, took part in the test. The results showed a very great dispersion, and as long /e:/, /ø:/, and /o:/ were identified more often with [i:, y:, u:] than with [e:, ø:, o:] (in a number of cases also with [ɛ, œ, ɔ]), I concluded that the listeners had not understood the instruction

1) I am grateful to the leaders of the Phonetic Institutes of Bonn, Hamburg, Kiel, and Köln for running the tests in their institutes.

(see below), and put the material aside for the time being.

In 1973 a group of 10 phoneticians and students in Kiel and 23 phoneticians and students in Köln listened to the test tape. The results did not differ very much from those obtained in Hamburg, although the dispersion was smaller. I therefore concluded that this type of answer could not be avoided and might give some information about German vowels. The results will be described in detail below.

The answer sheets for the test (as for the test in 1955) contained five vertical columns, one for each series, indicating the numbers 1-17 for series I, etc. There was a star before each number, and two before the numbers 5, 10, and 15, to indicate the tone signals.

At the top of the sheet was the diagram reproduced in fig. 1.

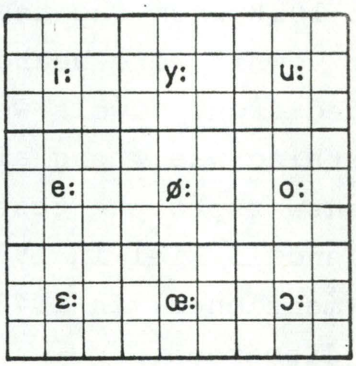

Fig. 1. Diagram placed on the answer sheet.

The instructions for the Danish listeners, which were spoken on the tape, contained the following information:

"You will now hear a series of vowels. Your task is to identify them by ear and take them down in phonetic transcription on the answer sheet to the right of the running numbers. The vowels are taken from different languages and are cut out of words. They are all very brief. In some cases a weak p or b may be heard after the vowel. Please, do not take notice of this. Each vowel is repeated three times ... (instructions about numbers and tone signals) ...

In order to obtain as precise an indication as possible of your auditory impression, the Danish long vowels have been used as a basis for the transcription. The vowels you hear are to be compared with the Danish long vowels [i:, y:, u:, e:, ø:, o:, ɛ:, œ:, ɔ:], which are indicated in the diagram on the top of the answer sheet. Each vowel symbol is placed in the small center square of a larger square. This is meant to be the placement of the normal Danish long vowels, whereas the surrounding smaller squares are intended for the placement of finer shades. If, for instance, you hear a vowel which has just the same quality as the long Danish [e:], you simply write the symbol e. If you hear an [e] which sounds somewhat [i]-like, you write an e with an arrow pointing upwards in order to indicate that you would place it in the small square just above the center square of e:, towards i:. If you find that it is an [e] which sounds somewhat [ø]-like, you must write an e with an arrow pointing to the right in order to indicate that you would place it in the small square to the right of the center square of e:, towards ø:. An [ɛ]-like [e] should be written with an arrow pointing downwards, and an [œ]-like [e] with an arrow pointing obliquely downwards to the right. Similarly an [o] which sounds [ø]-like should be indicated by an o with an arrow pointing to the left, etc. Please write the arrows clearly, so that it is possible to distinguish between horizontal and oblique arrows."

The comparison with Danish vowels was chosen because the listeners could not be expected to have sufficient training in Cardinal Vowels, and the procedure with arrows was chosen because, otherwise, there should have been a large square on the sheet for each stimulus. Of course, the listeners might make the mistake of comparing with Danish short vowels instead. In most cases this would not make much difference, since Danish short vowels are only slightly lower than the corresponding long vowels and some speakers have no difference whatever. The pairs /o:/o/, /ɔ:/ɔ/, and /a:/a/, however, are exceptions to this rule. The answers to the Danish vowel stimuli showed that the listeners had really used the long vowels as standards, since long /i:/, /y:/, and /u:/ were placed in the center squares, whereas short /i/, /y/, and /u/ were indicated to be slightly lowered. Moreover, the short /o/ was placed in the square of long [ɔ:], which is in agreement with its quality.

Some of the students had not understood that they were allowed to use the peripheral squares (e.g. raised i, lowered ε). This is relevant for the judgement of short German /ε, œ, ɔ/. Only the experts have placed these sounds as lowered Danish [ε:, œ:, ɔ:]. The answers about Danish and German /ε, œ, ɔ/ should therefore be judged with caution.

For the German listeners there were similar instructions, but as German does not possess a set of long low vowels, it was not possible to use long vowel qualities as standards in all cases. The vowel symbols in the lowest row had therefore no length marks, and the German listeners were asked to take the vowel symbols in the central squares to indicate the long German vowels in bieten, hüten, hupen, beten, Höhle, hoben, and the short vowels in Betten, öffnen, hocken. The sheets used in Kiel and Hamburg contained an extra diagram with these key words placed in the center square.

This mixture of long and short key vowels seems to have caused some difficulties.

In order to give a rough impression of the formant frequencies of the vowels to be used as standards by Danish and German listeners, the average formant frequencies of the long vowels (except /a:/) of eight Danish male speakers (from EFJ 1972) and the average formant frequencies of the relevant German vowels spoken by six German male speakers (Hans Peter Jørgensen 1969) are indicated in fig. 2. The short German /I, Y, U/ are indicated by crosses for comparison. The vertical axis indicates formant 1, the horizontal axis formant 2 for back vowels and formant $2'$ for front vowels according to Fant's formula (Fant 1959):

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

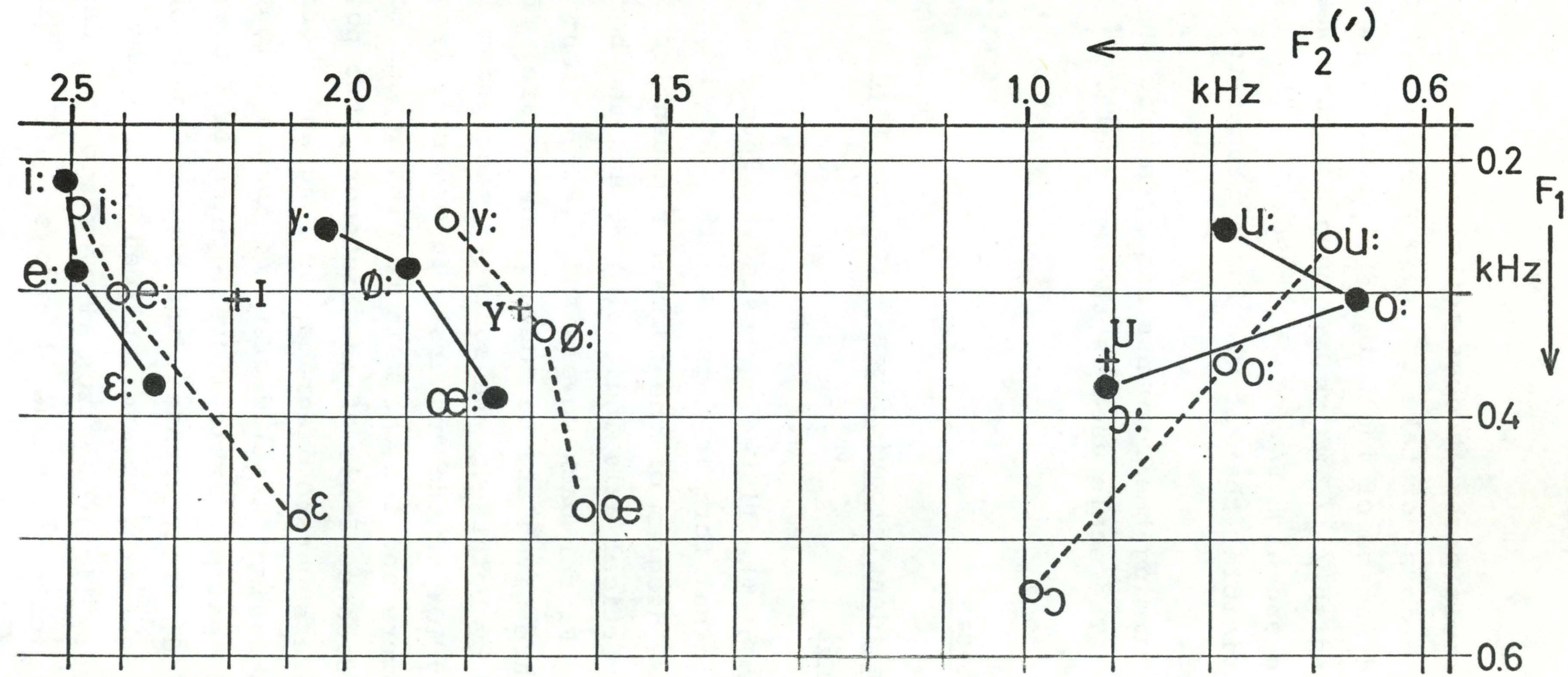

Fig. 2. Average formant frequencies of Danish and German vowels indicating approximately the frequencies of the vowels used as standards by the listeners

●——● The Danish long vowels /i:, y:, u:, e:, ø:, o:, ε:, œ:, ɔ:/ spoken by 8 Danish male speakers.

o- - - -o The German vowels /i:, y:, u:, e:, ø:, o:, ε, œ, ɔ/ spoken by 6 German male speakers.

+ The German vowels /I, Y, U/ for comparison.

Although this formula probably does not correspond precisely to perception (it does not take the formant levels into account), it has the advantage of including F_3, which is particularly important in Danish /i:/, which may have a rather weak and low F_2 and a strong and high F_3. In back vowels F_3 was so weak (and sometimes invisible) that it was found better to leave it out altogether.

This way of diagramming the formants has been used in all subsequent graphs. The scale used is the mel scale.

3.3. Results of the tests

3.3.1. Results of the identification tests for the main stimuli (tables 1 and 2)

The main results of the listening tests in 1963-64 and 1973 are given in graphical form in figs. 3 - 18. At the top of each figure is a diagram of the formant frequencies of the speaker with the vertical axis indicating F_1 and the horizontal axis indicating F_2 for back vowels and F_2' for front vowels. The stimuli are given at the top of each square. The answers are indicated by points in the squares, each point indicating approximately 10% of the answers. In order to leave out quite erratic answers and let the main results appear more clearly, one point indicates 5-14% of the listeners, two points 15-24%, etc. There are separate diagrams for long and short vowels of the two (in Danish three) degrees of tongue height, since there is a good deal of vertical overlapping in the answers. Front unrounded, front rounded, and back rounded vowels of the same tongue height are, however, placed in the same diagram since there is very little horizontal overlapping. Cases of overlapping are indicated by means of arrows. If, for instance, a front unrounded vowel is heard as rounded, the point is placed in the column for front rounded vowels, but an arrow pointing to the left indicates that the stimulus was a front unrounded vowel. Similarly, if a back vowel is heard as a front rounded vowel, the point is placed in the mid column with an arrow pointing to the right.

A. Danish listeners

a. Test 1963-64

The results for the three listening groups have been combined in the graphs (figs. 3 - 7). The percentages were calculated for each group separately, and the average taken of the three percentages. The answers of the three groups show very few divergencies. There is less dispersion in the expert group, which might be expected, but this may also be due to the fact that the number of listeners was smaller and they were allowed to listen twice. As mentioned above only the experts used the peripheral squares for the low vowels. Therefore, we will not treat the answers to these vowels in detail. Moreover, for some reason inexplicable to me the students of Danish have often placed German long /i:, y:, u:/ somewhat lower than the other two groups.

The Danish stimuli were mainly included in order to have a control of the procedure. The answers are given in fig. 3. They show that on the whole the vowels have been identified correctly. Short /i, y, u/ are heard as somewhat lowered compared to long /i:, y:/ and /u:/, which is in agreement with the formant frequencies, and short /o/ has been indicated as ɔ̠, which is also in agreement with the formants. The only disagreement between the acoustic chart and the answers is that some have heard /ɔ:/ and /ɔ/ as somewhat [o]-like, although they are not raised, but somewhat fronted compared to the average and particularly compared to the

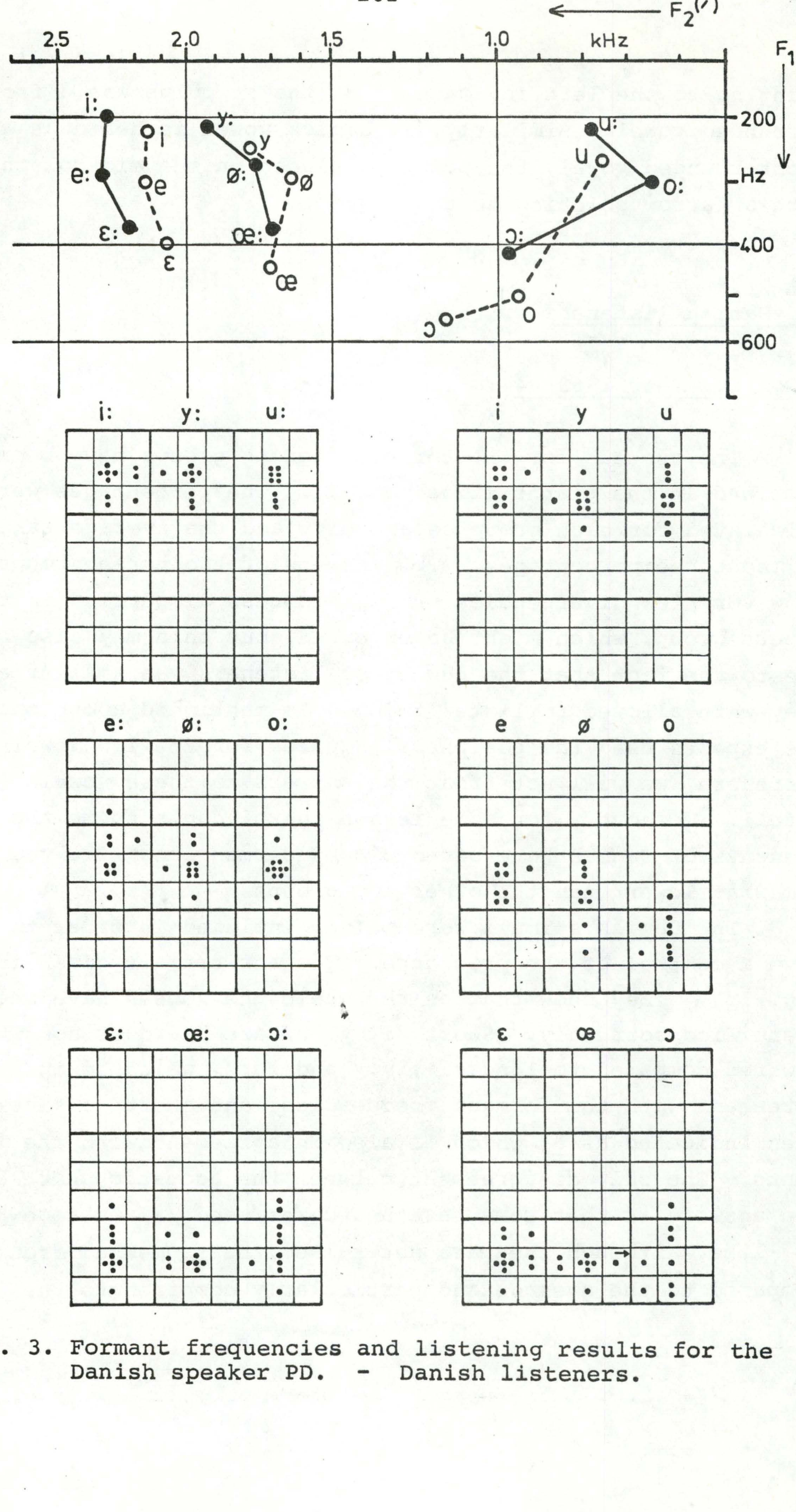

Fig. 3. Formant frequencies and listening results for the Danish speaker PD. - Danish listeners.

pronunciation of the younger generation. This fronting has been indicated by the expert group. (There may be some context effect here since /ɔ/ comes after /œ/, and /ɔ:/ after /y:/.)

German /i:, y:, u:/ are generally heard as lower than the corresponding Danish vowels. This is in agreement with the general subjective impression. HL's /i:, y:, u:/ are heard as particularly low, and this is in accordance with his unusually high formant 1. It is also in agreement with the position of formant 1 that HT's /u:/ is heard as lower than his /y:/ and /i:/. Generally, the differences in F_1 are not sufficient to explain the differences in auditory impression of tongue height. The higher formants are also of importance. German /u:/ has a somewhat lower F_2, /y:/ has a lower F_2 and F_3, and /i:/ a lower F_3 than the corresponding Danish sounds. This brings German /u:/ closer to Danish /o:/ (which has a lower F_2 than the somewhat fronted Danish /u:/), and German /y:/ and /i:/ closer to Danish /ø:/ and /e:/ (and the high and strong F_3 in Danish /i:/ is probably still more dominant for the auditory impression than Fant's formula shows). It should not be forgotten that lower vowels have not only a higher F_1, but also a different F_2, lowered in front vowels and raised in back vowels (see also fig. 2.).

German /e:, ø:, o:/ are also, except for HT, heard as lower than the corresponding Danish vowels. Here again it is not only due to F_1, but also to the higher formants. German /ø:/ has lower formants 2 and 3, and /e:/ has a lower formant 3, and this brings them closer to Danish /œ:/ and /ɛ:/, and German /o:/ has a higher formant 2, which brings it closer to Danish /ɔ:/ (see fig. 2.). HL's /e:, ø:, o:/ are heard as particularly low in accordance with his high F_1. NB's /ø:/ and /o:/ are also heard as particularly low, but this seems to be

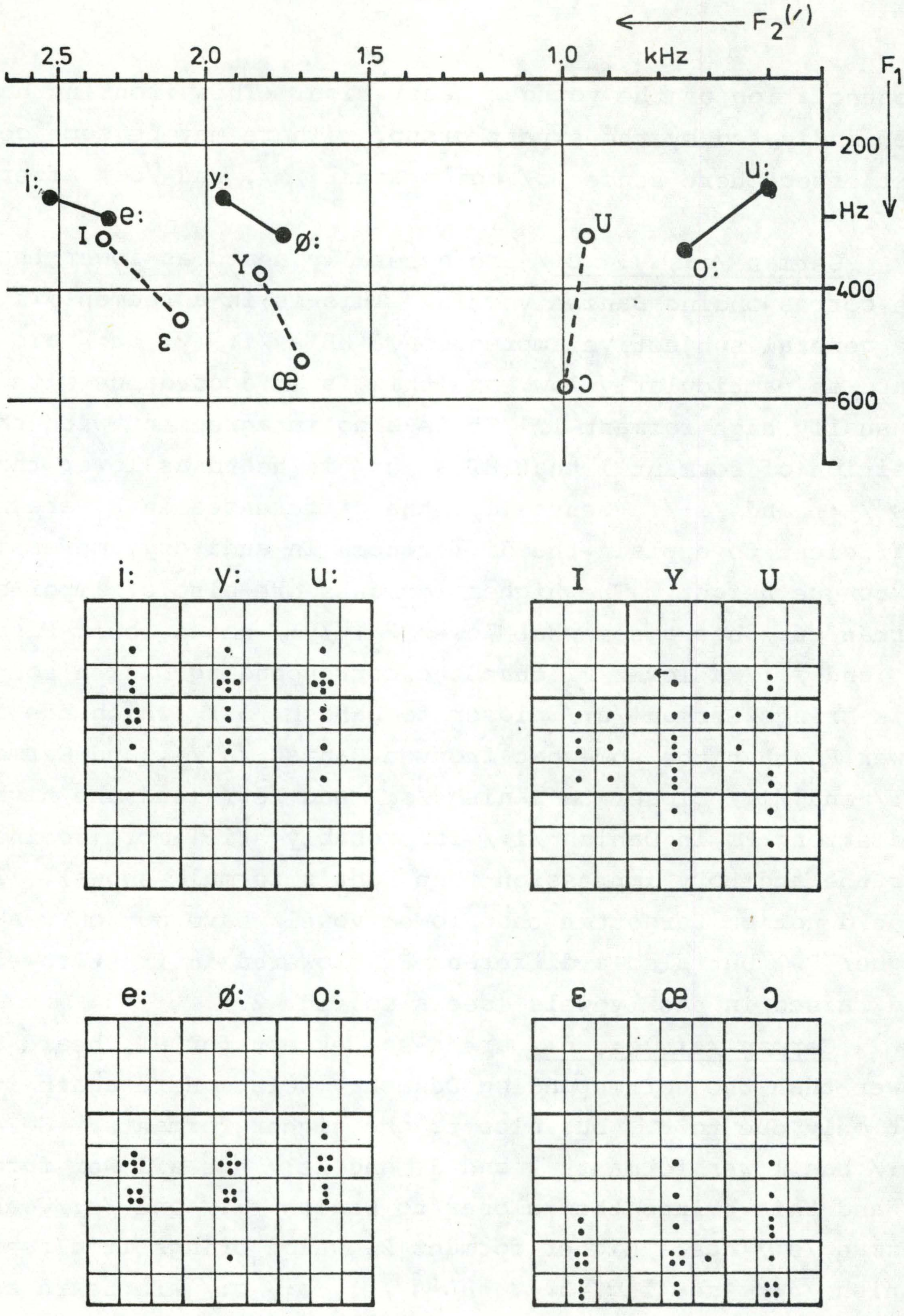

Fig. 4. Formant frequencies and listening results for the German speaker ED. - Danish listeners.

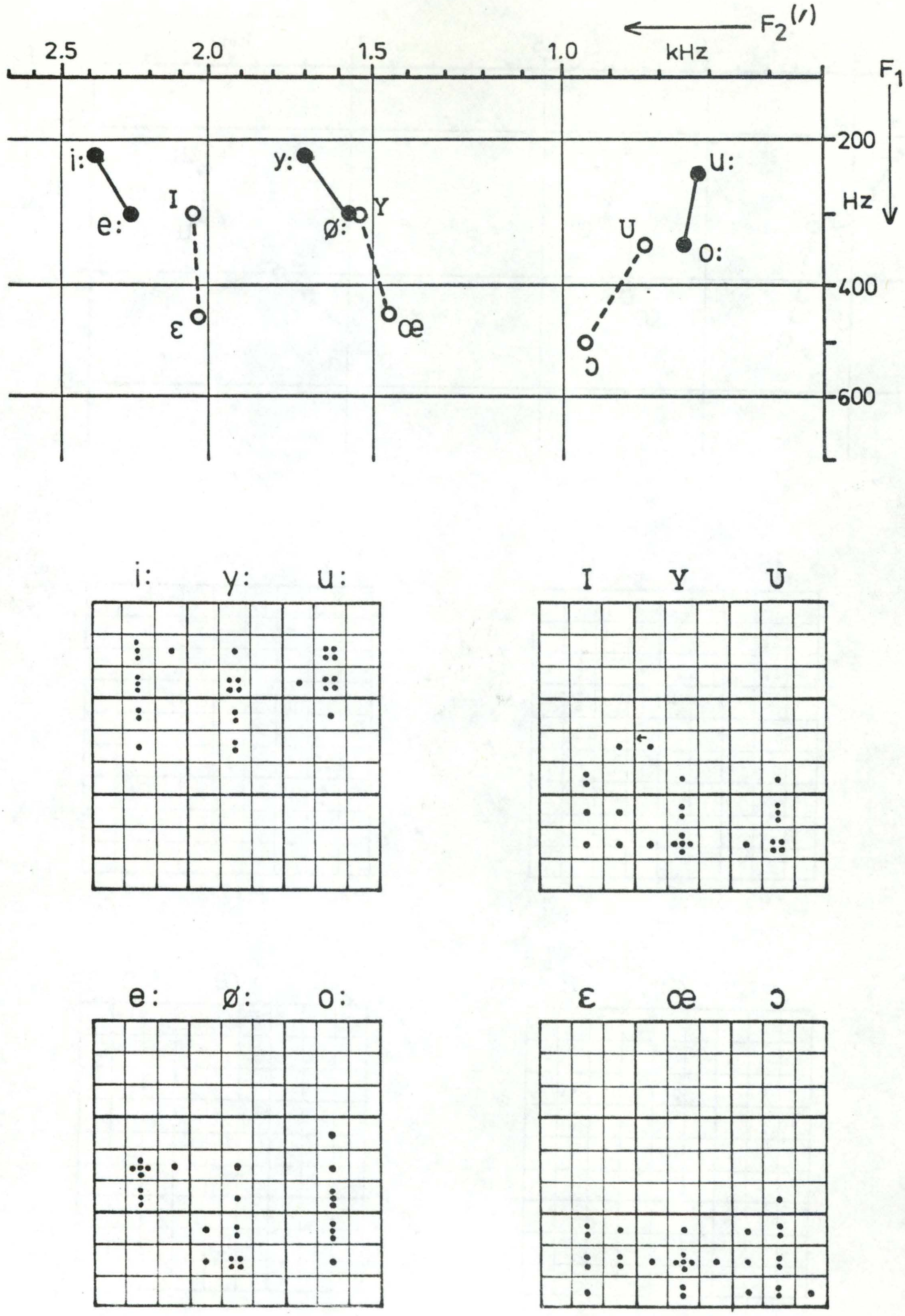

Fig. 5. Formant frequencies and listening results for the German speaker NB. - Danish listeners.

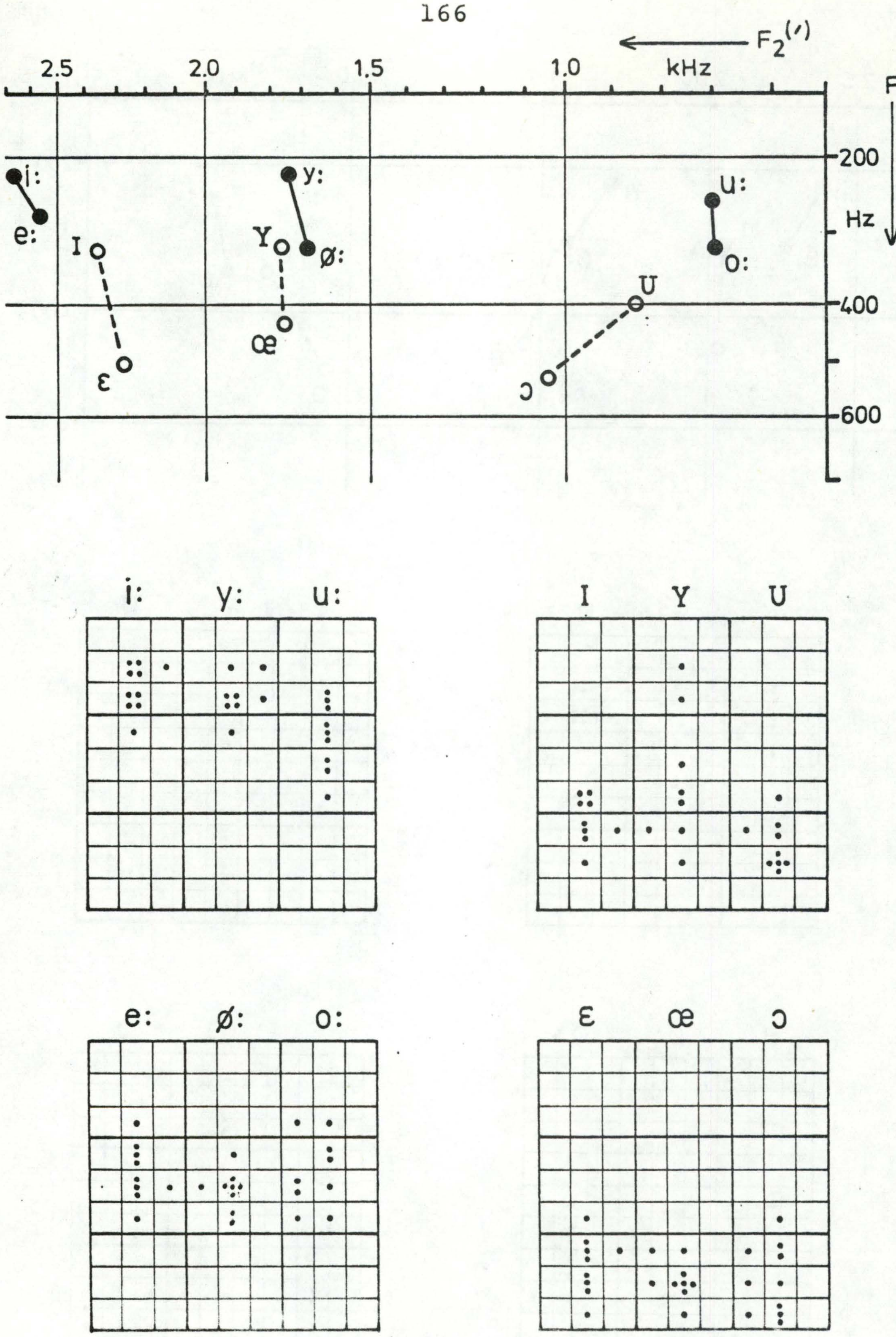

Fig. 6. Formant frequencies and listening results for the German speaker HT. - Danish listeners.

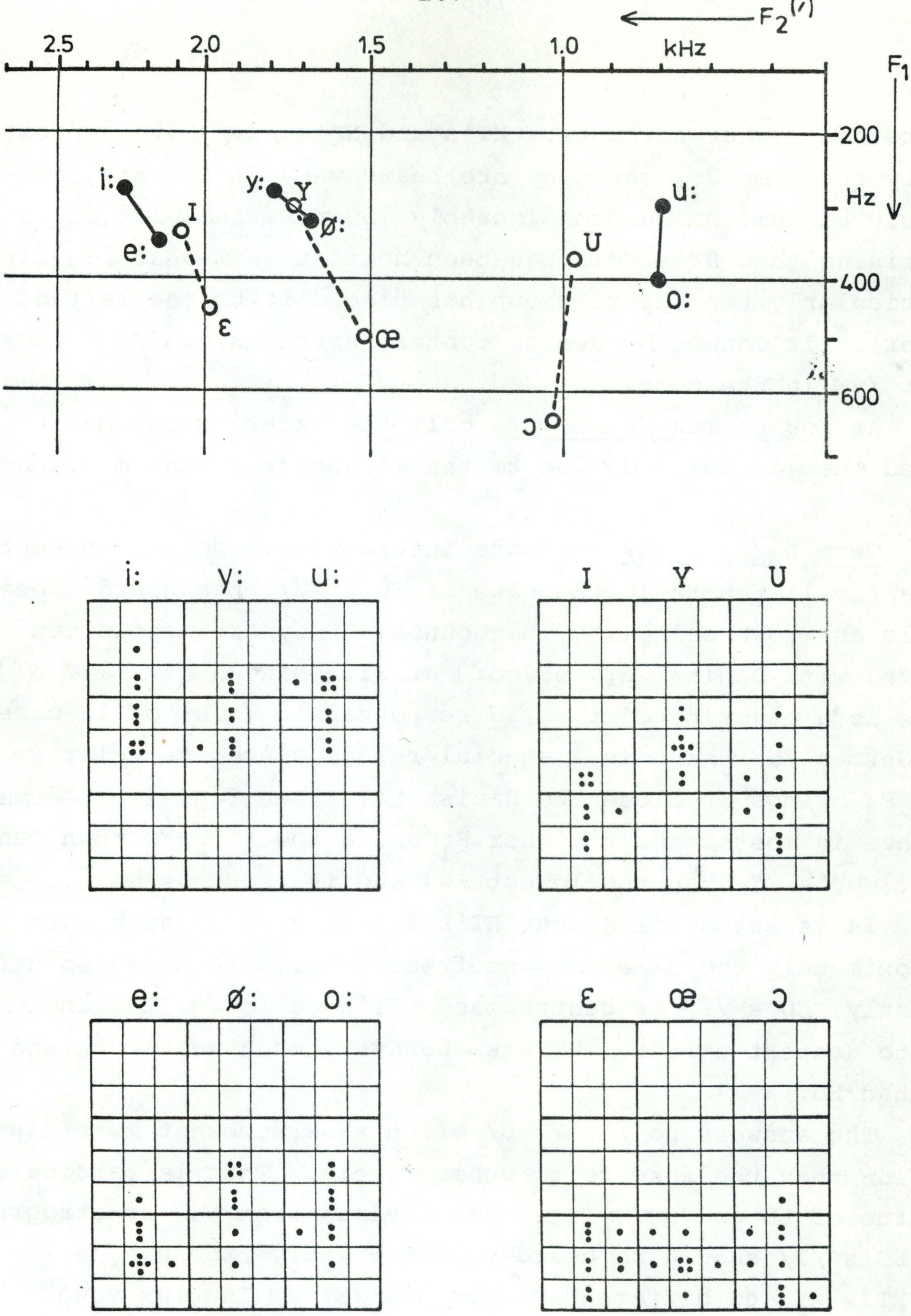

Fig. 7. Formant frequencies and listening results for the German speaker HL. - Danish listeners.

due to his higher formants. HT's and NB's /ø:/ have approximately the same F_1, but they are heard very differently, obviously because NB has considerably lower F_2 and F_3. It is surprising that HT's /o:/ has been heard as somewhat [ø]-like (particularly the expert group has placed it to the left of the center). It cannot be due to context effect since /o:/ comes after /y/ in the test.

As for German /ɛ, œ, ɔ/, only the expert group has placed them as lowered, due to the misunderstanding mentioned above.

German /I, Y, U/ are more interesting. Nobody (except for a few listeners in the case of ED's /U/) has heard these vowels as (lowered) [i, y, u]-sounds. They are most often equated with Danish [e:, ø:, o:] or with Danish [ɛ:, œ:, ɔ:]. There is a majority of ɛ, œ, ɔ responses in 7 out of 12 cases. For German /U/ there is a special reason since its relatively high F_2 brings it close to Danish [ɔ:] (see fig. 2). German /Y/ has in most cases a higher F_1 and a lower F_2-F_3 than Danish /ø:/. NB's /Y/ has the lowest F_2- and is heard as [œ:].

It is astonishing that HT's and ED's /I/, which have approximately the same formant frequencies, are heard so differently, ED's /I/ as centralized, HT's as low. It cannot be due to context effect. HT has, however, much weaker F_3 and F_4 than ED.

The answers to /I, Y, U/ often show somewhat more dispersion than the answers to other vowels. This is particularly true of ED and NB. It is not obvious from the spectrograms why ED's /I/ should be heard so differently from his /e:/ and HT's /Y/ so differently from his /ø:/. The lax vowels seem to make a less neat impression. But, on the whole, the differences in perception between /e:, ø:, o:/ and /I, Y, U/ for the different listeners can be explained from the formant frequencies.

b. Test 1955

The results of the 1955-test are in agreement with the results of the 1963-test. The seven Danish vowel segments were placed correctly. Short /i/ and /e/ were not placed lower than long /i:/ and /e:/, which is in accordance with the formants of the speaker.

German tense vowels were not heard as lowered compared to the Danish vowels, with the exception of the vowels in ED lieben (as in 1963), GR Höhle, and CH fühlen. But most of the examples were spoken by GR and CH, who both have unusually high higher formants in these vowels.

Of the lax /I, Y, U/, ED's vowel in immer and CH's in killen were heard as Danish [e], but GR killen as an [ø]-like [e]. The vowels of CH Kütte and GR Hülle were heard as [ø] and lowered [ø], respectively, GR Bulle was heard as [o], and Tunnel, with some dispersion, as [u] or [o].

The vowel of English did was heard as lowered [e] or raised [ε]; the response to Dutch tinnen were spread over [e], [ø] and [œ] (whereas the tense vowel in denen was heard as a clear [ẹ]).

It should be noticed that the tendency found in Holtse's test with synthetic vowels (see his article in this volume) and also in Rischel's unpublished test with synthetic vowels, viz. to perceive vowels as higher than would be expected according to known formant averages, is not found in the present tests.

B. German listeners

The answers from Kiel and Köln have been combined into the same graphs (figs. 8 - 12). In this case the average has been taken of all answers as one group. The Köln results were divided into experts (6), and students (17), but the Kiel results (10 persons) were not, although the group contained several phoneticians. A division into groups would have given

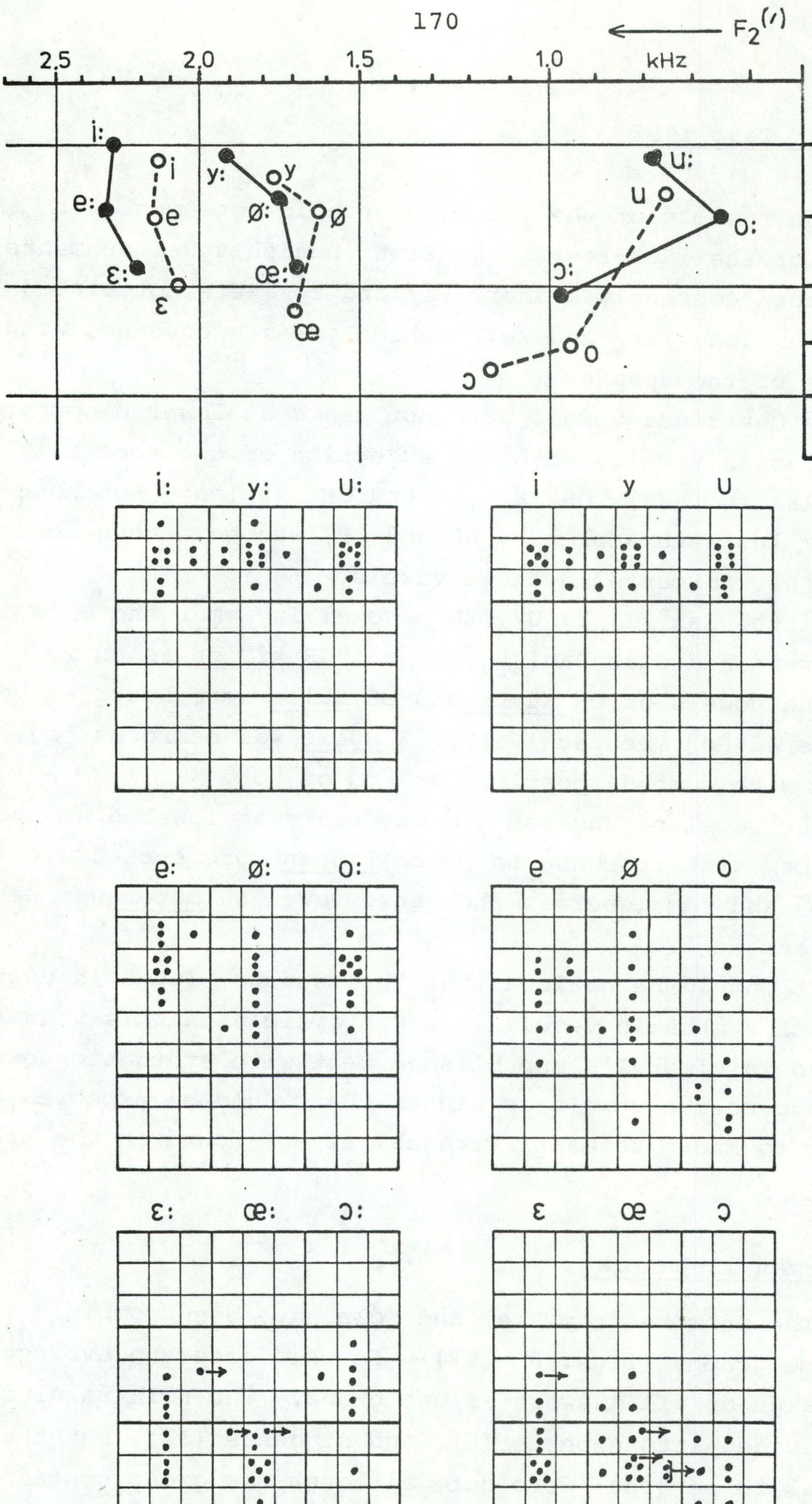

Fig. 8. Formant frequencies and listening results for the Danish speaker PD. - German listeners.

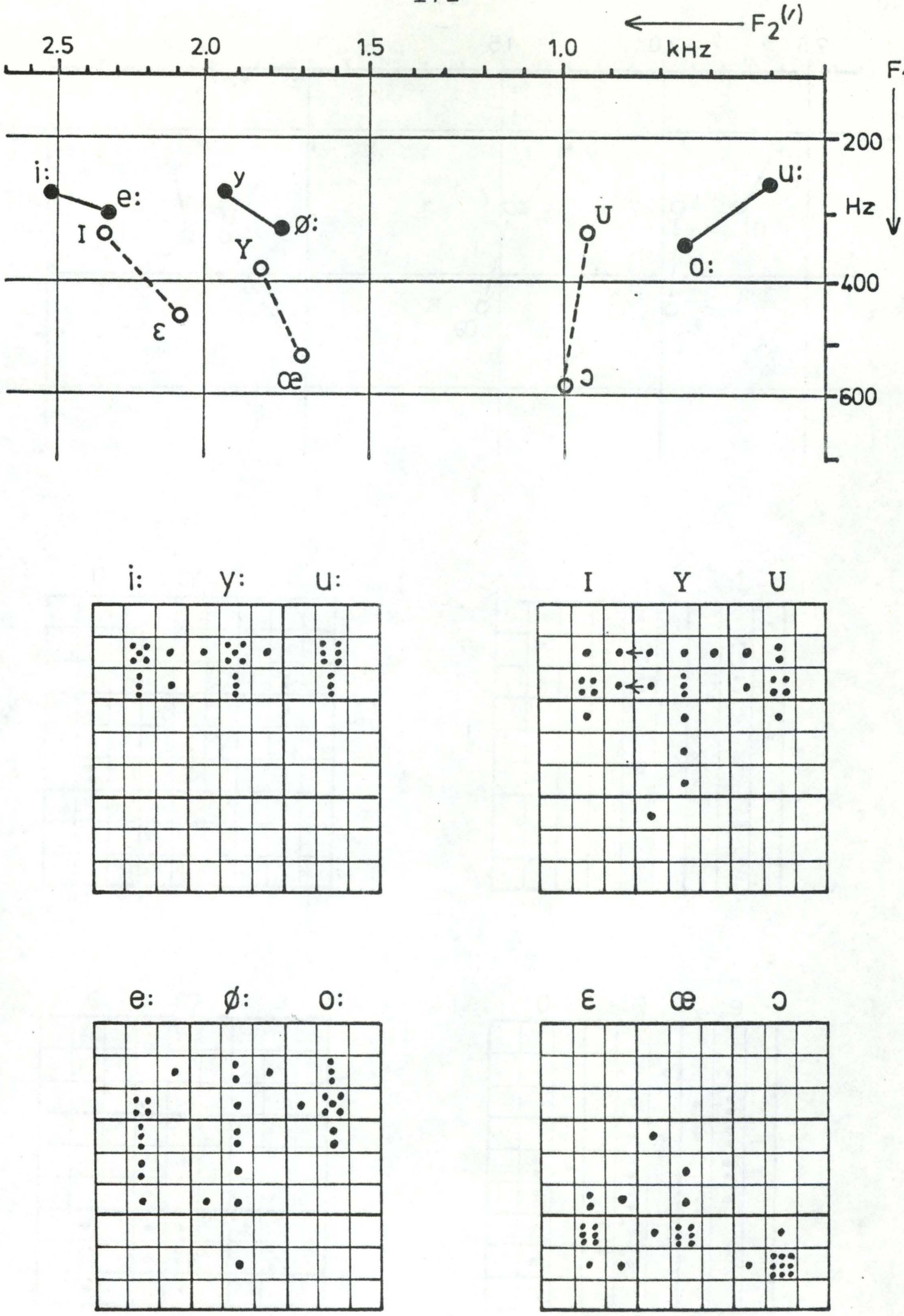

Fig. 9. Formant frequencies and listening results for the German speaker ED. - German listeners.

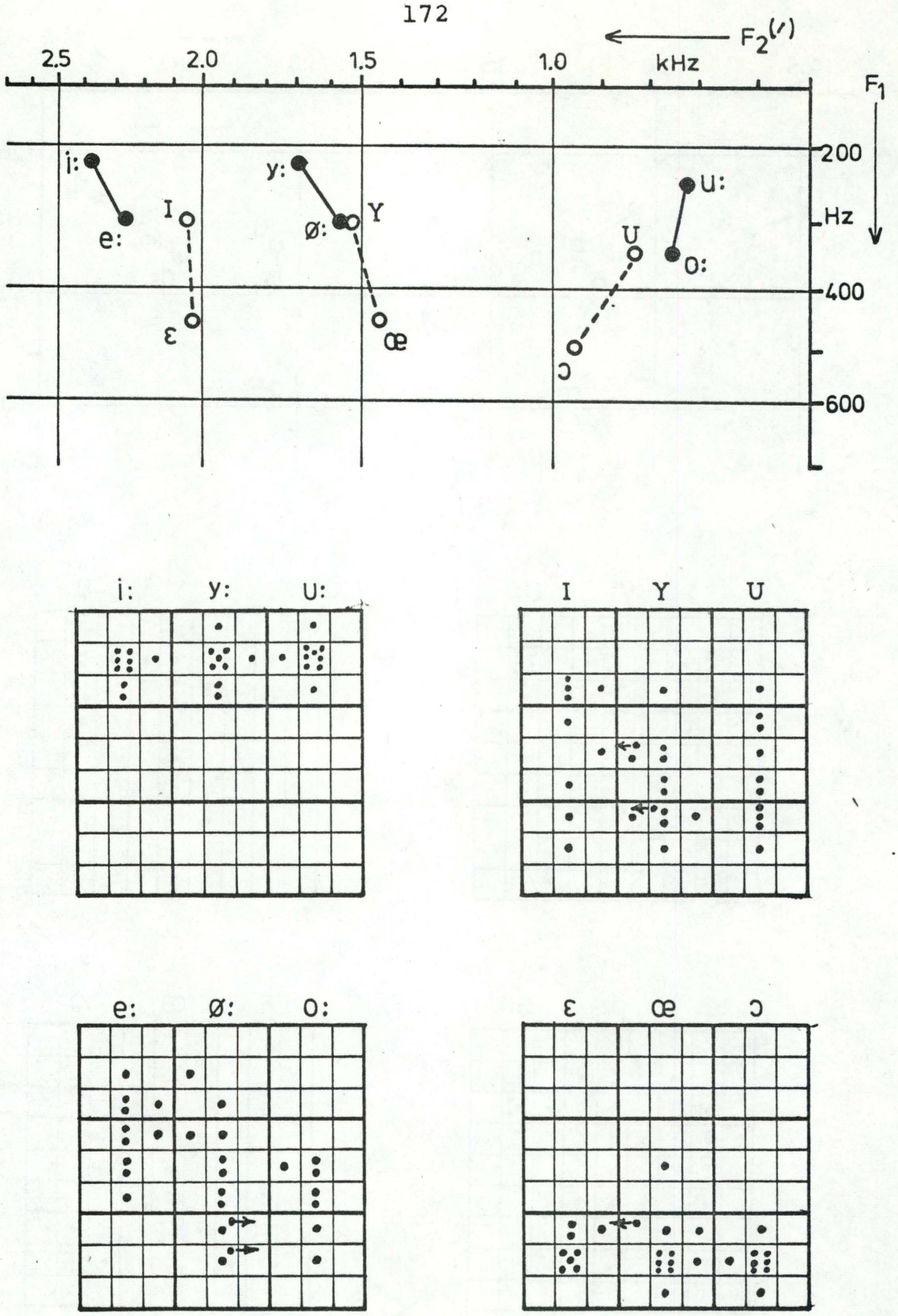

Fig. 10. Formant frequencies and listening results for the German speaker NB. - German listeners.

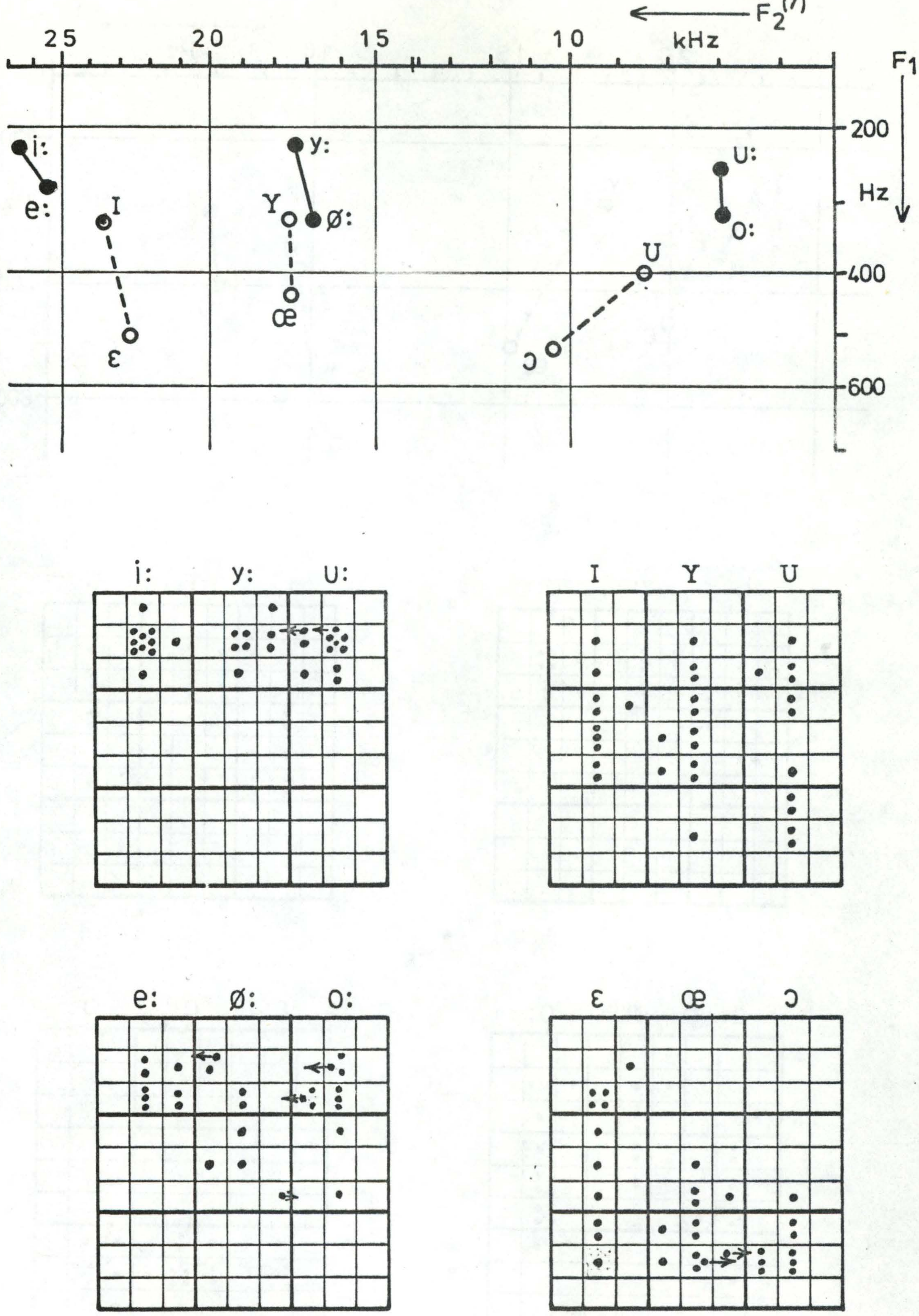

Fig. 11. Formant frequencies and listening results for the German speaker HT. - German listeners.

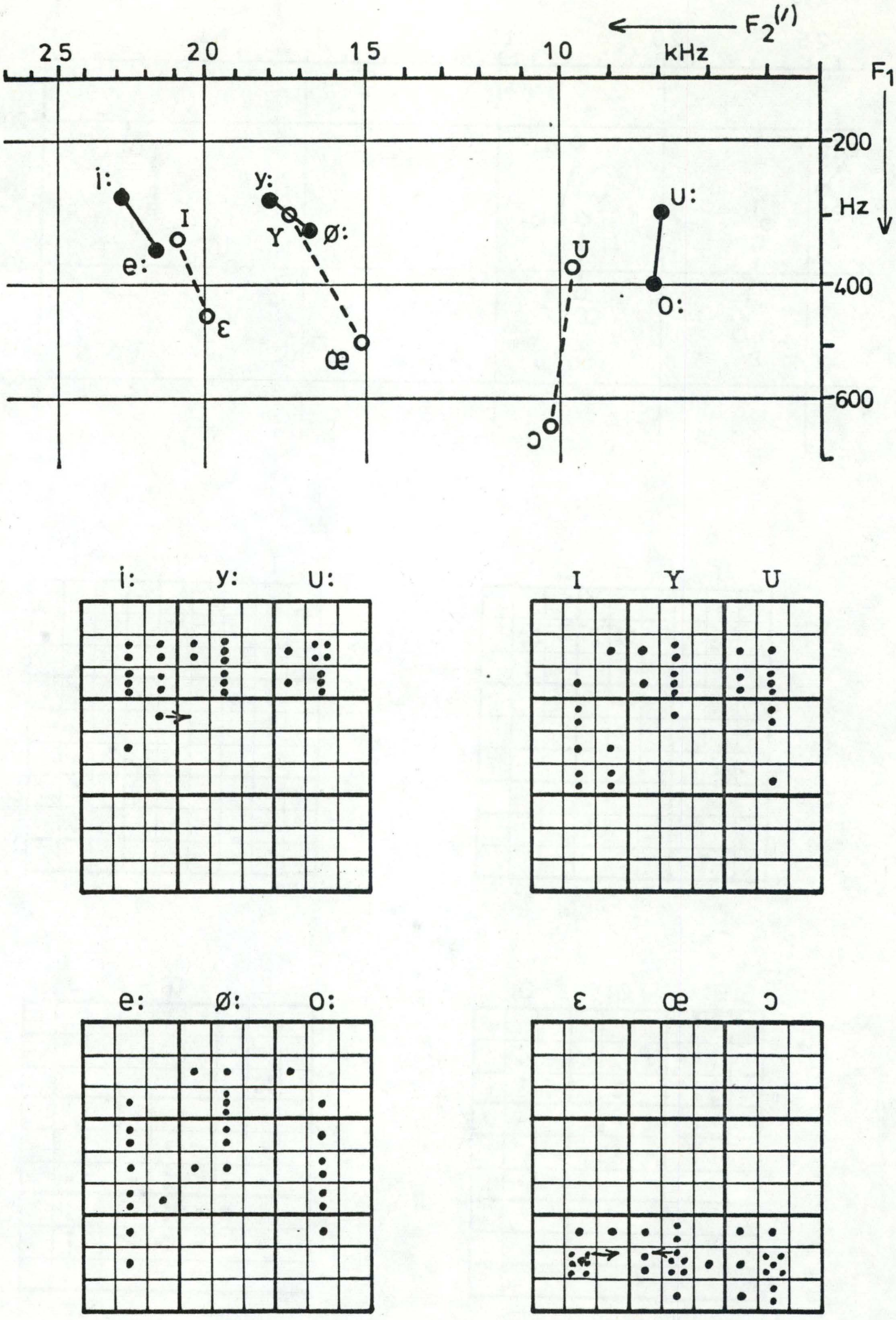

Fig. 12. Formant frequencies and listening results for the German speaker HL. - German listeners.

more weight to the expert answers than for the Danish groups. Moreover, it was easier to treat them as one group. It could also be done because there were no consistent differences between the groups.

There is, on the whole, more dispersion among the German listeners than among the Danish listeners, and the inclusion of the answers from Hamburg in the graphs would have made this still more apparent. There is even more dispersion than can be seen on the graphs, since percentages below 5% have not been included. In some cases with three single answers in the same direction from the central square, but in different subsquares, one point has, however, been put in the middle in order to give a better survey of the distribution. If there are many subsquares with only two answers, i.e. 6% of the listeners (which is just above the limit for one point), the number of points may exceed 10.

There is also more horizontal overlapping than in the Danish answers, so that more arrows have been necessary. This uncertainty may be due partly to the fact that the tape was 10 years old, and that it was played back on a different type of tape recorder. Some high frequencies may therefore have been lost, and the signal/noise level may have been less favorable, although the listening took place via earphones.

The answers to long /i:, y:, u:/ are, however, quite clear. The short /i, y, u/ of the Danish speaker and the long /i:, y:, u:/ of the German speakers, which were heard as lowered by the Danish listeners, are only heard as very slightly lowered by the German listeners (with the exception of HL, who has a very high F_1). There is a marked difference between the German and Danish listeners on this point, which supports the impression of a small difference between Danish and German high vowels, mainly depending on the higher formants.

The answers to /ɛ, œ, ɔ/ present few problems. German /ɛ, œ, ɔ/ are generally placed in the expected squares. It is not clear why ED's /œ/ is heard as [ø]-like (this was also done, to some extent, by the Danish listeners). That HT's /ɛ/ is heard as raised, and even in some cases as [i], by more than one third of the listeners must be due to his extraordinarily high F_2-F_3, which are even a good deal higher than the higher formants of NB's and HL's /I/.

It is understandable that the Danish low vowels are heard as raised. One might even have expected a more pronounced displacement. The fact that Danish /ɔ:/ and /ɔ/ are often heard as front rounded vowels can be explained by their relatively high F_2. When all single answers are taken into account, /ɔ:/ is heard as a front vowel by 24% and /ɔ/ by 39% of the German listeners (the corresponding percentages for Danish listeners are 3% and 17%).

The real problems concern the answers to /e:, ø:, o:/ and /I, Y, U/.

It is not astonishing that Danish /e:, ø:, o:/ are heard as raised, and /e:, o:/ even predominantly as /i/ and /u/. This corresponds well with the opposite tendencies for the perception of German sounds by Danish listeners and can be explained from the different formant positions. But it is astonishing that German /e:, ø:, o:/ have often been heard as [i, y, u]. These are even the predominant answers to HT's and ED's /e:/ and to HL's /ø:/. HT has very high F_2-F_3 for /e:/, and the Danish listeners have also heard his /e:/ as somewhat raised, but there are no obvious reasons in the other cases. It also happens that German /e:, ø:, o:/ are heard as open vowels, e.g. HL's /e:/ and NB's /ø:/. They have relatively low F_2-F_3. But the general dispersion over all three vertical fields compared to the concentrated responses of Danish listeners to

Danish /e:, ø:, o:/, and even, though less pronounced, to the corresponding German vowels, is surprising.

The explanation is probably that, since German long /e:, ø:, o:/ are qualitatively very close to /I, Y, U/, some listeners will spontaneously identify a short vowel of this quality with /I, Y, U/; it is therefore difficult for them to make a purely qualitative comparison with long vowels. And as /I, Y, U/ are the highest vowels of the lax vowel category and are written i, ü, u, they will be inclined to transcribe the stimuli as i, y, u and forget that these symbols were meant to represent the quality of long /i:, y:, u:/.

In this connection it is of interest that Bennett (1965) found that a synthetic vowel which is heard by German listeners as [o:] when long, is heard as [u] when shortened. And Lindner (1966) found that synthetic vowels heard as [e:, ø:, o:] when long, were heard as [i, y, u] when short. One might assume a general tendency to perceive shorter vowels as higher, but the results for the Danish listeners show that this is not the case. The different results for the German listeners must be due to the phonemic and orthographic system of German.[1]

The same difficulty arises, of course, for the responses to /I, Y, U/. The dispersion for these sounds is somewhat greater. In some cases, e.g. ED's /I/ and /Y/, there are more i, y-responses than to /e:/ and /ø:/. This does not seem to be justified by the formant frequencies; and, except for one case (HL /Y/), the lax vowels /I, Y, U/ are always acoustically closer to /e:, ø:, o:/ than to /i:, y:, u:/. It might be due to a specific quality of lax vowels (cp. that ED's /I/ is heard as centralized). But HT's /e:/ and /I/ show the opposite tendency: there are more e-responses to his /I/ and more i-responses to his /e:/, which might be explained by the very high F_2 of his /e:/. His /U/ is mostly heard as [ɔ], probably because of the high F_1.

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1) see postscriptum, p. 194

In any case, there are (just as for /eː, øː, oː/) a good many i, y, u-responses, which are not justified by the formant positions.

The results from Hamburg have not been included in the graphs because the somewhat larger dispersion would make the picture more blurred. The greater dispersion is partly due to the fact that both German /eː, øː, oː/ and /I, Y, U/ are more often identified with /ɛ, œ, ɔ/ than in the other groups, so that the answers are spread over the whole vertical scale, partly to the fact that in a few cases there is more horizontal overlapping (e.g. in HT's /ɛ, œ, ɔ/). The Hamburg listeners have, just as the other groups, been inclined to identify the short stimuli of /I, Y, U/-quality with short vowels, but some have apparently found them too open to be [i, y, u] and have chosen [ɛ, œ, ɔ].[1] Apart from this, the answers look very much like those of the other two groups. Almost all the listeners were from North Germany.

The very sharp cuts may have reinforced the impression of short vowels. Cohen et al. (1963) report that an abrupt decay favours short-vowel-responses for Dutch listeners. On the other hand, measurements of German vowels (EFJ 1941, Hans Peter Jørgensen 1969, EFJ and H.P. Jørgensen 1970) have not supported Sievers' old theory that the decay of short vowels should be more abrupt than that of long vowels in German.

Five of the listeners from Köln repeated the test later. The most consistent listener gave exactly the same response the second time in 53% of the cases, the least consistent in 21% of the cases, i.e. in most cases there was a change, but, generally, it was only one step in the diagram. This means, however, that one should not try to explain very small differences.

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1) Why this identification has been made especially by the listeners in Hamburg is difficult to explain. It may perhaps have something to do with the symbols used. On the answer sheets used in Hamburg, [ɛ œ ɔ] were written ĕ, ŏ̈, ŏ, and in the key words they were spelt e, ö, o (Betten, öffnen, hocken).

3.3.2. Comparison between perception of vowels in isolation and in words in various consonant surroundings

The German listeners in Kiel, Köln, and Hamburg listened to a small subsidiary test containing some of the same vowels in words. The task was exactly the same as for isolated vowels, but the result was very different.

The responses to HT hissen, hütten, hupfen are shown in fig. 13, and the responses to the corresponding isolated vowels by German and Danish listeners are presented again for comparison. It appears from the graphs that whereas /I, Y, U/ in isolation are often heard as [e, ø, o] and sometimes even as [ɛ, œ, ɔ] by the German listeners (and generally as somewhat lower by the Danish listeners whose standard vowels are somewhat higher), they are identified almost exclusively as [i, y, u], although somewhat lowered, when heard in words.

The corresponding vowels spoken by NB give a quite similar picture: the vowels in words were heard as higher. Moreover, whereas 24% of the German listeners heard the vowel in hissen as a front rounded vowel when presented in isolation, nobody made this identification when the vowel was presented in the word hissen. For HL the differences are less drastic since his /Y/ and /U/ are perceived as rather high, also in isolation.

In these cases the transitions were of a very small extent since the front vowels were found between /h/ and an alveolar consonant and the back vowels between /h/ and a labial consonant. The main reason for the different responses to the vowels in isolation and in words is no doubt that isolated segments are heard by most listeners as sounds, whose quality can be determined freely, whereas the same vowels spoken in words are identified immediately with the phonemes /I, Y, U/,

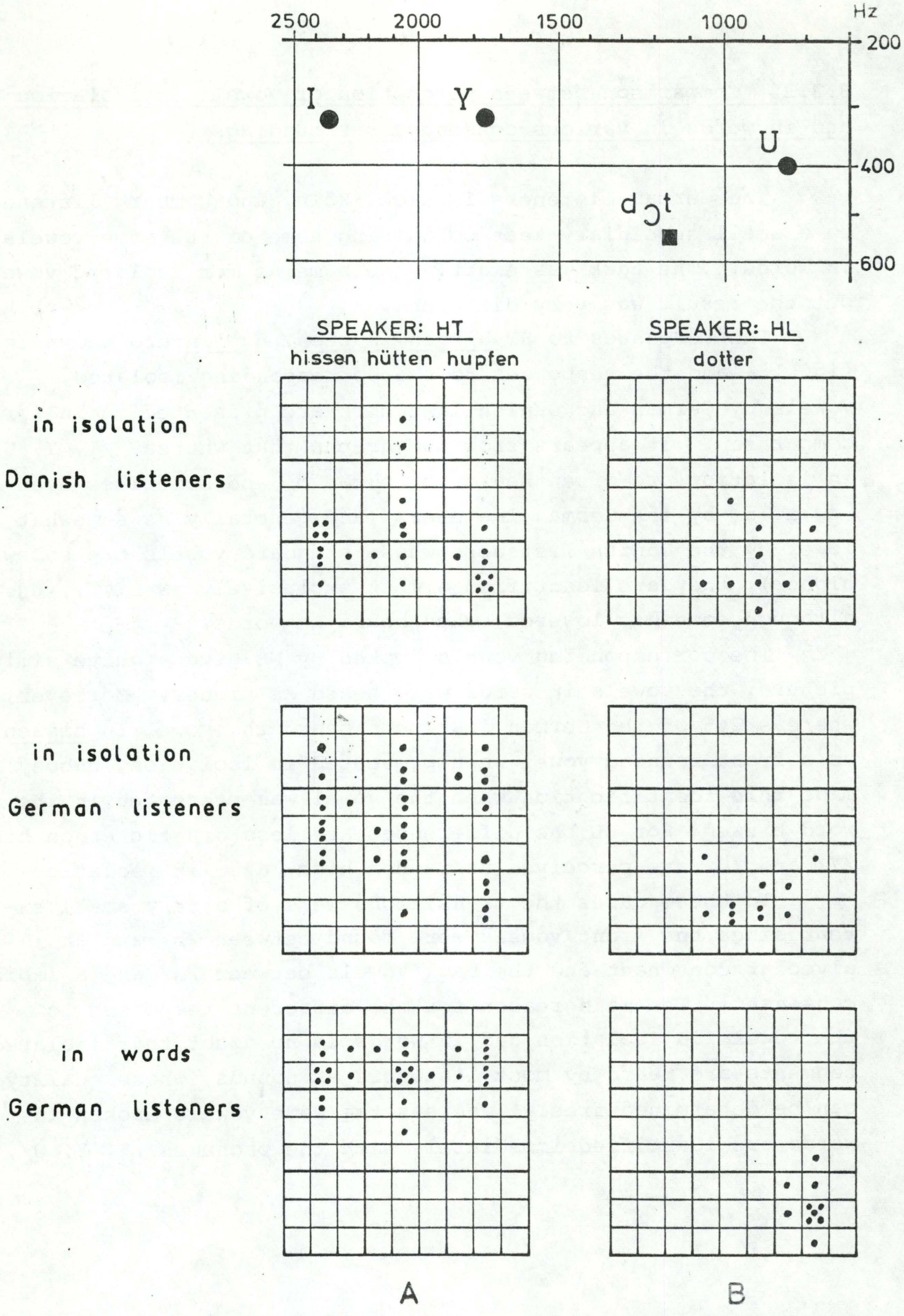

Fig. 13. Comparison between responses to vowels presented in isolation and in words.

i.e., they are identified in a categorical way, and it is difficult to abstract from this identification and listen to them as sounds.

The following graphs (figs. 13 - 16) give some illustrations of the perception of vowels in various consonant surroundings. Fig. 13 gives a picture of the perception of the vowel of Dotter spoken by HL and presented in isolation and in the word. When listening to this vowel in isolation, 69% of the German listeners and 77% of the Danish listeners identify it as a rounded front vowel because of its high F_2. When heard in the word, none of the German listeners hear it as a front vowel.

The formants of HL's Dotter are almost exactly the same as those in PD's /ɔ/, which was heard as a front rounded vowel by 39% of the German listeners, but not by the Danish listeners. The difference may partly be due to context effects. As mentioned above, PD's /ɔ/ comes after an /œ/; HL's /ɔ/, on the other hand, comes after an /U/ in the test.

Fig. 14 gives a picture of the perception of German /I/ in labial surroundings. Heard in isolation the vowel of NB bibbern is identified as a front rounded vowel by 35% of the Danish and 33% of the German listeners. In the word, none of the German listeners hears it as rounded. Presented in isolation, the vowel of ED Lippen is identified as a front rounded vowel by 78% of the Danish and 91% of the German listeners.

Lippen and bibbern have a lower F_2 than other words with /I/, close to Danish /ø:/, but the formant frequencies do not explain the difference in the results for NB and ED. It should, however, be noticed that ED's vowel has a higher fundamental.

In figs. 15 and 16 the responses to the vowels in hupfen and Dutzend, spoken by NB and HL, can be compared. NB's vowel

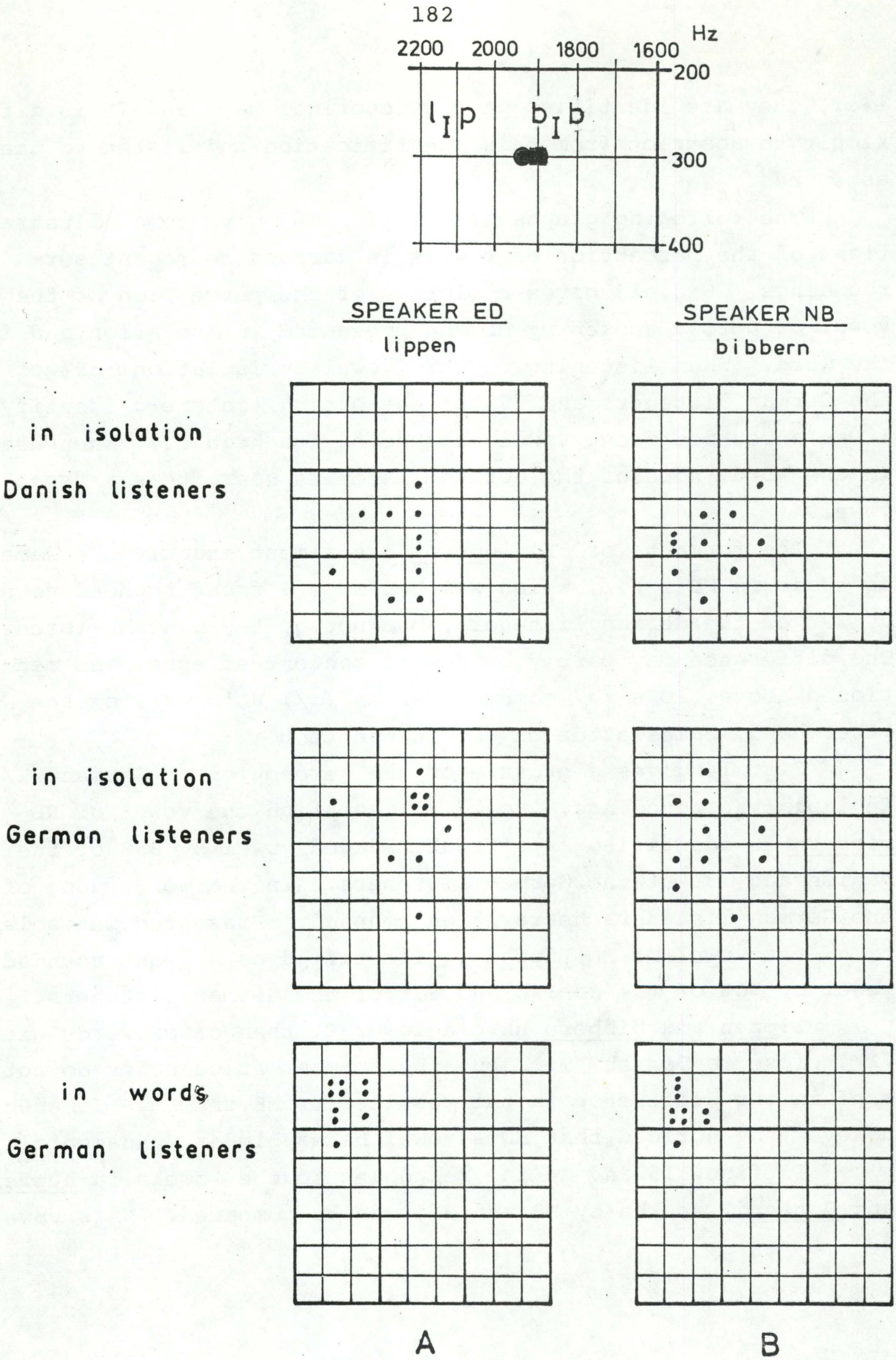

Fig. 14. Comparison between responses to vowels presented in isolation and in words.

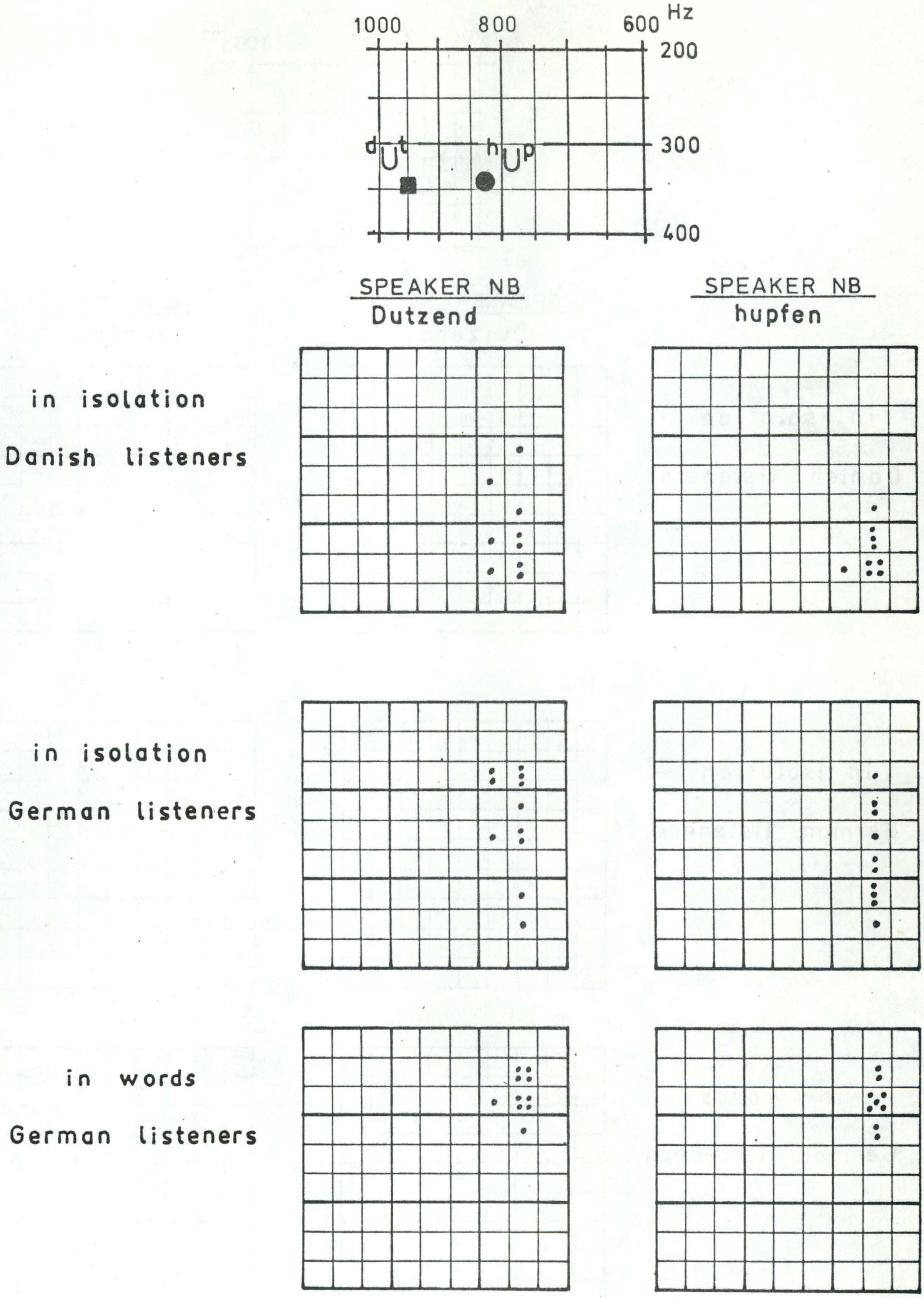

Fig. 15. Comparison between responses to vowels presented in isolation and in words.

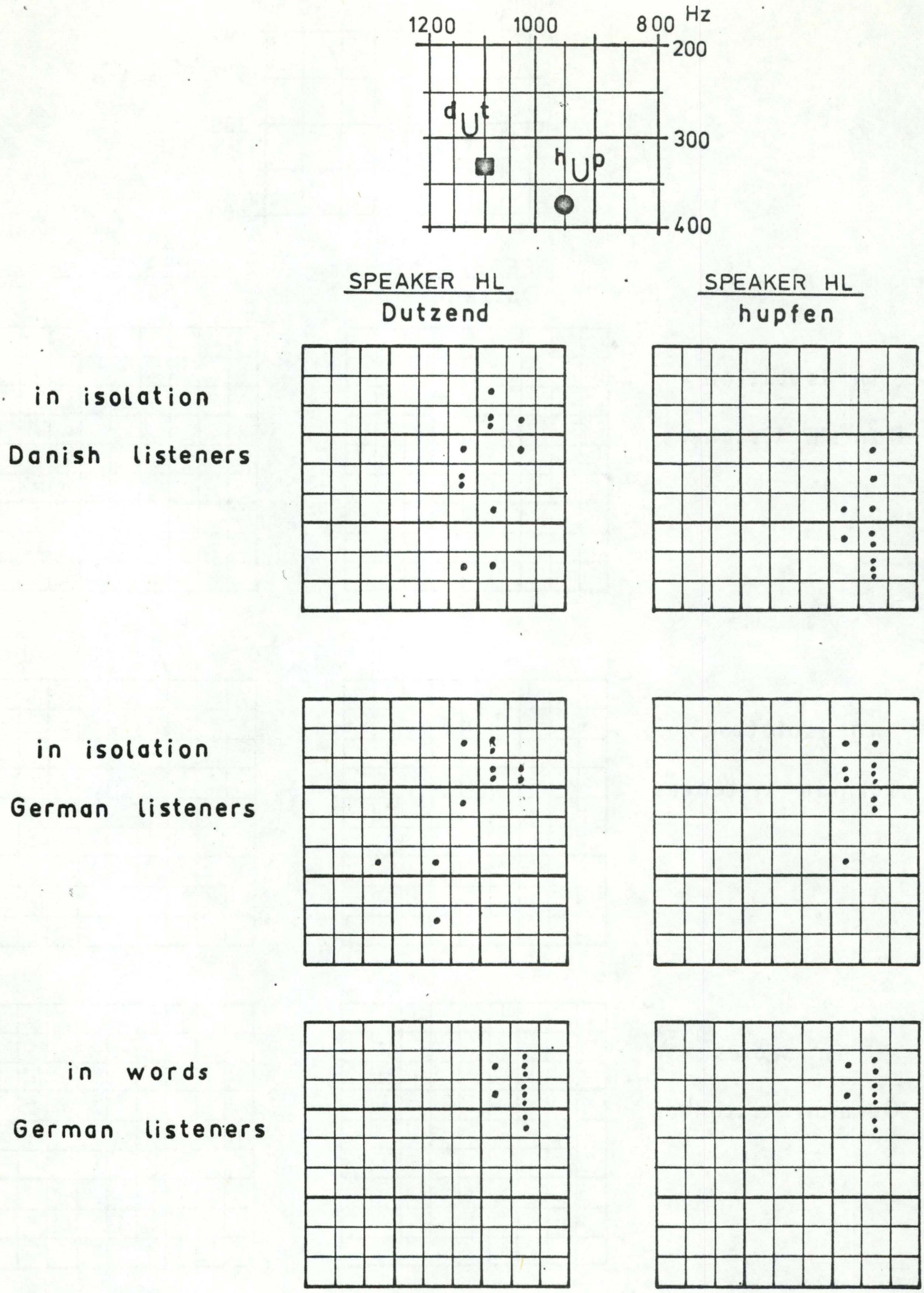

Fig. 16. Comparison between vowels presented in isolation and in words.

in Dutzend is not much fronted. It is rather so that his F_2 in hupfen is somewhat lower than normal, which makes the vowel resemble German [o:], whereas the vowel in Dutzend is identified as [u] by two thirds of the German listeners. The vowel in Dutzend comes close to Danish [ɔ:], and that of hupfen is in between [ɔ:] and [o:], and the listening results are in agreement with this.

HL has a much more fronted vowel in Dutzend with a high F_2. In isolation it is heard as a front rounded vowel by 37% of the Danish and 30% of the German listeners. In words this is never the case.

The results from Hamburg show the same differences between vowels in isolation and in words. The difference is even greater, since 60% of the Hamburg listeners heard HT's /I, Y, U/ as [ɛ, œ, ɔ], when isolated, and 90% as [i, y, u] in words. As for the vowels of Dutzend and Dotter, Lippe and bibbern, they were only presented in isolation. 45% heard a front rounded vowel in HL Dutzend and 84% in Dotter. The vowel of Lippe was heard as a front rounded vowel by 84% and that in bibbern by 16%.

The 1955-test contained some vowels of the same type. The vowel of ED Lippen was also used in this test. It was heard as [ø] (84% rounded front vowel). GR Lippe was heard as [œ], [u] in Tunnel was not heard as fronted.

The vowel of American English did was heard as [e] or [ɛ]; but the vowel of pip was heard as [œ] (83%), and the same was true of the /U/ of British English soot for most listeners (70%).

The different reaction to the vowels of hissen, hütten, hupfen in isolation and in words could be explained as the result of a phonetic vs. a phonemic perception. As /I, Y, U/ are the highest vowels of the lax category and are written

<u>i</u>, <u>ü</u>, <u>u</u>, they are heard as (lowered) [i, y, u] in words, although they are approximately of the same quality as [e:, ø:, o:]. This explanation is hardly sufficient in the cases <u>Lippe</u>, <u>Dutzend</u>, <u>Dotter</u>. Here the vowels differ from normal /I, U, ɔ/ in quality, and this difference should be noticeable, particularly to phoneticians, but when the vowels occur in words nobody hears these vowels as front rounded vowels, and only about 20 % hear a fronted variety of [U] and a retracted variety of [I]. But here a second factor comes into play: the change in F_2 is due to an automatic coarticulation feature, the vowel is influenced by the surrounding consonants, and there are also pronounced transitions to these consonants. The special features of the vowel are probably perceived as due to the consonants, i.e. the change of formant frequencies is compensated for in the perception.

It is not possible to decide on the relative importance of the two mechanisms (the categorical perception and the compensation for the influence of surrounding consonants) on the basis of the present experiments. For that purpose the tests should have included vowels in consonant surroundings in nonsense words besides the real words. But the reaction to <u>hissen</u>, <u>hütten</u>, <u>hupfen</u> shows at any rate that the categorization effect is strong. That the compensation effect is also at work appears from the experiments made by Lindblom and Studdert-Kennedy (1967). They placed synthetic [I] and [U]-vowels in symmetrical [w-w] and [j-j] surroundings and found a marked compensation effect in the perception of these stimuli.

<u>3.3.3. The effect of relatively small formant differences</u>

A few other vowels were included to see whether relatively small differences in formant frequencies would show up in the listening results. ED Ziege has a lower F_1 (25 Hz) and a higher F_2 (150 Hz) than ED lieben. This difference is clearly heard. 84% of the Danish listeners heard the vowel of lieben as [e:] (partly as a raised [e:]), whereas only 6% heard the vowel of Ziege as [e:], and the German listeners show a somewhat stronger tendency to consider /i:/ in lieben as lowered [i]. - ED Minne has a slightly lower F_1 (25 Hz) and a slightly higher F_2 (75 Hz) than Distel, and F_3 is 275 Hz higher. This difference is reflected in the answers of the Danish listeners. 24% heard an [i] in Minne, but only 5% in Distel, and 10% heard a front rounded vowel in Distel. All the other answers were e (and there were more raised e's for Minne and more lowered e's for Distel). There were also some small differences in the German answers. The vowel of Distel was sometimes heard as [y].

3.3.4. Results of the discrimination test

This test was very restricted; it comprised only three sets of four vowel segments of 50-80 msec.: /i:, e:, I, ɛ/ spoken by ED and GR, and /y:, ø:, Y, œ/ spoken by CH, and not all possible comparisons were made. It is therefore no use to apply any statistics to the material, and, moreover, it would be complicated, since the subjects were allowed to give three different answers: (1) highest degree of similarity in the first pair, (2) in the second pair, and (3) no difference. 31 Danish students participated in the test.

The results are given in table 5, and the formant frequencies of the vowels are shown in fig. 17.

TABLE 5

Results of a comparison test of the type i-I, i-e. The numbers in the first and second column indicate the percentage of listeners who considered the similarity to be greater in the first and second pair respectively.

ED				GR				CH			
i	I	e	=	i	I	e	=	y	Y	ø	=
	19	23	58		19	81	0		23	26	51
e	i	I	=	e	i	I	=	ø	y	Y	=
	10	87	3		65	35	0		19	71	10
I	e	i	=	I	e	i	=	Y	y	ø	=
	97	3	0		90	7	3		10	87	3
I	e	ɛ	=	I	e	ɛ	=	Y	ø	œ	=
	97	3	0		32	61	7		97	3	0
ɛ	I	e	=	ɛ	I	e	=	œ	ø	Y	=
	23	13	64		74	13	13		35	7	58

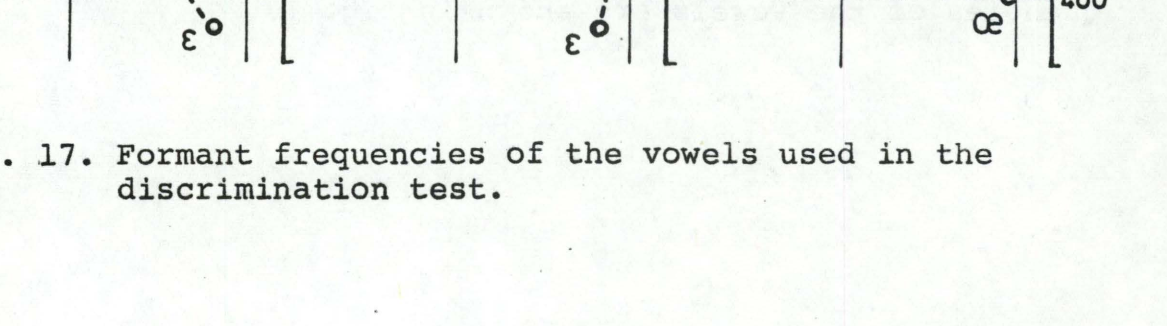

Fig. 17. Formant frequencies of the vowels used in the discrimination test.

It is obvious that the answers are in agreement with the acoustic diagrams, for instance the differences between the formant frequencies of ED and GR are clearly reflected in the answers. There is some indication that the vertical distance is more important than the horizontal distance when measured on the mel scale, cp. that the proximity of GR I-ε compared to I-e is only perceived by 61% of the listeners, whereas the proximity of I-e compared to I-i is perceived by 90%. This supports the assumption of a logarithmic scale as more appropriate than the mel scale (cp. EFJ 1972, footnote 5).

4. Conclusion

The following conclusions can be drawn from the experiments:

(1) For isolated vowel segments the placement of the stimuli in an acoustic F_1-F_2 (or F_1-$F_{2'}$) diagram gives, on the whole, a good basis for predicting the auditory impression, even as regards finer shades.

(2) The responses of German listeners to short segments of German /I, Y, U/ and /e:, ø:, o:/, however, cannot be explained on the basis of formant frequencies alone. The dispersion is considerable. Probably some subjects are able to listen for the quality and write them as e, ø, o, others are influenced by their short duration and tend to perceive them categorically as the phonemes /I, Y, U/, the highest lax vowels, and they write them accordingly as i, y, u. Still others identify them as short /ε œ ɔ/. The fact that /I, Y, U/ and /e:, ø:, o:/ are treated alike shows, however, their auditory similarity.

(3) The answers of Danish listeners to these sounds are more concentrated and in agreement with the formant frequencies. There is, however, a somewhat greater dispersion in their responses to /I, Y, U/ than to the other vowels (particularly for the speaker ED). This points to a more indefinite quality of /I, Y, U/, which is in agreement with their more central placement in the acoustic vowel diagram and with the indications of physiological laxness mentioned in section 2. This quality may present certain difficulties to listeners who have not got this type of vowels in their mother tongue.

(4) When vowels are presented in words, finer shades are not perceived, and the perception is dominated by phonemic categorization, automatic compensation for coarticulation effects, and influence from orthography.

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Postscriptum

After having finished this report I became aware of a paper by Rudolf Weiss, read at the seventh international congress for phonetic sciences in Montreal 1971 (Proceedings 1972, p. 633-636) which is relevant for some of the problems treated here.

Weiss has undertaken a perceptual test with 287 examples of German vowels spoken by a German phonetician in the environment b-tən and varied according to quality and quantity. The listeners were asked to identify the word, i.e. the decisions were phonemic, but in contradistinction to the test described in the preceding report they were not asked to identify by quality alone.

According to the graph p. 635, /e:/ and /ø:/ were perceived as /I/ and /Y/ respectively when shortened below approximately 150 msec, and /o:/ was perceived as /U/ when shortened below approximately 200 msec. This is in accordance with the interpretation of the answers to the test reported here.

Conversely lengthened /I/ was heard as /e:/, lengthened /Y/ as /ø:/ or /y:/, and lengthened /U/ as /o:/ or /u:/ according to the quality. As might be expected, North German subjects listened more for quality, South German subjects for quantity.