ACOUSTIC SYSTEM CONTRAST-MEASURE APPLIED TO ENGLISH VOWELS

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INTRODUCTION

In previous work on Dutch vowels (Koopmans-van Beinum, 1980) a measure which denotes the acoustic contrast of **whole** vowel **systems** in various speech conditions (acoustic system contrast ASC) was introduced.

The degree of contrast is to a great extent speech situation- and speaker-dependent. In order to create a measure for comparison of these degrees of acoustic contrast, we first calculated per speaker a speaker centroid by averaging all measured formant frequencies (F_1 and F_2). The position of the centroids in the formant field suggested a close relation with the lengths of the speakers' vocal tracts. Next we computed the total dispersion in each speach condition per speaker, assuming that the vowels of a specific language are distributed over the acoustic space in such a way that the contrasts between the vowels are maximal (Liljencrants and Lindblom, 1972).

For the four Dutch speakers this procedure resulted in adequately comparable ASC-values in the explored eight speech conditions showing clearly the way in which contrasts in the vowel system decrease when going from vowels pronounced in isolation to unstressed vowels in free running speech.

These results, however, evoke the question whether this ASC-measure is exclusively suited to the Dutch vowel systems, or is generally applicable to other languages as well. In a pilot study reported below we tried to answer this question for English vowel systems, although the speech material is rather scanty.

DATA COLLECTING

Speech material

Several years ago we collected material of a number of native speakers of Standard English for the investigation of certain aspects of English vowels (Deighton-van Witsen, 1973; Deighton-van Witsen and Koopmans-van Beinum, 1974).

Since the present study aims to be only a pilot investigation we decided to use part of this speech material, viz. items produced by two male R.P. speakers. The used material consisted of ten monophthongs spoken in isolation, and also the same vowels in four series of isolated words. This gave us the possibility of comparing English vowel systems with Dutch ones in two speech conditions.

The vowels pronounced in isolation had a key-word, besides the vowel printed on a card. These key-words were not used in the four word-series. The word-series consisted as far as possible in meaningful items of CVC combinations of which the initial consonant was [b] , [k] , or zero. The final consonants were respectively [d], [t], [z], and [s] or a cluster with [s] as its first element (Table 1).

Table 1 List of the ten English monophthongal vowels with four word-series.

[i]	bead	beat	bees	obese
[I]	bid	bit	(show)biz	abyss
[ɛ]	bed	bet	embezzle	best
[æ]	bad	bat	as	ass
[ɑ]	barred	art	bars	bask
[ɒ]	cod	cot	Boz	boss
[ɔ]	board	bought	sores	source
[ʊ]	could	foot	-	puss
[u]	food	coot	booze	boost
[ʌ]	bud	but	buzz	bus

These items were collected together with a lot of other material and the speakers only had a moment to look at each card. No oral instructions were given during the whole of the recording session.

Measurements

For purposes of comparison formant frequencies (F_1 and F_2) of the English vowels were measured in the same way as described in Koopmans-van Beinum (1980), making use of a special segment spectrograph (Wempe, 1979). The resulting spectrograms are very clear without influences of the fundamental frequency when only one period of the fundamental frequency is selected for analysis (see Fig.1).

For each vowel these measurements were done at one point in the vowel signal, viz. where the intensity of the vowel was maximal. Influences of pre- and postvocalic consonants may be reduced to a minimum now.

DATA PROCESSING AND RESULTS

The first step in data processing was to calculate for each vowel mean values of F_1 and F_2 per speech condition per speaker (see Table 2), and to plot the results of both speakers together in the F_1-F_2 plane (Fig.2). Next we calculated the speaker centroids by averaging per

Table 2 Mean values of formant frequencies (F_1 and F_2) in Hz for two English speakers in two speech conditions.

	Eng.speaker 1				Eng.speaker 2			
	vowels in isol. (n=1)		vowels in words (n=4)		vowels in isol. (n=1)		vowels in words (n=4)	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
[i]	270	2050	283	1838	250	2500	250	2123
[ɪ]	400	1720	393	1488	340	2150	340	1873
[ɛ]	570	1540	490	1365	530	1900	513	1750
[æ]	700	1350	645	1335	790	1590	775	1580
[ɑ]	660	1020	588	1005	720	940	720	915
[ɒ]	660	870	515	838	530	830	535	820
[ɔ]	440	700	433	675	490	640	455	650
[ʊ]	290	750	413	953	240	600	377	843
[u]	310	980	313	1165	250	940	265	1135
[ʌ]	630	1260	583	1085	820	1080	690	1048

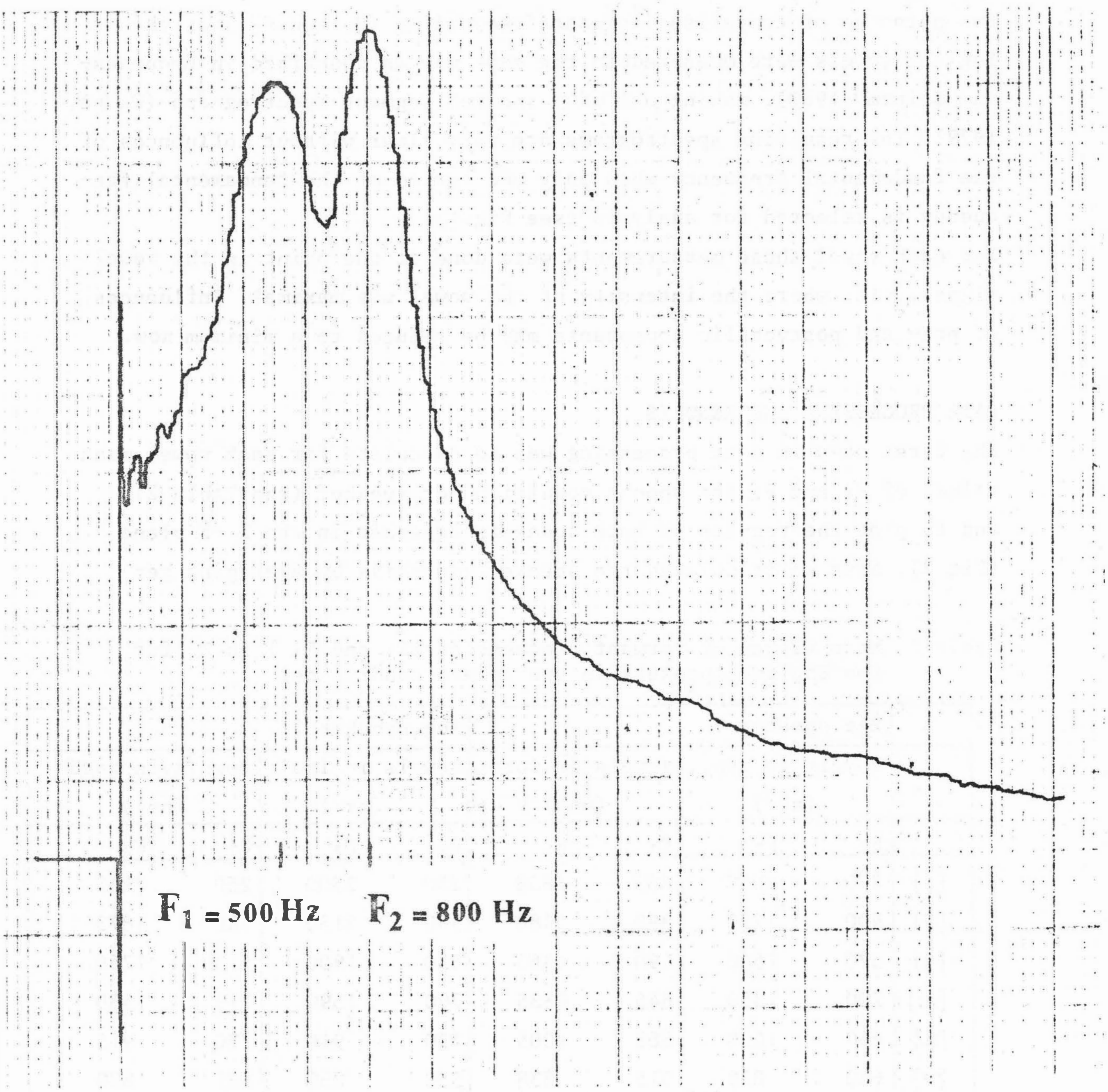

Fig.1 Spectrogram of one period of the vowel in <u>boss</u>, made after the method described in Wempe (1979).

speaker all measured F_1 and F_2 values, and we plotted the results in Fig.2 as well.
A closer look at Fig.2 shows that the vowel diagram of speaker 2 is considerably more extended than that op speaker 1, but the positions of both speaker centroids presume a difference in vocal tract length which indeed would be in correspondence with the difference in height of both speakers (respectively 1.80 m and 1.65 m).
Fig.3 shows the vowel diagrams of the two Dutch male speakers (see Koopmans-van Beinum, 1980) in the two speech conditions of vowels pronounced in isolation and vowels in isolated words. Here the indicated speaker centroids are calculated on the base of the F_1 and F_2 values in all eight speech conditions used in the study mentioned above.

Inspection of Fig.2 and 3 creates the impression that the reduction of vowel contrasts, when going from vowels in isolation to vowels in words, is much larger for the two English speakers than for the Dutch ones. The question arises, however, whether indeed this impression is reflected when applying an objective measure. Is it possible to use the acoustic system contrast-measure (ASC), which fits rather well for Dutch vowel systems, for English vowel sytems as well ?
Although no running speech material of the two English speakers is available we calculated the ASC-values of their vowel systems in isolation and in words only, in the same way as done for the Dutch speakers (Koopmans-van Beinum, 1980). In our previous work we defined acoustic system contrast (ASC) by means of the total dispersion, assuming that the vowels of a specific language are distributed over the acoustic space in such a way that contrasts between vowels are maximal.
In order to obtain results comparable among themselves we had to get rid of variations caused by differences in vocal tract lengths of the speakers. In the first instance this is done by transforming all formant values of the linear frequency scale into values on a logarithmic scale. (A modification of this procedure is in preparation, but not used in this study yet.)
In order to compare the shift intervals per vowel as well as per speaker we transformed $LF_1 = 100\ {}^{10}\log F_1$, 100 being chosen as a scale

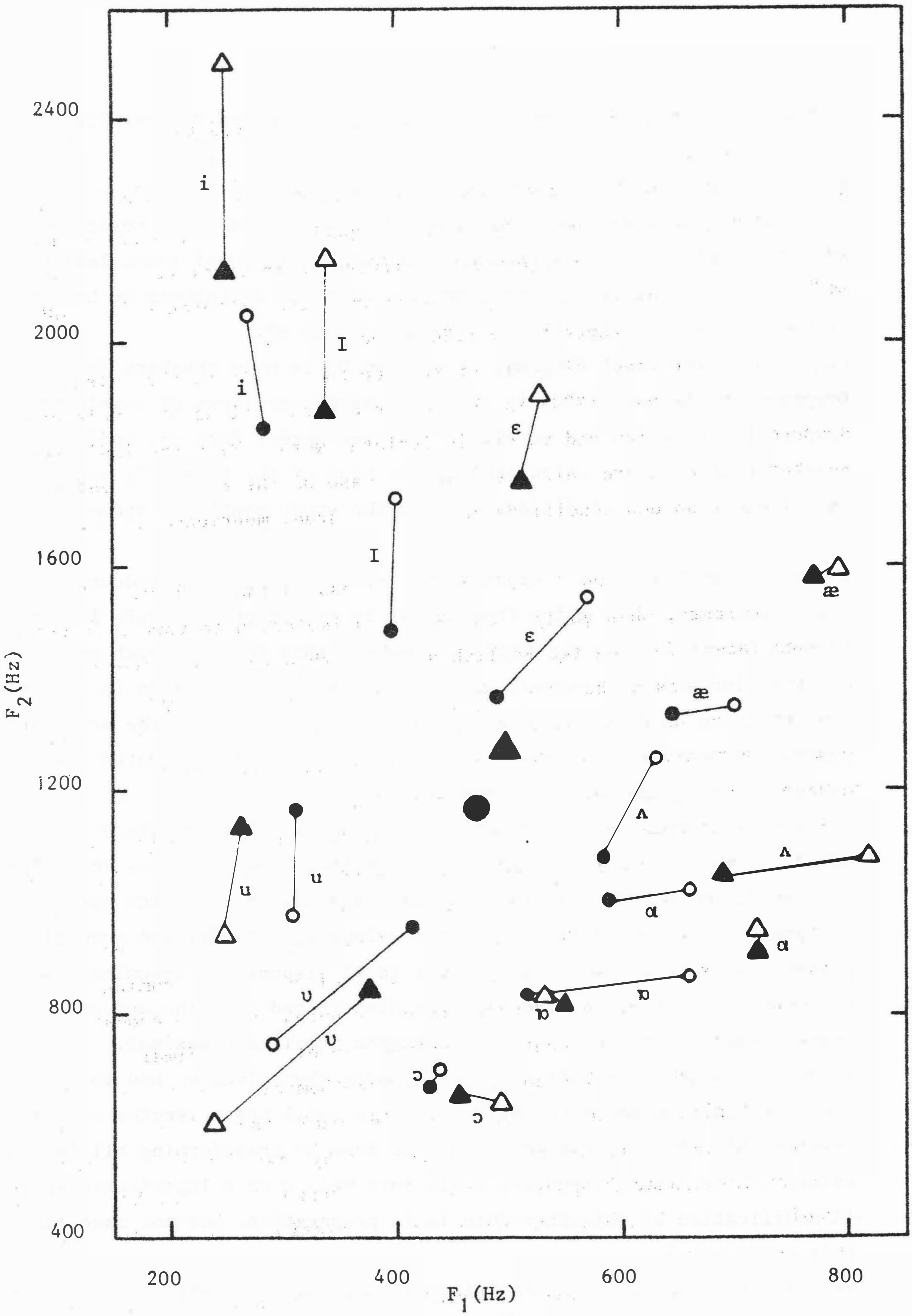

Fig.2 Mean formant frequencies of two English speakers in two speech conditions, plotted in the $F_1 - F_2$ plane (connected per vowel). Circles indicate speaker 1, triangles speaker 2, open symbols indicate vowels in isolation, filled symbols vowels in words. Speaker centroids are indicated by large filled symbols.

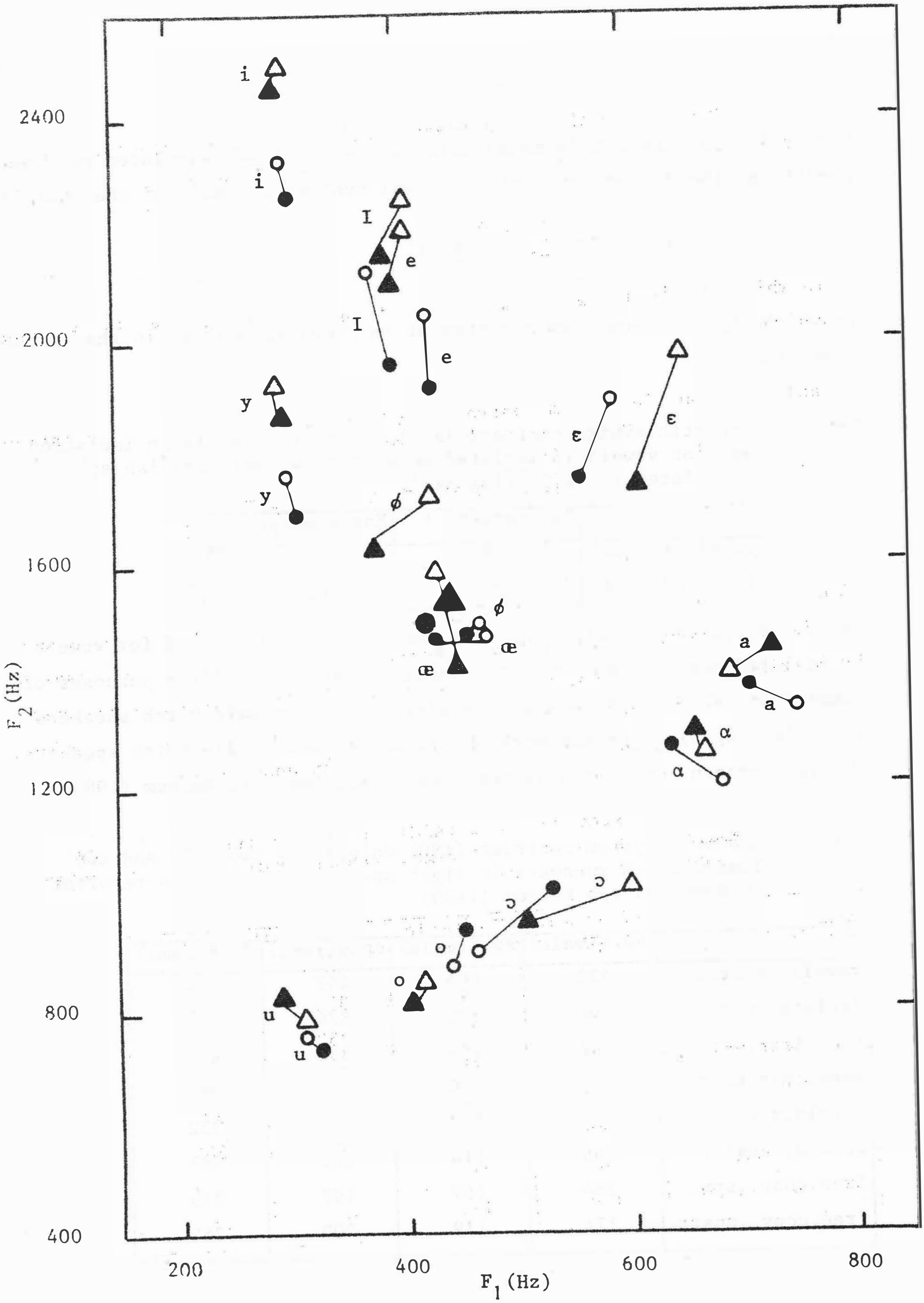

Fig.3 Mean formant frequencies of two Dutch speakers in two speech conditions, plotted in the $F_1 - F_2$ plane (connected per vowel). Triangles indicate speaker 1, circles speaker 2, open symbols indicate vowels in isolation, filled symbols vowels in words. Speaker centroids are indicated by large filled symbols.

factor in order to obtain manageable values. Next we calculated per speech conditiond the dispersion D of the vowel systems by means of the formula

$$D = \frac{1}{n} \sum_{i=1}^{n} | \vec{V}_i - \vec{S} |^2$$

in which V_i is a vowel in a system of n vowels, and S is the speaker centroid.

Table 3 Acoustic system contrast (ASC) values for vowels in isolation and for vowels in isolated words for two male English speakers calculated in $(100\ {}^{10}\log \text{Hz})^2$.

	Eng.speaker 1	Eng.speaker 2
vowels in isol.	458	836
isolated words	239	436

Table 3 displays the ASC-values for vowels in isolation and for vowels in isolated words of the two male English speakers, and for purposes of comparison Table 4 displays the results of the two male Dutch speakers (see also Fig.3), together with the values of two female Dutch speakers, in eight speech conditions as reported in Koopmans-van Beinum (1980).

Table 4 Acoustic system contrast (ASC) values for two male and two female Dutch speakers in eight speech conditions as reported in Koopmans-van Beinum (1980).

	sp.1(male)	sp.2(male)	sp.6(fem.)	sp.9(fem.)
vowels in isol.	433	404	447	634
isolated words	406	320	374	529
read text,str.	343	297	352	417
read text,unstr.	273	216	293	296
retold,str.	262	192	283	332
retold, unstr.	166	114	222	283
free conv.,str.	264	167	197	319
free conv.,unstr.	174	119	209	255

CONCLUSIONS AND DISCUSSION

The ASC-values of Tables 3 and 4 confirm our first impression: as thought the reduction in vowel contrasts is much larger for the two English speakers than for the Dutch ones, when going from vowels in isolation to vowels in isolated words.

About the cause of this difference we can only make some speculations, especially since no vowel material of other speech conditions is available.

The ASC-value of English speaker 1 for vowels in isolation is about the same size as the Dutch ones, that of English speaker 2 is extremely high. But both English speakers reduce their contrast values nearly to half when pronouncing vowels in words. We may hypothesize that the cause lies in the fact that a smaller number of monophthongal vowels constitutes the English vowel system. This would suppose a rule that, a vowel system involving fewer vowels has a larger degree of reduction expressed in ASC.

As a matter of course extensive investigations have to be done to prove this assumption.

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