VOWEL CONTRAST REDUCTION IN TERMS OF ACOUSTIC SYSTEM CONTRAST IN VARIOUS LANGUAGES*

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1. INTRODUCTION

The aim of this paper is to demonstrate that the measure for Acoustic System Contrast ASC (Koopmans-van Beinum, 1980) can be used not only for description and comparison of vowel contrast reduction in various speech conditions of one language, but also to compare the degree of vowel contrast reduction in various languages, whether these languages involve many vowels in their vowel system or only a few. We might hypothesize that systems involving fewer vowels would display more contrast reduction than richer vowel systems since the acoustic vowel space is less filled.
Next we want to show that the ASC measure can also be used to compare the degree of contrast between the set of long vowels and the set of short vowels in those systems that contain quantitatively paired vowels.
Finally some problems will be discussed with regard to the description of vowel contrast reduction in languages involving a substantial number of nasal vowels in their vowel system.

2. COMPARISON OF VOWEL SYSTEMS

Several studies on systematics in the distribution of vowels within

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monly reported difference of quality between long and short vowels of corresponding position is centralization of the short vowels (Lehiste, 1970, pp. 30-33). If so, then the resulting ASC values for the short vowel subsystems must be smaller than for the corresponding long vowel subsystems.

For vowel systems containing nasal vowels the following universal property holds: the number of nasal vowels in such a vowel system is equal to or smaller than the number of oral vowels (Ruhlen, 1975). In his sample Crothers (1978) has 50 languages (24%) with nasal vowels. In our study we take Polish (6 oral vowels and 2 nasal vowels) and French (12 oral vowels and 4 nasal vowels) as representative examples. Only the oral vowels are included in this study.

Fig. 1 displays the various vowel systems as used in this study. The vowels are represented in stylized diagrams according to the articulatory dimensions high-low and back-front, in the same way as used for the first time by Hellwag (1781). For Polish and French the nasal vowels are indicated separately, whereas for Hungarian and Frisian we give the short and corresponding long vowels also in a parallel way.

3. SPEECH MATERIAL AND MEASUREMENTS

The speech material in this study consisted of vowels spoken in isolation, vowels from isolated words, and vowels from a context. In most cases free conversation is used for this context whereas some rare vowels in a many-vowel system are selected from sentences read from a specific text. For each vowel in each of the speech conditions the formant values F1 and F2 are determined as the average over a number of tokens from the speech material. Since the distinction between stressed and unstressed syllables is not equally clear in all languages, we did not involve that distinction in our speech material apart from the fact that totally unstressed syllables have been omitted. For the Dutch data, which were the result of earlier measurements (Koopmans-van Beinum, 1980)

the vowel systems have demonstrated or confirmed that the natural languages of the world for the greater part display an acoustically and perceptually highly balanced dispersion of vowels in their vowel system (Liljencrants and Lindblom, 1972; Disner, 1980; Koopmans-van Beinum, 1983).
In order to attain our object as given in the Introduction we examined languages involving few vowels in their vowel system (Japanese, Polish), many vowels in their vowel system (Dutch, French, Hungarian, Frisian), languages with quantitatively paired vowels in their system (Hungarian, Frisian), and languages involving nasal vowels (Polish, French) of which only the oral vowels are used here. In a survey of vowel systems Crothers (1978) indicates that nearly half of his 209 sample languages have contrasting long and short vowels. In most cases (70%) the vowels of the two systems are equal in number and arrangement. Two languages in our investigation (Hungarian and Frisian) can be considered as representative examples (in the case of Hungarian the two vowels [a:] and [ɔ] are taken as a pair, although their qualities differ considerably). The most com-

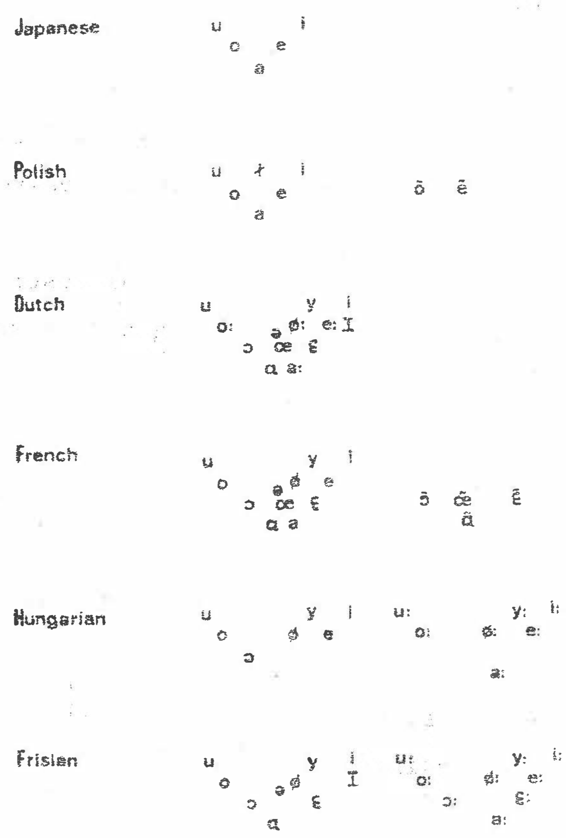

Fig. 1. Vowel systems for the languages used in this study.

we averaged the vowel data of the stressed and the unstressed syllables from free conversation.
For the Dutch material and for part of the French speech material formant frequencies (F1 and F2) were measured by spectral analysis (Wempe, 1979). For the other languages formant frequencies were measured by LPC analysis. In both methods a more or less stable central segment of the vowel was determined as being characteristic for the whole vowel part, and used for measurement.
Figs. 2 to 7 display the mean F1 - F2 position per vowel per speech condition, given in a logarithmic F1 - F2 vowel chart, for one speaker per language. The C-symbol indicates the speaker centroid, being the overall mean of the measured log F1 and log F2 values per speaker (the average value is calculated over all non-nasal vowels and all speech conditions).

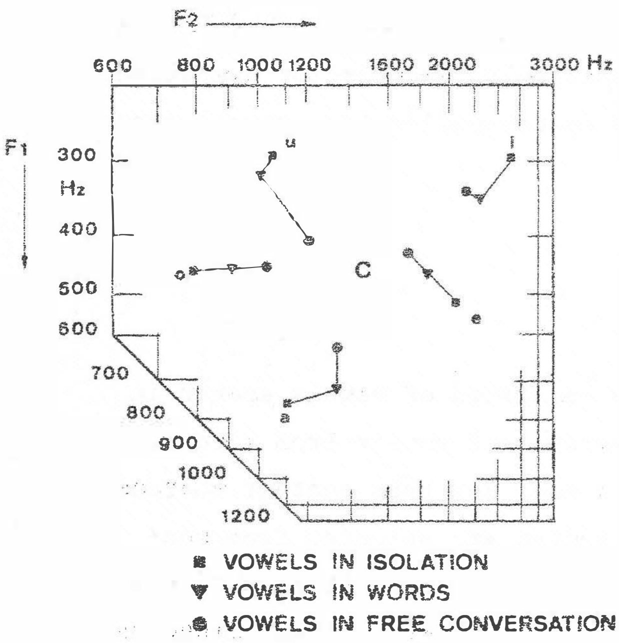

Fig. 2. Mean formant frequencies per vowel per speech condition (connected per vowel) in Japanese (speaker J1).
C indicates the speaker centroid.

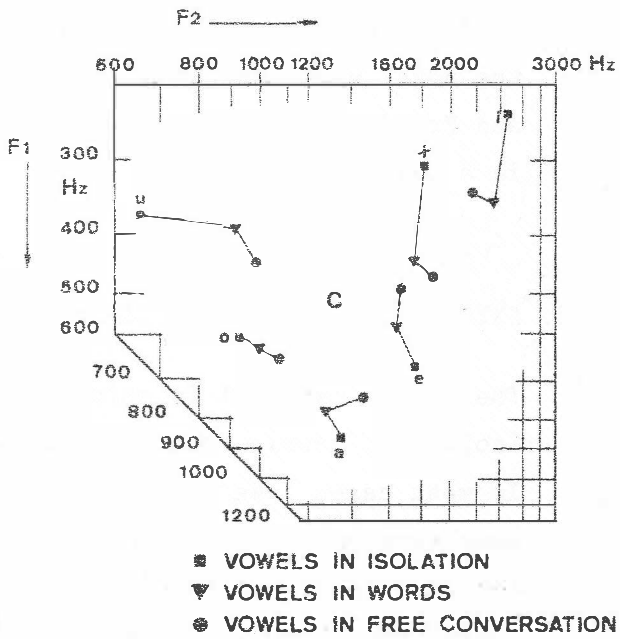

Fig. 3. Mean formant frequencies per vowel per speech condition (connected per vowel) in Polish (speaker P2).

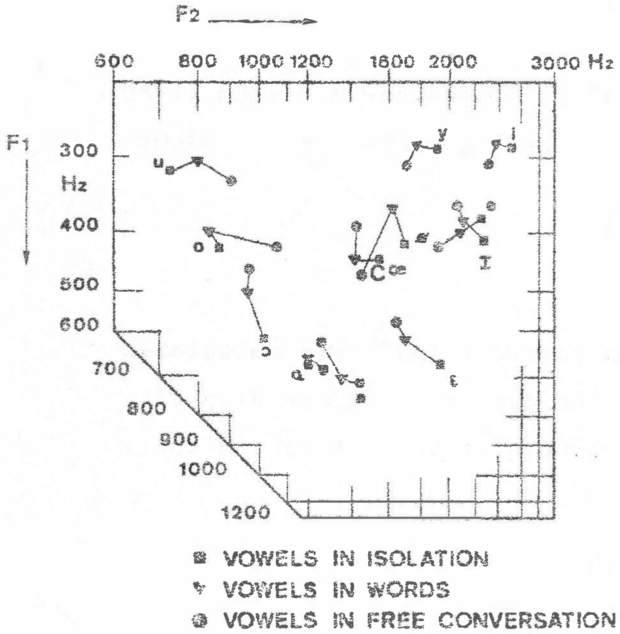

Fig. 4. Mean formant frequencies per vowel per speech condition (connected per vowel) in Dutch (speaker D1).

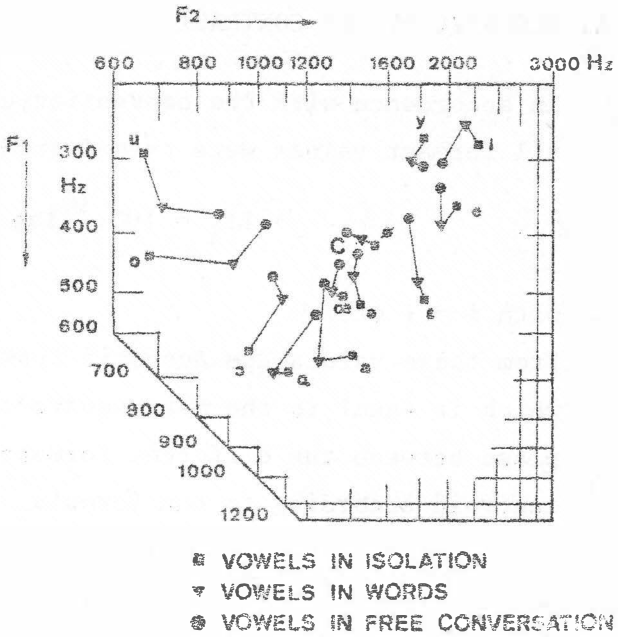

Fig. 5. Mean formant frequencies per vowel per speech condition (connected per vowel) in French (speaker F2).

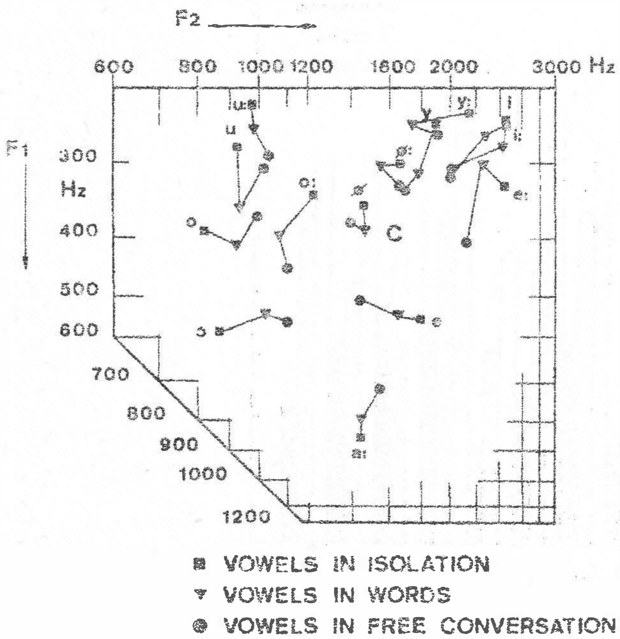

Fig. 6. Mean formant frequencies per vowel per speech condition (connected per vowel) in Hungarian (speaker H1).

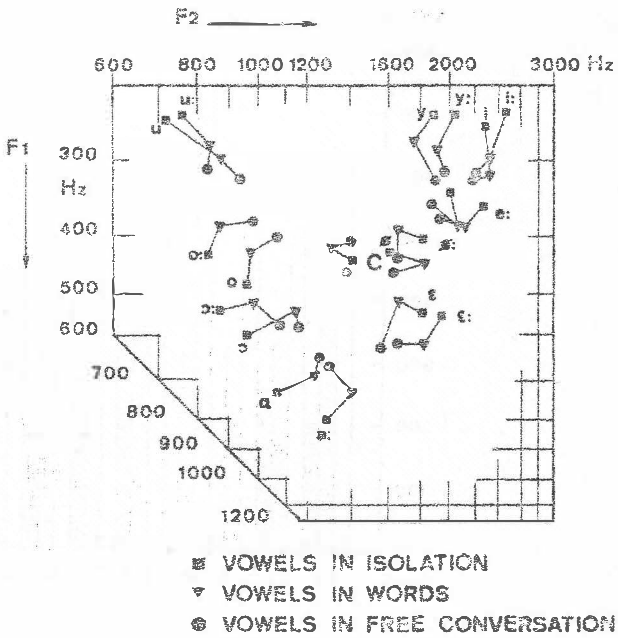

Fig. 7. Mean formant frequencies per vowel per speech condition (connected per vowel) in Frisian (speaker Fn1).

4. ACOUSTIC SYSTEM CONTRAST

In accordance with the convention used by Koopmans-van Beinum (1980) all formant values were transferred to the logarithmic expressions

$$LF_i = 100.{}^{10}\log F_i$$

with i = 1 or 2.

From these values the Acoustic System Contrast (ASC) was calculated which is equal to the mean square of the distances in the F1 - F2 plane between the different formant values for the vowels and the centroid according to the formula

$$ASC = \frac{1}{N} \sum_{j=1}^{N} (\vec{V}_j - \vec{C})^2$$

in which $\vec{V}_j$ is the two-dimensional vector for the vowel j in the F1 - F2 plane and $\vec{C}$ is the vector for the centroid C.

In this way we acquired the dispersion or total variance of the

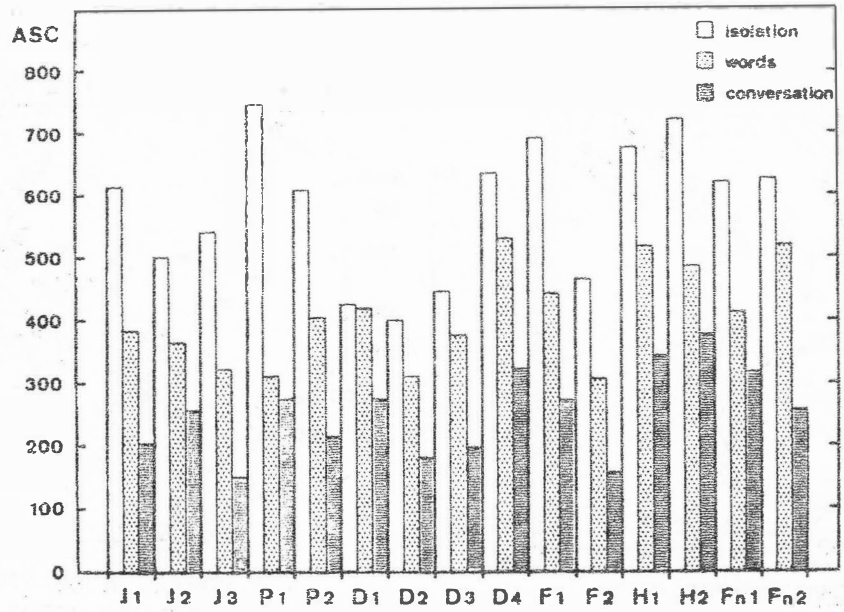

Fig. 8. Histogram illustrating the vowel contrast reduction for three Japanese speakers (J1, J2, J3), two Polish speakers (P1, P2), four Dutch speakers (D1, D2, D3, D4), two French speakers (F1, F2), two Hungarian speakers (H1, H2) and two Frisian speakers (Fn1, Fn2).

whole vowel system in each of the speech conditions, or the dispersion of subsets of the vowel system, e.g. long vowels versus short vowels, expressed in values comparable among themselves.
Table 1 gives the ASC values for each of the speakers and speech conditions used in this study, whereas in Fig. 8 the same data have been displayed in a histogram.

Table 1. ASC values in various languages

Language	Speaker nr.	Vowels in isolation	Vowels in words	Vowels in conversation
Japanese	1	613	383	206
	2	501	363	254
	3	540	322	149
Polish	1	744	311	273
	2	608	405	214
Dutch	1	426	418	272
	2	400	310	178
	3	447	374	197
	4	634	529	319
French	1	692	442	272
	2	463	306	157
Hungarian	1	675	515	341
	2	720	484	375
Frisian	1	621	408	317
	2	624	518	256

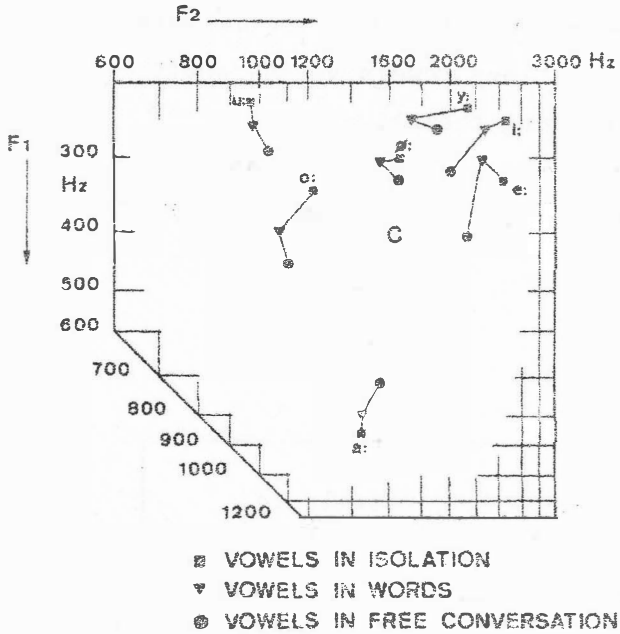

Fig. 9. Mean formant frequencies per vowel per speech condition (connected per vowel) in Hungarian (long vowels, speaker H2).

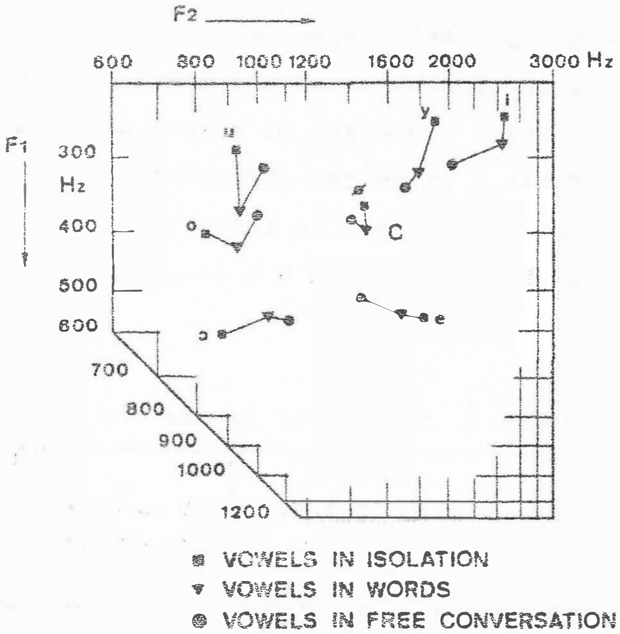

Fig. 10. Mean formant frequencies per vowel per speech condition (connected per vowel) in Hungarian (short vowels, speaker H2).

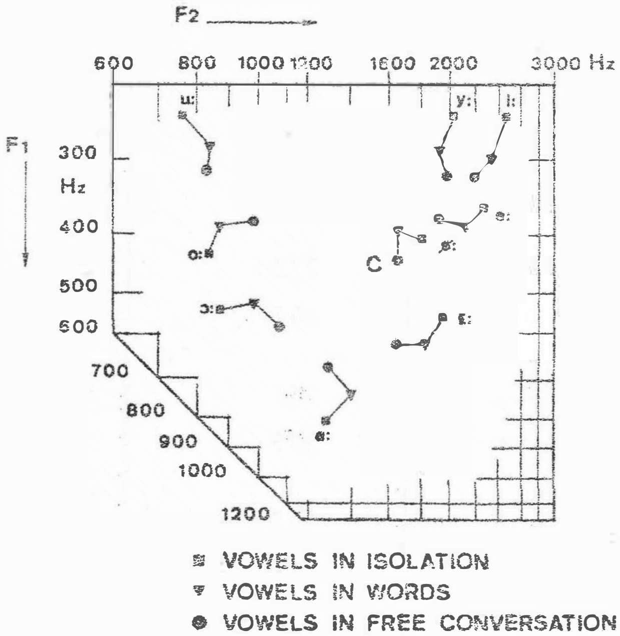

Fig. 11. Mean formant frequencies per vowel per speech condition (connected per vowel) in Frisian (long vowels, speaker Fn1).

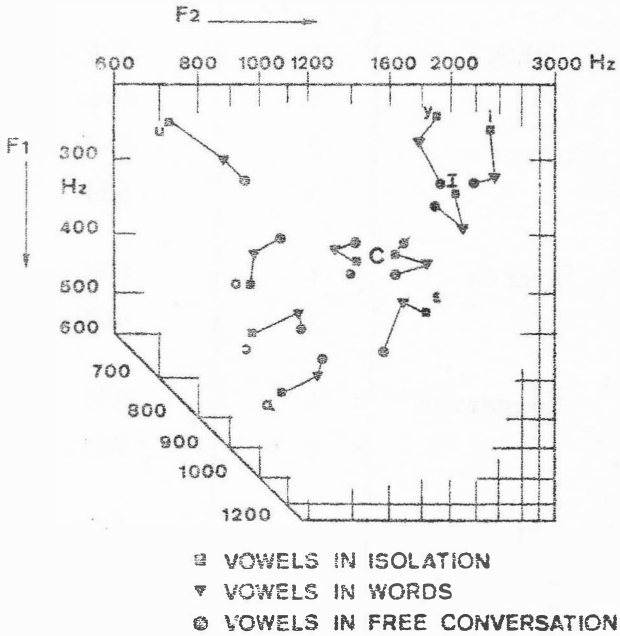

Fig. 12. Mean formant frequencies per vowel per speech condition (connected per vowel) in Frisian (short vowels, speaker Fn1).

5. COMPARISON OF THE RESULTS IN VARIOUS LANGUAGES

As can be seen in the vowel diagrams (Fig. 2 to Fig. 7) all languages in this study display a centralizing shift if one goes from vowels pronounced in isolation to vowels in conversation. The calculated values of the acoustic system contrast ASC give the possibility to compare the degree of reduction between the various speech conditions and languages as well as between the various speakers (Table 1 and Fig. 8). There is no indication for a systematic difference between vowel systems with a small number of vowels and those with a large number of vowels, as was hypothesized in the Introduction. Although we did not yet perform any statistics on these data, and the number of speakers per language is very low, it seems to be justifiable to conclude that vowel contrast reduction occurs as a universal property of all languages, the differences in the amount of reduction being mainly speaker dependent. This supposition is reinforced by the fact that speaker 3 of Japanese, speaker 2 of Dutch, and speaker 2 of French, are the very speakers with the smallest ASC values in free conversation, and were judged by their interviewers to be the speakers least careful in pronouncing.

Table 2. ASC values for the subsystems of long and short vowels for two languages.

Language	Speaker nr.	Vowels in isolation		Vowels in words		Vowels in conversation	
		long	short	long	short	long	short
Hungarian	1	768	583	695	336	428	255
	2	859	582	596	372	430	321
Frisian	1	680	562	460	355	354	280
	2	655	593	563	473	289	223

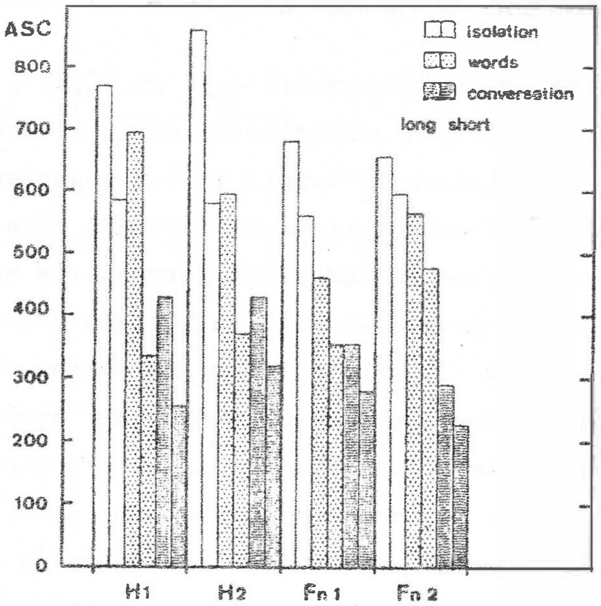

Fig. 13. Histogram illustrating the vowel contrast reduction for two Hungarian and two Frisian speakers, where the ASC values are indicated separately for the long vowels (left) and the short vowels (right).

In the case of languages with equal numbers of long and short vowels (Hungarian and Frisian) the vowel diagrams for the long and short vowels are given separately in Fig. 9 to Fig. 12, whereas the separately calculated ASC values are given in Table 2 and in Fig. 13 in a histogram. Here we find for the long vowels in each speech situation a larger value of the ASC than for the short vowels, which illustrates the fact that in general long vowels are more peripheral than the corresponding short ones.

6. VOWEL SYSTEMS WITH NASAL VOWELS

In our initial attempt to include in this study some languages involving nasal vowels in their vowel system (cf. Polish and French), we came across several problems, some of them of methodological nature.

In the first place part of the recorded nasal vowels turned out to yield very unreliable measurements, or even measuring was impossible. This made our data on nasal vowels very incomplete.
If measuring was possible, a second problem arose in the application of the ASC algorithm, because of the special, 'nasal' low formant frequency, beside F1 and F2 frequencies. Are we allowed to leave these nasal formants out of consideration, and can the F1 and F2 of nasal vowels be compared with those of oral vowels without further ado? These two problems decided us to exclude the nasal vowels from the present study. But this decision caused another methodological problem: If indeed a vowel system is acoustically and perceptually highly balanced, then the nasal vowels will make up an essential part of this balance and therefore must not be excluded.
In the case of the Polish vowel system we believe the loss is not too serious, since both nasalized vowels (õ and ẽ) are more or less in balance in the vowel system. The problems for the French vowel system are much more serious, since exclusion of the nasalized

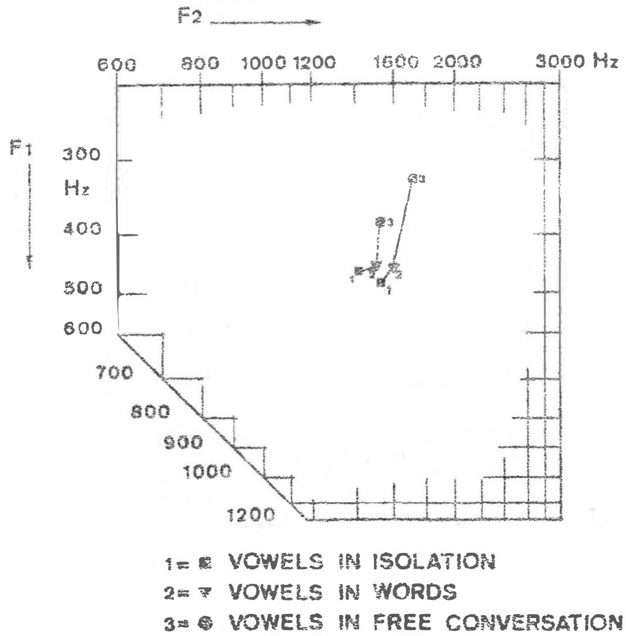

Fig. 14. Shift of the centroid for two French speakers.

vowels (ɔ̃, œ̃, ɑ̃ and ɛ̃) might disturb the balance. Indeed, results concerning the French oral vowels display deviations from the other results: whereas in all other cases the centroids per speech condition stay stable, we can establish a clear shift of these centroids into the direction of 'high front' for both French speakers (Fig. 14). Nieboer (forthcoming) who performed the measurements of the French speech material, suggests a phenomenon of 'anteriorism', being the very French articulation base, instead of the centralizing reduction tendency in other languages when going from vowels pronounced in isolation to vowels in free conversation. However, which is the role of the nasal vowels in this respect? In any case a role we had to leave out of this study but one that earns more attention in future research on vowel systems.

REFERENCES

Crothers, J. (1978). Typology and Universals of Vowel Systems. Universals of Human Language. Vol. 2: Phonology. Edited by J.H. Greenberg. Stanford University Press, Stanford, California.

Disner, S.F. (1980). Insights in vowel spacing: results of a language survey. UCLA Working Papers 50: 70-92.

Hellwag, C.F. (1781). Dissertatio inauguralis physiologico medica de formatione loquelae. Tübingen. Facsimile with a translation in Dutch, Institute of Phonetic Sciences, Amsterdam 1967.

Koopmans-van Beinum, F.J. (1980). Vowel Contrast Reduction: An acoustic and perceptual study of Dutch vowels in various speech conditions. Diss., University of Amsterdam.

Koopmans-van Beinum, F.J. (1983). Systematics in vowel systems. In: M.P.R. van den Broecke, V.J. van Heuven and W. Zonneveld (Eds.), Sound structures: Studies for Antonie Cohen. Foris Publications, Dordrecht, 159-171.

Lehiste, L. (1970). Suprasegmentals. MIT Press, Cambridge, Mass.

Liljencrants, J. & Lindblom, B. (1972). Numerical Simulation of Vowel Quantity Systems: The Role of Perceptual Contrast. Language 48, 839-862.

Nieboer, G.L.J. (forthcoming). Klinkercontrastreduktie in het Frans. To appear as IFA-report 77, Institute of Phonetic Sciences, Amsterdam.

Ruhlen, M. (1975). A Guide to the Languages of the World. Language Universals Project. Stanford University.

Wempe, A.G. (1979). An experimental segment spectrograph based on some notes on frequency analysis of speech segments. Proceedings of the Institute of Phonetic Sciences Amsterdam 5, 44-102.