Final report: Phonetic analyses of some non-European languages (LUCLA)

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The acronym stands for a phonetic collaboration between Lund University and UCLA on a project sponsored by the Swedish Council for Research in the Humanities and the Social Sciences. The aim of the project was to provide phonetic data and analyses of Egyptian Arabic, Hausa, and Standard Chinese. Mona Lindau was responsible for Hausa, Kjell Norlin for Arabic, and Jan-Olof Svantesson and Eva Gårding (not paid) were responsible for the Chinese part. The Research Council granted additional financial support for Jialu Zhang (Acoustics Institute, Academia Sinica, Beijing) who spent three months at the phonetics department in Lund. We have also enjoyed the collaboration of Paul Kratochvil (Faculty of Oriental Languages, Cambridge) and Kristina Lindell and Magnus Nordenhake (Department of East Asian Languages, Lund University). Peter Ladefoged (Phonetics Laboratory, UCLA) provided much technical support, computer programs, and encouragement. Taghrid Anbar (Cairo University) spent three months at Lund with a scholarship from the Swedish Institute, working on the pedagogical application of Arabic.

The goals of the project in the grant proposal were stated as follows:

1. Analysis of speech sounds and prosody.
2. Cross-linguistic comparisons.
3. Pedagogical applications

A major principle of the project was to collect data of the selected languages in a uniform manner, so that valid cross-linguistic comparisons can be made. The data collection consists of tape recordings of several speakers for each language so that the results are representative of the language, not just of a single speaker. Ten speakers of Kano Hausa were recorded in Nigeria, eight speakers of Cairo Arabic were recorded in Lund, and six speakers of Standard Chinese were recorded in Lund, Stockholm, and Beijing. These data were then subjected to acoustic analyses which have been presented as papers in journals (see Bibliography). The major results of the cross-linguistic studies are summarized below.

Stops

(The consonant systems of the three languages are shown in the appendix.)

All three languages have labial, dental/alveolar, and velar stops that are common in the languages of the world. Chinese has two series of stops, voiceless unaspirated and voicelesss aspirated. Hausa and Arabic have voiced and voiceless stops and in addition they have a third, more unusual, stop series. In Hausa this third series is described as "glottalized", in Arabic the third series is pharyngealized.

The durations of the closure and the aspiration in the stops were measured for all three languages. Data for closure duration and aspiration for Swedish from Löfqvist (1976) was used for comparison. Figure 1 shows a diagram of the mean values of these durations. The duration of the aspiration in Hausa, Arabic and Swedish are 30-60 milliseconds. These values are typical of languages with a voiced/voiceless contrast. In Chinese both series are voiceless and the burden of contrast lies in the aspiration. The duration of the aspiration in the so-called unaspirated stops is 5-30 ms. The aspirated stops have a very long aspiration (about 100 ms). The closure durations are significantly different in the three languages, being the longest in Swedish, and the shortest in Hausa. The Hausa stops are thus generally shorter than Swedish stops. There was not a good correlation between closure duration and aspiration, so the relationship between closure duration and aspiration appears to be language specific.

The "glottalized" stops in Hausa are usually written /ɓ/, /ɗ/ and /k'/. The main characteristic of these stops in Hausa is a laryngealized phonation lasting throughout the stop and well into the following vowel for the voiced /ɓ/ and /ɗ/, and following the release of the voiceless /k'/. In addition, the voiced /ɓ/ and /ɗ/ are either implosive or weakened to [w] and [ð], respectively, and /k'/ is ejective. Just as the regular stops, these laryngealized stops are relatively short compared to implosives and ejectives in other languages. Mainly due to their laryngealized phonation, the implosive Hausa stops differ considerably from implosives and ejectives in neighbouring, unrelated Niger-Congo languages. This supports the notion that the glottalized consonants in Hausa are indigenous rather than borrowed (Lindau 1984).

Arabic plain and pharyngealized voiced stops show no significant difference in duration or waveform, and the voiceless plain and pharyngealized stops do not differ in the duration of the aspiration.

Fricatives

A method was developed to describe fricatives acoustically by measuring the spectral center of gravity and the dispersion of spectral energy on the frequency scale from critical band spectra. The fricatives were then plotted in this "space". In addition spectral intensity was considered. See Norlin (1983) and Svantesson (1983). Figure 2 shows the Chinese and Arabic fricatives

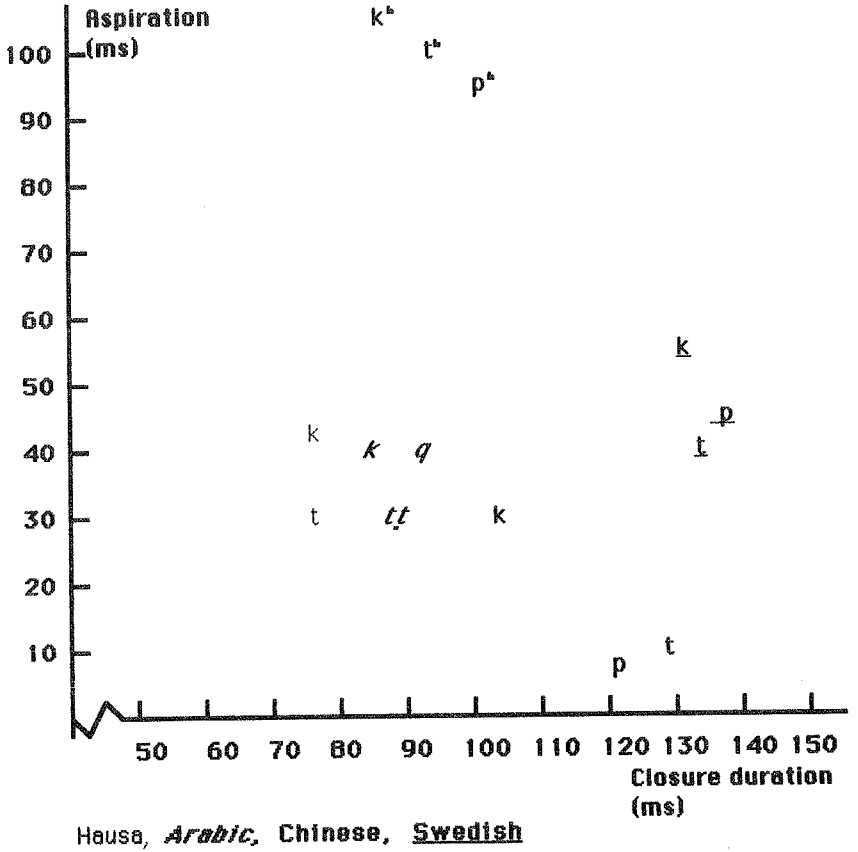

Figure 1. Aspiration and closure duration.

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plotted with the spectral dispersion against the center of gravity. The fricatives are distributed in two classes, one front and one back. The front fricatives are separated from each other by a combination of these two parameters. The back fricatives of Arabic all have a relatively even distribution of energy with a low center of gravity. It is clear that these two parameters will not separate the back fricatives from each other. An additional parameter of spectral intensity is needed to separate all the fricatives from each other in Arabic.

Comparing the fricatives in the two languages we see, not surprisingly, that the seven voiceless fricatives of Arabic take up a larger part of the available fricative space than the five voiceless fricatives of Chinese. The /ʃ/ fricatives

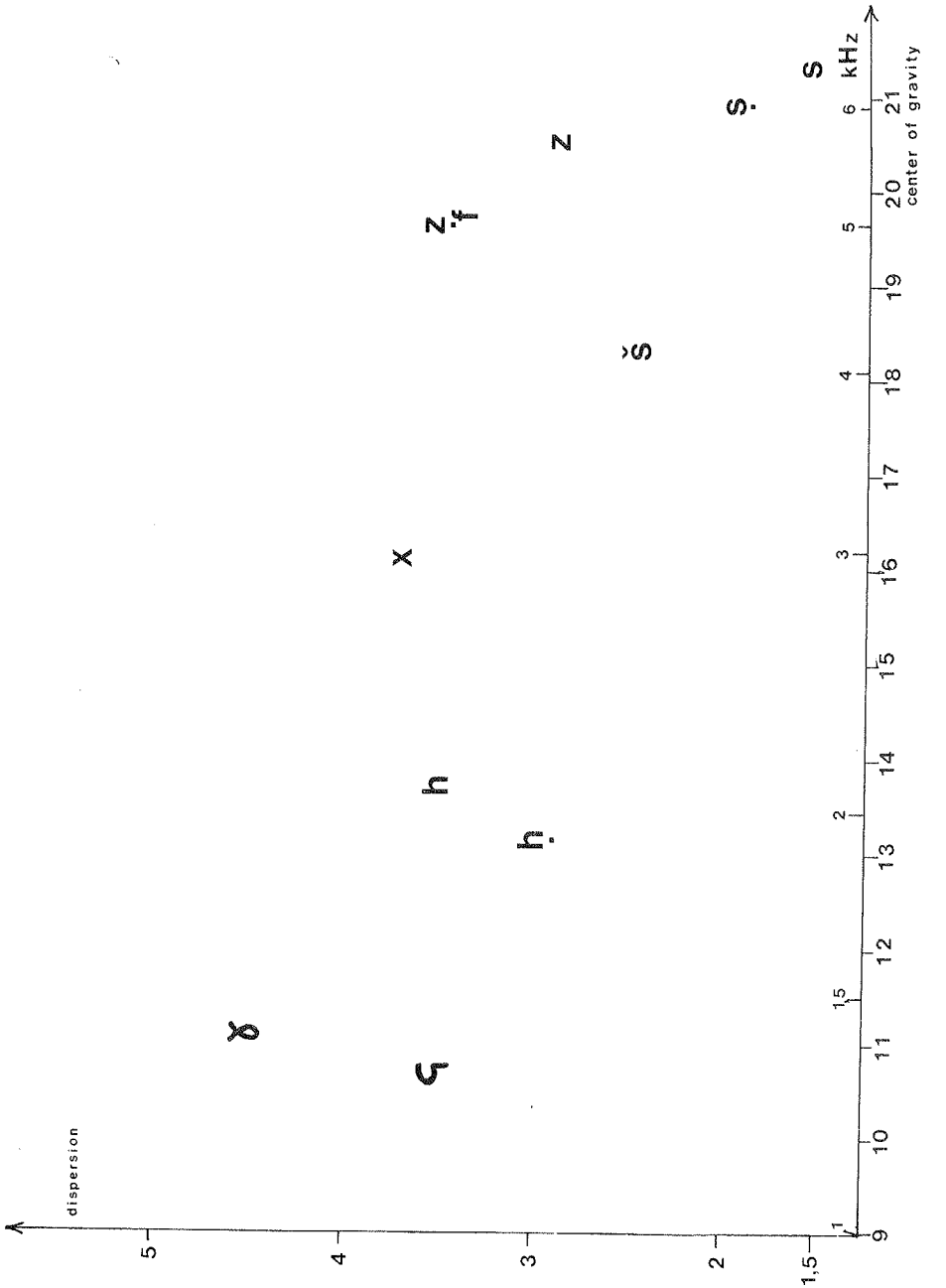

Figure 2a. Arabic fricatives.

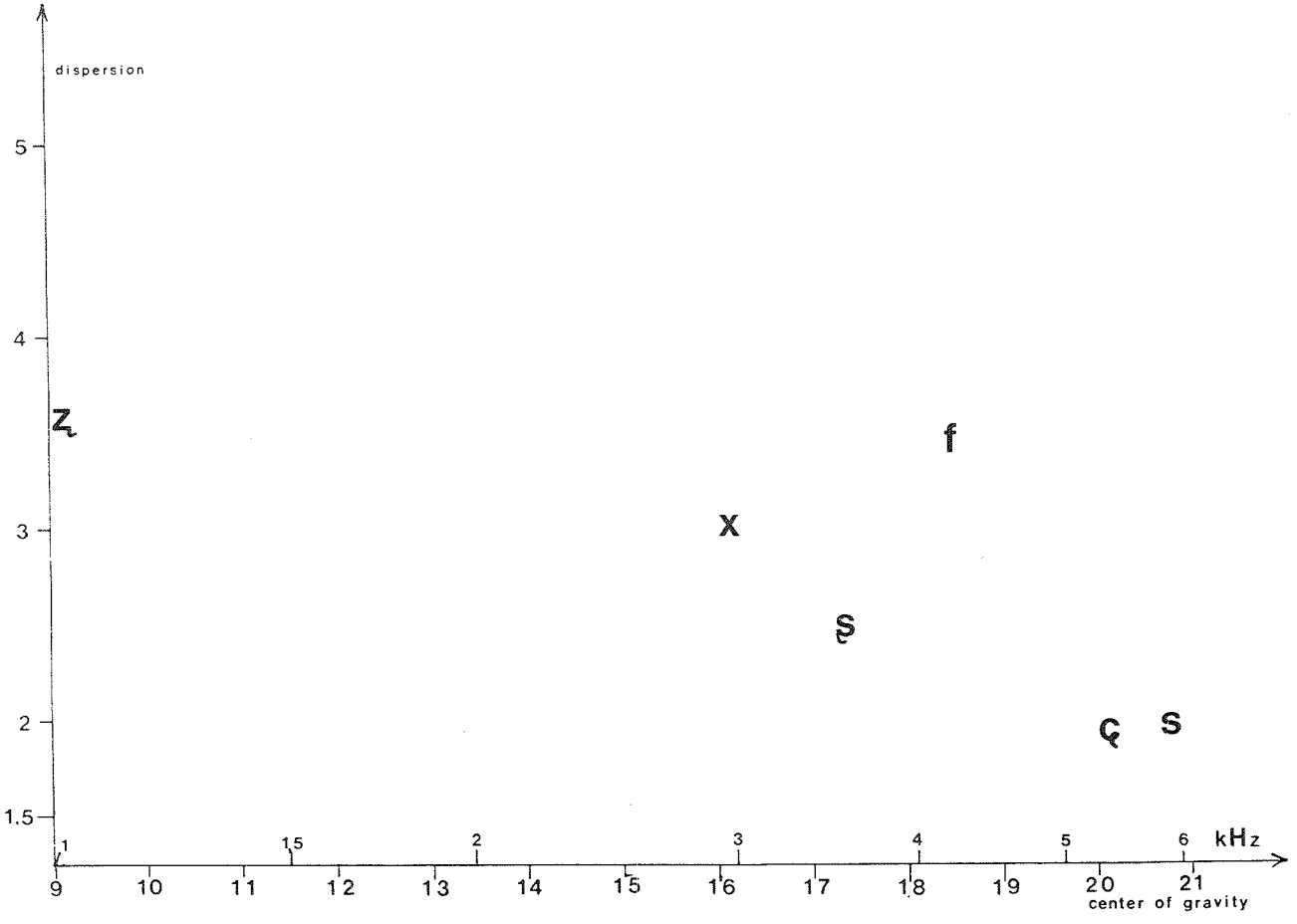

Figure 2b. Chinese fricatives.

in the two languages are very similar, while the /s/ fricatives differ. The Chinese /s/ has a lower center of gravity than the Arabic /s/.

Vowels

Hausa and Arabic are examples of languages with the most common vowel system of all, a five vowel system with the vowels distributed more or less along the periphery of the acoustic vowel space. Both languages have five long and three short vowels. But in spite of their common phonological system and their genetic relationship the vowel systems of Hausa and Arabic do not behave in the same way.

Acoustic properties of Hausa vowels and diphthongs were investigated. The results show that Hausa is best described as having a five vowel system, where these five basic vowels have the qualities of the long vowels. Long vowels are derived as double basic vowels. Phonetically the long vowels are about twice as long as the short ones. The qualities of the short vowels are significantly different from those of the long vowels, but these quality differences can be accounted for by an undershoot mechanism in the speech production.

The results also indicate that the vowel system is currently undergoing changes. Figure 3 shows a formant chart of the long vowels in Hausa from the same environment of between alveolar consonants. The long /oo/ has merged with long /uu/. The formant frequencies of these two vowels are not significantly different. In other environments, the /oo/ is still somewhat lower than /uu/, so the merging of /uu/ and /oo/ is not complete. The basic vowel system may also be additionally modified by the fact that the diphthong /ai/ in most environments has lost its diphthongal quality and monophthongized to long [ee]. However, this monophthongized long [ee] is not the same as the basic long /ee/. Figure 4 shows a formant chart of the monophthongized long [ee] in comparison with the basic long /ii/ and /ee/. Although there is some overlap between the two long [ee] vowels, these two vowels are nonetheless significantly different (paired t-test: $p<0.005$).

Thus the long vowels in Hausa seem to be in the process of transition from a common type of symmetric five-vowel system to an asymmetric system of /ii/, [ee]>/ai/, /aa/, /uu/.

Figure 5 is a formant chart of the three short vowels in Hausa. Both charts show variation between speakers for each vowel, but the back vowels vary considerably more than the front vowels. The tendency for more variation in the back vowels has also been demonstrated for other languages (Keating and Huffman1984).

In Arabic, long plain vowels form well separated clusters with some overlapping for /ii/ and /ee/. Short plain vowels are central compared with the long ones, except short /a/ which occupies approximately the same place as long /aa/. Pharyngealized long and short vowels show the same relationships as the plain ones, except for some overlapping of /uu/ and /oo/. Comparison of the

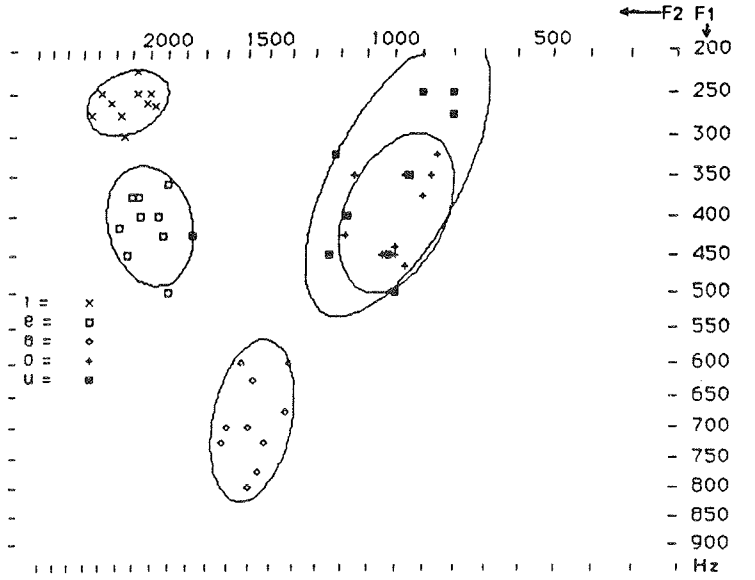

Figure 3. Long vowels in Hausa.

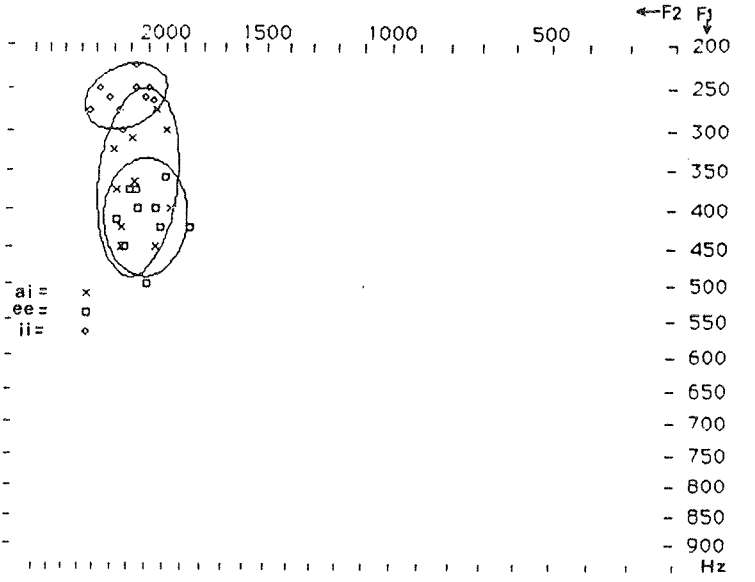

Figure 4. Hausa [ee].

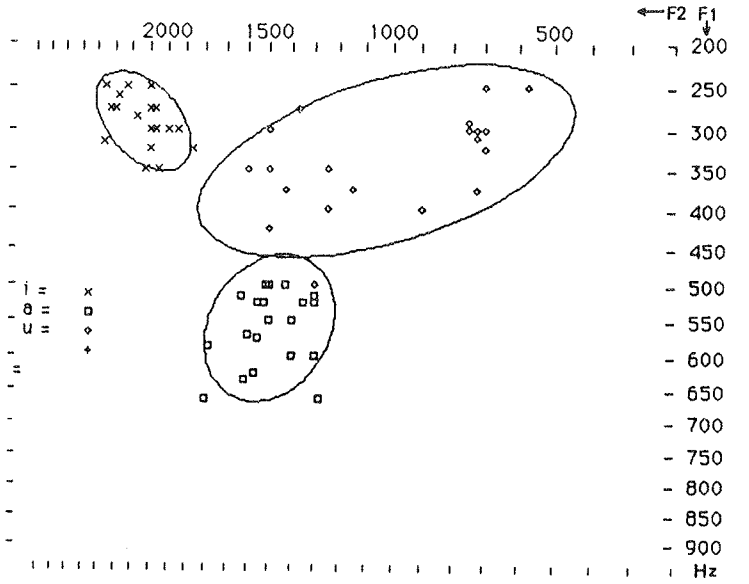

Figure 5. Short vowels in Hausa.

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vowels in plain and pharyngealized contexts shows differences related to the features high-low and front-back. The difference between plain and pharyngealized allophones is highly significant for long /aa/, is less prominent for /ii/ and /ee/, whereas there is only a small difference or no difference at all for /uu/ and /oo/ (Figure 6). On the other hand, short pharyngealized vowels are more back than short plain ones (Figure 7).

The Chinese vowel system is an example of an unusual distribution of vowels. Chinese has the peripheral /i/, /u/, /a/ and /y/, as well as a middle vowel /ɤ/ with the allophones [ɤ], [o] and [e]. Figure 8 shows the formant chart of Chinese. All the vowels show about the same amount of variation between speakers. The vowels /i/ and /y/ overlap on the F1 - F2 chart, but when the third formant is considered, there is a significant difference in F3 between these two vowels.

Diphthongs

The diphthongs /ai/ and /au/ were studied for Hausa, Arabic, Chinese, and English (Lindau-Webb et al. 1985). Data from American English (Gay 1968) was also used for comparison. A model was devised where the diphthongs are described in terms of formant frequencies of steady state vowels linked by a transition. The interpolation is described using a trinomial equation.

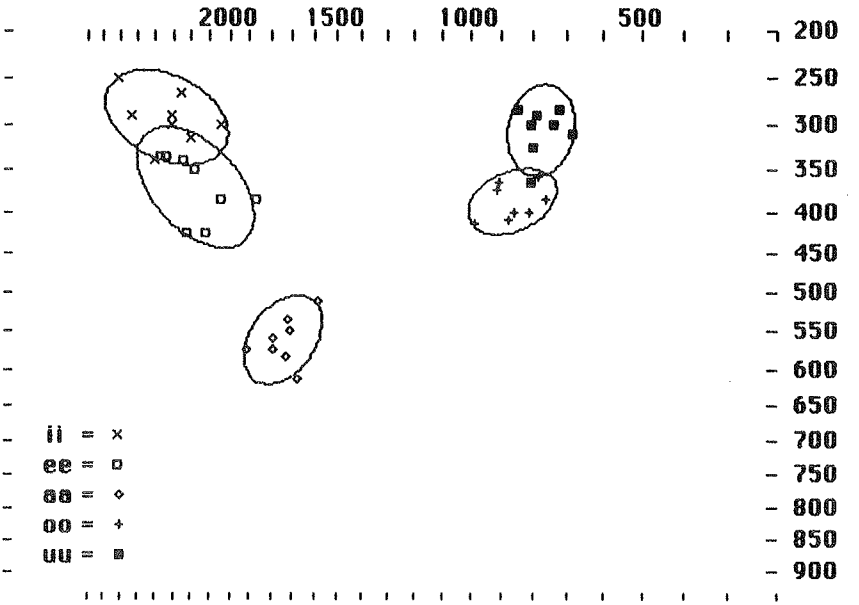


Figure 6a. Long plain vowels in Arabic.

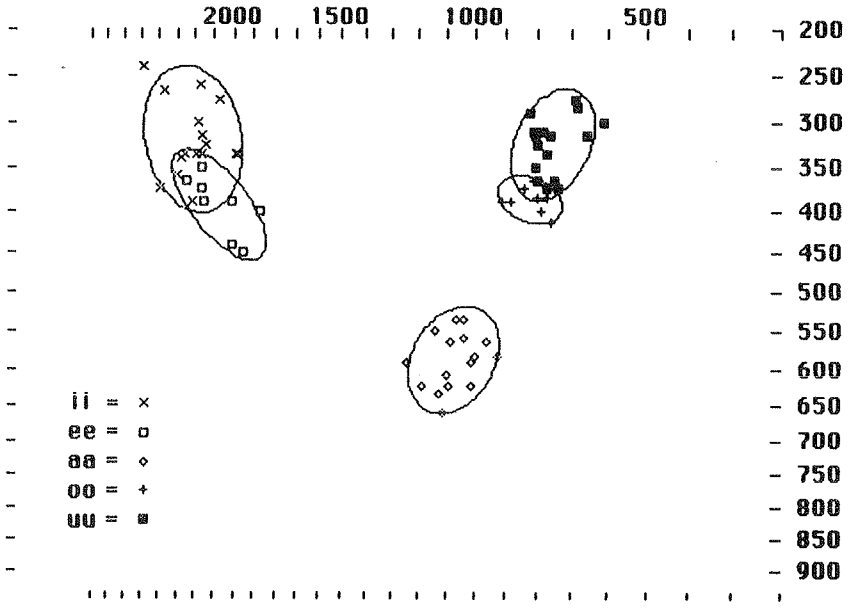


Figure 6b. Long pharyngealized vowels in Arabic.

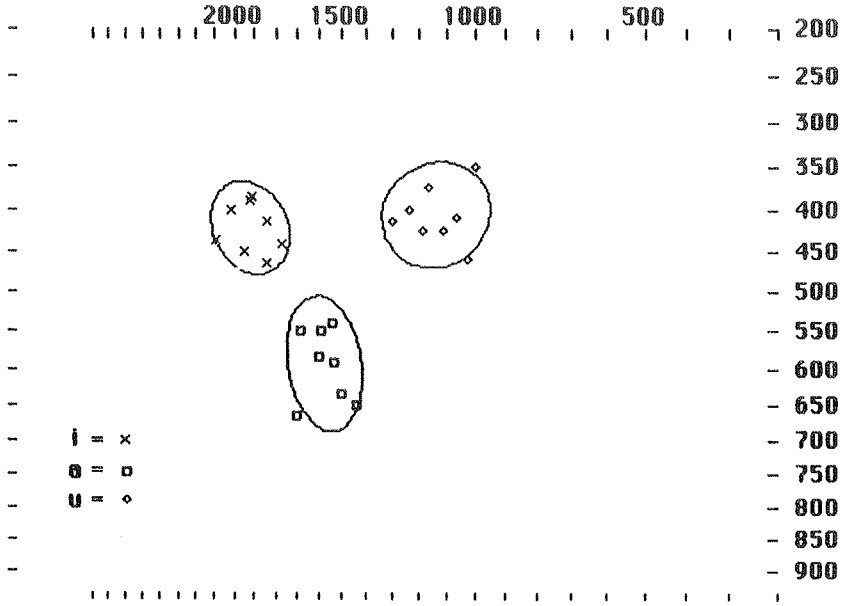


Figure 7a. Short plain vowels in Arabic.

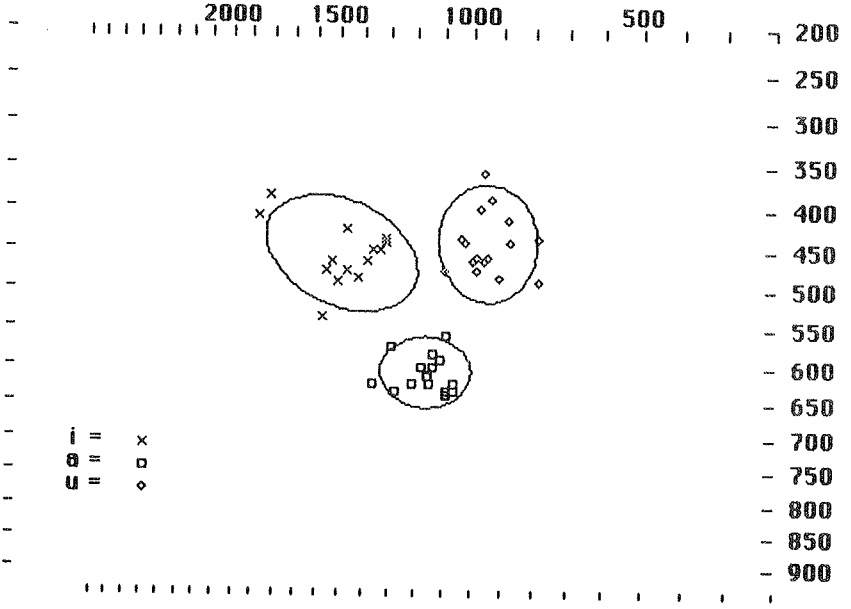


Figure 7b. Short pharyngealized vowels in Arabic.

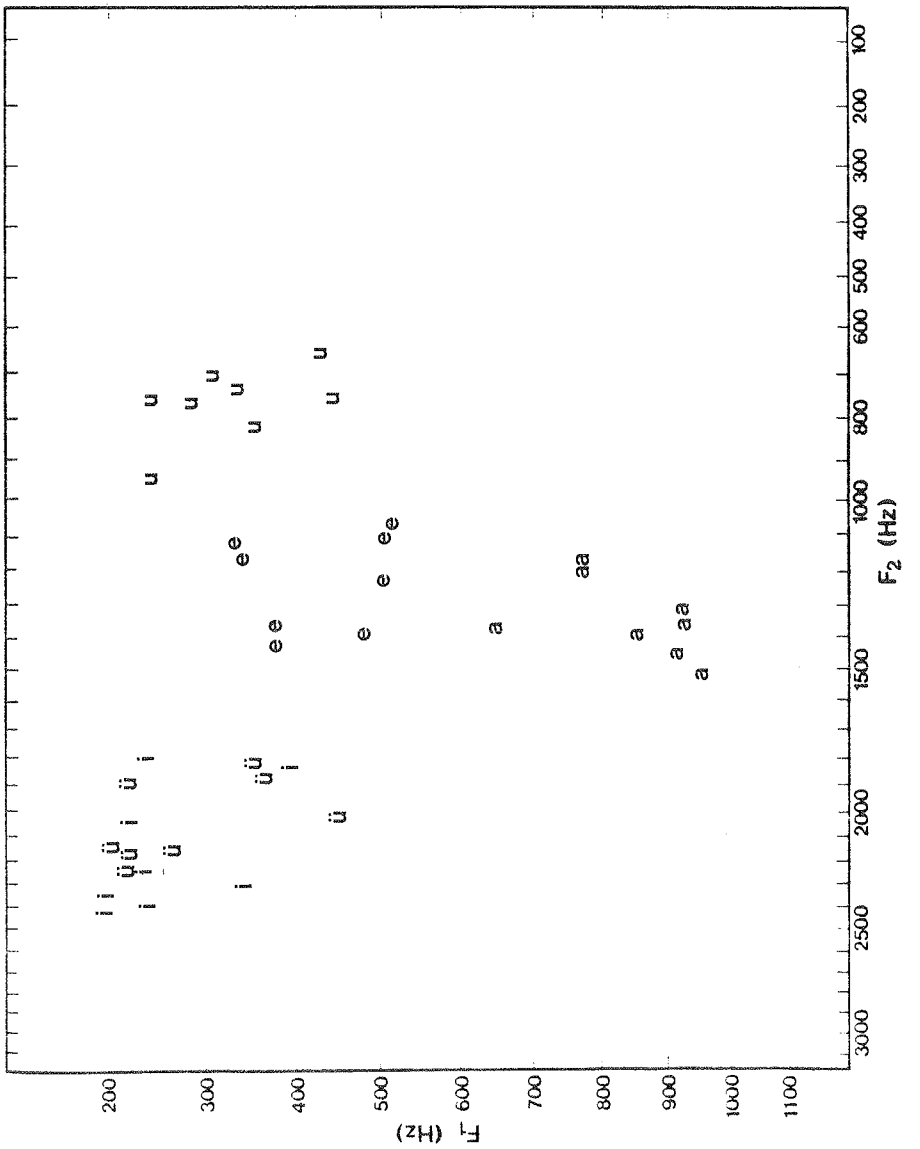


Figure 8. Chinese vowels.

The results show that not only do these diphthongs behave differently in different languages, but the two diphtongs may behave differently from each other within one language, thus supporting language-specific, and even diphthong-specific treatment of diphthongs. In Hausa and Arabic the transition takes up a small percentage of the whole diphthong, while in Chinese and English the tendency is for the transition to take up a large part of the diphthong. Thus the timing of the diphthongal transition is not constant for the "same" diphthong in different languages. The different timing relationships can be predicted from a principle of "the further to go, the longer it takes" (Fischer-Jørgensen 1964) for the /ai/ diphthong, but not for /au/. Thus the transitional rate and duration may be language specific, and even diphthong specific. Also the strategy of the transition taking longer time, if it has a longer time to go is not universal. Later research at UCLA demonstrated that in California English and in Japanese, speakers tend to follow the opposite strategy of "the further the faster".

Prosody

A similar material consisting of statements and questions in focus-free sentences and statements with focus in one of three possible positions was collected for all three languages (examples of pitch curves from the three languages are given in Figure 9). The descriptive framework developed at the Phonetics Department of Lund University over a number of years was used in the analysis.

The assumptions behind this model have recently been summed up in the following way (Gårding 1985):

1. Global intonation stretching over a phrase or a sentence can be separated from local intonation bearing on lexical accents and tones by regarding the accents and tones as superimposed on the global intonation.

2. Any undulating curve (e.g. an intonation curve) can be efficiently described by interpolation between local maxima and minima that we call turning-points.

3. Some of the turning-points for an intonation curve have a rather fixed position relative to the acoustic segments.

4. Giving the positions of these fixed turning-points in time and frequency is an economic way of describing an intonation curve.

5. The local up-and-down structure of an intonation curve usually repeats itself in a global up-and-down structure. This larger pattern is expressed by the tonal grid which in the ideal case is obtained by joining consecutive maxima and minima separately.

6. That part of the grid where the direction or width of the grid is changed or where the grid takes a jump is called a pivot. It marks focus or boundaries of prosodic phrases.

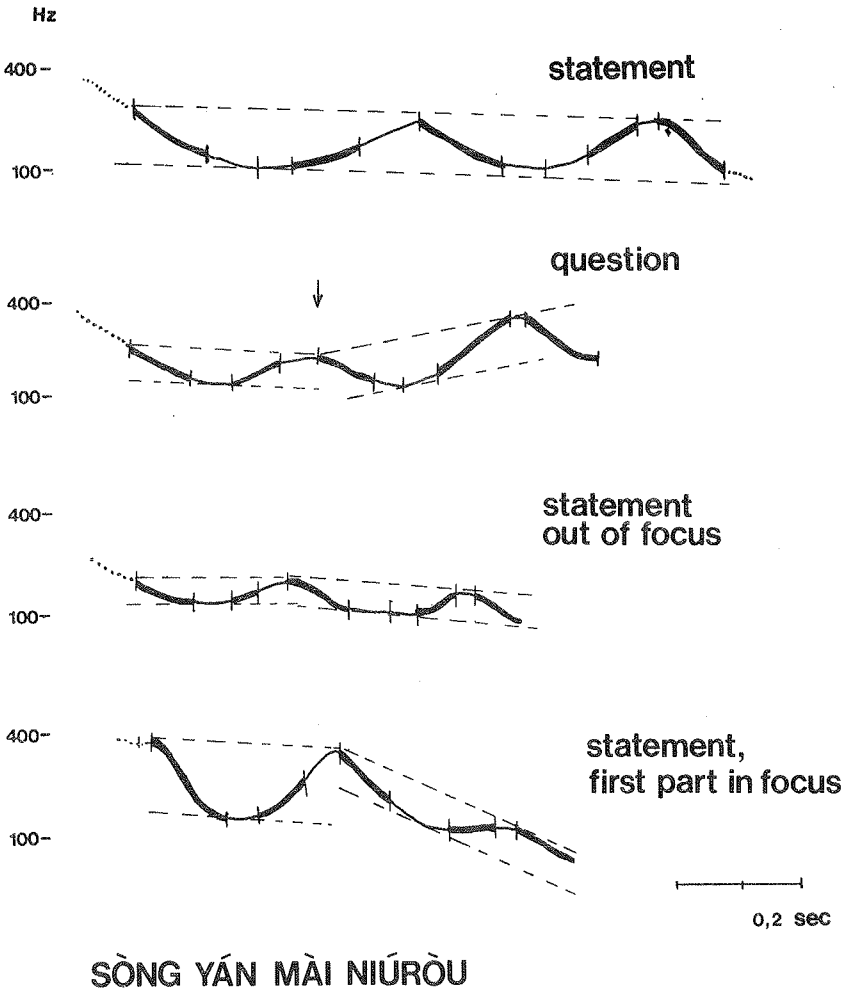


Figure 9a. Intonation curves for Chinese.

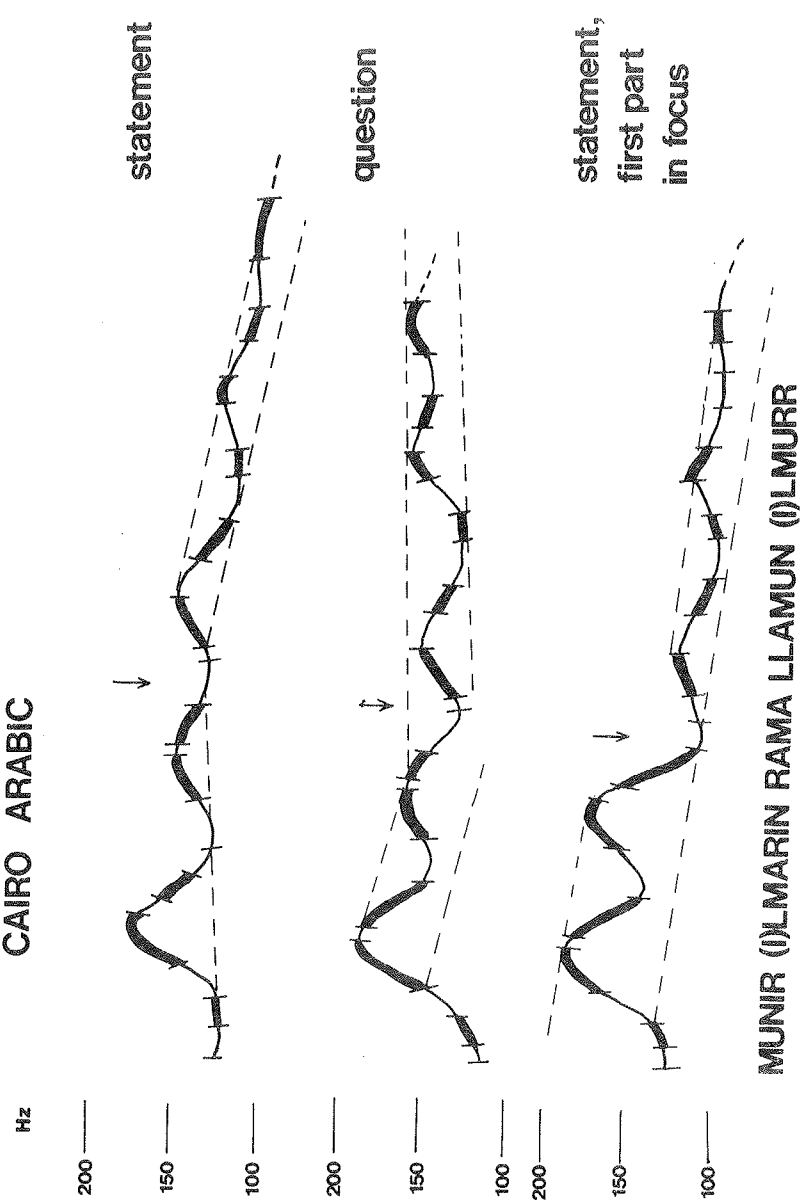


Figure 9b. Intonation curves for Arabic.

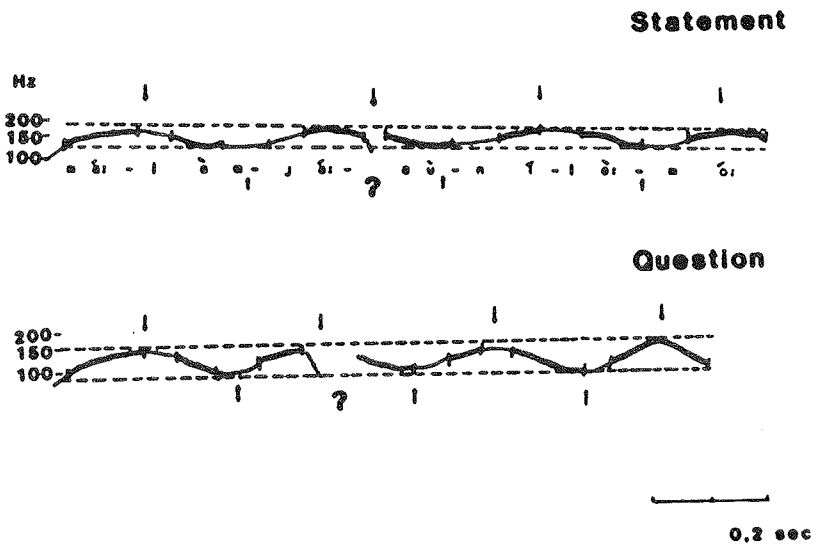


Figure 9c. Intonation curves for Hausa.

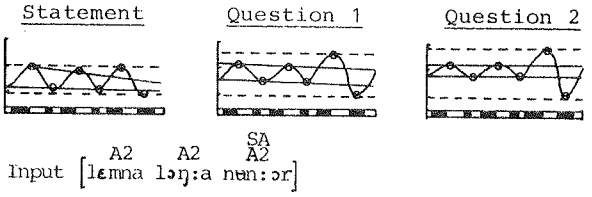
The acoustic correlates behind the concepts of the model and their communicative functions are summarized in Figure 10.

This model of intonation was successfully applied to all three languages, which represent different prosodic systems. Chinese is a tone language with four tones, Hausa is a tone language with two tones, and Arabic is a stress language.

The main result is that once the lexical tones and accents have been factored out, the intonational patterns associated with the global functions of intonation (see Figure 10) are similar.

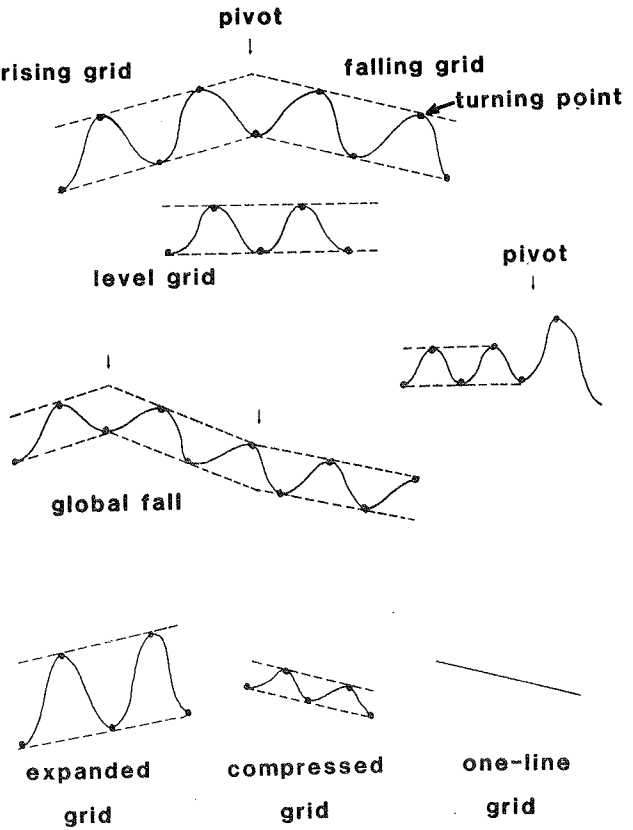
A generative scheme had been suggested for Swedish dialects, in which the global features were to be generated first as a frame of auxiliary lines (later called the tonal grid). The slope of these lines was dependent on speech act type and the length of the utterance. Later the accents were inserted in relation to the grid and the segments according to lexical assignment rules typical of a particular dialect. After some context adjustments the final curve could be obtained by interpolation between the points (Bruce and Gårding 1978).

This scheme had also been applied to syntactically marked and unmarked questions which had been analyzed as having a dialect-independent frame of more or less straightened out and narrowed auxiliary lines expressing question intonation with the same dialect-independent timing of the accentual turning-points as in the statement (Gårding 1979, p. 213):



The difference between the intonation types is thus a difference in the grid, whereas the rules that generate the highs and lows pertaining to the accents remain the same, except for an optional local rule producing a terminal rise in questions (Gårding 1983, p. 21).

This model was applied to Chinese in a qualitative way by Gårding, Zhang and Svantesson (1983). Interspeaker and intraspeaker variability in the tonal (F_0) signal was studied in the Chinese material. The results show the usefulness of the acoustic parameters of the model, turning-point, tonal grid and pivot, which permit rather precise statements. The main observations are that the four speakers use the same lexical and intonational patterns with turning-points very much fixed relative to the segments. From this follows that certain falls and rises are also fixed. Pivots (correlated with phrases) differ from speaker



Intonation parameters	Function	
	Semantic	Syntactic
turning points	words, morphemes	d:o
pivots	constituents (theme/rheme)	d:o (subject/predicate)
grid:direction	speech act type	sentence type
grid width, position	information weight (focus)	clause type

Figure 10. Concepts of the model and their communicative functions.

to speaker, showing their dependence on tempo and style. When pivots do occur, they are in the same location correlated to the syntactic/semantic structure. There is also variability in the manifestation of sandhi rules, which can be regarded as signals of semantic/syntactic coherence. Individual variation was found in the voice range, which varied from one speaker's declamatory style of two octaves to one octave used by the others (Gårding 1985).

Lindau (1986) developed an algorithm that generates schematic F_0 curves of simple statements of two different lengths and questions in Hausa following the general principles of the intonation model above: Rules for intonation and tones are separated and intonation is represented as grids of (near) parallel lines, inside which tones are placed. The direction of the grid lines is associated with sentence type, with a downward slope for statement and straightened out lines for question. The tones are associated with turning-points of the F_0-contour. These turning-points tend to have fixed locations at the end of the syllable with the associated tone. A high tone has a high turning-point in the grid and a low tone has a low one.

Local rules may also modify the exact vertical placement of a tone within the grid. The continuous F_0 contour is modeled by concatenating the tonal points using polynomial equations. Thus the final pitch contour is modeled as an interaction between global and local factors. As for Swedish and many other languages the slope of the intonational grid was found to depend on the type of sentence (statement or question), and the length of the sentence. In addition, the slope of the grid in Hausa is also affected by the tone pattern of the sentence.

The data demonstrate clearly the independence of global and local factors. An observation strengthening this view is that the intonation of sentences consisting of high tones only exhibits a downwards slope. This kind of slope cannot be explained by reference to local rules of downstepping but is best described as a manifestation of global intonation.

As in the other languages studied in the project, the different speakers made use of very different pitch ranges in sentences on alternating High and Low tones. This was attributed to non-linguistic factors of attitude and personality of the speaker. As has been shown for the other languages, more involvement and interest results in a larger pitch-range (see also Bruce 1982).

In addition to the straightened out grid lines in questions, the last High tone of the sentence is locally raised, sometimes followed by a fall. An interesting feature is that this raised High also tends to have a delayed turning-point. This delay is in Hausa related to the height of the peak, conforming to the same principle that we found for the diphthongal transitions: the further to go, the longer it takes.

Question-word questions are characterized by a slight downward slope, where the amount of slope is something in between that of statements and yes-no

questions. These results are similar to those of Gårding (1979) and Thorsen (1978). Thorsen concluded that the more morphosyntactic cues there were in the questions, the more the slope looked liked that of statements. Question intonation in Arabic and Chinese also follows this pattern. In other words, the less morphosyntactic cues to its type the sentence carries, the more work will the intonation have to do.

Perception

Chinese, with its four tones, is a suitable testing ground for an intonation model. While in Sweden, Zhang, using the ILS program, explored the importance of the timing of turning-points in relation to the grid for the recognition of specific tones. This work was continued by Gårding, Kratochvil and Svantesson, who could list features which appeared to be invariant for a particular tone as a result of perceptual tests of synthetic stimuli which had configurations intermediary between Tone 3 and Tone 4. One invariant feature was that the first half of the tone (including the fall) seemed to be important for Tone 4 and the second part for Tone 3. It seemed, then, that the significant parts of the tones both included changes from one mode to another mode (i.e. turning-points). The result may not be without general perceptual significance.

Effects of the project

For Chinese scholars, our intonation model is attractive because it offers a simple way of handling the interaction between tone and intonation. Collaboration has continued and is continuing between Lund and the Acoustics Institute of the Academia Sinica, Beijing. Shi Bo, a graduate student from that institute, who is studying in Lund with a scholarship from the Swedish Institute, is concerned with the perception and identification of global features, as part of her intention of making the model more quantitative. Her stimuli were tested during Gårding's 1986 visit to the Academia Sinica. The perception of tonal movements is also interesting to David House who is trying to give the model a perceptual orientation (see also Gårding and House 1985). Our work on diphthongs is now being continued at UCLA.

Pedagogical applications

The pedagogical applications of our project have not been completed. A manual with pronunciation drills for Chinese with phonetic illustrations is now being completed by Magnus Nordenhake. This book is a Swedish translation and adaptation of a manual for English students by Paul Kratochvil. Taghrid Anbar and Kjell Norlin are collaborating on a contrastive study of Arabic and Swedish.

Summary

The project has resulted in new material from languages which are given preferential treatment by Lund University. The segmental systems, in particular stops, fricatives and vowels have been thoroughly investigated. The same methods, some of them developed within the project, were used for all

three languages, thus enabling direct comparison between them and laying a foundation for future research on other languages and for pedagogical applications.

Prosodic features have been successfully analyzed in all three languages by means of the intonation model developed here. The model has been implemented in an algorithm producing statements and questions in Hausa. Apart from this technical achievement, the model serves as a convenient frame for further explorations of the interaction of tone (accent) and intonation. At the same time we have strengthened our claim that the model gives a general frame for any prosodic system and that it sheds light on the structure of intonation in general.

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Appendix
Consonant systems:

Hausa:

	b	t d	c ɟ	k g	kʲ gʲ	kʷ gʷ	ʔ		
	ɓ	ɗ		k'	kʲ'	kʷ'			
ɸ		s z	ʃ				h		
		s'							
	m	n							
		l							
		r							
		ɽ							
	w		j						
			ʄ						

Arabic:

	b	t d		k g	q	ʔ		
		ṭ ḍ						
f		s z	ʃ	χ ʁ	ħ ʕ	h		
		ṣ ẓ						
	m	n						
		l						
		r						
	w		j					

Chinese:

pʰ	tʰ				kʰ			
p		t				k		
		tsʰ	tʂʰ	tɕʰ				
		ts	tʂ	tɕ				
f		s	ʂ ʐ	ɕ		x		
	m	n		ŋ				
				l				

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