Vowels and Diphtongs in Standard Chinese

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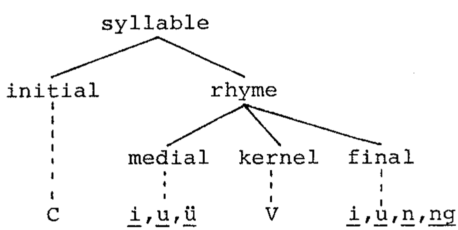
In this article, the acoustic properties of Standard Chinese (pǔtōnghuà) vowels and diphthongs are described. This is one of the most interesting areas of Chinese phonetics, since there are only five monophthongic vowel phonemes, which form an unusual system, but as many as eleven diphthongs, and also two triphthongs. The diphthongs exemplify different types of timing of steady states and transitions between them, and it will be seen that not only the formant frequencies of the steady states and their relation to the vowel goals, but also the timing of the transitions betweeen the steady states is important, and differs between different Chinese diphthongs and also differs from the "same" diphthong in other languages.

Pīnyīn spelling (underlined) is used throughout, except in the section on phonology, where a more phonemic transcription is sometimes used (within /.../).

1. PHONOLOGY

A Standard Chinese syllable can be analyzed into an initial consonant and a rhyme. The rhyme has a kernel vowel which can be preceded by one of the medials i, u or ü, and followed by a final, which is either one of the vowels i or u, or one of the consonants n or ng:



(In traditional Chinese phonology, the medial is not considered a part of the rhyme.)

Because of the large amount of interaction between the vowels and both the preceding and the following consonant (if any), it is possible to analyze the phoneme system in several different ways, and this has also been done, see e.g. Chao 1934, Hartman 1944, Hockett 1947, Cheng 1973. In particular, the phonemic status of [ɿ] and [ʅ], i.e. if they are the allophones of a separate phoneme, or are allophones of /i/ (as assumed here) has been analyzed differently by different authors.

Here the following vowel phoneme system will be assumed:

i	ü		u
		e	
		a	

The vowel /i/ has the allophone [ɿ] after dental sibilants (s, z [ts] and c [tsh]), the allophone [ʅ] after postdental sibilants (sh [ʂ], zh [tʂ], ch [tʂh] and r [ʐ]), and is otherwise [i].

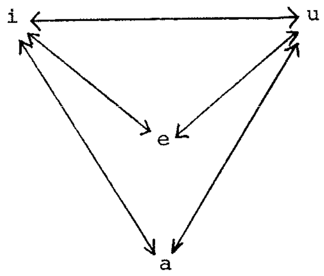
There is no contrast between (phonetically) different mid vowels, so they will be regarded as allophones of a phoneme written /e/. It has the allophone [ɤ] as a single-vowel rhyme (written e in the pīnyīn spelling),but in other rhymes it has allophones ranging from [o] to [e].

In the pīnyīn spelling there is a vowel o, which occurs only after labial consonants (b, p, f and m). Acoustically, o is very similar to the diphthong uo, which is in complementary distribution with o, so o will be regarded as a notational variant of uo. o is also written in the diphthongs ou, uo and ao, which are phonemicized as /eu/, /ue/ and /au/ (see below).

The following diphthongs and triphthongs occur:

iu	/iu/	ui	/ui/
ia	/ia/	ai	/ai/
ua	/ua/	ao	/au/
ie	/ie/	ei	/ei/
uo	/ue/	ou	/eu/
üe	/üe/		
iao	/iau/	uai	/uai/

The system of diphthongs is rather symmetrical, and with the exception of üe all the diphthongs can be obtained by going from one of the four vowels /i/, /u/, /e/ or /a/ to any other (except that */ea/ and */ae/ are not found). Also the triphthongs /iau/ and /uai/ are symmetric to each other:



There is also a syllable consisting of the vowel er [ɚ], which is usually analyzed as /er/. In the regular syllable inventory (as written by Chinese characters), there is only this single syllable (in three different tones) with the final r, and this rhyme cannot be preceded by an initial consonant. It can be added, however, to other syllables as a suffix, with the phonetic result of an r-colouring of the syllable, with somewhat different effect on different rhymes. It is not entirely clear if this "erization" (érhuà) is a feature of Standard Chinese, even though it is a common feature of Běijīng pronunciation, since there is a tendency to regard erization as a vulgarism and to avoid it in Standard Chinese. Erization will not be treated in this article.

The following rhymes occur:

i			in	ing
ü			ün	
u	ui		un	ong /uŋ/
iu				iong /iuŋ/
e	ei	ou /eu/	en	eng
ie				
üe				
uo /ue/				
a	ai	ao /au/	an	ang
ia		iao /iau/	ian	iang
			üan	
ua	uai		uan	uang
er				

2. PROCEDURE

Four speakers of Standard Chinese were recorded. Two of the speakers (B and C) were born and raised in Běijīng, one (A) was born in Sūzhōu and moved to Běijing when he was six years old, and one (D) is from Liáoníng and has lived in Běijīng since he was 12.

For each speaker, syllables containing each rhyme were recorded in a sentence frame (wǒ bǎ ___ zì xiě hǎo), and each sentence was read twice. The syllable initial was chosen as a dental (d when possible), and the syllables were in the high (first) tone whenever possible, and otherwise in the rising (second) tone.

The recordings were made in sound-treated rooms in Lund or Stockholm.

For each syllable, wide-band spectrograms were made on a Kay Digital Sona-Graph 7800. The frequencies of the first three formants, and also the durations of the vowels were measured on the spectrograms.

3. FORMANT FREQUENCIES

Formant frequencies of Standard Chinese vowels have also been published by Howie 1976 (for one speaker), Brotzman 1963 (reported by Howie), and Wú and Cáo 1979 (showing only charts of average F1 and F2 values).

The formant frequencies as measured in the middle of monophthongic vowels in the context C___# are given in Table 1.

The formants of the five main allophones of the vowel phonemes (i [i], ü [y], u [u], a [a] and e [ɤ]) are plotted on Figure 1, and the formants of er [ɚ] and the /i/ allophones [ɿ] and [ʅ] are plotted on Figure 2.

The vowels [ɿ] and [ʅ] are usually described as vocalic [z̩] and [ʐ̩]. According to Cheng 1973:13, X-ray studies by Zhōu and Wú 1963 (not available to me) show that compared to [i], the highest point of the tongue is slightly more front and the back of the tongue is slightly higher for these vowels. (The non-IPA symbols [ɿ] and [ʅ], which are generally used in Chinese linguistics were introduced by Bernhard Karlgren, who took [ʅ] from the Swedish dialect alphabet, where it denotes the "Viby i" occurring in Swedish dialects. This alphabet was widely used in Swedish dialectology, and its main inventor, J.A. Lundell, was Karlgren's teacher.)

The vowel pairs i and ü and e and er do not differ much in F1 or F2, but are clearly separated by F3, the second member of each pair having much lower F3 than the first.

The first two formants of vowels before nasals (i.e. in the contexts C___n and C___ng) are given in Table 2 and on Figure 3. The main differences as compared to open-syllable vowels are: i is lowered in nasal contexts, e and a are fronted before n, and u is considerably lowered before ng (where it is written o in the pīnyīn spelling) and fronted-lowered before n.

For the diphthongs and triphthongs, the first two formants for each steady state in the spectrograms were measured, as well as the duration of each steady state and the duration of the transition between the steady states. The formant frequencies were measured in the middle of each steady state.

These results are shown in Table 3 (diphthongs) and Table 4 (triphthongs). Steady state formant frequencies and duration data for diphthongs before a nasal (n or ng) are given in Table 5.

In Figure 4, schematic drawings of average diphthong and triphthong formant frequency movements are shown on a F1-F2-diagram.

The endpoints of diphthongs which do not involve the phoneme /e/ are rather close to the respective vowel phoneme average (represented by a star on Figure 4), while the startpoints differ more, so that for instance ao /au/ and ai start from positions higher than a, and ui starts from a (acoustically) much more central position than u. Diphthongs which contain the phoneme /e/ (realized monophthongically as [ɤ]), i.e. ie, üe, ei, ou /eu/ and uo /ue/ contain [e] ~ [ɛ] or [o]-like allophones of /e/.

As Figure 4:2 shows, the final a component of the diphthongs ua and ia is much fronter before the nasal n than before ng [ŋ].

4. DURATIONS

In Standard Chinese, there is no phonemic length distinction for vowels, but there has been some discussion in the literature about vowel quantity, in the context of tonal phonology. Woo 1969 represents contour tones (e.g. three out of four Standard Chinese tones) as sequences of level tones, and this presupposes that contour tones are assigned to sequences of more than one voiced segment. This causes no problem for rhymes which consist of diphthongs, triphthongs or a vowel followed by a nasal, but for monophthongic vowels in open syllables it means that they must be represented as a cluster of two identical vowels. To justify this, Woo presents acoustical data which shows that vowels are longer in the context C___# than when followed by a nasal or when included in a diphthong, and says that "It is generally assumed that all pure vowels are normally long, and that vocalic clusters, which are diphthongs, consist of two "short" members" (Woo 1969:25). Walton 1983:174 doubts that there is such a general agreement, but their discussion concerns phonological interpretation rather than the physical properties of the sounds.

Also this investigation shows that the different components of a diphthong, and also vowels before nasals, are shorter than single vowels in open syllables (see Figure 5).

On the other hand, diphthongs and vowel-nasal rhymes are in most cases longer than single-vowel rhymes. Thus Woo's statement (1969:27) that "the duration of the syllabic nucleus appears to be a constant also, irrespective of whether it is a long vowel [i.e. a single vowel in an open syllable], a diphthong, or a vowel + nasal cluster" is not confirmed by this study (Woo's data came from syllables said in isolation, however).

It is well-known that the duration of Standard Chinese rhymes is dependent on the tone of the syllable (see e.g. Kratochvîl 1968, Woo 1969:24-30), and thus both the tone and the segmental composition affect the duration of a rhyme. A preliminary investigation (Nordenhake and Svantesson 1983) shows that the effects of the different tones on the duration vary with the position of a syllable within a sentence, so that for instance the falling (fourth) tone has the shortest duration of all tones in sentence final position, while it is the longest tone in sentence medially.

In this investigation, high-tone syllables have been used whenever possible. (In a few cases, syllables with rising (second) tone were used; duration data from such syllables are marked with a star in the tables and figures, since they are not comparable with the other (high tone) data.) The question how the tones affect the duration and the vowel quality - especially the quality of the diphthongs seem to be somewhat dependent on the tones - will thus not be taken up here, but will be made the subject of a special study.

Figure 5 shows average duration values for all speakers. The durations of open syllable vowels are given in Table 1, and in Table 2, durations of vowels in rhymes with final nasal are given, together with the duration of the nasal. For monophthongs followed by a nasal, the vowel is generally shorter than the nasal, and also shorter than the same vowel in an open syllable, but also here the duration of the entire rhyme is longer than for an open syllable.

For the diphthongs of a language, not only the goal values and the way the start and end values of the diphthong relates to these goals (which are here assumed to be vowel phonemes of the language) are important, but also the dynamics of the diphthong, i.e. the way the formant frequencies change with time. This can be quantified in different ways; the way chosen here is to measure the formant frequencies of the steady states and the durations of the steady states and of the transition between them, and to calculate the ratio between the transition duration and the total duration. (It would also be possible to calculate the velocity with which the formant frequencies (especially F2) change during the transition.) These data are given in Table 3, and are plotted on Figure 6.

This kind of analysis reveals differences between the "same" diphthong in different languages, e.g. [ai] in Standard Chinese, Hausa and Arabic (these two languages have been analyzed with the same methods as used for Chinese). In Hausa (data from Mona Lindau) and Arabic (Norlin 1984), these diphthongs can be regarded as a succession of two vowels [a] and [i], which are nearly identical to the short [a] and the [i] of the respective language, both as regards quality (formant structure) and quantity (duration). Thus, a speaker of Hausa or Arabic first makes an [a], then goes quickly to [i] and produces that vowel. So there are two steady states, each with about the same length as a short vowel, and a short transition in between.

In Chinese, this diphthong is more gliding, with relatively short steady states, and a long transition (average ratio of transition to total duration is 50.5% for this diphthong). Furthermore, the total duration of a diphthong is usually longer than that of a monophthongic vowel (see Figure 6), but not about twice as long (as is the case in Arabic and Hausa).

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Table 1. Formant frequencies and duration of Standard Chinese monophthongic vowels in the context C ___ #.

Vowel		Speaker	F_1	F_2	F_3	duration (ms)
i	[i]	A	200	2370	3430	175
			240	2400	3400	165
		B	220	2040	2960	180
			340	2320	3270	170
		C	240	1800	3360	150
			400	1830	3390	195
		D	200	2420	3600	185
			230	2360	3510	200
		mean	259	2192	3365	177
ü	[y]	A	210	2140	2580	150
			220	2220	2490	160
		B	270	2150	2340	140
			460	2070	2630	170
		C	360	1820	2450	180
			380	1900	2670	155
		D	220	2200	2510	150
			220	1890	2340	175
		mean	292	2040	2501	160
u	[u]	A	360	810	2460	150
			240	760	2730	150
		B	430	640	2430	165
			330	720	2610	150
		C	240	940	2280	140
			310	700	2620	145
		D	450	760	2750	150
			280	760	2720	150
		mean	330	761	2575	150
a	[a]	A	770	1200	2530	145
			930	1290	2600	185
		B	770	1180	2360	190
			930	1340	2620	190
		C	650	1340	2640	155
			960	1500	2530	120
		D	860	1370	2800	195
			920	1450	2810	185
		mean	849	1334	2611	171

Table 1 (cont.)

Vowel	Speaker	F_1	F_2	F_3	duration
<u>e</u> [ɤ]	A	340	1170	2550	220*
		330	1130	2600	235*
	B	510	1080	2500	205*
		500	1120	2570	225*
	C	380	1360	2310	160*
		380	1430	2200	190*
	D	500	1260	2580	240*
		480	1400	2560	215*
	mean	428	1244	2484	211*
<u>er</u> [ɚ]	A	400	1480	1890	225*
		500	1480	1820	335*
	B	490	1420	1750	250*
		600	1380	1760	280*
	C	430	1430	1710	195*
		440	1370	1760	240*
	D	440	1320	1630	435*
		450	1340	1720	330*
	mean	469	1402	1755	261*
<u>i</u> [ɿ]	A	240	1160	2700	85
		270	1170	2800	120
	B	370	1200	2710	155
		420	1210	2790	190
	C	400	1240	2620	290
		440	1380	2700	145
	D	490	1220	2600	135
		480	1280	2620	140
	mean	389	1232	2692	140
<u>i</u> [ʅ]	A	430	1750	2300	115
		280	1970	2510	130
	B	480	1690	2510	155
		450	1710	2580	170
	C	470	1600	2620	135
		440	1590	2760	130
	D	510	1710	2220	140
		510	1700	2470	125
	mean	446	1715	2496	137

Table 2. Formant frequencies and durations of monophthongic vowels before nasals.

Rhyme	Speaker	F_1	F_2	Duration (ms) vowel	nasal	total
in	A	260	2200	110	150	260*
	B	470	2230	100	155	255*
	C	380	1900	90	140	230*
	D	240	2400	130	115	245*
	mean	337	2182	107	140	247*
ün	A	260	2110	95	175	270
	B	450	1880	100	150	250
	C	380	1800	80	145	225
	D	240	2050	95	125	220
	mean	332	1960	92	149	241
un	A	240	1080	75	190	265
	B	440	1130	80	165	245
	C	350	1100	85	155	240
	D	500	1150	95	130	225
	mean	382	1115	84	160	244
en	A	490	1500	80	155	235
	B	570	1520	75	160	235
	C	490	1440	65	135	200
	D	680	1720	75	135	210
	mean	557	1545	74	146	220
an	A	820	1610	135	145	280
	B	840	1420	110	130	240
	C	750	1550	100	100	200
	D	870	1590	145	95	240
	mean	820	1542	122	117	240
ing	A	450	2230	110	145	255
	B	410	2310	70	140	210
	C	330	2140	95	135	230
	D	460	2320	105	120	225
	mean	412	2250	95	135	230
ong	A	480	890	55	155	210
	B	430	760	45	160	205
	C	520	830	100	140	240
	D	490	780	85	125	210
	mean	480	815	71	145	216
eng	A	500	1410	80	165	245
	B	430	1200	85	170	255
	C	520	1470	90	150	240
	D	470	920	70	165	235
	mean	480	1250	81	162	244

Table 2 (cont.)

Rhyme	Speaker	F_1	F_2	Duration vowel	Duration nasal	total
<u>ang</u>	A	830	1310	125	145	270
	B	830	1270	120	130	250
	C	670	1200	115	140	255
	D	900	1340	100	150	250
	mean	807	1280	115	141	256

Table 3. Formant frequencies and durations of steady states in diphthongs in the context C__#

	Speaker	F_1	F_2	F_1	F_2	Duration[1] t_1	t_2	t_3	tot.
<u>iu</u>	A	220	2330	250	740	55	60	75	240
	B	410	2080	410	820	30	60	80	210
	C	370	1930	410	720	45	55	75	175
	D	490	2360	500	830	45	60	85	245
	mean	372	2175	392	778	44	59	79	216
<u>ui</u>	A	250	1480	270	2340	70	25	100	210
	B	350	1530	330	1900	40	30	70	165
	C	390	1260	480	2050	40	50	50	190
	D	460	1400	480	2160	50	35	90	205
	mean	362	1418	390	2112	50	35	78	192
<u>ia</u>	A	410	2050	800	1350	40	90	100	235
	B	350	1900	860	1280	20	65	100	210
	C	410	1910	700	1260	25	65	100	190
	D	400	2270	900	1890	20	80	130	230
	mean	392	2032	815	1445	26	75	107	216
<u>ai</u>	A	830	1710	240	2330	45	110	20	185
	B	710	1700	420	1840	50	100	50	205
	C	660	1720	400	1960	30	100	50	180
	D	810	1760	470	2300	70	65	30	170
	mean	752	1722	382	2108	49	94	38	185
<u>ua</u>	A	480	1040	720	1320	90	20	125	245
	B	460	910	710	1180	40	50	110	200
	C	480	900	830	1310	45	35	110	210
	D	450	850	980	1320	50	20	170	245
	mean	468	925	810	1282	56	31	129	225
<u>ao</u>	A	640	1160	400	770	55	55	80	235
	B	690	1120	520	820	120	30	50	235
	C	520	890	350	800	70	50	60	200
	D	880	1200	480	850	120	25	60	235
	mean	682	1092	438	810	91	40	62	226
<u>ie</u>	A	220	2300	550	2050	95	15	30	160
	B	350	2200	620	1880	95	20	40	160
	C	290	1920	540	1640	55	30	45	150
	D	210	2470	500	2170	80	20	50	180
	mean	268	2222	552	1935	81	21	41	162
<u>ei</u>	A	420	1650	320	2270	25	115	20	180*
	B	500	1760	340	2050	20	60	90	170*
	C	- - - -							
	D	- - - -							
	mean	460	1705	330	2160	22	87	55	175*
<u>uo</u>	A	480	770	550	1110	120	30	45	205
	B	420	810	620	1220	110	25	30	215
	C	260	720	520	1080	100	20	50	190
	D	420	720	470	920	110	20	50	230
	mean	395	755	540	1082	110	24	44	210

1. t_1 = duration of first steady state; t_2 = duration of transition between the steady states; t_3 = duration of second steady state.

Table 3 (cont.)

	Speaker	F_1	F_2	F_1	F_2	Duration t_1	t_2	t_3	tot.
ou	A	480	1000	280	800	35	20	115	200
	B	360	950	350	780	25	20	120	200
	C	500	1250	320	1090	50	40	80	175
	D	540	1090	420	780	45	25	100	205
	mean	470	1072	342	862	39	26	104	195
üe	A	260	1940	510	1850	60	15	60	140
	B	450	1920	580	1700	50	20	80	160
	C	270	1840	520	1610	55	25	65	145
	D	300	2250	500	1740	60	25	85	170
	mean	320	1987	527	1725	56	21	73	154

Third formants of the diphthongs ie and üe:

		ie		üe	
Speaker:	A	3070	2670	2240	2600
	B	2790	2680	2280	2520
	C	2710	2460	2210	2420
	D	3210	2730	2500	2640
	mean	2945	2635	2307	2545

Table 4. Formant frequencies of triphthong steady states.

	Speaker	F_1	F_2	F_1	F_2	F_1	F_2	duration
iao	A	420	2270	440	1250	440	900	250
	B	350	1940	590	1080	510	940	250
	C	390	1840	520	1240	400	980	225
	D	430	2460	640	1400	520	980	260
	mean	398	2128	548	1242	468	950	246
uai	A	360	1270	620	1720	370	2180	205
	B	390	1230	620	1700	400	1930	195
	C	480	1350	590	1680	500	1850	180
	D	470	1180	740	1510	480	1970	220
	mean	425	1257	642	1652	437	1982	200

Table 5. Formant frequencies and durations for diphthongs before nasals.

Rhyme	Speaker	F_1	F_2	F_1	F_2	duration vowel	duration nasal	duration total
ian	A	290	2320	900	1690	185	115	300
	B	310	2200	630	1750	120	130	250
	C	370	1900	670	1650	130	105	235
	D	460	2390	500	1920	185	90	275
	mean	357	2202	675	1752	155	110	265
üan	A	310	2080	500	1720	165	110	275
	B	300	1820	550	1330	145	110	255
	C	450	1800	730	1620	130	115	245
	D	280	2100	630	1630	170	90	260
	mean	335	1950	602	1575	152	106	259
uan	A	450	910	690	1410	155	110	265
	B	380	1000	580	1390	135	140	275
	C	500	1130	630	1510	130	130	260
	D	430	930	700	1320	185	85	270
	mean	440	992	650	1407	151	116	267
iong	A	250	2110	260	1500	100	135	235
	B	420	1710	400	940	70	150	220
	C	330	2100	330	820	65	140	205
	D	250	2160	270	980	90	120	210
	mean	312	2020	315	1060	81	136	217
iang	A	430	2280	720	1180	140	110	250*
	B	600	2170	860	1240	120	125	245*
	C	540	2100	700	1110	150	110	260*
	D	290	2360	850	1370	140	100	240*
	mean	465	2227	782	1225	137	111	249*
uang	A	500	960	730	1090	115	135	250
	B	370	930	560	1180	120	140	260
	C	510	840	620	1110	110	135	245
	D	490	910	700	1280	125	115	240
	mean	467	910	652	1165	117	131	249

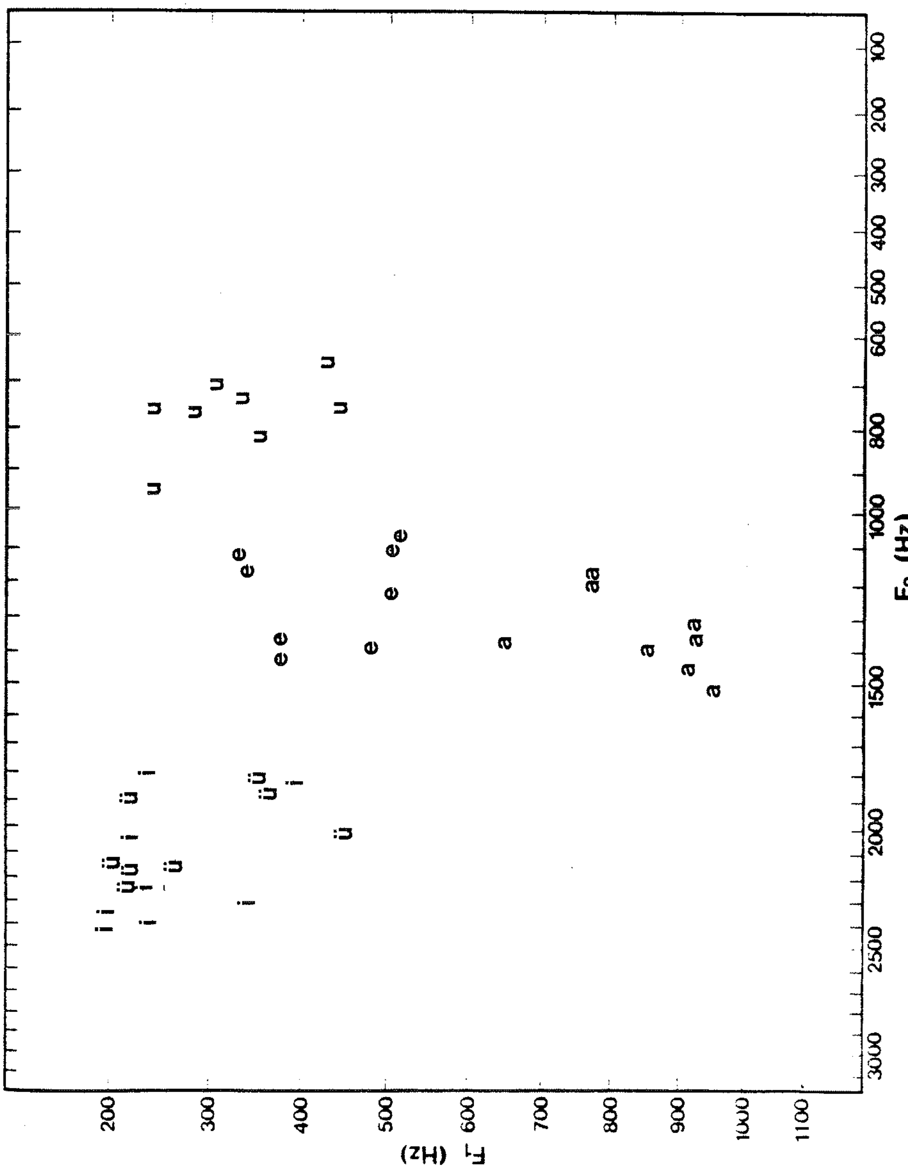

Figure 1:1. F_1-F_2-diagram for the five vowel phonemes.

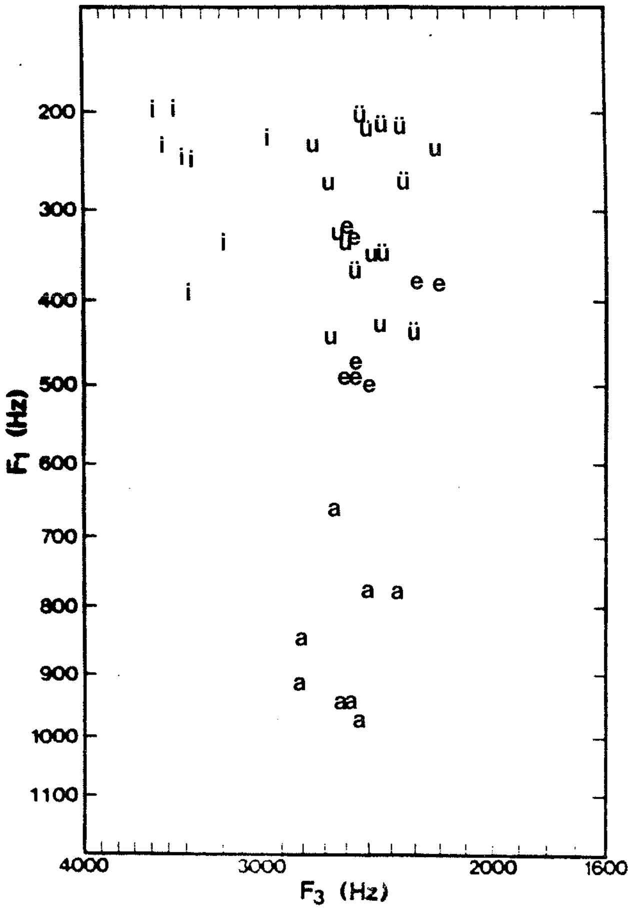

Figure 1:2. F_1-F_3-diagram for the five vowel phonemes.

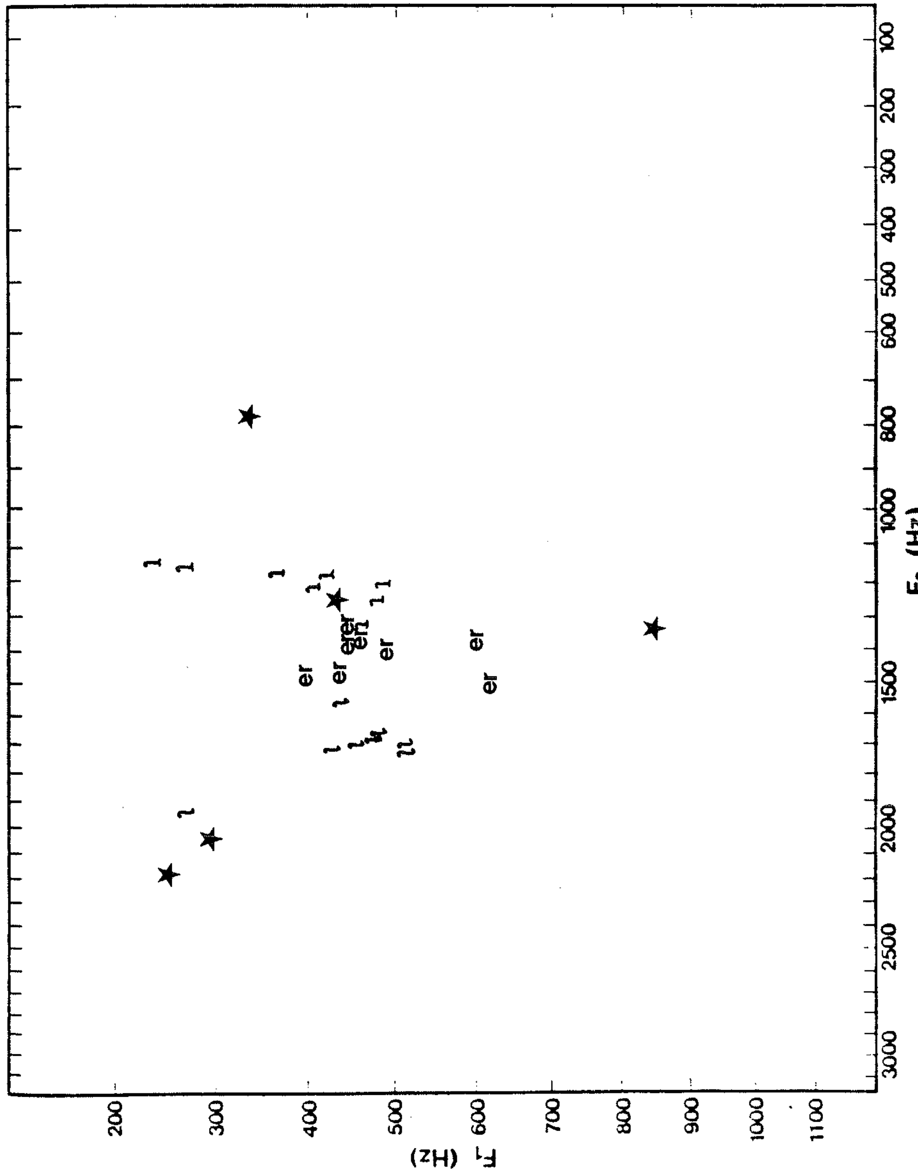

Figure 2:1. F_1-F_2-diagram for [ɚ], [ɿ] and [ʅ]. The stars represent the averages for the five main allophones of the vowels.

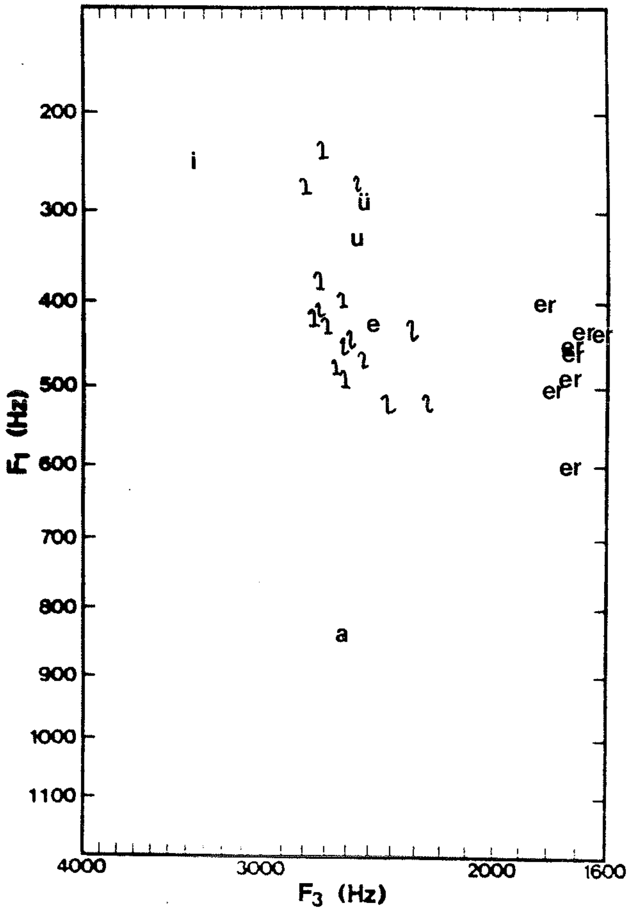

Figure 2:2. F_1-F_3-diagram for [ɚ], [ɿ] and [ʅ]. The letters i, ü, u, e and a represent average formant values for these vowels in open syllables.

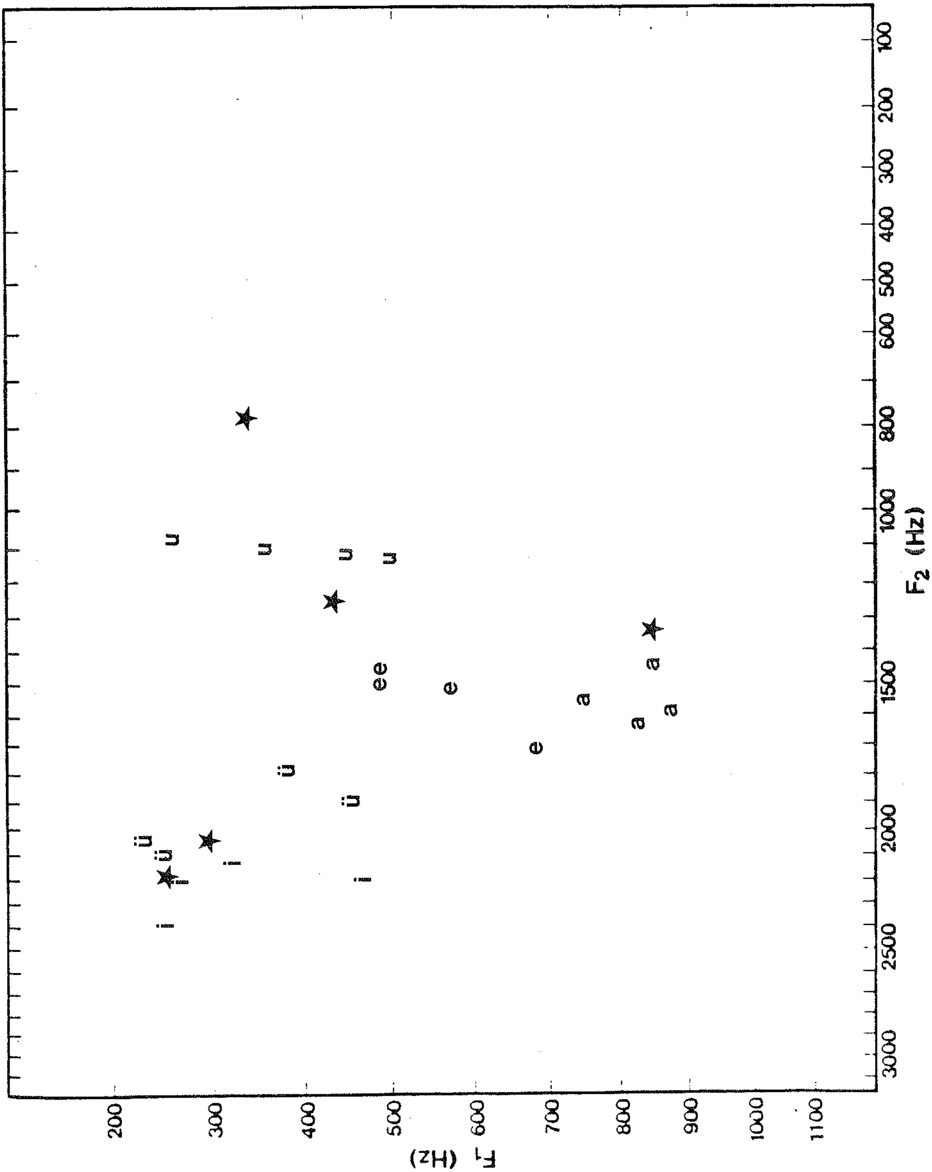

Figure 3:1. F_1-F_2-diagram for vowels before n. The stars represent average formant values for vowels in open syllables.

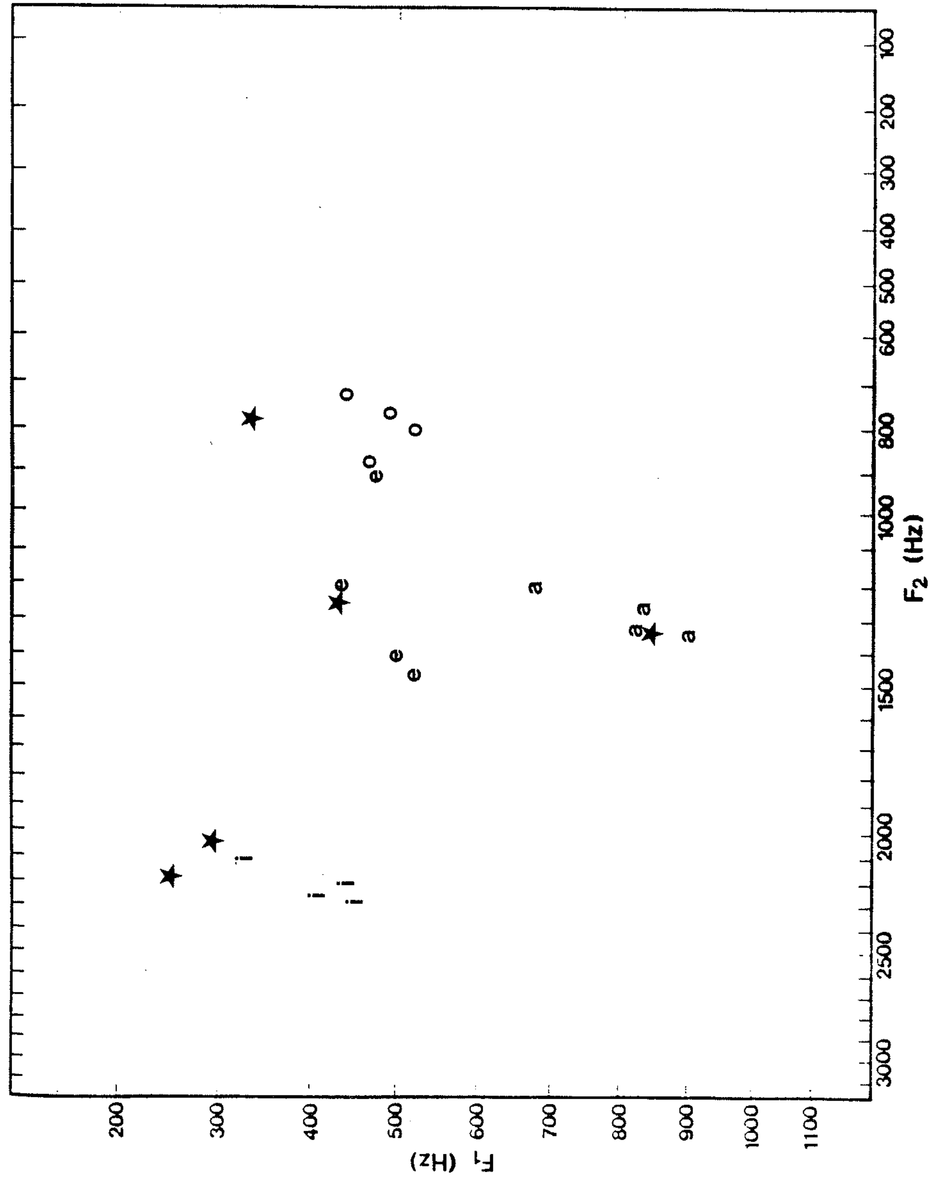

Figure 3:2. F_1-F_2-diagram for vowels before <u>ng</u>.

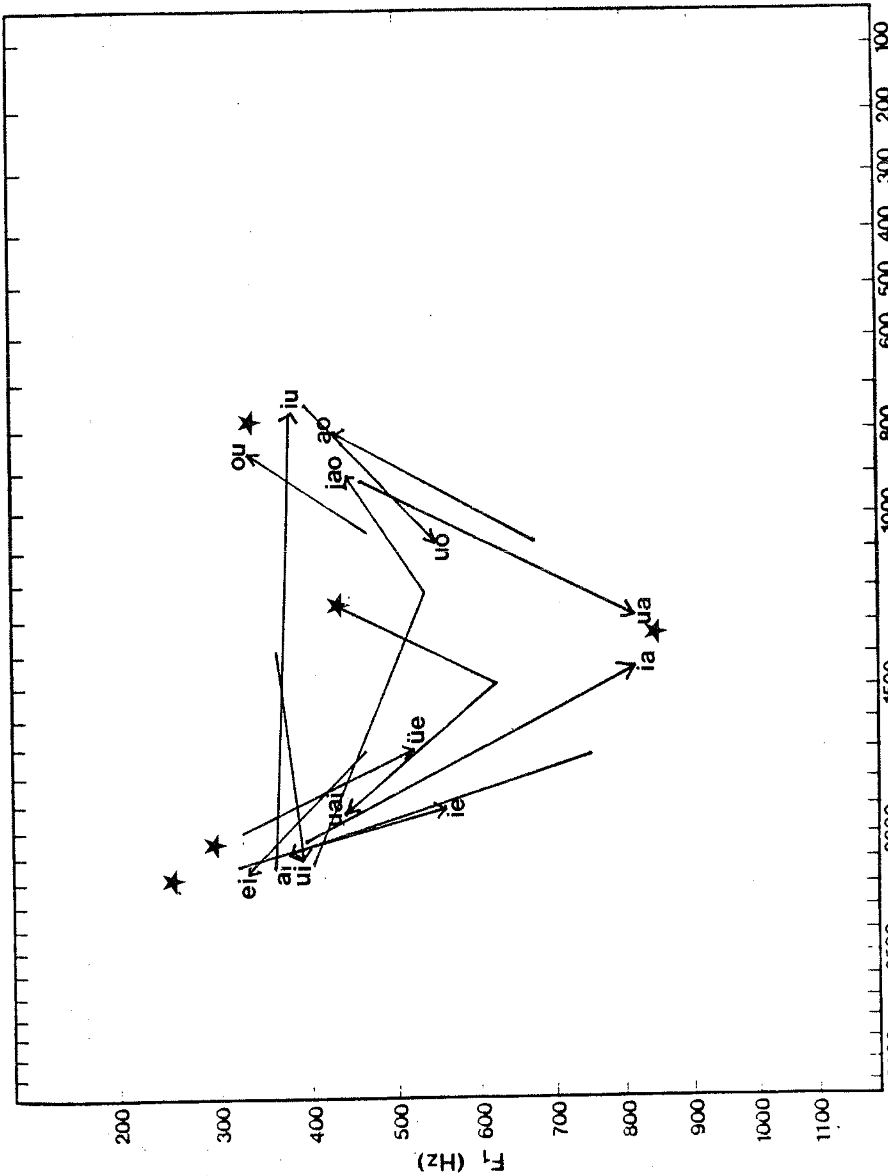

Figure 4:1. Diphthongs before Ø.

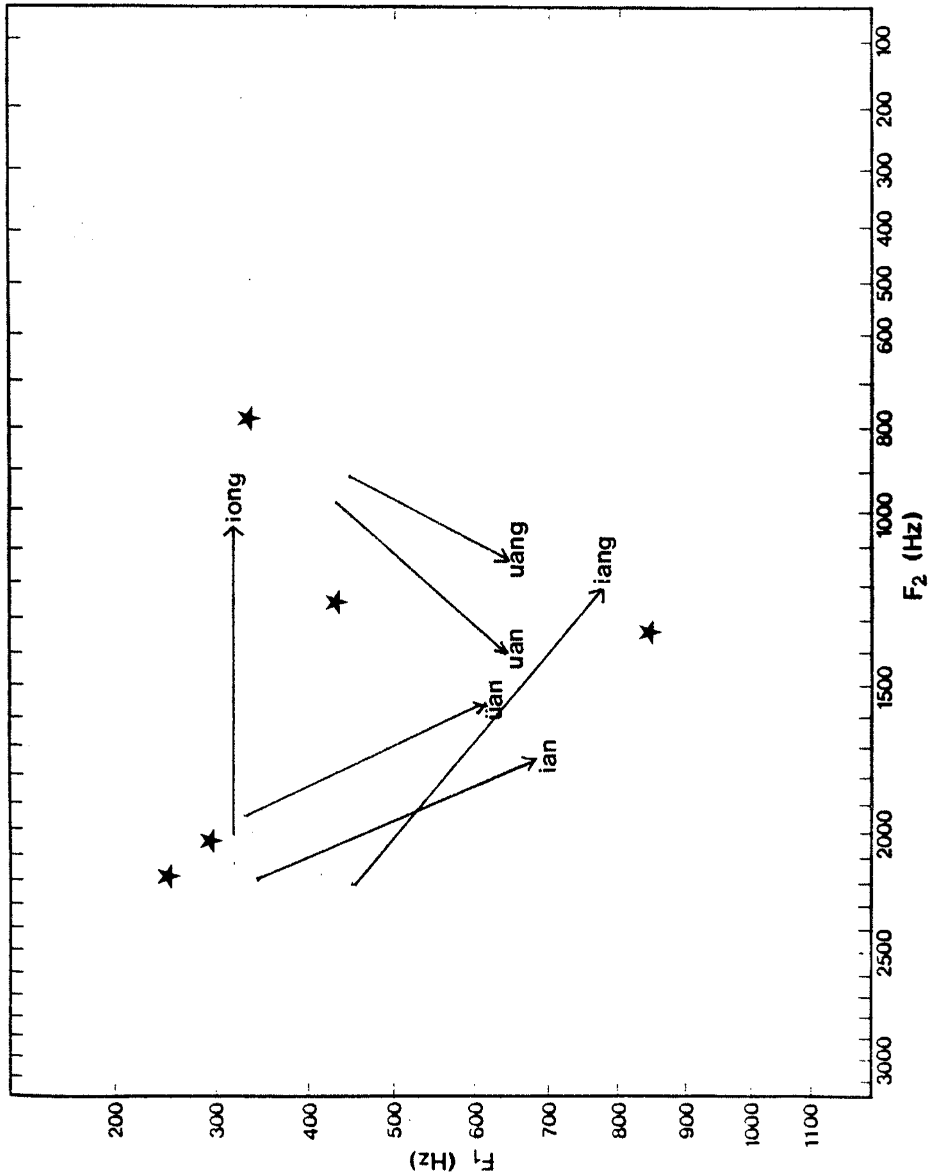

Figure 4:2. Diphthongs before nasals.

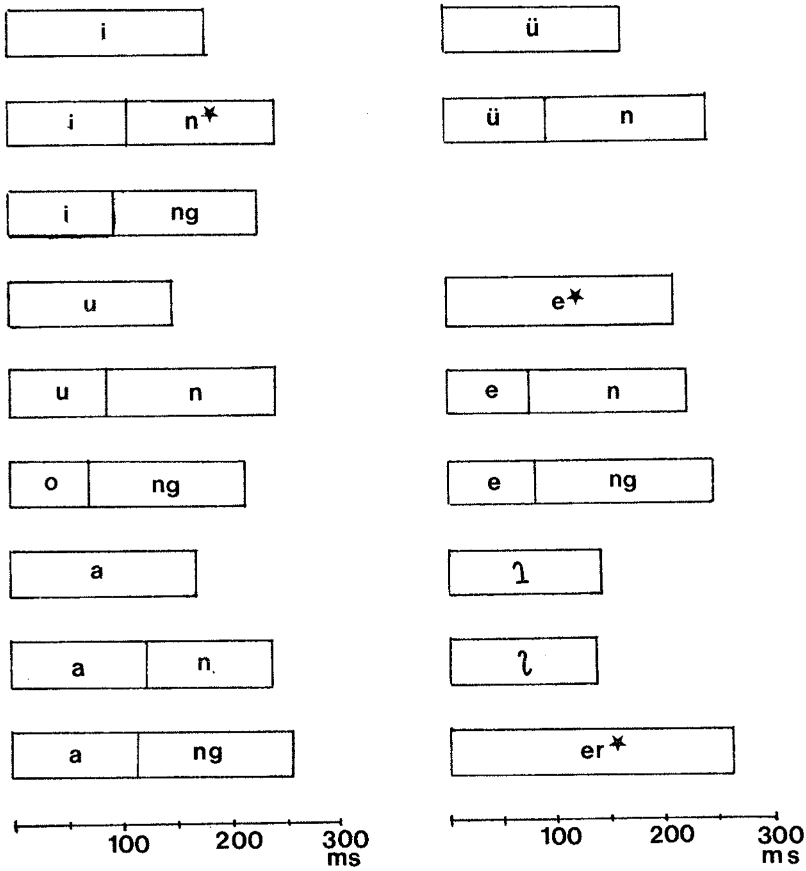

Figure 5:1. Duration of monophthongs.

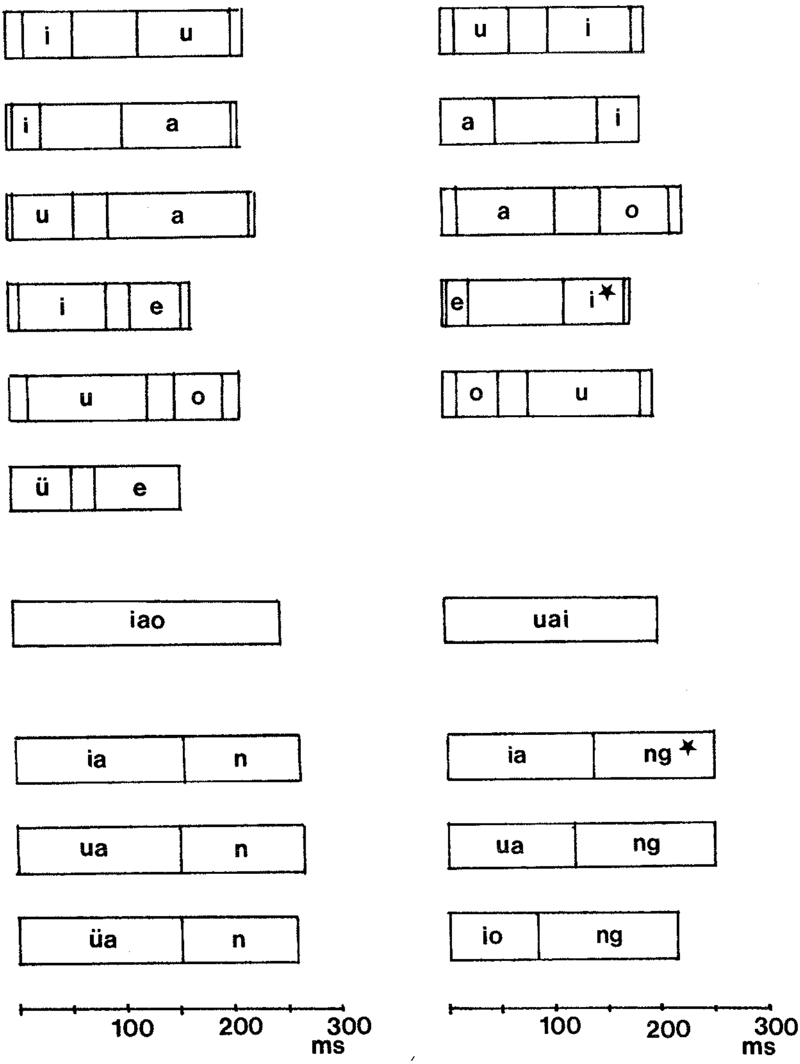

Figure 5:2. Duration of diphthongs and triphthongs.

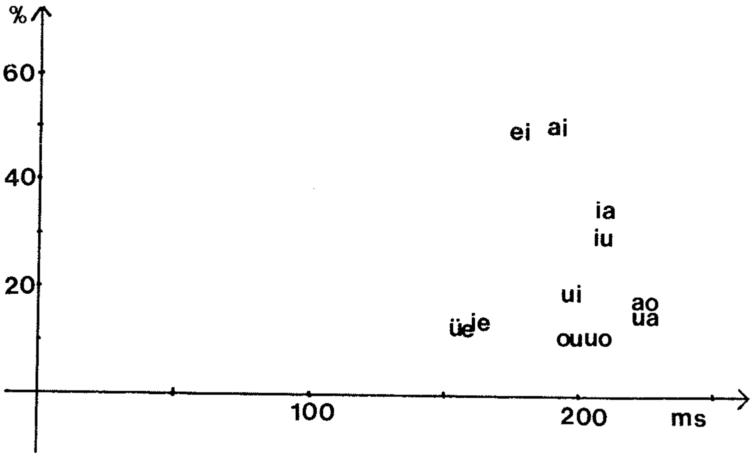

Figure 6. Transition percentage plotted against total duration for the diphthongs.