

# Acoustic Analysis of Vowels and Diphtongs in Cairo Arabic

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## 1. INTRODUCTION

This paper reports an investigation on acoustic properties of vowels and diphtongs in Cairo Arabic. The two classes of plain and pharyngalized consonants in Cairo Arabic are also discussed, using the alveolar fricatives /s/ and /ṣ/ as an illustration (Norlin 1983). The effects on vowels in the environment of these consonant classes are demonstrated.

Arabic belongs to the Semitic branch of the Afroasiatic language family. Like all varieties of Arabic, Cairo Arabic has few contrasting vowel phonemes, giving place to a number of vowel allophones. Cairo Arabic has five contrasting long vowels: /ii, ee, aa, oo, uu/, and three short vowels: /i, a, u/. The long mid vowels are derived from the diphtongs /ai/ and /au/. The diphtongal qualities are still preserved in Standard Arabic. In Cairo Arabic the long mid vowels /ee/ and /oo/ are shortened under certain morphological conditions and merge with short /i/ and /u/ phonetically. In addition, Cairo Arabic does have three phonetic diphtongs, [iu, au, ai] in a subset of the vocabulary. These are usually analyzed as /iw, aw, ay/ (Harrell, 1957).

Syllable structure is rather simple. The following syllables occur: CV, CVC, CVV, CVVC, CVCC. The last two syllables can only occur in word final position and, of course, form monosyllabic words.

## 2. PROCEDURE

Most of the data illustrating vowels are taken from real monosyllabic words of the types CVVC and CVCC, set in a sentence frame ?ulna ... kamaan (we said ... again), preceded and followed by dental consonants. All contrasting vowel phonemes and the three diphtongs occur in this position. To get examples of short [e] and [o], some disyllabic words were included, since they cannot occur in monosyllables. Long /ii, aa, uu/ also

occur in a stressed syllable in disyllabic words, since vowels are not found between these consonants in monosyllables.

Six speakers of Cairo Arabic recorded the sentences to give five tokens of each utterance. The recordings were made in the studio of the Phonetic Department in Lund. The recordings of vowels and diphthongs were analyzed from broad-band spectrograms from a Kay Digital Sonagraph 7800. For the vowels the first two formants of the five tokens were traced and superimposed on each other to get an idea of variation within each speaker. The variation proved to be very small and can in all cases be considered to be within the measurement error. Therefore three tokens were selected for analysis. The long and short vowels were all monophthongs. Formant frequencies were measured from a steady state portion of the formant. Mean formant values representing each vowel of each speaker were calculated, tables 1 and 2. Using a lab computer the formant values in Hz were converted to mel and plotted on an acoustic chart with  $F_1$  and  $F_2$  in the usual way. Vowel duration was measured from five tokens and mean values calculated, table 3. For the diphthongs the first two formants were measured together with the duration of each steady state and the duration of the transition. The formant frequencies were measured in the middle of each steady state.

### 3.1. RESULTS: VOWEL DURATION

Vowel durations were first considered separately in plain and pharyngalized environment. The results show that vowel duration is not significantly different between plain and pharyngalized long vowels, nor between plain and pharyngalized short vowels in these environments. Therefore plain and pharyngalized vowels are considered together. Table 3 shows the mean duration for all the vowels. The difference in length between long and short vowels is rather large. Short vowels are about half the duration of long ones.

### 3.2. RESULTS: VOWEL QUALITY

Figure 1 is a formant chart of plain, long vowels. Plain, long vowels are well separated with no overlapping, except for long /ii/ and /ee/ touching each other. Figure 2 shows a formant chart of the three plain, short vowels. These vowels are also

well separated clusters. Figure 3 also shows plain, short vowels, but it includes the non-phonemic [e] and [o]. Here short [e] and [o] show nearly complete overlapping with short /i/ and /u/. Their non-phonemic status is stated in literature, but phonetic data supporting the linguistic analysis is generally not presented. In some text-books there is even a claim that there is a phonetic difference between [i] and [e] on the one hand, and [o] and [u] on the other (Abdel-Massih 1975). Figures 4 and 5 show formant charts of the pharyngalized long and short vowels.

#### 4. DISCUSSION

##### 4.1. Vowel length and vowel quality

Difference in vowel length influence vowel quality. For both plain and pharyngalized environments the long vowels are more peripheral, whereas the short vowels are inside the space of the long vowels with the exception of long /aa/ and short /a/ where the quality difference is small. Both plain and pharyngalized long /ii/ differ significantly ( $p < 0.001$ ) from short /i/ along both  $F_1$  and  $F_2$ . The short /i/ vowels are lower and further back than the long /ii/ vowels. Short /u/ vowels are lower and more front than long /uu/ vowels. Both sets of long /aa/ differ to some extent from their short counterparts along  $F_2$ . The short vowels tend to be further back. The differences along  $F_1$  between long and short /a/ vowels are non-significant: long and short vowels have the same vowel height. It seems as if vowels in Cairo Arabic are anchored on the low vowels and the short vowels /i/ and /u/ do not reach the vowel quality of the long ones, figure 6.

##### 4.2 Vowel quality in plain and pharyngalized environment.

An earlier study (Norlin 1983) analyzed all the fricatives in Cairo Arabic. These include the pharyngalized fricatives /s/ and /z/. In this study FFT spectra of the fricatives were converted to critical band spectra. The center of gravity of the critical band spectra was plotted against dispersion, figure 9. The center of gravity in the spectra was also plotted against the mean intensity level of the spectra in dB, figure 10. The results from this earlier study showed that the plain and pharyngalized consonants are different, even if the difference

is small.

Considering the effects of plain and pharyngalized environments on vowel quality, a comparison between long vowels shows that there is a complete overlapping for both sets of long /uu/. Pharyngalized long /ii/ shows a small difference from its plain counterpart in that it is slightly lower and further back. Pharyngalized long /aa/, however, is greatly affected, showing a considerable difference in the  $F_2$  dimension from its plain counterpart: the pharyngalized /aa/ is much further back than the plain /aa/, figure 7.

A comparison between the plain and pharyngalized short vowels shows that the pharyngalized short /u/ does not overlap with plain short /u/, as is the case with the long counterparts. It is further back. The short pharyngalized /i/ is also further back than plain /i/. The two sets of short /a/ differ in the same manner: pharyngalized short /a/ is further back. Thus all short vowels are further back in pharyngalized environment. Fig. 8.

In conclusion, it is evident that the pharyngalization process affects the whole syllable. On the one hand, plain and pharyngalized consonants differ consistently. On the other hand, vowels in plain and pharyngalized environment differ in more complex ways. Plain and pharyngalized low vowels always show a considerable difference in the  $F_2$  dimension, regardless of length, the pharyngalized vowels being more back. High long vowels show small or no difference, whereas short high vowels always are further back than plain ones.

## 5. DIPHTHONGS

Most Standard Arabic diphthongs /ai/ and /au/ have in Cairo Arabic developed into long /ee/ and /oo/. They also exist in Cairo Arabic, however, in a number of purely dialectal words and some Standard Arabic words commonly used in daily speech. In addition, there exists a third diphthong [iu] due to morphophonemic rules in verb conjugation. A comparison between the short vowels and the corresponding segments in the diphthongs shows some differences in vowel quality. In the diphthongs,  $F_1$  frequencies are always identical with  $F_1$  in short vowels, but  $F_2$  is always lower, making diphthong segments more back.

The rate of transition between the two components in diphthongs is fast, around 30-35 milliseconds in all the diphthongs. It seems as if the diphthongs in Cairo Arabic are made by stringing the short vowels together with a fast transition, figures 11, 12, 13.

#### ACKNOWLEDGEMENTS

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#### REFERENCES

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- Harrell, R.S. 1957. The phonology of colloquial Egyptian Arabic. New York: American council of learned societies.
- Norlin, K. 1983. Acoustic analysis of fricatives in Cairo Arabic. Working Papers 25:113-137. Phonetics Laboratory, Lund University.

Table 1. Formant frequencies of long and short plain vowels in Cairo Arabic.

Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>
/ii/	1	225	2600	3050	/aa/	1	625	1700	2700
		275	2575	3150			600	1650	2650
		250	2650	3100			625	1675	2675
	2	300	2275	3150		2	550	1750	2475
		300	2325	3000			550	1825	2500
		300	2325	3150			575	1800	2500
	3	275	2250	2900		3	525	1700	2600
		250	2275	2850			575	1750	2675
		275	2250	2800			500	1700	2650
	4	300	2050	2775		4	525	1600	2500
		300	2100	2800			500	1625	2500
		300	2000	2800			500	1525	2500
	5	300	2300	2925		5	575	1750	2600
		300	2325	3025			575	1775	2550
		275	2300	3000			575	1825	2525
	6	350	2200	3150		6	550	1675	2700
		300	2200	3125			550	1750	2700
		300	2200	3200			550	1700	2700
	mean	288	2289	2997		mean	557	1710	2594
/ee/	1	300	2250	2800	/oo/	1	400	750	2650
		300	2400	2800			350	750	2500
		400	2375	2825			400	800	2500
	2	425	2100	2700		2	400	850	2225
		400	2125	2650			400	900	2225
		450	2150	2650			425	875	2250
	3	375	2075	2700		3	400	950	2350
		400	2025	2700			450	1000	2375
		375	2050	2700			400	1000	2400
	4	400	1825	2500		4	350	900	2250
		350	1875	2600			350	850	2200
		400	1900	2500			400	975	2400
	5	350	2275	2700		5	400	825	-
		325	2225	2650			400	850	2400
		350	2225	2700			400	775	2400
	6	350	2200	3100		6	400	775	2400
		375	2200	3100			325	775	2500
		325	2150	3050			350	800	2450
	mean	369	2135	2746		mean	389	856	2381

Table 1 (cont.)

Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>		
/uu/	1	275	775	2675	/a/	1	550	1600	2725		
		300	700	2650			575	1600	2700		
		275	700	2500			625	1600	2700		
	2	250	825	2300		2	650	1500	2450		
		300	850	2275			625	1475	2500		
		300	875	2325			625	1525	2500		
	3	275	750	2475		3	550	1575	2525		
		300	825	2500			550	1600	2600		
		300	800	2350			550	1600	2525		
	4	300	800	2275		4	550	1500	2575		
		300	850	2200			525	1600	2550		
		300	775	2225			550	1525	2600		
	5	325	700	-		5	600	1500	2625		
		300	650	-			575	1575	2600		
		300	700	-			600	1525	2500		
	6	300	725	2350		6	525	1650	2800		
		300	725	-			600	1700	2750		
		300	775	-			525	1700	2825		
	mean	294	767	2392		mean	575	1575	2614		
	/i/	1	400	1875		2750	/u/	1	400	1150	2750
			375	1950		2725			400	1100	2725
375			1900	2750	475	1075			2900		
2		475	1850	2425	2	450		975	2250		
		475	1825	2550		450		1050	2350		
		450	1850	2500		475		1050	2250		
3		425	1875	2550	3	400		1175	2250		
		425	1825	2600		450		1175	2375		
		400	1825	2600		425		1200	2400		
4		400	1750	2500	4	400		1250	2250		
		475	1750	2500		375		1200	2300		
		450	1800	2425		425		1250	2225		
5		400	1925	2625	5	350		1100	2500		
		375	1925	2625		375		1250	2400		
		400	1925	2600		400		1150	2400		
6		450	1950	2825	6	425		1050	2550		
		450	1900	2800		400		1100	2400		
		450	2000	2800		400		1050	2600		
mean		425	1872	2619	mean	415		1131	2438		

Table 2. Formant frequencies of long and short pharyngalized vowels in Cairo Arabic.

Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>
/ii/	1	250	2400	2800	/uu/	1	325	725	3000
		275	2400	2800			250	675	2975
		275	2325	2825			250	675	-
	2	300	2150	2625		2	300	875	2375
		300	2200	2725			300	775	2450
		300	2200	2700			325	800	2500
	3	300	2200	2600		3	250	825	2500
		350	2125	2575			325	850	2400
		325	2100	2600			300	800	2500
	4	325	2000	2425		4	325	825	2500
		350	2000	2475			300	800	2500
		325	1925	2425			325	800	2575
	5	350	2200	2700		5	300	650	2700
		350	2175	2750			325	700	2650
		300	2200	2700			325	625	2750
	6	350	2175	3150		6	350	800	-
		300	2150	3100			300	750	-
		350	2150	3100			300	750	-
mean	315	2171	2726	mean	304	761	2598		
/aa/	1	600	1125	2900	/i/	1	400	1375	2800
		600	1100	2900			450	1250	2800
		675	1050	2975			450	1300	2900
	2	550	1000	2250		2	475	1525	2500
		600	1000	2375			450	1550	2450
		600	1000	2350			475	1525	2400
	3	600	1100	2300		3	475	1475	2500
		550	1100	2300			475	1475	2475
		550	1050	2300			475	1475	2500
	4	550	1050	2400		4	450	1325	2400
		500	1025	2350			450	1300	2375
		550	1125	2300			425	1300	2300
	5	550	1050	2750		5	350	1850	2550
		525	1025	2675			400	1800	2625
		525	1025	2750			400	1800	2675
	6	575	1225	2775		6	400	1900	2725
		650	1300	2500			400	1800	2725
		550	1200	2725			425	1900	2650
mean	572	1086	2549	mean	435	1551	2575		



Table 2 (cont.)

Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>	Vowel	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>3</sub>
/a/	1	650	1200	2800	/u/	1	500	900	2300
		625	1200	2850			500	1000	-
		600	1225	2750			400	975	2300
	2	650	1100	2500		2	400	800	2350
		650	1100	2525			450	750	2500
		625	1075	2500			450	825	2350
	3	600	1175	2350		3	500	1100	2400
		600	1150	2275			450	1100	2225
		550	1100	2400			475	1100	-
	4	600	1050	2300		4	450	1050	2500
		600	1150	2400			450	1100	2475
		575	1125	2300			400	975	2350
	5	550	1050	2875		5	375	925	2600
		550	1100	2850			400	900	2700
		575	1125	2875			400	975	2725
	6	600	1250	2800		6	400	1000	-
		550	1300	2850			400	1000	-
		575	1325	2800			400	925	-
mean		596	1156	2611	mean		433	967	2444

Table 3. Vowel duration, plain and pharyngalized vowels, mean values in milliseconds.

/ii/	131	/i/	67
/ee/	153	/a/	84
/aa/	158	/u/	75
/oo/	185		
/uu/	139		

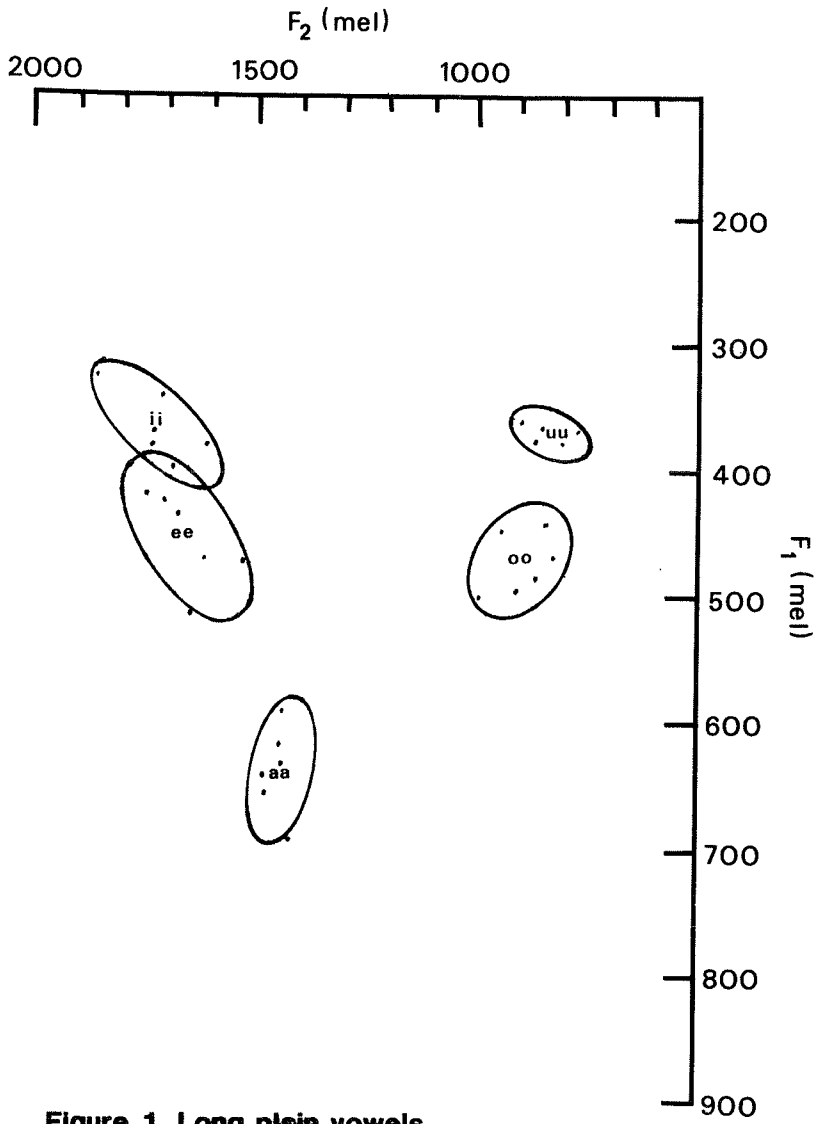
Table 4. Formant frequencies and durations of diphthongs in Cairo Arabic.<sup>1</sup>

Diphthong	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>1</sub>	F <sub>2</sub>	t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	tot.	
iu	1	300	1850	300	800	60	50	50	190	
		450	1850	425	850	40	50	50	175	
		425	1800	375	775	30	55	35	170	
	2	450	1750	350	1000	30	25	40	125	
		450	1700	325	850	60	30	35	155	
		475	1750	450	1025	45	25	40	125	
	3	450	1800	375	950	50	35	40	150	
		500	1800	325	900	65	40	25	160	
		450	1850	350	925	50	40	40	150	
	4	475	1750	375	800	60	25	45	145	
		400	1675	325	800	40	25	40	135	
		475	1725	350	850	50	25	45	140	
	5	400	1900	300	800	55	40	40	160	
		375	1850	300	750	60	40	60	190	
		400	1825	325	750	50	40	50	165	
	6	425	1700	325	775	50	30	50	150	
		400	1650	350	800	50	30	50	155	
		450	1625	375	800	50	30	50	170	
	mean		430	1769	350	844	49	35	44	156
	ai	1	650	1600	400	2450	60	25	85	170
			675	1675	375	2450	60	20	90	170
			700	1700	400	2500	75	25	90	185
		2	650	1700	375	2000	75	30	60	165
			650	1600	400	2000	80	35	65	185
675			1675	425	2100	70	40	70	180	
3		575	1750	400	2200	70	20	80	165	
		600	1650	400	2100	50	30	85	170	
		550	1650	450	2025	70	30	75	180	
4		600	1775	325	2075	70	30	55	175	
		575	1725	350	2025	70	30	60	160	
		575	1675	350	2050	70	30	70	170	
5		525	1700	325	2250	70	30	80	180	
		650	1700	375	2250	60	30	80	170	
		625	1625	350	2250	60	35	95	190	
6		600	1800	350	2225	75	30	95	195	
		600	1750	350	2225	70	30	100	200	
		575	1800	300	2200	70	30	85	185	
mean			614	1697	372	2187	68	29	79	177

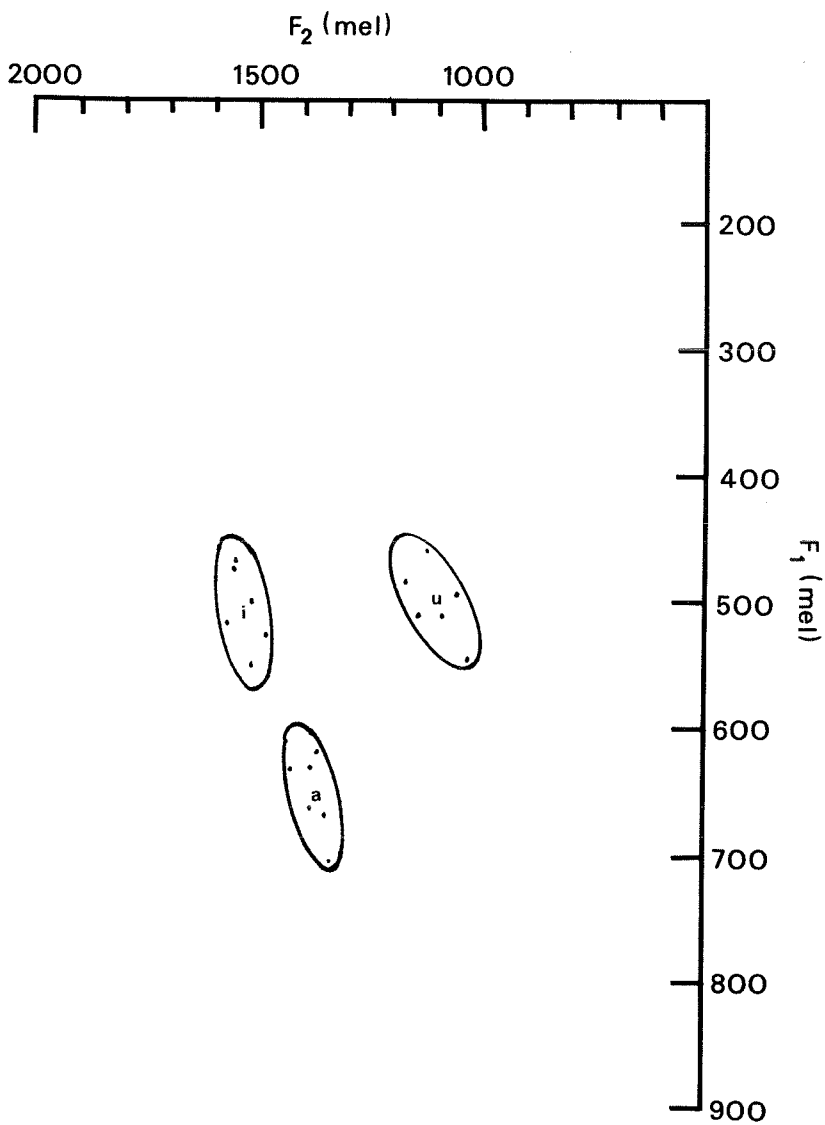
1.  $t_1$  = duration of first steady state,  $t_2$  = duration of transition between the steady states,  $t_3$  = duration of second steady state.

Table 4 (cont.)

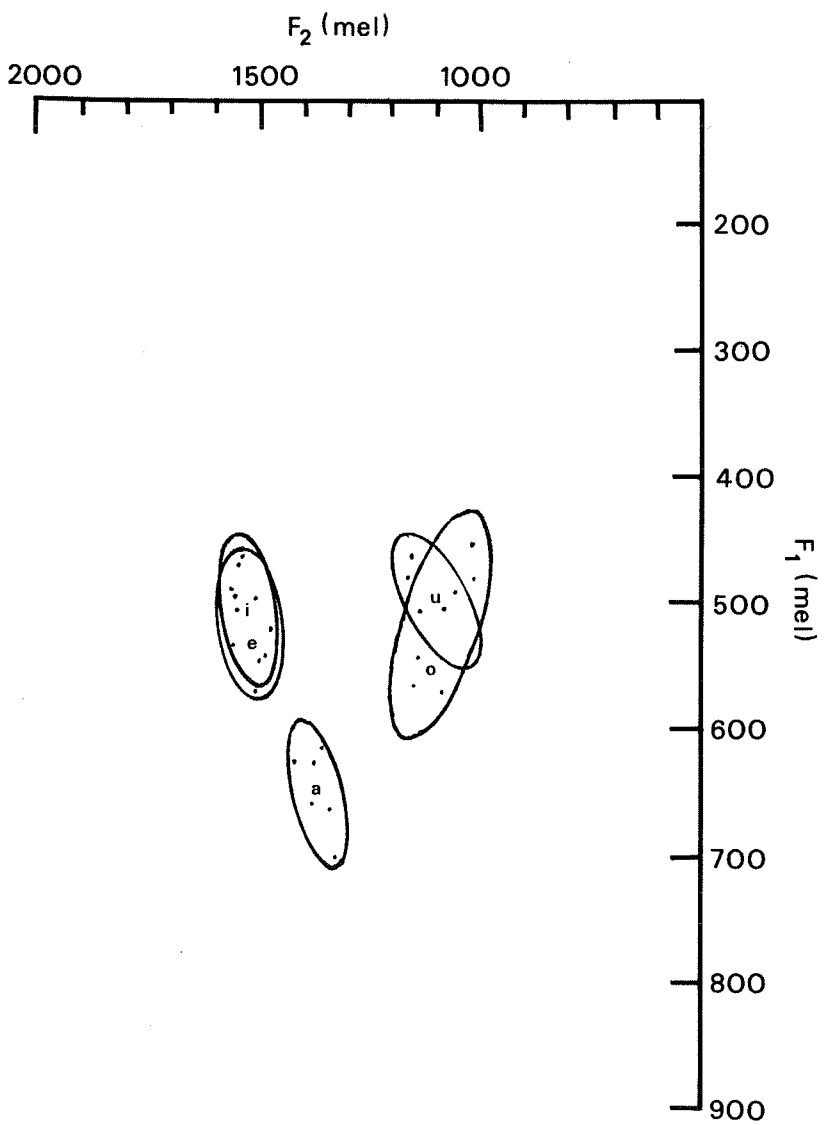
Diphthong	Speaker	F <sub>1</sub>	F <sub>2</sub>	F <sub>1</sub>	F <sub>2</sub>	t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	tot.
au	1	575	1375	325	750	70	30	65	190
		625	1400	400	775	65	45	55	180
		625	1450	400	800	70	40	55	180
	2	550	1425	400	1075	70	25	40	140
		575	1450	425	1100	70	25	40	135
		600	1375	425	1100	70	30	35	140
	3	550	1500	425	1025	70	40	35	160
		550	1500	425	1000	80	35	40	150
		550	1500	425	1075	65	40	55	180
	4	525	1425	375	1050	50	25	40	125
		500	1400	400	1100	50	25	30	120
		550	1400	400	950	60	20	30	125
	5	700	1500	450	825	60	30	40	145
		650	1525	375	850	60	40	30	150
		600	1575	350	700	60	35	35	145
	6	600	1625	425	850	50	40	50	180
		575	1575	400	850	50	40	60	180
		600	1575	425	825	55	40	55	190
mean	583	1476	403	928	63	34	44	156	



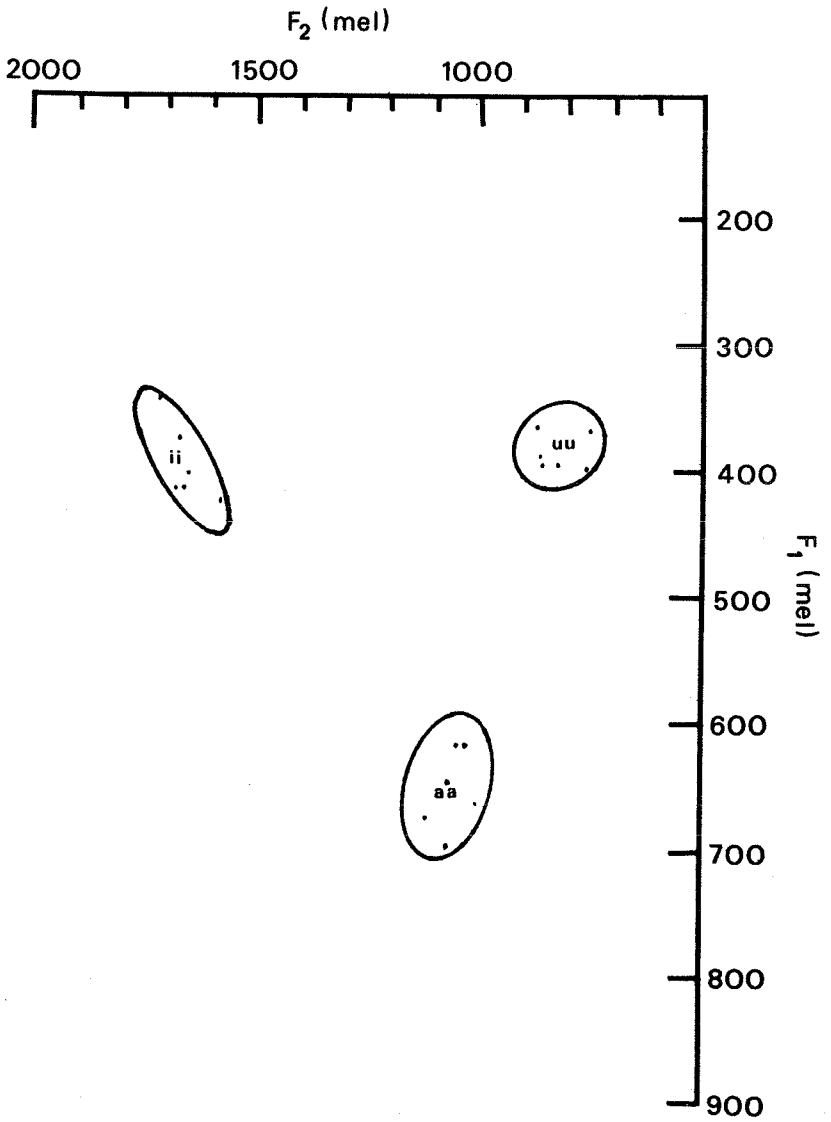
**Figure 1. Long plain vowels.**



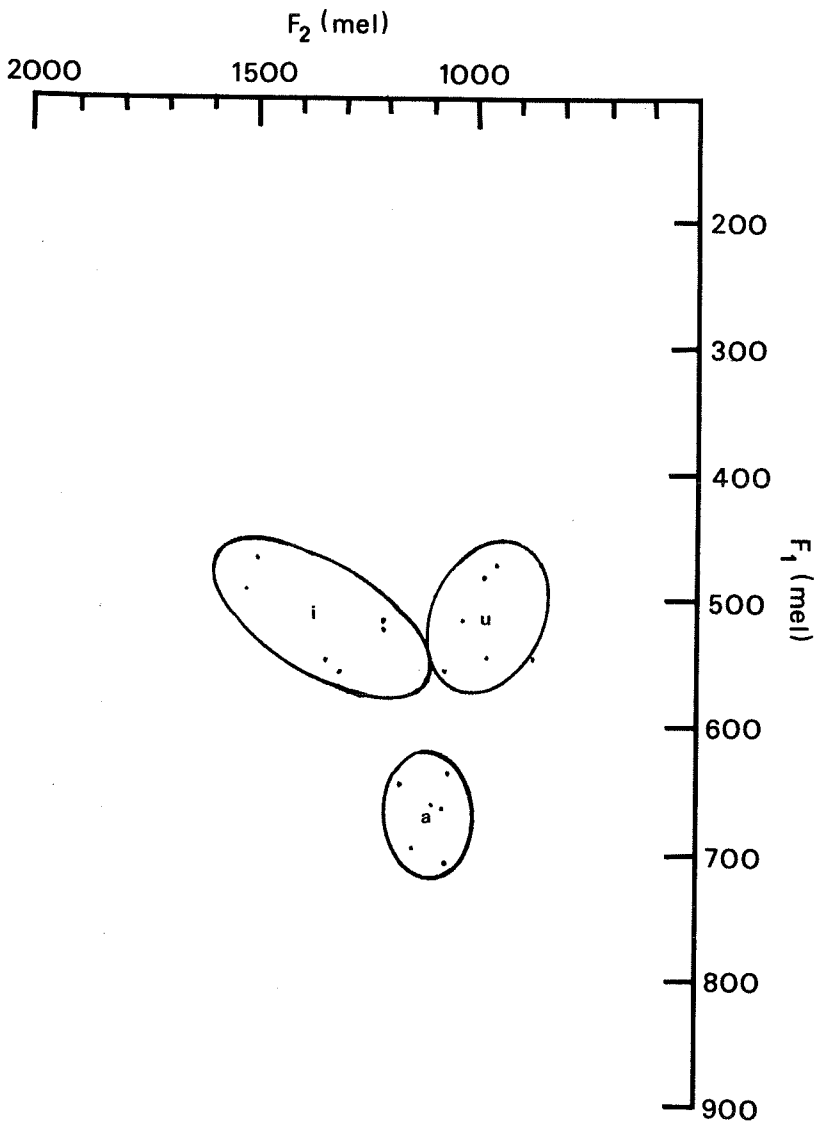
**Figure 2. Short plain vowels.**



**Figure 3. Short plain vowels.**

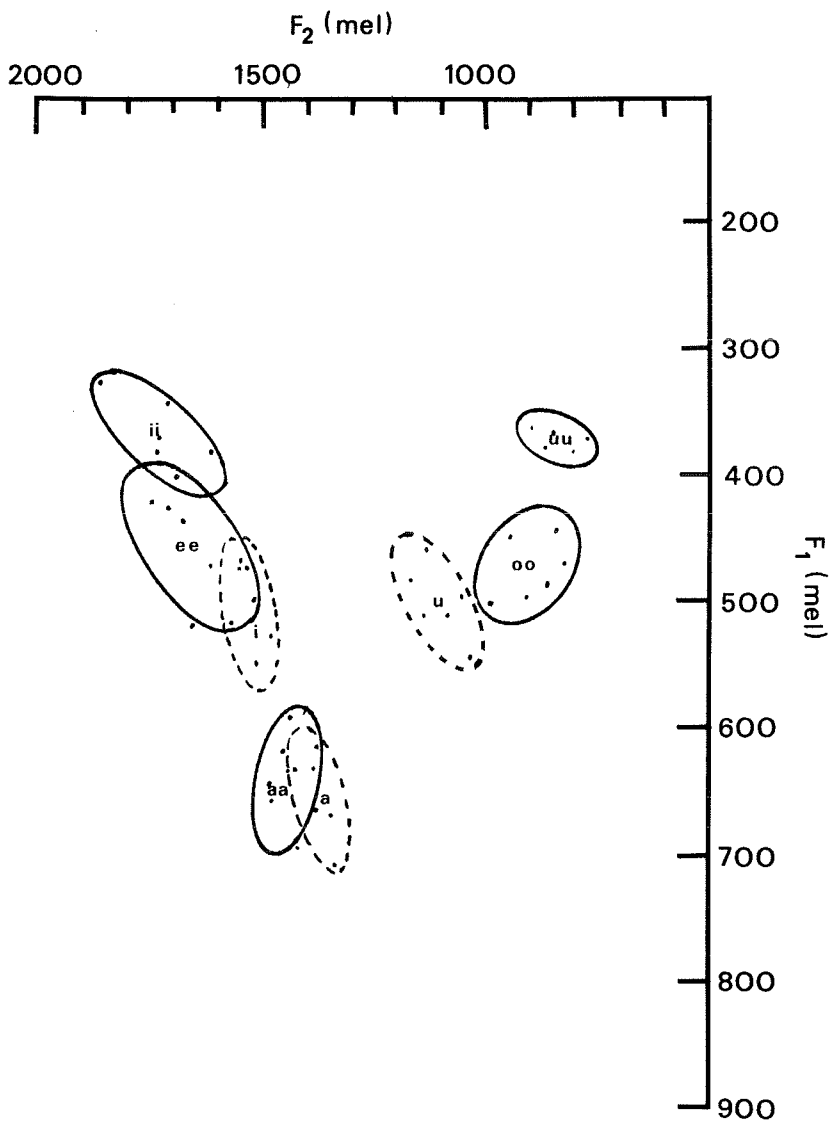


**Figure 4. Long pharyngalized vowels.**



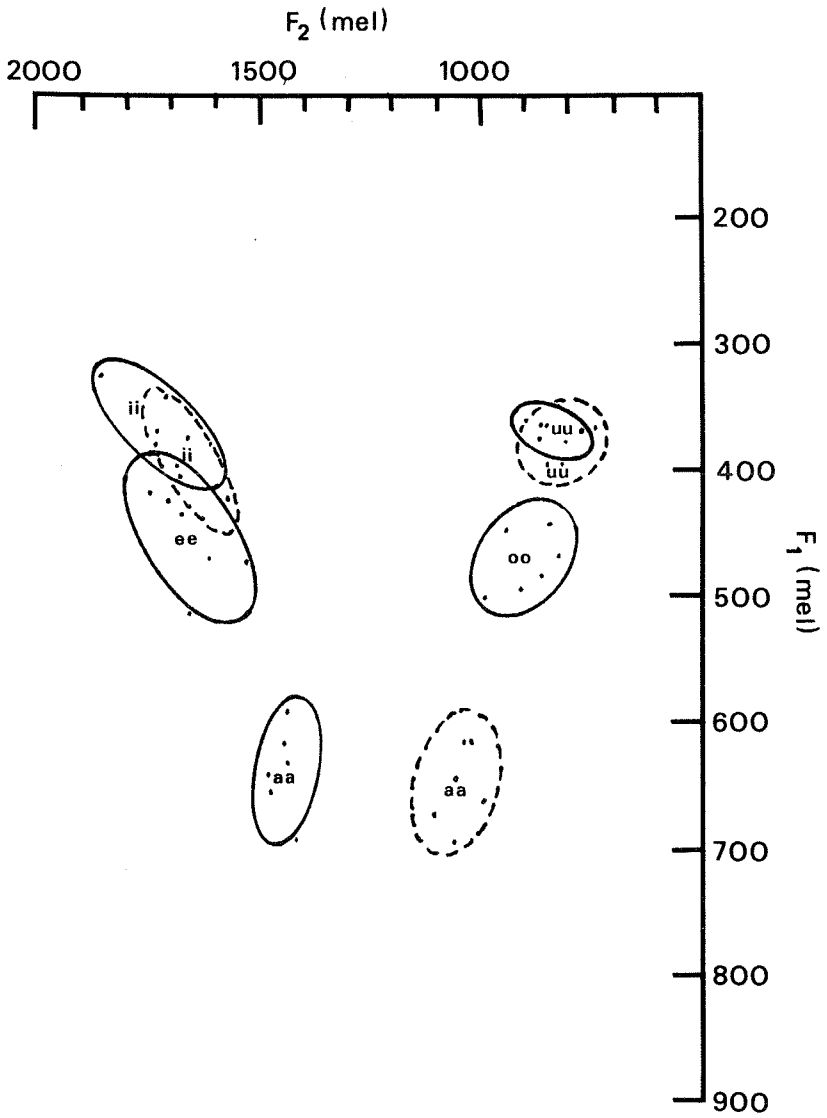
**Figure 5. Short pharyngalized vowels.**





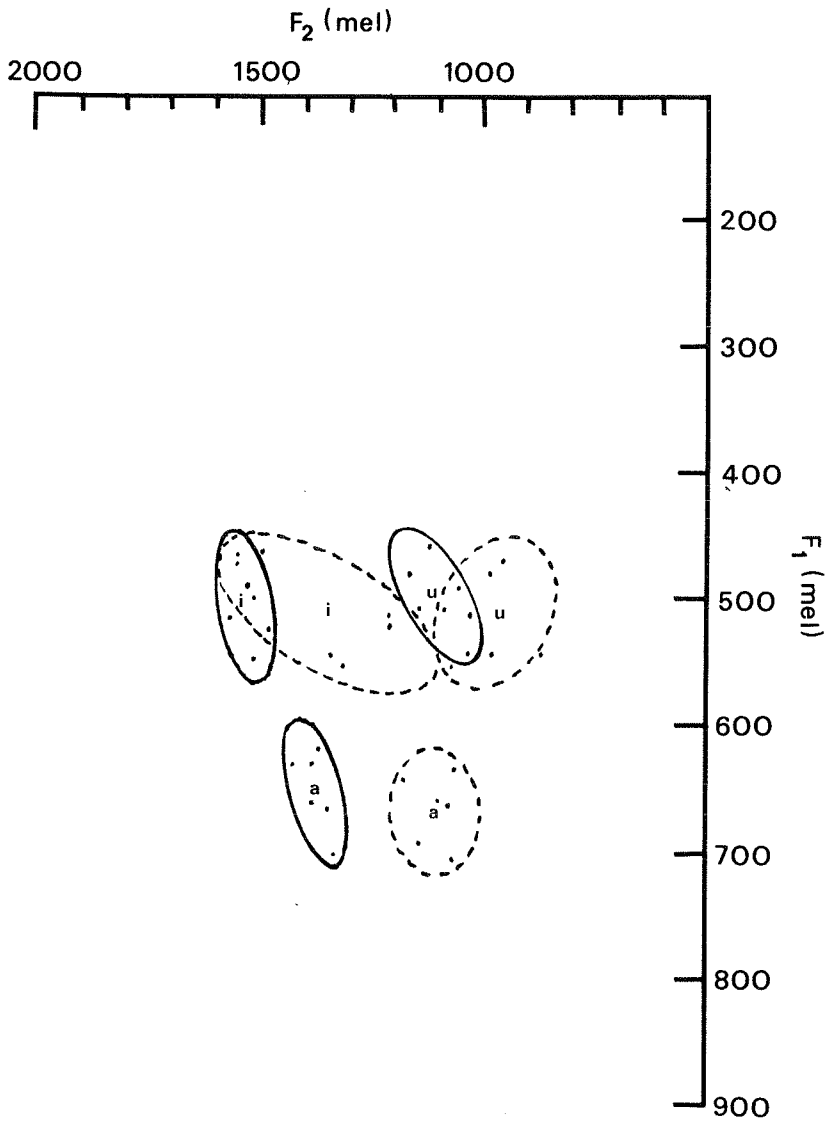
**Figure 6. Long and short plain vowels.**

— long vowels  
 - - - short vowels



**Figure 7. Long plain and pharyngalized vowels.**

- plain vowels
- - - pharyngalized vowels



**Figure 8. Short plain and pharyngalized vowels.**

— plain vowels

- - - pharyngalized vowels

Figure 9

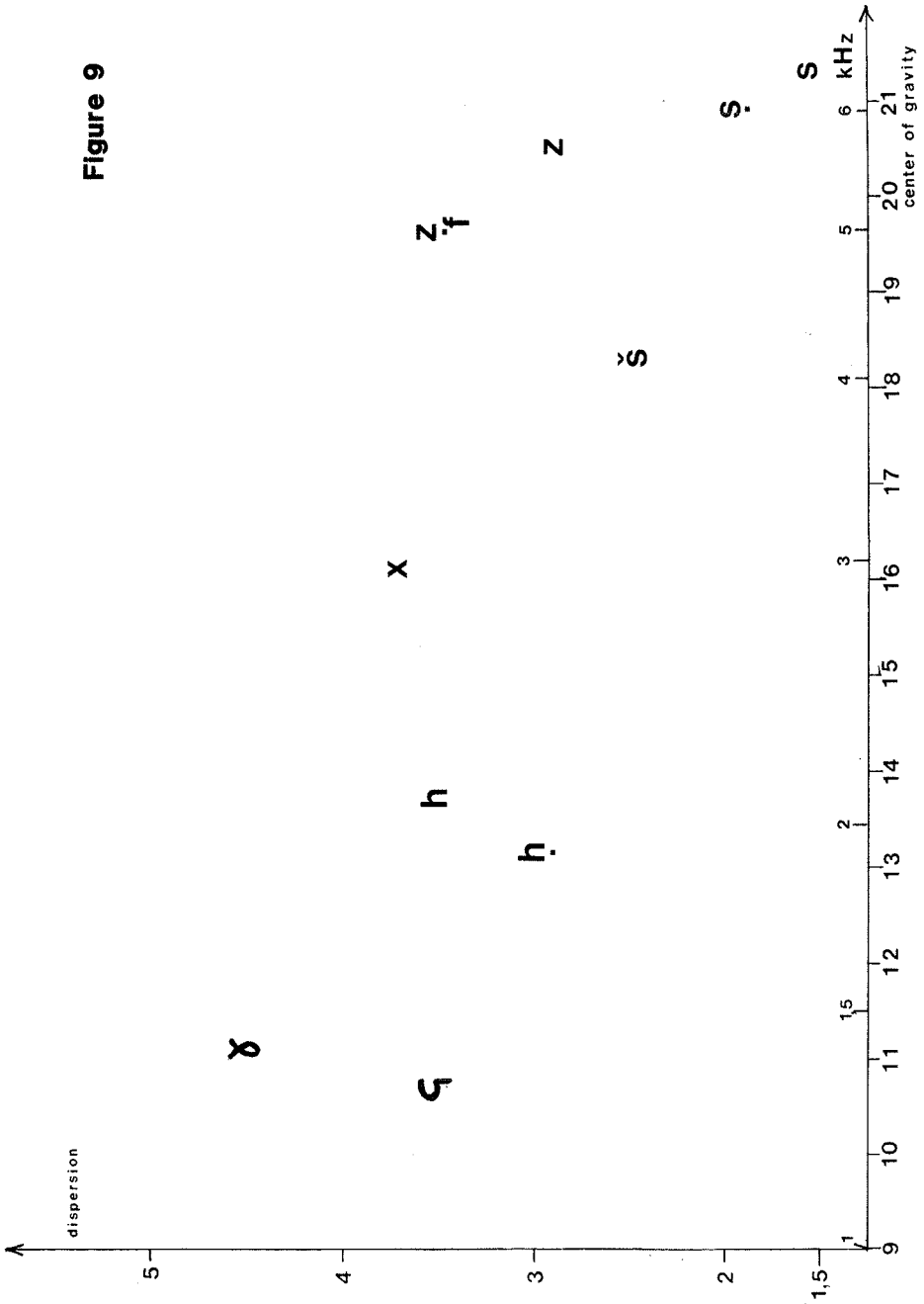
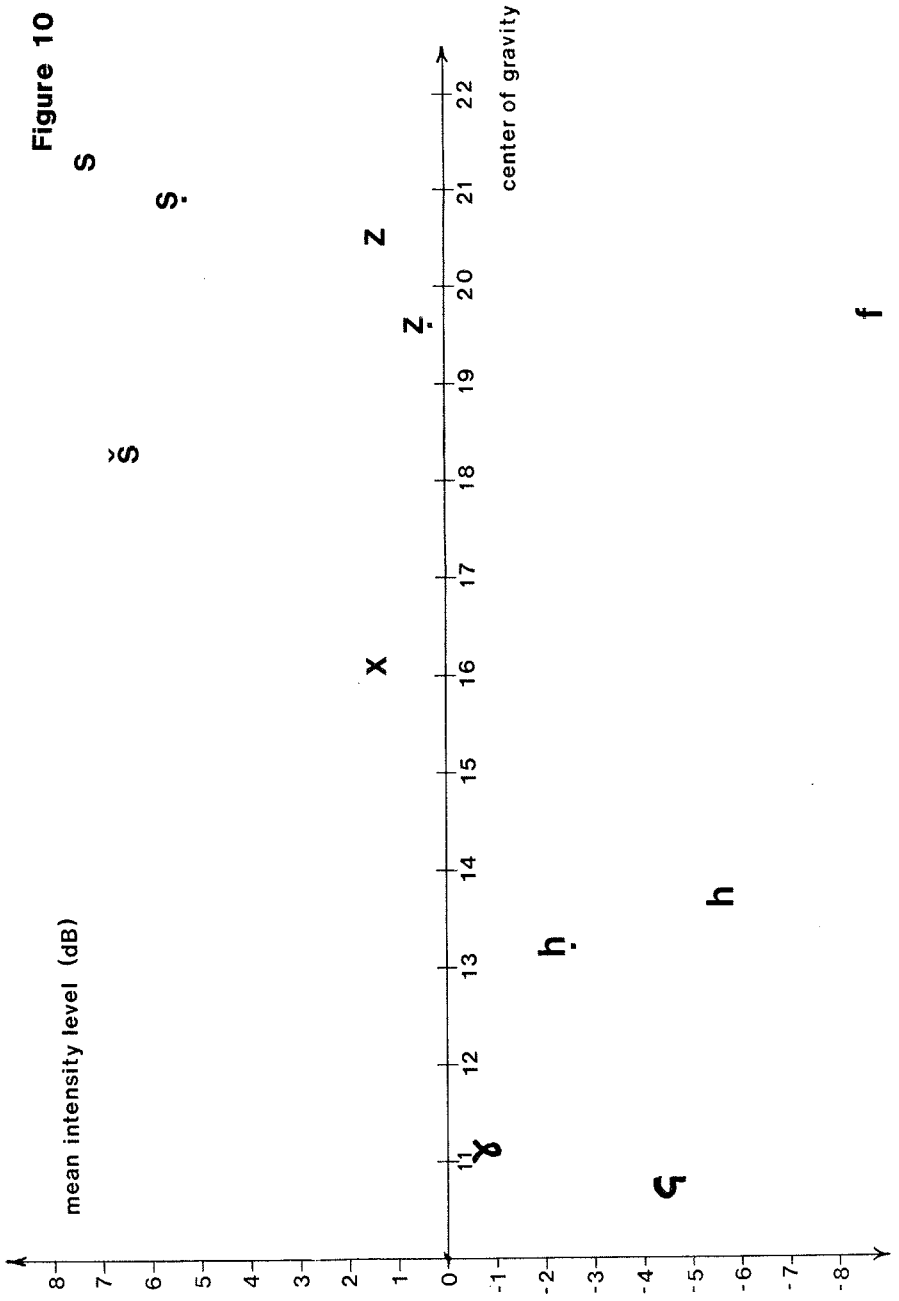


Figure 10



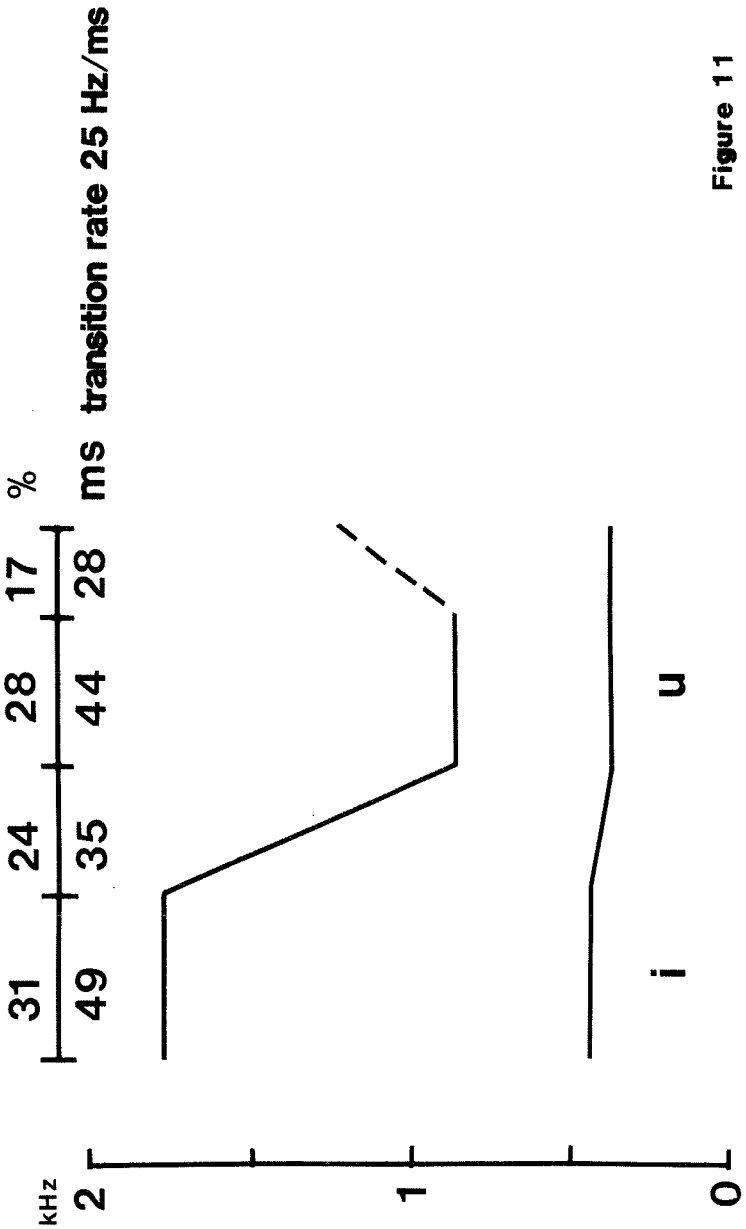


Figure 11

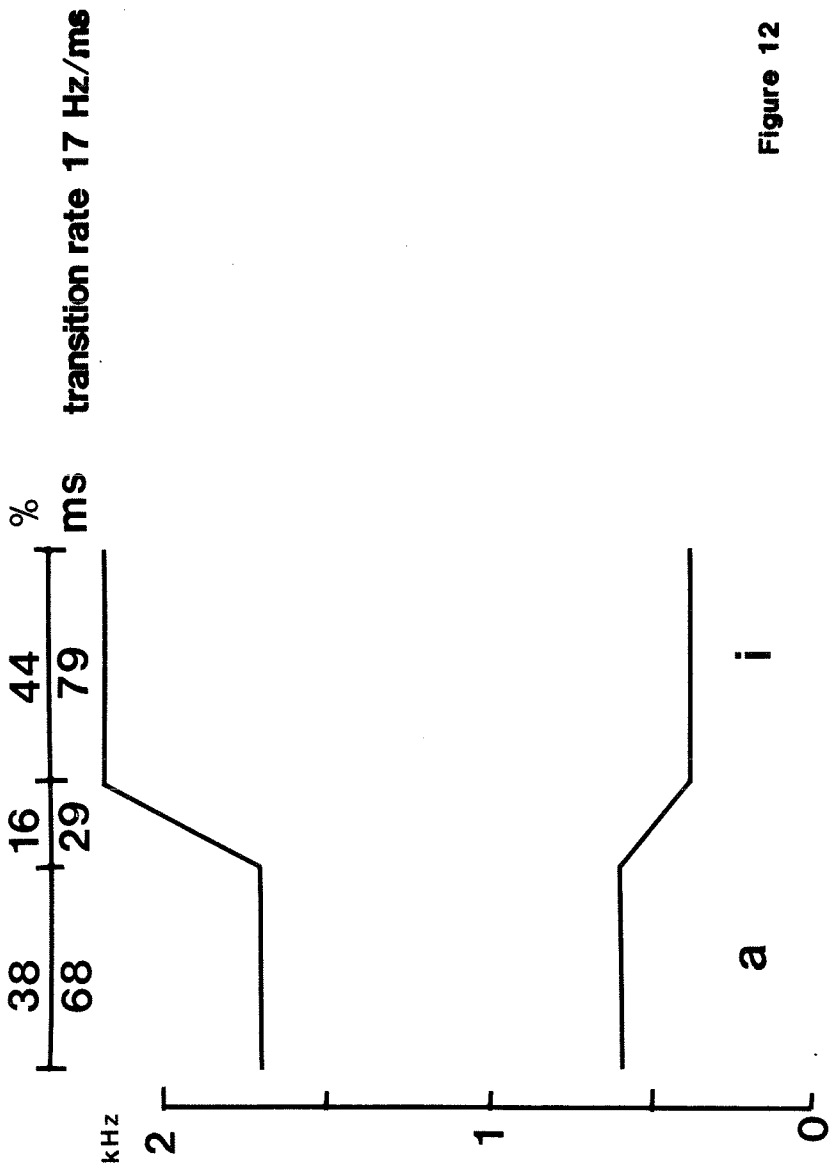


Figure 12

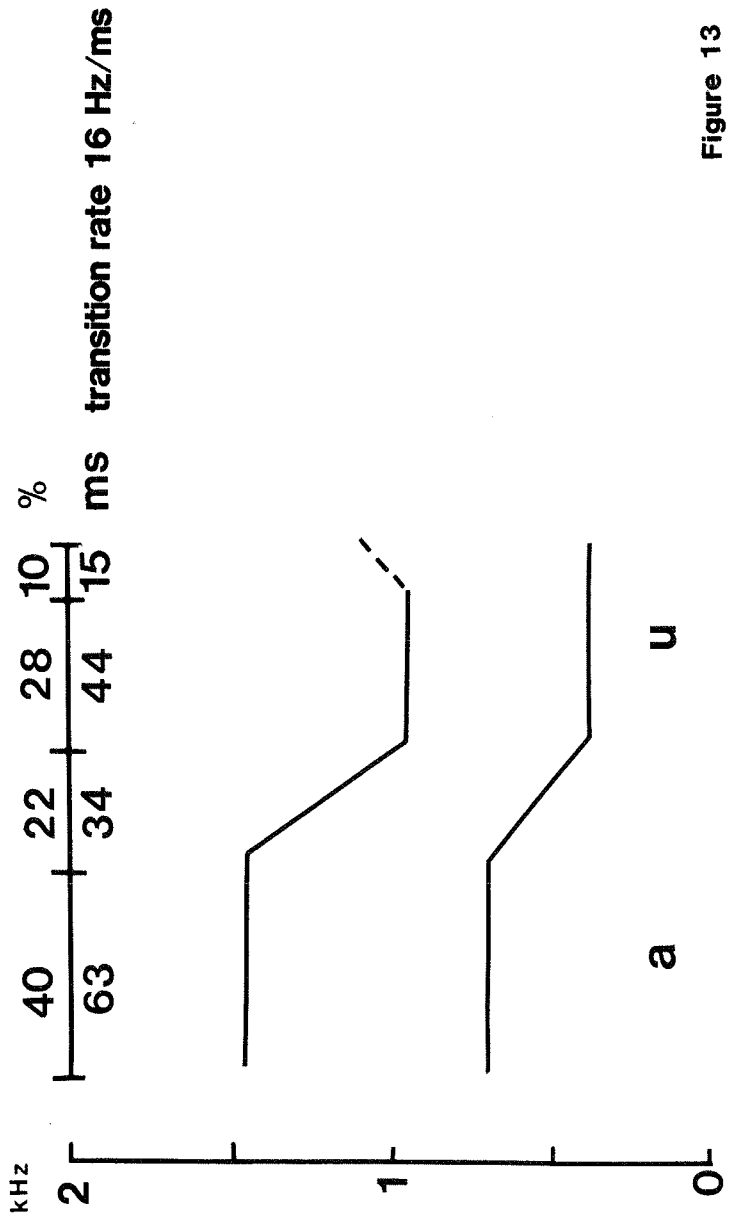


Figure 13