Phonetic Structures of Iaai

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1. Introduction

Iaai [ja:i] is a one of the twenty-five or so indigenous languages of New Caledonia, a French "overseas territory" in the South Pacific. This territory consists principally of the large island called Grande Terre and an archipelago of three smaller islands to the east known as the Loyalty Islands. Iaai is spoken by about two thousand people on Ouvéa, the northernmost of the Loyalty Islands. Its closest linguistic relatives are the other Loyalty Islands languages, Drehu (Lifou) and Nengone (Mare). All the New Caledonian languages are generally assigned to a separate New Caledonia group of the Oceanic branch of Austronesian languages.

The most authoritative description of Iaai is Ozanne-Rivierre (1976), which outlines the phonology and morphology of the language in some detail and provides a syntactic sketch. The earlier outline grammar by Tryon (1968) is superceded by this work. A bilingual Iaai-French dictionary was published by Ozanne-Rivierre in 1984, based in large part on texts collected by Jean Guiart in 1948 but supplemented by more recent materials. There are no prior studies which have focussed on the phonetics of the language, and in particular no published instrumental phonetic studies of Iaai.

A second Austronesian language, belonging to the Polynesian group, is also spoken on Ouvéa. This language is called Faga Ouvéa (also West Uvean) and is closely related to the languages of Futuna and the Polynesian enclaves in southern Vanuatu. It is this language which has given the island its present administrative name. In the second half of the eighteenth century Polynesian-speaking settlers arrived and occupied the northern and southern extremities of the island, where their descendants remain dominant. At both the northern and the southern language boundaries there are areas of bilingualism, but Iaai remains the dominant language of the central part of Ouvéa, including the adminstrative capital of Fayaoué [fajawe].

Iaai has been influenced by a variety of other languages in addition to Faga Ouvéa. It contains a considerable number of lexical borrowings from English as English-speaking missionaries from the London Missionary Society established themselves on Ouvéa in 1858 and opened schools as early as 1859. The orthography established by these Protestant missionaries and continued by their successors from the Paris Mission remains in use, reinforced by its use in the Bible translation of 1901, although attempts have been made to introduce a more consistent and better-suited orthography (Wahéo and Wahéo 1987). The missions employed catechists from Samoa, providing another source of Polynesian influence. As in the rest of New Caledonia, the current medium of instruction in schools on Ouvéa is French, and most speakers of Iaai are reported to be fairly fluent in French. A substantial number of Iaai speakers live in Nouméa and other parts of Grande Terre, where command of French is close to essential for economic success.

Data

For the present study of the phonetic structures of Iaai, selected words were chosen from Ozanne-Rivierre's grammar and dictionary to illustrate all of the contrastive segments of the language. These words were checked for currency with Tai Wahéo and then recorded by two male and three female native speakers in two separate sessions. The resulting corpus of data consists of high quality analog audio recordings of 140 words spoken in isolation by these five speakers. To minimize background noise a Shure SM10A close-recording headset microphone was used for all audio recordings. In addition, simultaneous video-audio recordings were made for all five speakers, focusing on labial articulations. To examine coronal consonant articulations in more detail, palatographic data was collected for 1 male speaker and the 3 female speakers. The data were collected by the first author in February 1993 in Nouméa, New Caledonia.

A number of aspects of this language are of particular phonetic interest. For an Austronesian language, Iaai has a relatively large vowel inventory consisting not only of ten different vowel qualities, but also a phonemic length distinction. In distinguishing these vowels, large differences in lip rounding and spreading are used and these are independent of the front-back distinction. Moreover, there are interesting limitations on the distribution of certain vowels according to the consonant context. The consonant inventory is also quite extensive. The language has three coronal places of articulation, dental, retroflex and pre-palatal, for stops and nasals. In the stops, these three places appear to be acoustically differentiated along lines which differ from most other languages of the world which make use of such distinctions. The Iaai consonant inventory also contains voiced and voiceless sonorants which have phonemic status. What follows will present a general phonetic survey of the language, with emphasis laid on these various aspects of particular interest.

2. Vowels

2.2 Vowel contrasts and distribution

Iaai has a maximal system of ten distinctive vowel qualities. Phonologically distinct vowel qualities are shown on a conventional vowel chart in Figure 1:

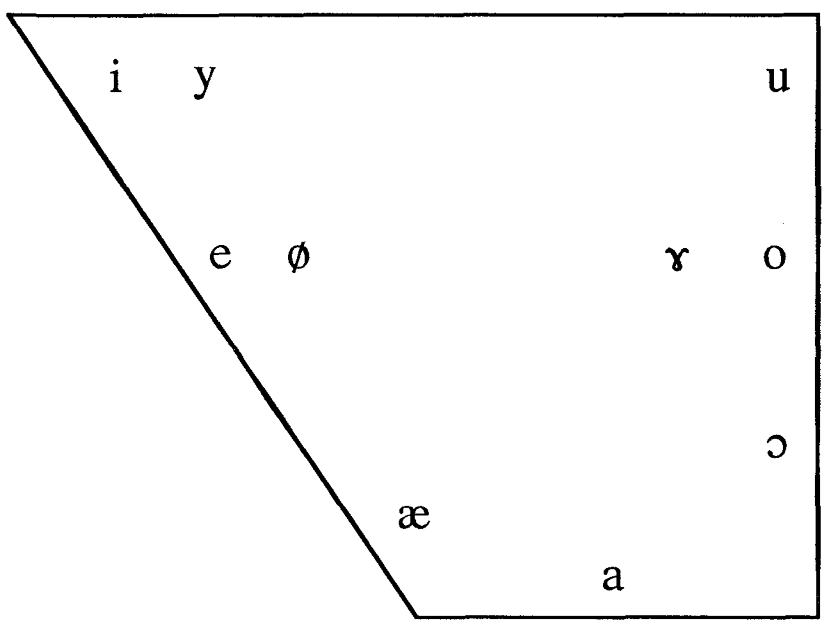


Figure 1: Distinctive vowel qualities of Iaai.

The placement of symbols on this chart follows closely the descriptions given by Ozanne-Rivierre (1976), with the exception that what is transcribed /ɤ/ here is represented as /ə/ in her analysis and described by her as a central rather than a back mid unrounded vowel. The formant pattern of this vowel seems to indicate that it is a back vowel similar in height to /o/, /e/ and /ø/.

Lip position pictures certainly show it to be quite unrounded. These properties of the vowel will be discussed in more detail below. We also prefer to use the symbol [æ] for the lowest of the front vowels on the chart, rather than [ɛ]. This symbol indicates its phonetic quality more precisely, as Ozanne-Rivierre noted.

Each of the vowels occurs distinctively long and short. There are no auditorily salient differences in the qualities of the vowels depending on their length. Words illustrating the twenty quality and length distinctions are shown in Table 1 below:

Table 1: Word illustrating vowel quality and length distinctions in Iaai.

Vowel (IPA)	Exemplar (IPA)	Exemplar (Orthography)	Gloss
i	**ito**	*ito*	'round hut'
ii	**ṭii**	*trii*	'tea'
y	**yɤɤ**	*ûöö*	'tree'
yy	**yy**	*ûû*	'quarrel' (n)
e	**ṭeṇ**	*trenr*	'rich'
ee	**eet**	*eet*	'fishing line'
ø	**møk**	*mok*	'ill, dead'
øø	**møøk**	*mook*	'close eyes' (v)
æ	**ɥæk**	*vëk*	'four'
ææ	**m̥ææk**	*hmëëk*	'heavy'
a	**at**	*at*	'person'
aa	**aat**	*aat*	'wounded'
ɔ	**θɔm**	*thâm*	'peck' (v)
ɔɔ	**θɔɔn**	*thâân*	'cook in stone oven'
o	**oṭ**	*otr*	'lobster'
oo	**tooṭ**	*tootr*	'marry' (v)
ɤ	**ɤṭ**	*ötr*	'pot'
ɤɤ	**lɤɤ**	*löö*	'banana leaf'
u	**u**	*u*	'yam'
uu	**uu**	*uu*	'fall' (v)

There are some notable limitations, largely associated with labial consonants, on the distributions of certain of these vowels. The low vowels /a/ and /æ/ are largely in complementary distribution. The low front vowel /æ/ is restricted to occurrence after the labial consonants /**b, m̥, m, p, f, ɥ,ɥ̊** and the vowel /y/. Ozanne-Rivierre notes that /æ/ occurs to the exclusion of the low central vowel /a/ after /ɥ/, /ɥ̊ and /y/, that is, after consonants and vowels with rounded lips and a high front tongue position. On the basis of a search of the dictionary, it seems also to be the case that /a/ occurs to the exclusion of /æ/ after /**bw, mw, m̥w, w**/, a fact that Ozanne-Rivierre does not comment on. However, after /**b, m̥, m, p, f**/ the vowels /æ/ and /a/ contrast in comparable environments, although no exact minimal pairs are available. Among illustrative pairs are **m̥an** 'oily' and **mæn** 'strength', **maaṭ** 'tern' and **mæṭ** 'ripe; weak', **fat** 'gift to chief', **fææṭ** 'pull alongside'. The subset of consonants /**b, m̥, m, p, f, ɥ,ɥ̊** and the vowel /y/ also condition a fronted [œ]-like variant of the lower mid back rounded vowel /ɔ/.

The mid front rounded vowel /ø/ occurs in only a few words — little over half a dozen are listed by Ozanne-Rivierre. In each case this vowel is followed by a velar consonant and in all except one of these words it is preceded by a labial consonant, usually **/m/**. The words, apart from those listed in table 1 are **ɲamøk** ‘mourning cries’, **eekemøk** ‘burial ground’, and **møxon** ‘shortness of breath’, all three of which might be etymologically related to **møk** ‘ill, dead’ and **omøk** (a species of edible fish), **beboŋ** ‘rotten’ and **ɲøøk** ‘dedicate’. The last is the only word which does not have a labial consonant before the vowel in addition to the following velar.

We will return to the question of what might account for some aspects of these distributional restrictions in a later section after the consonant inventory has been described.

2.2 Acoustic analysis

In order to characterize the vowels of Iaai acoustically two set of measurements were made. For the first, an average of three words containing each vowel quality and of each length were selected from the audio recordings of each of the five speakers. The selected words largely fall into two series; those with a labial preceding the vowel, and those with a coronal consonant following the vowel. Vowels in the environment of labial consonants were included since this is where the biggest distinction among vowels exists. By including labial environments for each vowel wherever possible we hoped to control for differential effects of surrounding consonants on the acoustic pattern of the vowels. However, the data are not fully balanced for consonant environment, and some caution should be exercised in interpretation of the results.

Waveforms were digitized and measurements taken using the Kay Elemetrics Computer Speech Laboratory. Measurements for the first three vowel formants were taken during the steady-state portion of the vowel, which often but not always corresponded with the area of greatest vowel amplitude. An FFT averaged over 51.2 msec, and an overlaid LPC averaged over 30 msec, both centered at the middle of the steady-state, were used to determine vowel formants, except in cases where the duration of any steady-state portion was less than 51.2 msec. In these few cases, a 25.6 msec FFT and 20 msec LPC window were used, to avoid including formant transition effects contributed by consonants. For both men and women an LPC filter order of 12 coefficients was usually optimal for identifying formants. Some problematic cases were examined with different settings.

Measurements were also made to examine the intrinsic pitch of vowels using a further time-aligned window containing a narrowband spectrogram. The frequency of the tenth harmonic, or the next lowest reliably identifiable harmonic, was recorded at the vowel steady-state, clear of the raising or lowering effects of adjoining consonants. This frequency was then divided by the harmonic number to obtain an accurate estimate of F0. Cases in which the auditory impression suggested that a marked intonation pattern had been used, such as a rising question contour, were excluded.

Measurements for vowel duration were taken using a simultaneously displayed, time-aligned waveform, energy curve and wideband spectrogram. The most reliable duration measurements are those of vowels between stops or clearly demarcated nasals or laterals but the data contained too few such instances to make a sufficient number of measurements. Consequently the duration measurements include a variety of contexts, including both open and closed syllables and vowels with and without a preceding consonant. However, a number of glide-vowel sequences were excluded because of the difficulty of segmenting them.

The second set of measurements were made from the audio track of the video-recordings. In this case frequencies of the first three formants were determined in a similar fashion to that outlined above using the Kay CSL. The purpose in this case was to correlate the formant measurements with lip position measures made from the video images. These results will be described following the discussion of the consonant articulations.

2.2.1 Vowel formants

The acoustic pattern of the vowels in an F1 vs F2 space for the female and male speakers respectively are shown in Figures 2 and 3. These plots show a vowel symbol for each individual token measured, with an ellipse drawn centered on the mean and having radii of 2 standard deviations along the first two principal components of the distribution. While the axes are marked in Hz they are scaled on the Bark scale. Only nine vowels are plotted since only a few tokens of the restricted vowel /ø/ in a single context are available. Long and short vowels are not distinguished in the figures since there are no consistent effects of length on the formant values. That is, long vowels do not consistently have a higher or lower F1 or F2, nor are they more peripheral or more central in the acoustic vowel space than their short counterparts. Analyses of variance for female and male speakers separately showed that /o/ has a significantly higher F1 (i.e. is perceptually lower) than /oː/ for the three female speakers but not for the men, /y/ had a significantly lower F2 than /yː/ for the men but not for the women, and /æ/ had a significantly lower F2 than /æː/ for the women, which was matched by a trend in the same direction among the men. Both groups of speakers also showed a trend for a higher F1 in /ɤ/ than in /ɤː/.

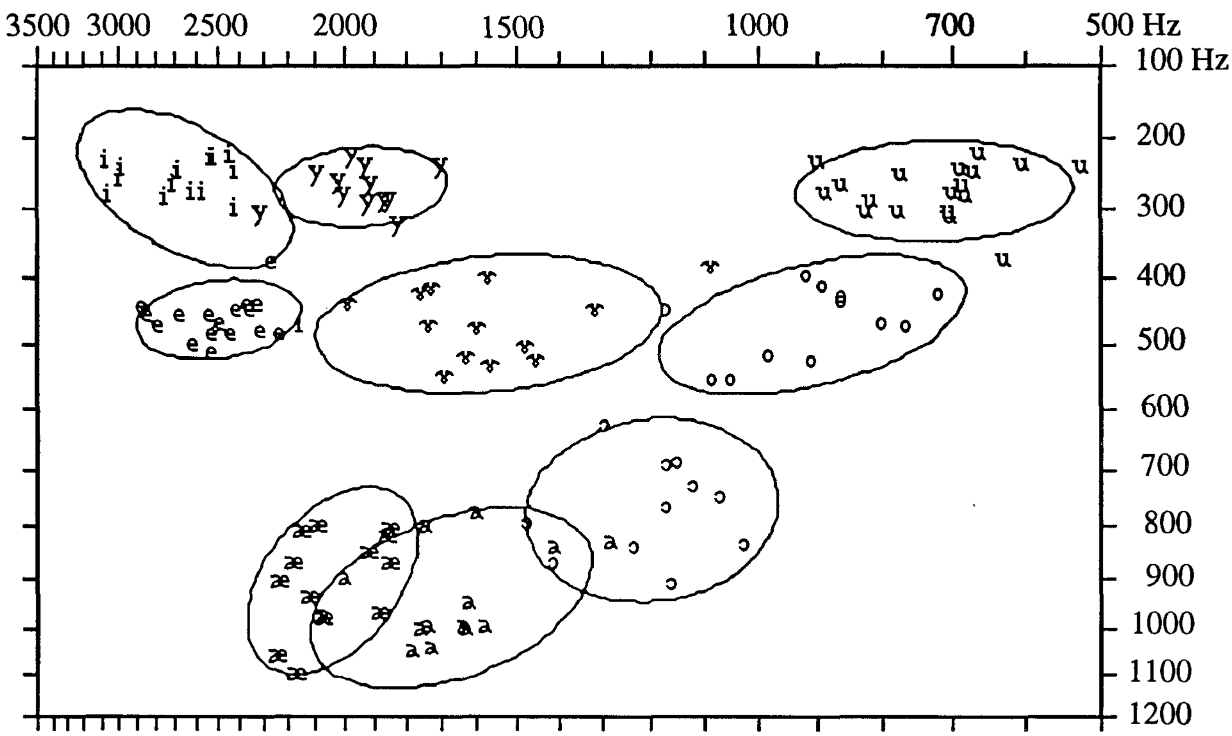


Figure 2: F1 vs F2 for female speakers, long and short vowels together.

Figure 2 shows that these nine vowels are well separated in the F1/F2 space for the women speakers. There is a very distinct demarcation between high, mid and low vowels in the F1 dimension, but the F2 values are distributed in a more gradient fashion. The ellipses for the three non-low front vowels /i, y, e/ are quite compact on the Bark scaling used. (Note that the ellipse plotted for /i/ would be considerably smaller and have a more horizontal orientation but for a single token which falls in the range of F1/F2 values for /e/. Auditorily this vowel token, in the word orthographically represented as *hwii*, sounds like a mid rather than a high vowel and it might well be that this word for this speaker indeed has an instance of the vowel /e/ rather than /i/.) In the F2 dimension, the mid back unrounded vowel /ɤ/ lies almost equidistant from the back rounded /o/ and the front unrounded /e/ vowels, whereas the front rounded /y/ is much closer to front unrounded /i/ than to back rounded /u/. The low vowels /a/ and /æ/ show considerable overlap, but recall that the contrast between these vowels is somewhat marginal.

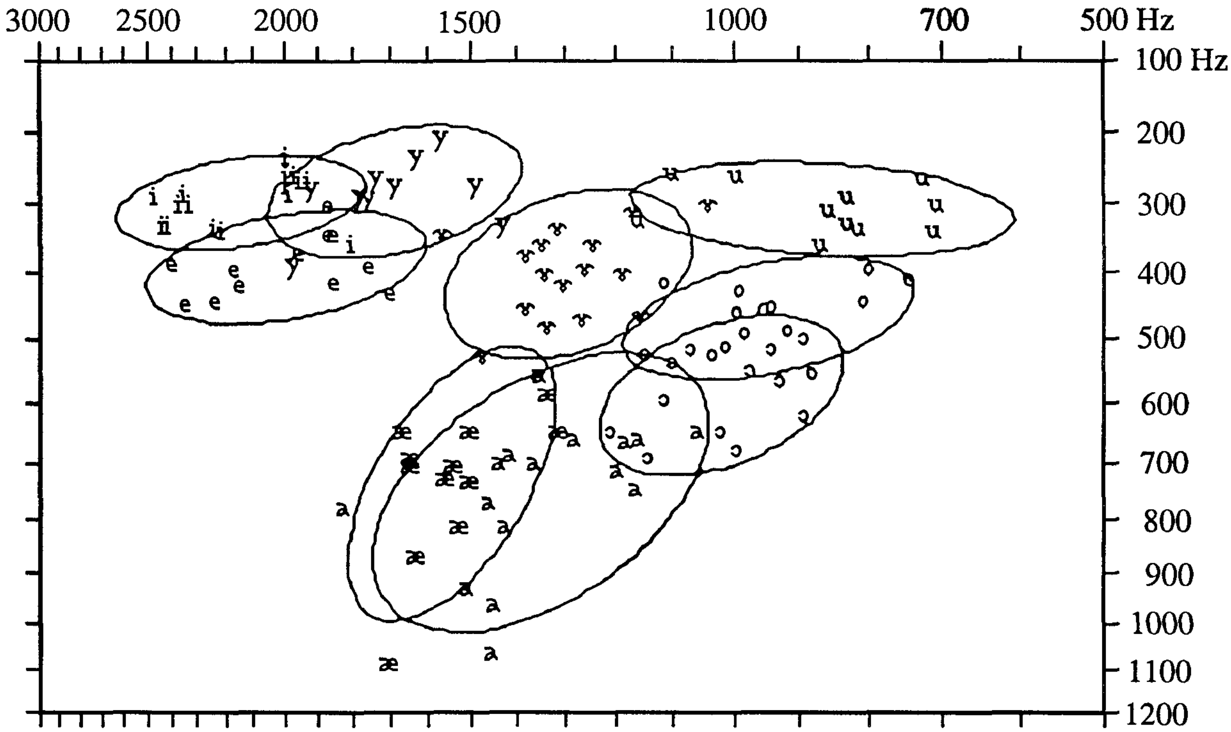


Figure 3. F1 vs F2 for male speakers, long and short vowels together.

The measurements made on the vowels of the two male speakers, shown in Figure 3, display a greater degree of overlap in their distributions. There are several factors which contribute to this effect. The two male speakers show some individual difference in their typical F2 for non-low front vowels /i, y, e/, most visible in the appearance of two clusters of tokens for /i/. One speaker has a generally higher F2 for vowels in this area than the other, but no comparable difference is observed between the speakers for vowels in other regions of the F1/F2 plane. For a different reason, /u/ shows a greater dispersion of values than for the women; this is because the short variants have more coarticulation with coronal consonants for these two speakers, resulting in perceptually fronted variants. Even allowing for these factors, it is still apparent that there is less separation, particularly in the F1 dimension, between the vowels of these male speakers. In particular /ɔ/ is less clearly a low vowel, and the distinction between /o/ and is /ɔ/ markedly reduced. However, the relative relationships between the three high vowels and the three mid vowels with respect to F2 are comparable to those seen for the female speakers.

2.2.2. *Intrinsic pitch of vowels*

Intrinsic pitch was examined for the vowels, to test whether Iaai conforms to the general tendency observed in the world's languages for vowel height to show a positive correlation with fundamental frequency, for example for high vowels to have higher F0s than low vowels when other things are equal. Vowels were grouped into three categories, high, mid and low, including long and short variants together but omitting mid front rounded /ø/ as in Figures 2 and 3 above. Mean values of F0 for different vowel heights are plotted in Figure 4 and listed in Table 2.

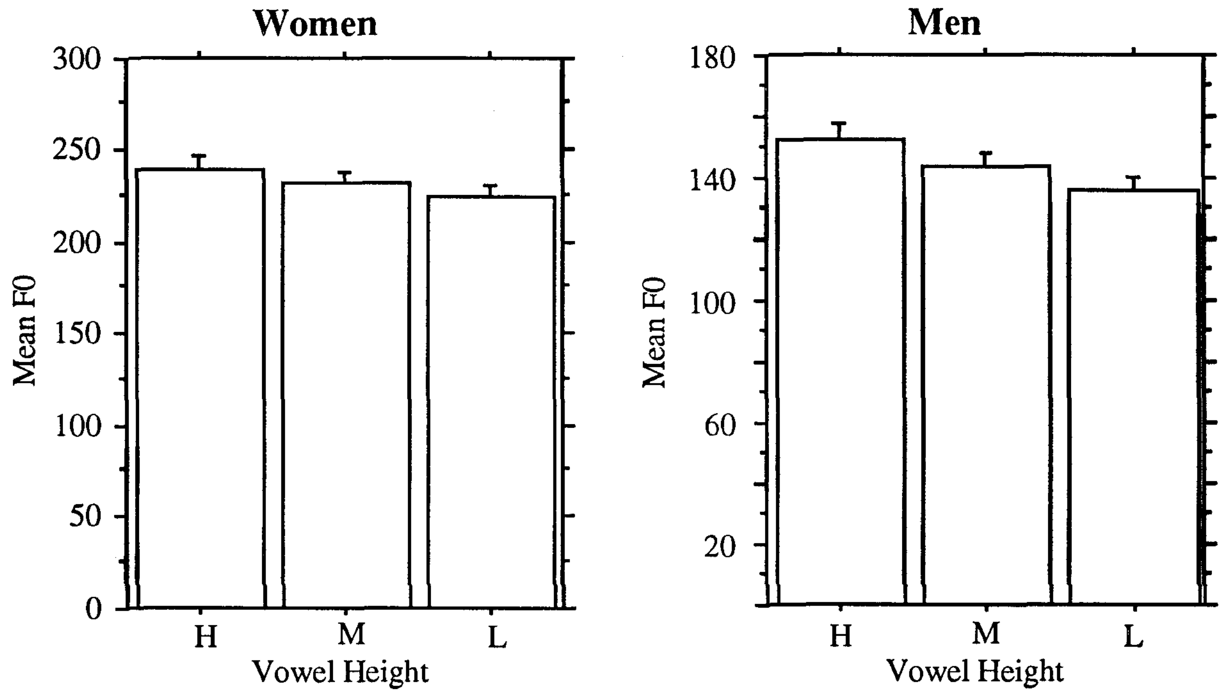


Fig 4. Intrinsic pitch of Iaai vowels according to vowel height categories for 3 female and 2 male speakers. Error bars show 95% confidence interval

Table 2. Vowel Height and F0 (values rounded to nearest integer)

	Women			Men		
	n	***F0***	***s.d.***	***n***	***F0***	***s.d.***
High	**43**	240	22	37	152	15
Mid	**41**	233	15	40	144	12
Low	**37**	224	19	37	136	13

Analysis of variance shows that there is a significant effect of vowel height category on the fundamental frequency. This effect is more apparent in the male speakers than in the females, but is significant for both; for the women $F(2, 118) = 6.304$, $p = .0025$, and for the men $F(2, 111) = 13.84$, $p < .0001$. Each pairwise comparison of adjacent heights is significant for the male speakers at better than the .05 level but only the comparison between high and low classes reaches significance for the female speakers. The magnitudes of these differences are comparable to those found in studies of relatively careful speech in other languages.

2.2.3 Vowel duration

An indication of the durational differences between long and short vowels can be obtained from the mean durations plotted in Figures 5 and 6. Since the environments in which the durations were measured include a variety of segmental and syllabic contexts which are not fully matched across the vowel categories, these data cannot provide reliable estimates of inherent durational differences. Nonetheless, it is striking that the long versions of **/y/** and **/ɤ/** are longer than most others; these are the two vowels in this set with values of lip-rounding opposite to those normally found cross-linguistically. The very large variance in the duration of **/u/** for male speakers suggests that some words expected to have a lexical long high back vowel may be pronounced with a short vowel.

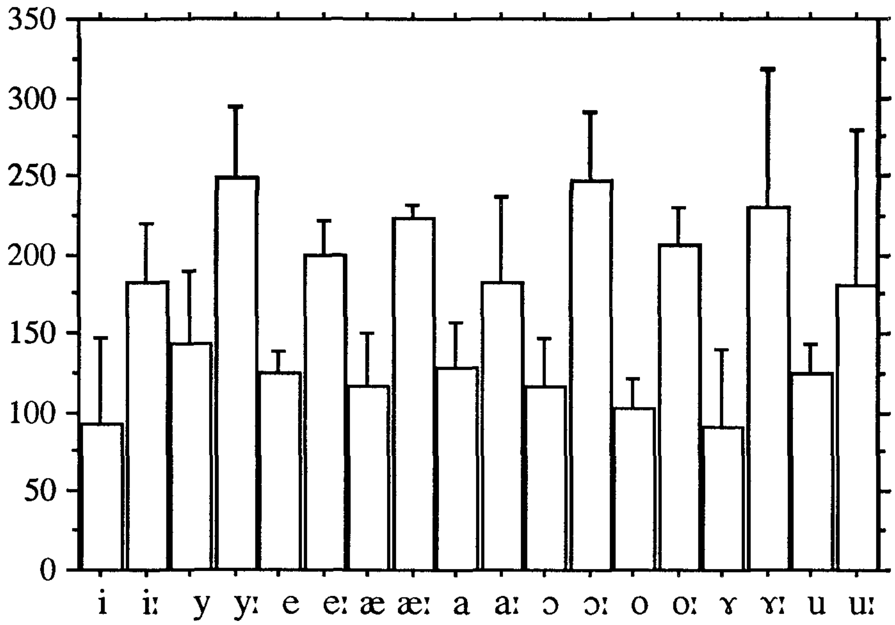


Figure 5. Mean durations in ms of nine long and short vowels for the three female speakers. Error bars show 95% confidence level.

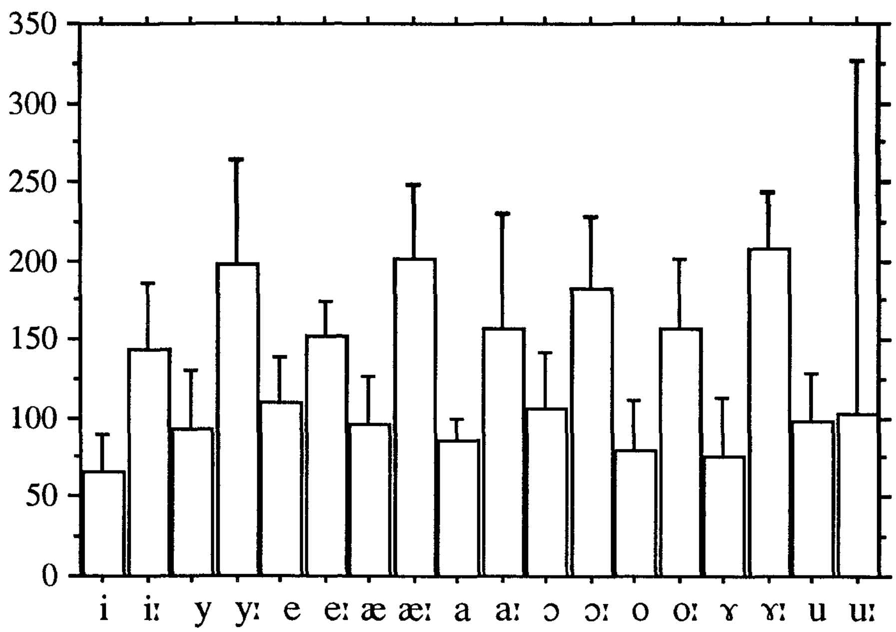


Figure 6. Mean durations in ms of nine long and short vowels for the two male speakers. Error bars show 95% confidence level.

Aggregating the durations of the long and short vowel classes does provide a good estimate of the overall difference in their length. Long vowels are about twice the duration of short. The results are shown separately for men and women in Table 3. Because of the unreliable estimate of the duration of /u/ for the males, only eight vowels are included in this comparison for the male speakers.

Table 3. Mean durations in ms of long and short vowels for female and male speakers.

	Short	Long	Difference	Ratio
Women (9 vowels)	116.1	211.1	95.0	1.85
Men (8 vowels)	89.4	175.1	85.6	2.0

Lip position

A second set of vowel formant measurements was made on words designed to illustrate the range of lip positions for the 10 vowels, which were videotaped. Data for three of the speakers have been analyzed so far. The words used and the formant values measured for these three speakers are shown in Table 4.

		F1			***F2***			***F3***		
Word	*Vowel*	*Spkr H*	*Spkr B*	*Spkr J*	*Spkr H*	*Spkr B*	*Spkr J*	*Spkr H*	*Spkr B*	*Spkr J*
trii	i	253	289	256	2866	2492	2563	3328	3294	3102
ûû	y	265	261	268	1799	1895	1752	2946	2395	2607
eet	e	462	444	494	2018	2466	2450	3483	3126	3001
møøk	ø	386	492	511	1382	1588	1525	2264	2361	2739
vëët	æ	741	845	743	1479	1905	2247	2358	2939	2947
aat	a	708	996	1056	1140	1556	1554	2281	2519	2883
thâân	ɔ	640	893	691	1135	1423	1106	2329	2635	2955
otr	o	458	491	489	1079	1491	958	2230	2648	2504
ötr	ɤ	468	486	504	1425	1468	1615	2176	2670	3041
trutru	u	328	281	346	829	1399	812	1347	2423	3180

The lip positions are illustrated in the panels of Figures 7 and 8 for two of the speakers studied. These figures were produced by viewing the time-coded videotape frame-by-frame and determining the frame in which the lips reached the culminating position of the gesture for the particular vowel. This frame was then digitized and a number of distances between lip points were measured in the transverse plane. These distances were a) Lip Height — distance between the lower surface of the upper lip and the upper surface of the lower lip at the center; b) Lip Width — the vertical distance between the point of contact of the lips at the left and the point of contact on the right; c) Lip Corner distance — the horizontal distance between the corners of the lip, i.e. the lateral margins of the vermilion border; d) Side Contact distance — the horizontal distance over which the lips are in contact between the corners and the aperture. This measure was simply calculated by subtracting b from c for each measurment. Also e) Lip Area — the area of the visible opening enclosed by the lips was measured. Since these data are measured from a frontal view, there is no quantitative data on lip protrusion. However, some idea of the degree of protrusion associated with the various rounded vowels can be obtained from inspecting the video frames. Some useful information on the position of the tongue can also be obtained for those vowels with a more open jaw position.

/i/ ṭii “tea”

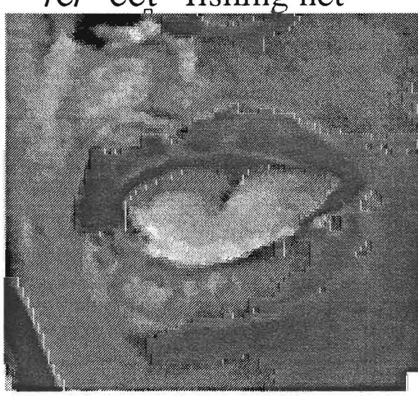
/y/ yy “dispute”

/uu/ kaluu “fall down”

/e/ eet̪ “fishing net”

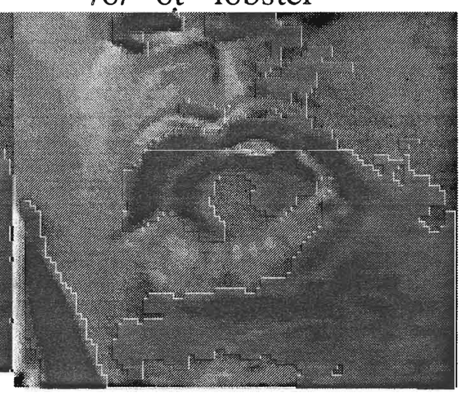
/ø/ møøk “close eyes”

/o/ oṭ “lobster”

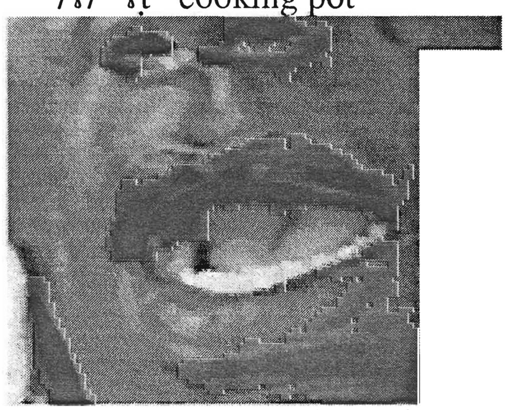


/æ/ mææk “heavy”

/ɤ/ ɤṭ “cooking pot”



/ɔ/ t̪ɔɔn̪ “oven”



/a/ aat̪ “wounded person”

Figure 7. Lip positions for ten Iaai vowels: male speaker H.

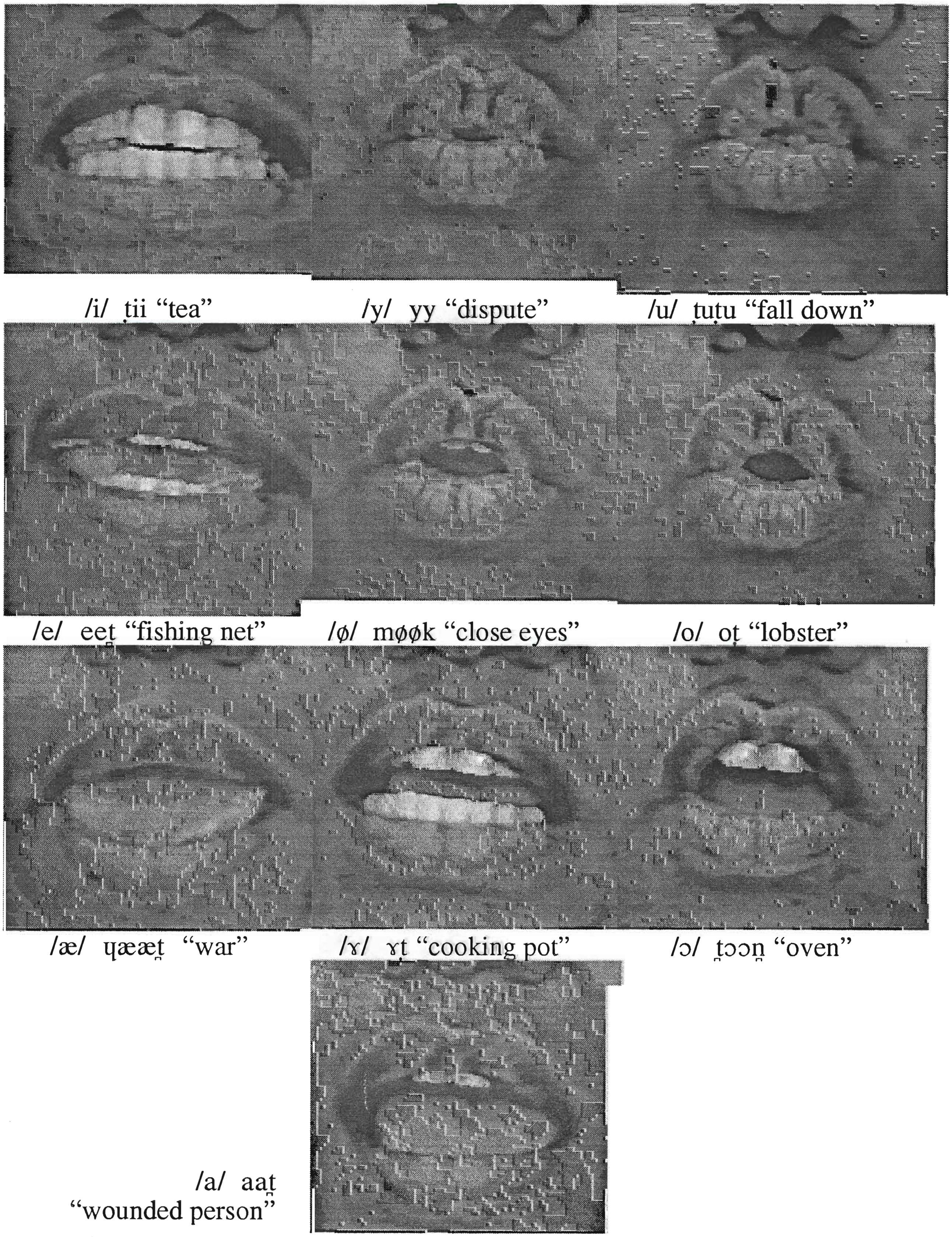


Figure 8 Lip positions for ten Iaai vowels: female speaker J.

Lip measurement results for three speakers, one male and two female, are shown in Table 5. In order to normalize across the different speakers, all measurments were converted to standardized scores (with a within-speaker mean of zero and standard deviation of 1) before means were calculated and statistical tests performed. This transformation of the data, to a good approximation, sets the value of a neutral lip position to zero. The values in Table 5 are the means of the within-speaker standardized scores. From this one can see, for example, that the area of the aperture between the lips in pronouncing /ɤ/ is very close to the mean lip area, /y/ and /u/ have the smallest area, indicated by the large negative number, and /a/ has the largest area.

Table 5. Mean normalized lip measurement values for the ten Iaai vowels, from 3 speakers.

Word	*Vowel*	*Lip Height*	*Lip Width*	*Lip Corners*	*Lip Sides*	*Lip Area*
trii	i	0.53	0.70	0.89	0.31	0.69
û	y	-1.41	-1.15	-0.63	0.70	-1.14
eet	e	0.19	1.26	1.27	-0.08	0.51
møøk	ø	-0.45	-0.75	-1.10	0.12	-0.78
vëët	æ	1.22	0.87	0.79	-0.62	1.12
aat	a	1.38	1.03	0.45	-1.18	1.51
thâân	ɔ	0.61	-0.05	-0.61	-0.71	0.14
otr	o	-0.75	-1.01	-0.84	0.55	-0.92
ötr	ɤ	-0.15	0.40	0.70	0.12	-0.01
trutru or kaluu	u	-1.17	-1.29	-0.92	0.79	-1.12

Another view of the lip measurement data is shown in Table 6, which ranks the vowels in terms of each of the measures, with the vowel having the lowest value appearing at the top of the column and the vowel with the lowest measure at the bottom.

Table 6. Rank order of the vowels on each of the normalized lip measurement. Vowels are ordered from smallest to greatest value.

Rank	*Lip Height*	*Lip Width*	*Lip Corners*	*Lip Sides*	*Lip Area*
1	y	u	ø	a	y
2	u	y	u	ɔ	u
3	o	o	o	æ	o
4	ø	ø	y	e	ø
5	ɤ	ɔ	ɔ	ø	ɤ
6	e	ɤ	a	ɤ	ɔ
7	i	i	ɤ	i	e
8	ɔ	æ	æ	o	i
9	æ	a	i	y	æ
10	a	e	e	u	a

Examining Tables 5 and 6 we see the following generalizations. The vertical distance between the lips (Lip Height) is least for rounded non-low vowels, and greatest for unrounded low vowels. Although a three-way classification of vowels by height (high, mid, low) predicts a significant amount of the variance in the lip height, the four mid vowels show quite substantial differences with rounded mid vowels having higher lip position than unrounded ones. Most strikingly, the unrounded high vowel /i/ is more open than /e/ at the lips. The difference between /i/ and /e/ is made by raising the jaw independently of the lips, as can be seen from the position of the teeth in the video frames. The overall pattern is broadly similar for the horizontal measure of the lip opening (Lip Width), with the vowels receiving similar rank orders, except that /e/ is wider than /i/, and indeed any other vowel, and /ɔ/ has substantially less width than the other low vowels. As Table 7 shows, the correlation coefficient between Lip Height and Width is .82, but whereas Lip Height does not divide rounded from unrounded vowels Lip Width does. The distance between the outside corners of the lips (Lip Corners), however, is the best of our measures at effecting such a separation. All five rounded vowels have negative values of at least -0.61, and all the unrounded vowels have positive values of 0.45 or greater. Moreover, the Lip Corner distance relates well only to the classification of vowels by rounding and not to classification by height as well. It is likely that this measure is the best index of lip protrusion when measurements are only taken in a flat plane, transverse to the body. Drawing the corners of the lips closer together is a consequence of protruding them.

The measurement of contact at the sides of the lips (Lip Sides) was added following the suggestion of Goldstein (1991:98) that "rounded vowels must be produced with contact along the sides". Although rounded high vowels have the greatest amount of side contact this measure does not serve to separate rounded and unrounded vowels in general. This measure does not separate the Iaai vowels into rounded and unrounded classes, and little of the variance in the Lip Sides measure can be predicted from the classification of vowels by rounding, $F(1, 29) = 2.87$, $p = .1011$) (nor by height or backness either).

Naturally enough, both Lip Height and Width measurements are very highly correlated with Lip Area (.95 and .92 respectively). Since /y/ and /u/ have the smallest height and width, they have the smallest area of lip opening, having almost identical mean normalized values. In this respect Iaai differs from a number of other languages with a similar pair of vowels, such as French, Swedish, Cantonese and Finnish, where the lip area for /y/ is considerably larger than that for /u/, and is comparable to that for /i/ (Linker 1982). Iaai also has a larger than expected area for /i/. The lip area measure broadly separates rounded from unrounded vowels with vowel height ranking vowels within those groups. The salient exception occurs with /ɔ/ and /ɤ/. These two vowels have similar area, but only because they have different degrees of Lip Height and Width that balance each other out. Not unexpectedly, none of the lip measures predict the backness of vowels.

Table 7. Correlation matrix between the normalized lip measures and also the within-speaker normalized formant values of the first three formants.

	L Area	*L Height*	*L Width*	*L Corners*	*L Sides*	*F1*	*F2*
L Height	.95						
L Width	.92	.82					
L Corners	.68	.51	.84				
L Sides	-.5	-.58	-.44	-.1			
F1	.64	.74	.5	.19	-.59		
F2	.39	.26	.54	.62	.03	-.27	
F3	.43	.39	.53	.59	-.15	-.11	.64

The correlation analysis shown in Table 7 indicates that the normalized F1 correlates most highly with Lip Height. Standard acoustic theory predicts a relationship between vowel height and F1; the more open a vowel is the higher the F1 frequency. F2 and F3 both correlate most highly with the Lip Corner measure. This measure is associated with rounding and is hypothesized to be related to lip protrusion; low values indicate protruded lips. Since increasing the effective vocal tract by protruding the lips lowers the frequency of these higher formants, the correlation is presumably attributable to this component of their variation. Since these formants are also very sensitive to the location of constrictions inside the oral cavity, the strength of the correlations with this lip measure are quite striking.

A few other observations can be made on the vowel articulations visible in Figures 7 and 8 concerning tongue and jaw positions. A very front tongue position, with the tongue tip appearing pressed against the lower teeth, is visible in both /e/ and in /æ/. The tongue is also quite visible in /a/, indicating that this vowel is central rather than back. It is not possible to resolve whether the tongue is central or back in /ɤ/ from these pictures, but the probability seems greater that it is back. The position of the teeth in /ɤ/ show that the jaw tends to be higher in this vowel than in the other mid vowels.

3. Consonants

Table 8 shows the consonants that we provisionally accept for Iaai. The set of consonants is the same as recognized by Ozanne-Rivierre, although we categorize a few of them in slightly diffent terms. In particular, the segments that we transcribe as /ɥ̊ ɥ/ are here categorized as approximants rather than as fricatives. As Ozanne-Riviere noted, these segments are indeed somewhat intermediate between the these two traditional categories and might be described as either. Some frication is sometimes audible but it is weak in amplitude (see Figures 10 and 12 below). We however also choose to emphasize that there seem to be two articulatory strictures involved in the production of this pair of consonants. In addition to the labial constriction - the location at which some frication can often be observed, there is also a raising of the front of the tongue. Hence they are transcribed with symbols that represent labial-palatal approximants; another way to represent this aspect of their production in the transcription would be to use the complex symbols /ϕ^j, β^j/. This palatal articulation is surely connected to the distributional constraints affecting these labial consonants which were discussed in the presentation of the vowel system. It is possible that all the "plain" labials in front or fronted vowel environments should be considered to be palatalized, and opposed to labials with audible rounding or in back vowel environments by a contrast of secondary articulations. We do not feel that we have enough evidence at the present time to address either the phonetic or phonological questions raised by the consonant/vowel interdependencies in Iaai, but will provide a brief comment below.

Table 8. Symbols for consonants in Iaai.

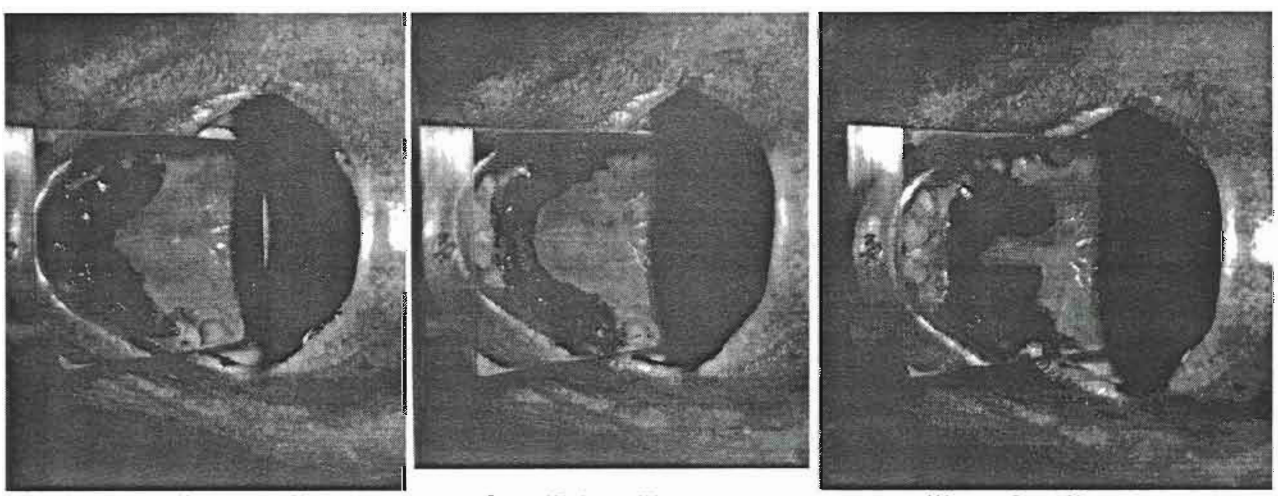
	Labial	Labialized Labial	Dental	Alveolar	Retroflex	Pre-palatal	Velar
Plosive	p b	b^w	t̪ d̪		ṭ ḍ	c ɟ	k g
Nasal	m̥ m	m̥^{w} m^w	n̪̊ n̪		ṇ̊ ṇ	ɲ̊ ɲ	ŋ̊ ŋ
Fricative	f		θ ð	s		ʃ	x
Central Approx.	ɥ̊ ɥ	w̥ w					h
Lateral Approx.				l̥ l			
Flap					ɾ̣		

Note: /ɾ̣/ appears only intervocalically

Unlike the majority of New Caledonian languages, the voiced stops of Iaai are not accompanied by any prenasalization. Two other marked characteristics of the consonant system are the contrast of several places of articulation within the coronal region, and the occurrence of a large variety of voiceless sonorants. We will focus our discussion of the Iaai consonants on these areas.

3.1 Coronal stops

Palatograms of the three coronal series of stops were made of four speakers, using the technique described in Ladefoged (1994). Linguagrams were also obtained from one male speaker. Illustrative palatograms of the difference in coronal places of articulation for this speaker are shown in Figure 9. The figure shows views in a mirror placed in the mouth to show the upper surface; blackened areas indicate where the tongue made contact during the articulation. The dental in /at̪ / has a relatively large contact area entirely covering the upper front teeth and the alveolar ridge. The linguagram confirms that the contact is laminal, or more precisely apico-laminal (Dart 1991), and includes a considerable extension of the contact laterally back toward the molar teeth on both sides. The 'retroflex' stop in /ḍa/ involves a much narrower band of contact which falls entirely behind the teeth toward the back part of the alveolar region. The linguagram shows this contact is strictly apical, with only the narrow anterior-facing surface of the tongue tip and a small area on the upper surface of the tip involved. There is markedly less lateral contact behind the front closure than for the dental, indicating that the center of the tongue is lower in this articulation. For the pre-palatal stop in /ca/ there is a broad contact area from the back of the alveolar ridge to a point about at the location of the second molars. The linguagram shows that the contact is strictly laminal, with no contact on the frontmost part of the tongue (about the first 1 cm).



at̪ *at* "person" ḍa *dra* "blood" ca *ca* "leg, foot"

Figure 9. Palatograms illustrating the three coronal stop places of Iaai.

The palatograms obtained from the other speakers, who are of a slightly younger generation, tended to show a less clear articulatory distinction in the location of the contacts on the palate and in the tongue contact area between these coronal places of articulation. However, all speakers observed maintain a three-way acoustic distinction. The dental place is characterized by a lack of frication of the release, and if voiceless and prevocalic, by a very short voice onset time (VOT). Both the palatal and retroflex places are characterized by a noisy and sustained release. The noise of the release seems to be concentrated in the area of the third formant resonance for the palatal and the fourth formant for the retroflex. These characteristics are illustrated in the three waveforms and spectrograms in Figure 10, from the same male speaker who provided the palatograms in Figure 9..

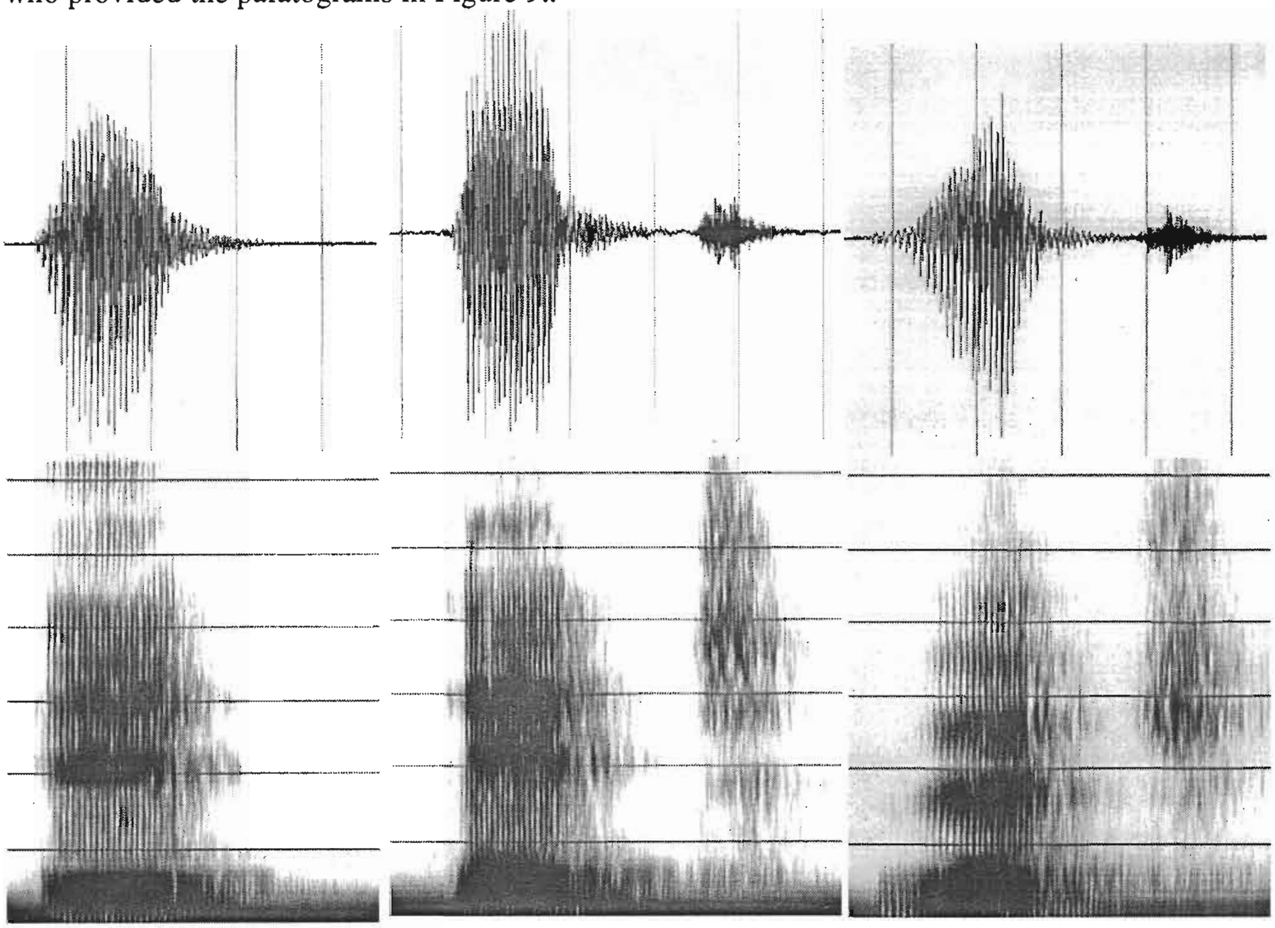


Figure 10. Waveforms and spectrograms of final voiceless dental, retroflex and palatal stops in /eet̪/ “fishing net”, /t̪eeṭ/ “excrement” and /ɥœœc/ “light (a fire)”, spoken by a male speaker. Calibration lines are at 100 ms intervals on the waveforms and at 1000 Hz intervals in the spectrograms.

The very weak release of the dental can be seen both in the final consonant of /eet̪/ “fishing net”and in the initial of /t̪eeṭ/ “excrement”. It contrasts very obviously with the energetic noisy release of the other two voiceless coronal stops in final position. The duration of this noise portion tends to be longer in the palatal than in the retroflex. In two words with matched vowel environments, the five speakers had a mean noise duration of 157 ms in /l̥it̪/ “(be) black” versus 204 ms in /ic/ “drink”. In onset position a mean VOT of only 13 ms was measured in /taŋ/ “basket” versus 75 ms in /caan/ “foot (3sg possessed)”. Additional examples of final /t̪/ and /ṭ/ are shown in Figure 12. In a number of languages, laminal dental stops are accompanied by a long noisy release, whereas apical alveolar or retroflex stops have short release. This appears to be typical for Australian languages (see Anderson and Maddieson 1994, this volume) and for Dravidian languages (e.g. Dart 1991), so that it has been proposed as a universal pattern (Stevens, Keyser and Kawasaki 1986). However, an opposite distribution has been observed in several African languages (e.g. Maddieson, Spajić, Sands and Ladefoged 1993) in addition to Iaai.

3.2 Voiced and voiceless sonorants

Nasals and lateral and central approximants in Iaai demonstrate a voicing contrast. A minimal pair illustrating the contrast between voiced and voiceless lateral approximants in the words /lɤŋ/ "night" and /l̥ɤŋ/ "(be) black" is shown in Figure 11. Note that the major resonance above 3000 Hz in the voiced lateral is matched by a corresponding resonance in the voiceless excitation at the onset of /l̥ɤŋ/. This voiceless portion is followed by about 80 ms of voiced lateral before the vowel. Although quantitative studies are incomplete on this point, the strong impression is that a relatively long transitional voiced portion is typical for the voiceless approximants in Iaai. This may be a residue of the origin of these devoiced segments from the coalescence of a sequence of /h/ and a sonorant. Although the voiceless continuants appear in many non-derived forms, a significant number of pairs of words with voiced and voiceless sonorant initials are derivationally related to each other. As Ozanne-Rivierre points out, there is also a parallel alternation between words with initial vowels and initial /h/. Some examples of these two types are listed in Table 9.

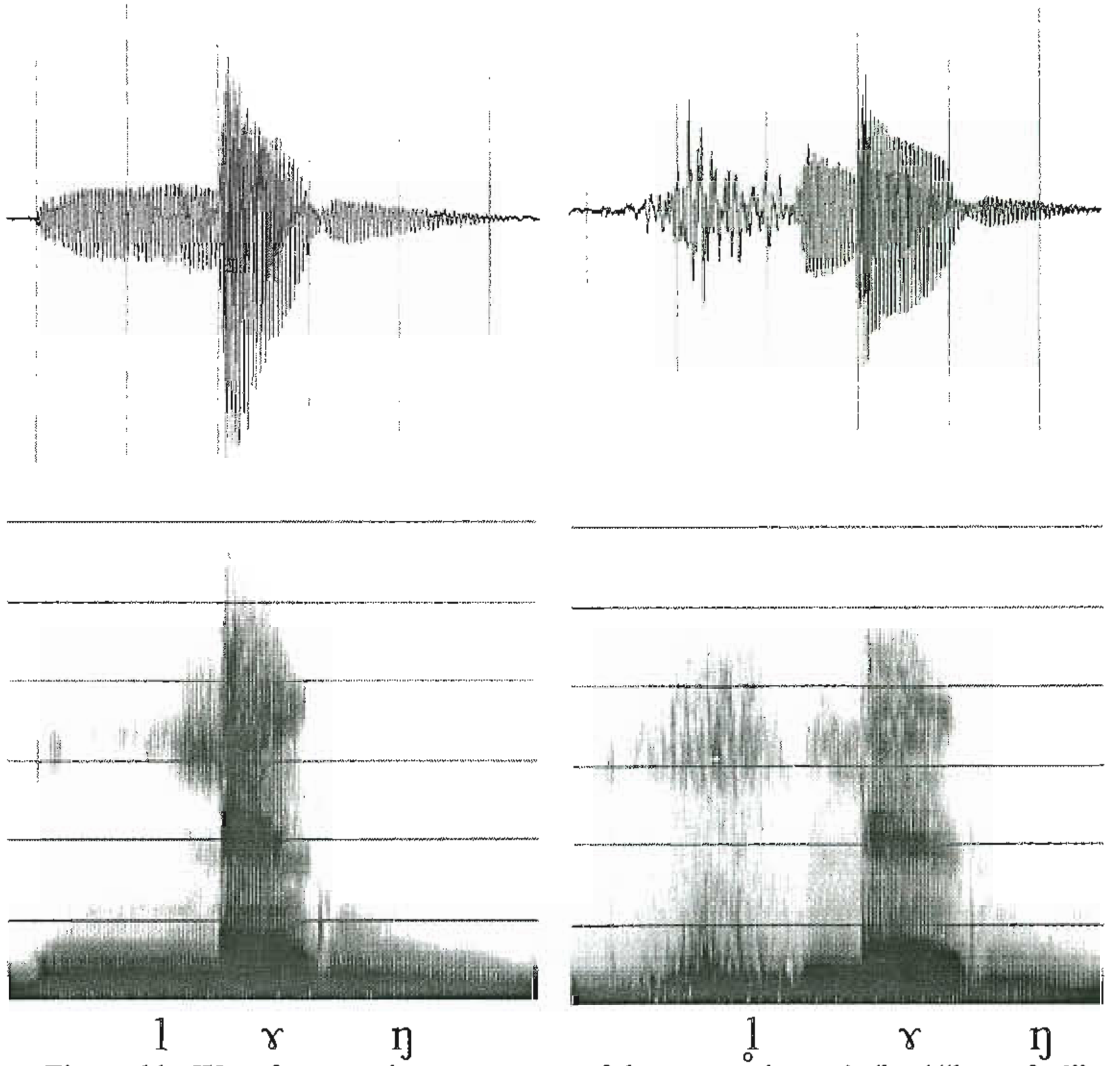


Figure 11. Waveforms and spectrograms of the contrasting pair /lɤŋ/ "hear, feel" and /l̥ɤŋ/ "close, stop up" spoken by a female speaker.

Table 9. Some examples of alternation of voiced and voiceless sonorants and initial vowel and /h/ from Ozanne-Rivierre (1976, 1984).

weɲe	"name (vb, determ.)"	w̥eɲii	"name (vb, indet.)
wiɤɤ	"turn, change" (+ obj)	w̥iɤɤ	"turn, change" (incorp obj)
naŋ	"brandish"	ŋ̊ɤŋ	"brandish" (incorp obj)
litr	"night"	l̥iṭ	"(be) black"
yca	"choose, select"	hyce	"choose, select" (incorp obj)
an	"eat"	han	"eat" (incorp obj)

3.3 Labial consonants

Samples of some of the labial consonants are shown in Figure 12 (see also /ɥœœc/ "light (a fire)" in Figure 10. Note that there are quite extensive and slow second formant transitions during the vowels in the first two words, falling in /møk/ and rising in /mwɤɤṭ/. Since in a labial nasal the tongue is free to anticipate the articulatory position of the following vowel and the releasing movement of the lips is rapid, these transitions are unlikely simply to be due to the effect of the labial articulation. In the case of /mwɤɤṭ/ a secondary articulation of labialization (actually labio-velarization) is recognized in the transcription, involving an /u/-like accompaniment to the nasal and producing a quasi-diphthongal vowel portion in the word. In /møk/ the onset F2 is considerably higher than in /mwɤɤṭ/ and continues a resonance that is visible in the nasal at about 1500 Hz. The comparable resonance in /mwɤɤṭ/ is only at about 1000 Hz. /ɥææt/ shows a similar onset F2 frequency. The fall in F2 over the whole of the vowel in /møk/ cannot be satisfactorily attributed to the effect of the final velar. Although velars in rounded vowel environments often have a low F2 close to that of the vowel, there is no reason for the F2 to have been so much higher at the onset of the vowel unless the labial nasal has some property which is responsible for it. Both the timing and the frequency aspects of this pattern can be explained by the assumption that there is a secondary palatal articulation accompanying the onset nasal. Iaai might thus have a system similat to that found in some Micronesian languages, where there are no truly "plain" labials, but every labial consonant has a secondary articulation attached to it. The illusion of occurrence of plain labials arises when the secondary articulation matches closely with the articulatory and acoustic attributes of the adjoining vowel.

4. Concluding remarks

This paper has provided some observations on the phonetics of the vowels and consonants of the Iaai language which make clear that this language has some properties of more than ordinary interest. We also feel that this examination has provided some ideas for further analysis of some of the phonological characteristics of the Iaai system. In both of these areas we are very aware that there is much more to be done.

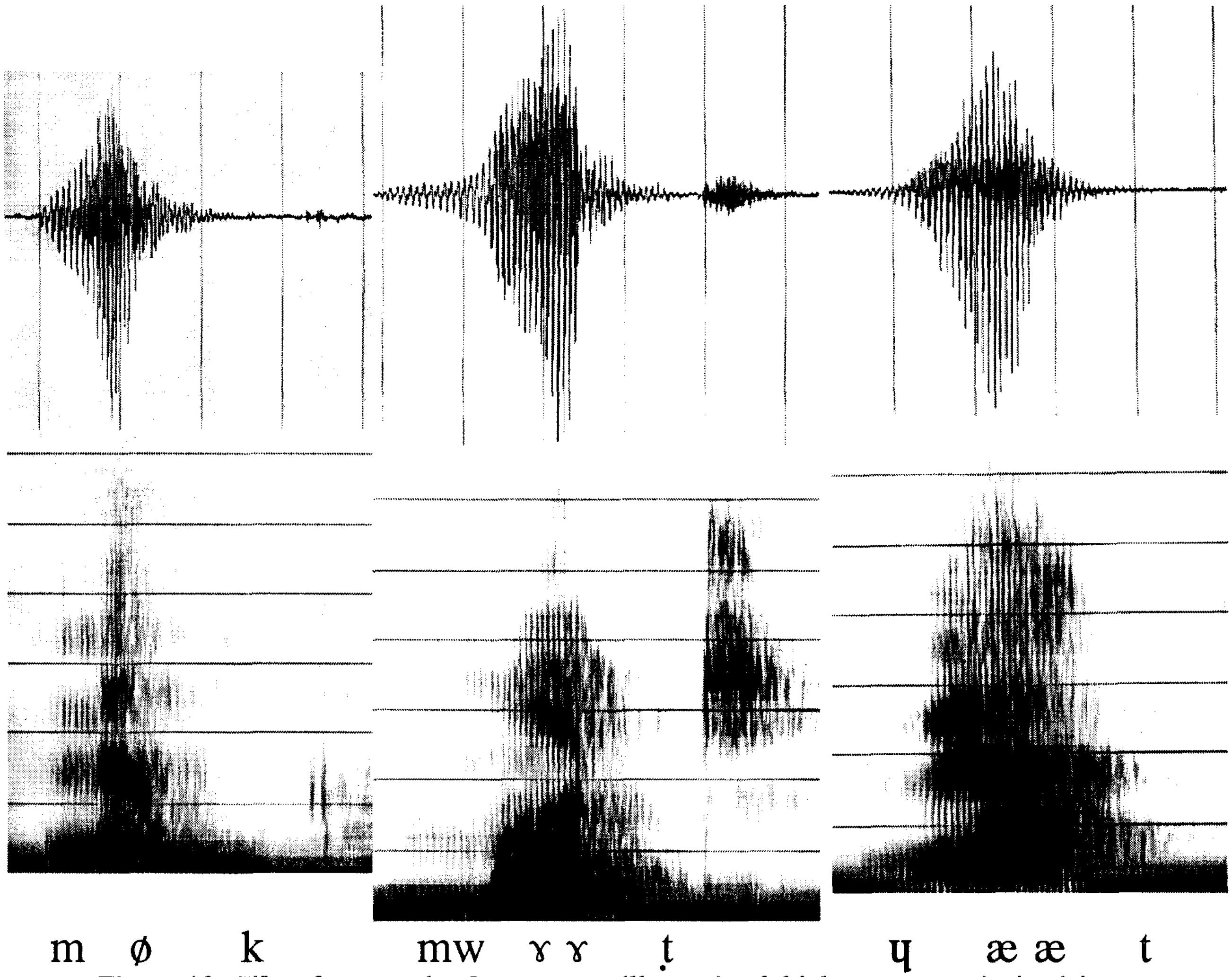


Figure 12. Waveforms and sp[ectrograms illustrating labial consonants in /møk/ “dead, ill”, /mwɤɤṭ/ “live” and /ɥææt̪/ “light (a fire)”, spoken by a male speaker.

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