A SPECTROGRAPHIC STUDY OF ALLOPHONIC VARIATION AND VOWEL REDUCTION IN WEST GREENLANDIC ESKIMO*

Sidney Wood

SUMMARY

West Greenlandic Eskimo vowel spectra have been investigated in carefully pronounced words and in continuous speech, and spectral differences observed between the two situations. Spectra have been compared in two consonantal environments - pharyngeal (uvular) and non-pharyngeal. In order to reconstruct vowel articulations, reference has been made to the three-parameter model of vowel production. It is inferred from this that stressed vowels in non-pharyngeal environments would require pharyngeal to velar constrictions for /a/, velar for /u/ and palatal for /i/. For the allophones in pharyngeal environments, the necessary constrictions would be low-pharyngeal for /a/ and uvular for /i/ and /u/. Fully reduced vowels in non-pharyngeal environments would have uvular to velar articulations with fairly narrow degrees of constriction, and in pharyngeal environments low-pharyngeal to uvular articulations with a narrower degree of constriction. In both cases, the mouth-opening would have been less than moderate. The regression of vowel spectra from target to reduced is apparently mainly associated with a narrowing of the range of mouth-openings, while there can be some centralization of constriction locations towards the velar region provided the degree of constriction remains small. An approximation to the uniform tube does not seem to have been a likely configuration for this informant's weak vowels.

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1. INTRODUCTION

1.1 West Greenlandic Eskimo

1.1.1 W.G. Eskimo has three vowel phonemes, /a, i, u/, but a fourth abstract morpho-phoneme /ə/ can be posited to explain certain morphological alternations. This abstract unit is expressed either as [i] or [a], merging with the reflexes of /i/ and /a/. This investigation is based on the three-phoneme solution, but it will not have biased the results to ignore /ə/ since its reflexes have no separate identity in speech. W.G. has four contrasting articulations for stops, from front to back /p, t, k, q/. There has been some dispute about the contrasting articulations of the back pair – velar/uvular or palatal/velar. There is a back fricative /ʁ/ corresponding to /q/. The informant's pronunciation of /q, ʁ/ sounded very retracted, probably below the velum, and will be referred to as "pharyngeal". The question of whether it was at or below the uvula will be left open. A short description of Eskimo is given by Hill (1958: Appendix A).

1.1.2 When vowels precede [q] or [ʁ], the body of the tongue is retracted in anticipation of the consonant articulation. For /a/ and /u/, this results in cardinal 5 [ɑ] and cardinal 6 or 7 [ɔ] – [o] respectively, while palatal /i/ is said to be uvularized and sounds like a retracted cardinal 3, [ɛ̈], or the plain back cardinal 14 or 15, [ʌ] – [ɤ]. The exact description of this allophone has been a matter of controversy. It has been transcribed by Thalbitzer as [ɜ] and by Uldall and Lawrenson as [ᵊ] (Lawrenson 1934).

1.1.3 Investigation of the spectra of these vowels may to some extent clarify the problem of the nature of the vowel allophones before [q] and [ʁ].

1.2 Transcription

The vowel allophones will be denoted as follows:

position	/a/	/i/	/u/
In pharyngeal environments (before [q] or [ʁ])	ɑ	ɨ	o
In non-pharynageal environments (before consonants with any other place of articulation than [q] or [ʁ])	a	i	u

1.3 The Investigation

The investigation is devoted to the following topics:

(a) § 4.1 deals with allophonic variation. The spectral and inferred articulatory differences between vowels in the pharyngeal and non-pharyngeal environments are considered separately for three different situations: (i) stressed vowels in carefully pronounced words at § 4.1.1, (ii) stressed vowels in contiuous speech at § 4.1.2, (iii) weak vowels in continuous speech at § 4.1.3. Articulations are inferred from the three-parameter model of vowel production (cf. § 2.5).

(b) § 4.2 deals with vowel reduction. The progressive centralization of spectra from stressed to weak vowels is considered separately for the two major sets of allophones. Inferred articulations for the spectra of fully reduced vowels are given in § 4.2.2. The degree of correlation between the first two formants of different renderings of a phoneme is examined in § 4.2.3. In particular, the articulatory centralization associated with the spectral centralization along the regression of the formant frequencies for each phoneme is discussed in § 4.2.3 (c, d).

(c) § 4.3 brings together the inferred articulations, and a rule is proposed to generate [ɑ], [ɨ] and [o] from /a/, /i/ and /u/ respectively in pharyngeal environments. The place of articulation of the pharyngeal consonants, hitherto an open question in this paper is also discussed.

2. PROCEDURE

2.1 Informant and Recordings

The informant is an adult male native speaker of the Holsteinsborg dialect. He has recorded a set of carefully pronounced isolated words with stressed vowels in pharyngeal and non-pharyngeal environments, and a passage of continuous speech (a few pages from the novel "Singnagtugaq" by Mathias Storch). The recordings were made in the phonetics laboratory of Copenhagen University. The analysis was carried out at Lund with a Voiceprint spectrum analyser.

2.2 Speech material

2.2.1 Single word utterances

The carefully pronounced words contained 30 stressed vowels, as follows:

	/a/	/i/	/u/
non-pharyngeal environments	7	6	5
pharyngeal environments	4	4	3

2.2.2 Continuous speech

(a) Analysis of the continuous speech was broken off after 262 phonetic syllables. This gave 250 syllables containing vowel spectra, while the remaining 12 were rejected because their nuclei were carried by consonants, for example:

...pisinialeramik...

[pəʒ-n̥-nje-ˈlɔʁ-əm-ək]

"as they wanted themselves to do business"

cf. spectrogram at Fig. 1 a.

The informant's reading was very informal and the speaking rate rather fast - an average of 375 syllables per minute. The passage of continuous speech is consequently characterized by considerable contraction of syllables. For example:

(i) ...kînáinitdlo nalunángileq ingmingnut...

[kɪ-ˈnaj-nəl̥-l̥o-ə-ˌlaŋ-ə-ˈlɪm-mɪn-ət]

"and from their faces/was obvious/to themselves"

(ii) ...qimáinardlugit uvagut ingmíkut...

[qə-ˌmajn-nɑl̥-ˌl̥ju-wɪm-məkt]

"simply leaving them/we/ourselves"

cf. spectrograms at Fig 1 (b, c)

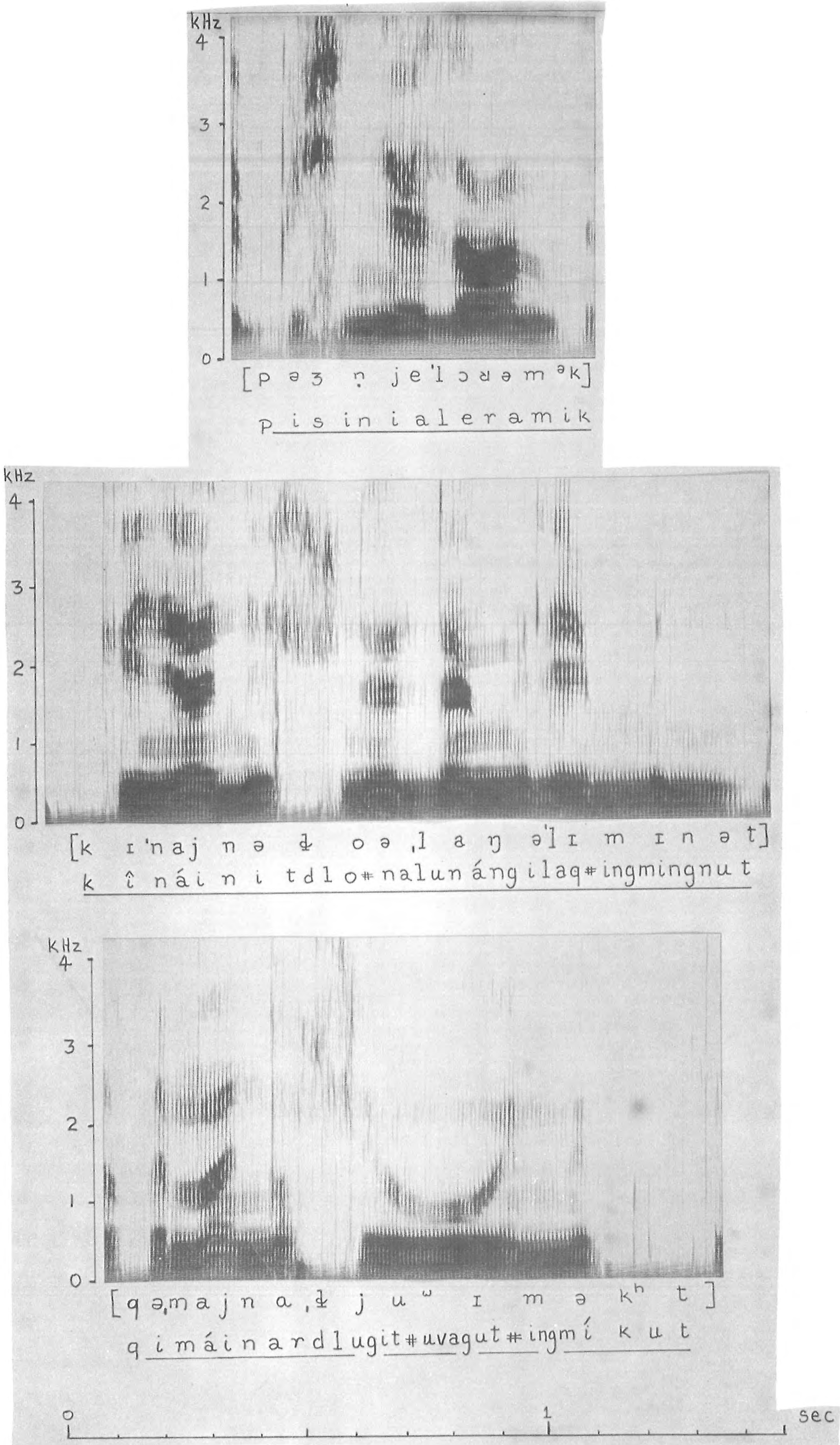

Figure 1. Examples of syllable contraction in continuous speech

(b) the 250 syllables contained the following vowels:

	/a/	/i/	/u/
Strong, non-pharyngeal	25	7	18
Weak, non-pharyngeal	48	52	38
Strong, pharyngeal	15	8	2
Weak, pharyngeal	10	13	14

(c) Many of these vowels were severely distorted by the contraction of syllables. The following smaller set of vowels is taken from syllables that were without any doubt undistorted:

	/a/	/i/	/u/
Strong non-pharyngeal	22	7	16
Weak non-pharyngeal	14	17	12
Strong pharyngeal	15	8	2
Weak pharyngeal	7	11	9

These are the vowels used for Figs. 2 (b,c,e,f).

2.3 Formant frequencies

The spectra of all vowels were sampled once only at a point in time where they were presumed most closely to approach a supposed target spectrum (denoted F_{1o}, F_{2o} ... F_{no}), cf. Fig 2.

2.4 Stress judgements

Levels of phonetic stress have been judged subjectively against a three-grade scale. The strong and medium grades are pooled in the results. The numbers of stressed and weak vowels have already been given above, § 2.2.

The stress levels refer to sentence stress in the informant's speech, and not to any abstract underlying lexical stress categories.

2.5 Inferred articulations

In an attempt to reconstruct articulations for the observed spectra, recourse is made to the three-parameter model of vowel production (Chiba and Kajiyama 1941, Fant 1960 and 1968, Stevens and House 1955 and 1961). According to this model, the resonator configuration can be specified by (i) the cross-section area at the narrowest constriction, A_o cm^2, (ii) the distance of that point from the source, d_o cms, and (iii) the opening area/length ratio, A/l cms. Particular reference is made to the data given by Stevens and House (1955: Fig. 5) for contours of constant formant frequency for different magnitudes of the parameters in an acoustic tube simulation of the typical adult male vocal tract. This version of the model has the tube radius at the constriction, r_o cm., rather than the cross-section area πr_o^2. Vocal tract cross-section areas corresponding to tube constriction radii are:

Constriction radius in the tube	r_o	0.3 cm	0.6 cm	0.8 cm	1.0 cm
Corresponding cross-section area in the vocal tract	A_o	0.3 cm^2	1.1 cm^2	2.0 cm^2	3.1 cm^2

The following points must be borne in mind when inferences are made from this model:

(a) The model assumes a constant tube length. In human speech, a palatal gesture of the tongue lifts the larynx via the hyoid bone. Consequently, the vocal tract is shorter for palatal vowels, especially for [i]. This might influence the articulations inferred for palatal vowels.

(b) An unknown quantity in this type of reconstruction is the magnitude of the cross-section area A_o. Several alternative solutions must therefore be compared, for selected values of this parameter. It is often possible to set a maximum permissible limit beyond which it is impossible to generate given spectra. The effect of increasing A_o is gradually to neutralize the parameter d_o and to reduce the total possible spectral variation. Fant 1960 (Table 2.33-1) gives the following constriction cross-section areas for a set of Russian vowels:

0.65 cm^2 [ɑ, i]   1.0 cm^2 [o, u, ɨ]   2.0 cm^2 [e]

This same range of cross-section areas will be used in the discussion, except that the lower limit will be set at Steven and House's smallest degree r_o = 0.3 cm (A_o = 0.3 cm^2).

For palatal constrictions, and to some extent velar constrictions, we can expect the degree of constriction to be a function of jaw-opening (cf. the data quoted above for the Russian vowels where A_o was 0.65 cm^2 for /i/ and 2.0 cm^2 for /e/), but for pharyngeal constrictions, the degree of constriction can be small even with a large jaw-opening (A_o for the Russian /ɑ/ was 0.65 cm^2).

(c) The model does not concern itself with the articulatory degrees of freedom of the human vocal tract, and it is therefore capable of making combinations of parameter values that would hardly occur in natural speech. The articulatory degrees of freedom are discussed by Lindblom and Sundberg (1969: § 2). The same authors have also investigated the acoustic consequences of movements of the lip, tongue, jaw and larynx (1971). In the present investigation, [u] spectra are found which could be generated with a constriction low in the pharynx, or [i] spectra with an extremely large mouth-opening. Our knowledge of general phonetics would say that such articulations are very unlikely for these vowels and would limit the choice of acceptable inferences.

(d) The data given by Stevens and House is for a resonator with typical adult male dimensions. But it is not certain that the informant is representative of the typical case. The pitches of his second formant were almost normally distributed about a mean of 1200 mels (1325 Hz) when sampled at 0.025 second intervals through the continuous speech. The mean of this distribution differs individually between speakers and is possibly related to vocal tract dimensions. If so, this informant's mean F2 pitch (which is on the low side) might indicate that he has a larger-than-average vocal tract. There is then a risk that the model will underestimate the distance from source to contriction for this informant, especially when this distance is large - i.e. for palatal constrictions.

3. RESULTS

3.1 Fig. 2 (a-f) shows the F_{1o}/F_{2o} areas of stressed vowels in the single word utterances, and stressed and weak vowels in continuous speech, for post-vocalic non-pharyngeal and pharyngeal environments. The areas represent the full variation observed for each phoneme - the only factors taken into account have been speaking situation, stress and the pharyngeal environment, for which spectra have been plotted separately.

3.2 Fig. 3 shows the frequencies F_{1o}, F_{2o} and F_{3o} of the stressed vowels in single word utterances, ranked by ascending F_{1o}, for the non-pharyngeal and pharyngeal environments. There are the same 30 vowels as for Fig 2 (a, d). Fig. 4 shows the frequencies F_{1o}, F_{2o} and F_{3o} of stressed vowels in continuous speech, ranked by ascending F_{1o}, for non-pharyngeal and pharyngeal environments. Fewer vowels were available here than for Fig. 2 (b, e) because F3 was sometimes weak and did not always register on spectrograms.

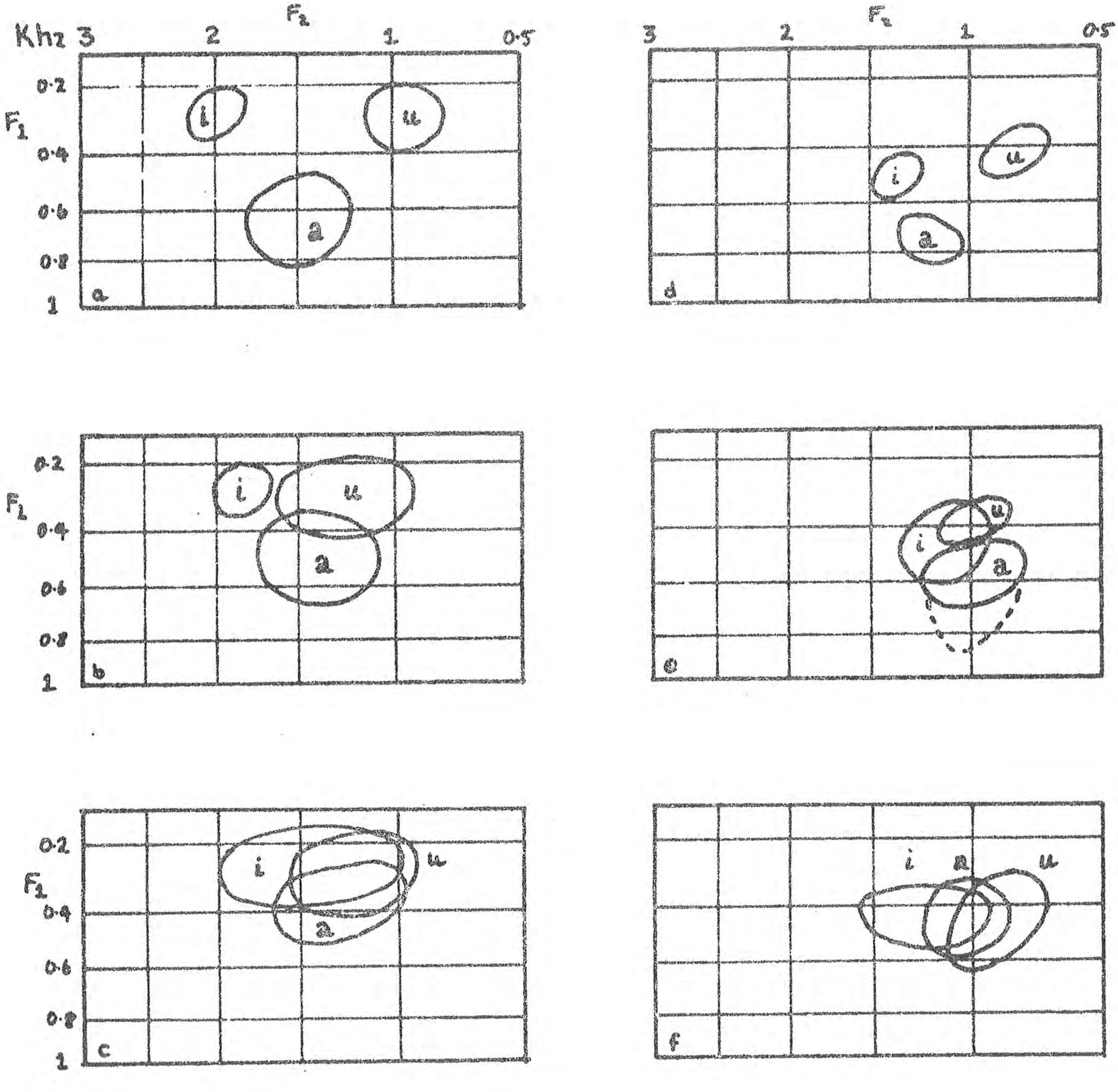

Figure 2. F_{1o}/F_{2o} areas of stressed vowels in carefully pronounced single word utterances (a, d), stressed vowels in continuous speech (b, e) and weak vowels in continuous speech (c, f), in non-pharyngeal(a, b, c) and pharyngeal (d, e, f) environments.

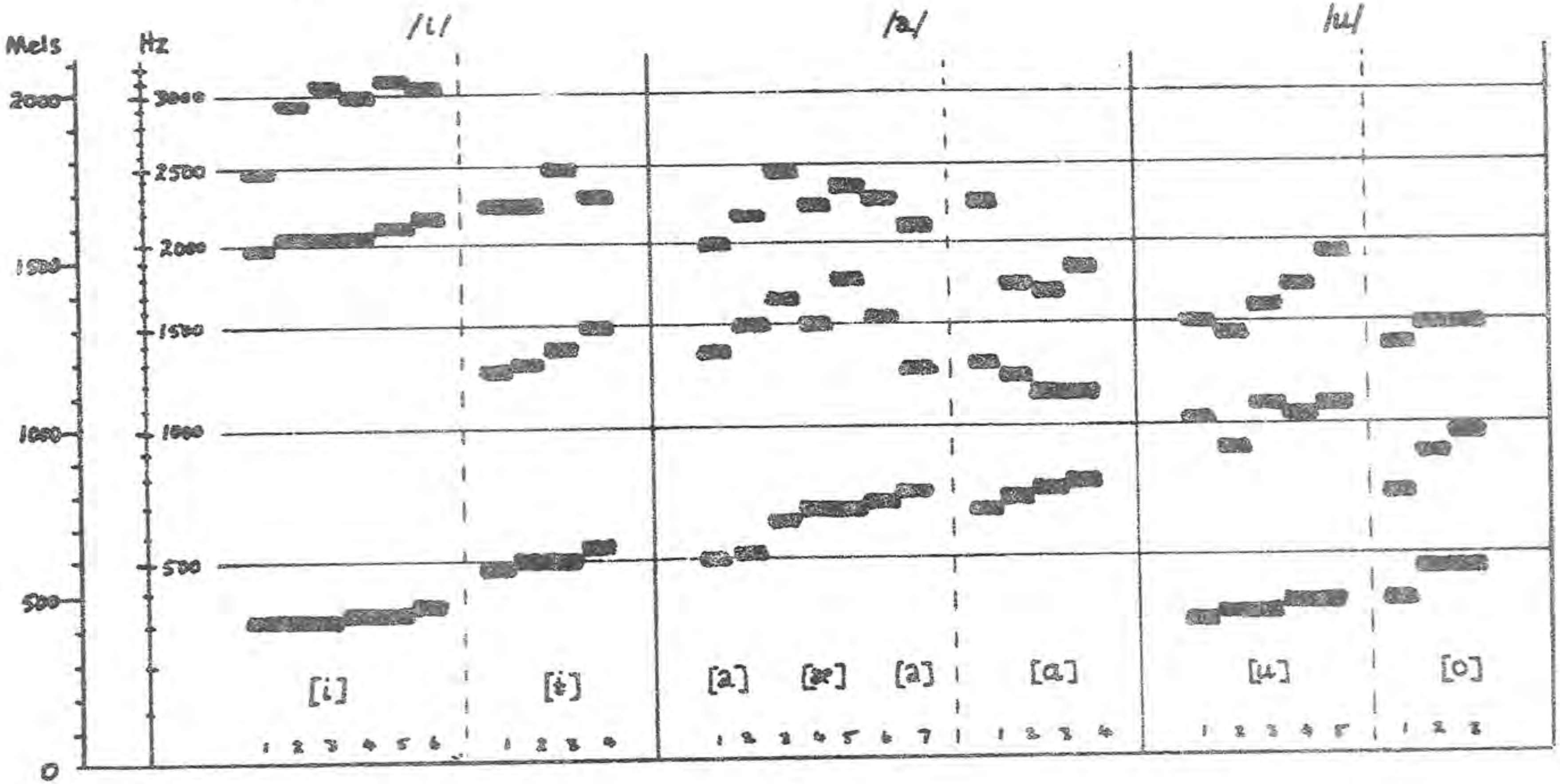

Figure 3. F_{1o}, F_{2o} and F_{3o} of stressed vowels in carefully pronounced single word utterances.

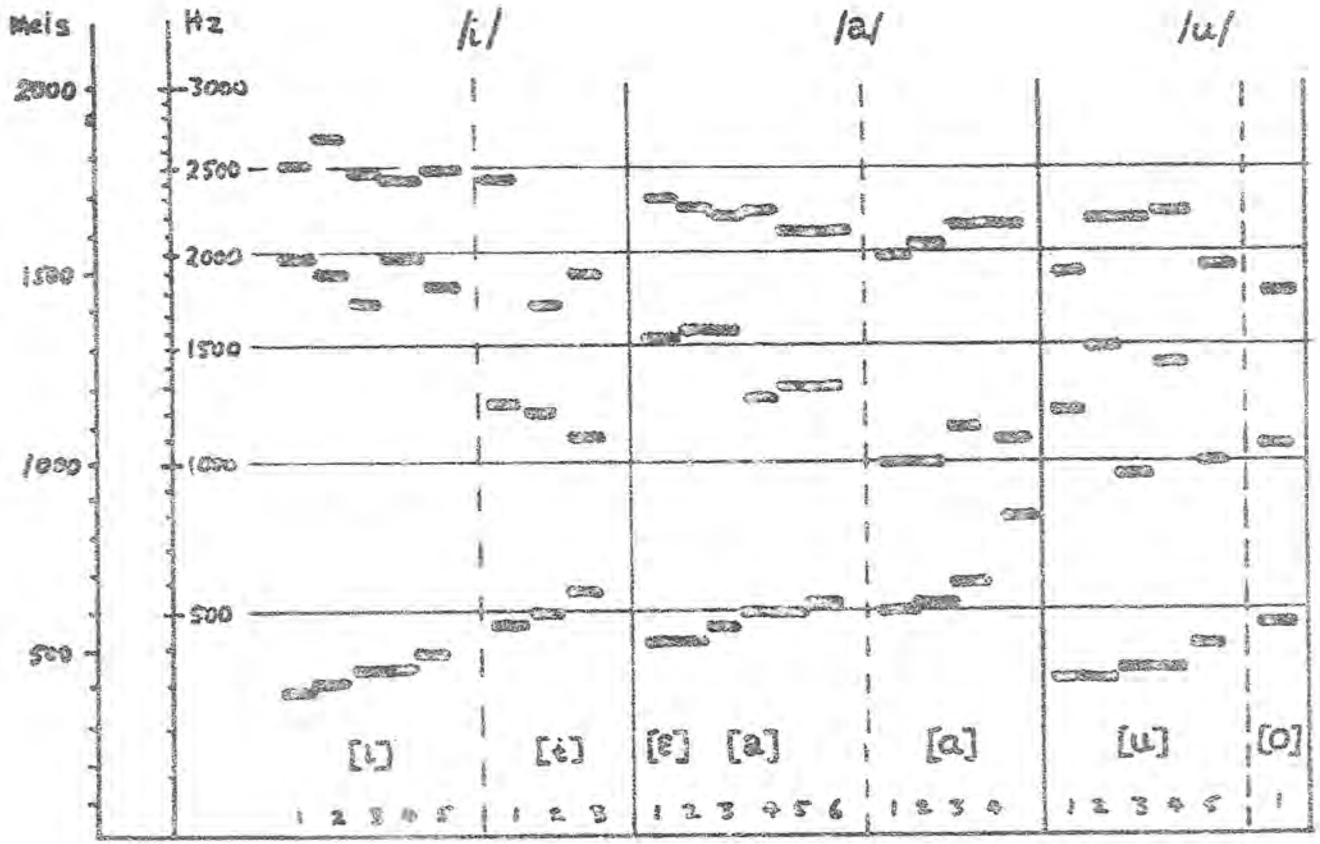

Figure 4. F_{1o}, F_{2o} and F_{3o} of stressed vowels in continuous speech.

4. DISCUSSION AND CONCLUSIONS

4.1 Allophonic variation

4.1.1 Single word utterances

(a) Fig. 2 (a,d) shows that the three phonemes were spectrally well separated in both environments. In non-pharyngeal environments, these spectra were peripheral to the total area used. In pharyngeal environments F_{2o} was lower for all phonemes, and F_{1o} higher for /i/ and /u/.

(b) Fig. 3 shows the frequencies of the first three formants of the distinctive spectra of stressed vowels in the single word utterances, ranked by ascending F_{1o}. For allophones of /i/ and /u/, there was a clear drop of F_{2o} and F_{3o} between the non-pharyngeal and pharyngeal allophones. For /a/, however, there appears to be a continuum with no abrupt spectral gap between the allophones. It is interesting to note that WG orthography distinguishes between the allophones of /i/ and /u/, but not between those of /a/ (i – e, u – o, a).

(c) What are the articulations that can be inferred for these peripheral spectra? Fig. 5 a gives the place of constriction and relative mouth-opening for the non-pharyngeal environments, for three degrees of constriction. A small constriction (A_o = 0.3 cm^2) would generate all the spectra. With wider constrictions, some of the spectra are cut off. For the intermediate case, A_o = 1.1 cm^2, many of the possible /u/ spectra would require constrictions low in the pharynx ($4 < d_o < 7$ cms.) which we might intuitively feel to be unlikely. Similarly, some of the /i/ spectra would require exceptionally large compensatory mouth-openings. In the largest case quoted, A_o = 2.0 cm^2, none of the /i/ spectra would be possible and much of /u/ is still improbably low in the pharynx. It seems almost certain that these two

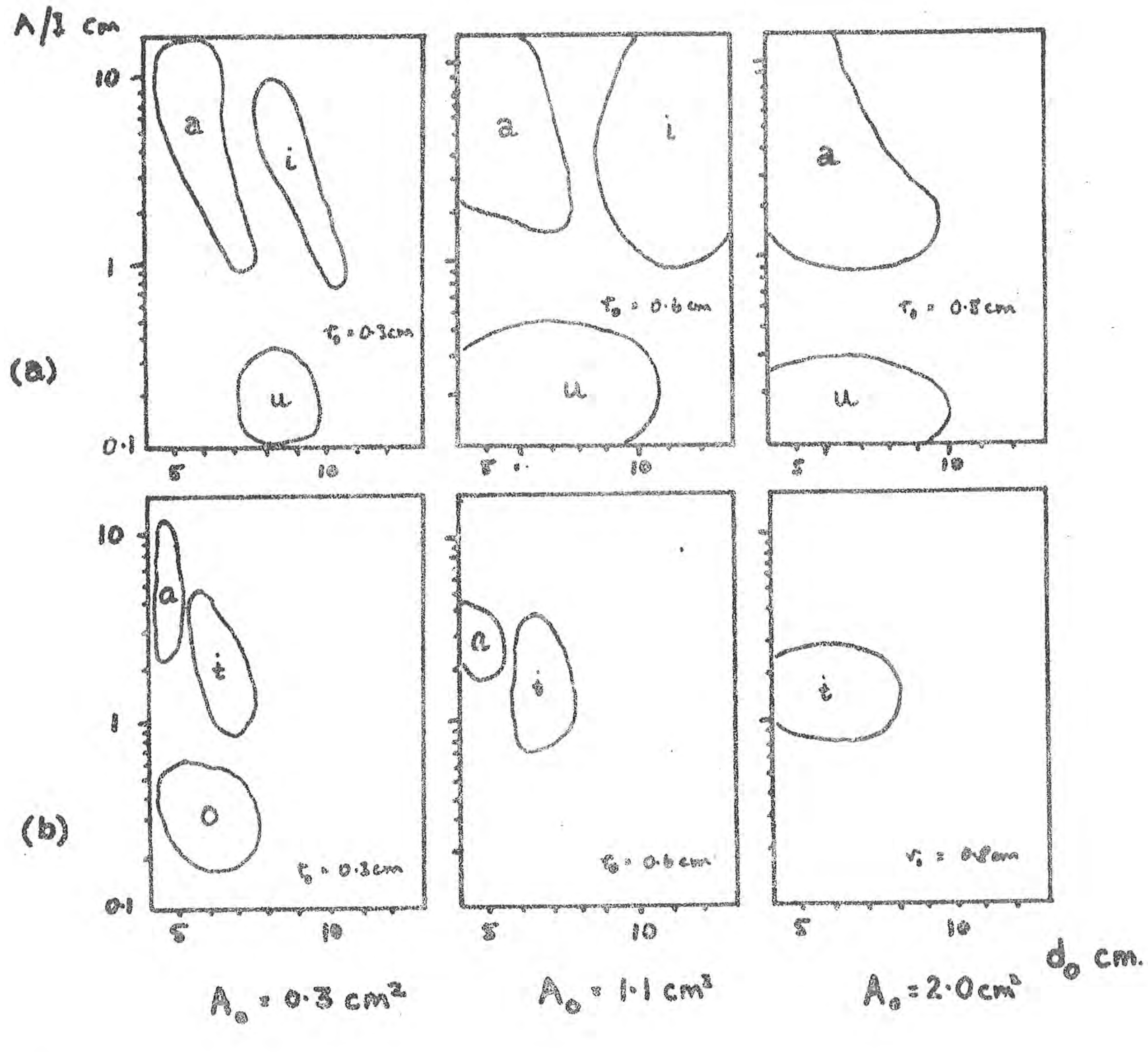

Figure 5. Contours of articulation for the informant's stressed vowel spectra in carefully pronounced single word utterances: (a) non-pharyngeal environments, and (b) pharyngeal environments, for three different degrees of constriction. Based on Stevens and House's contours of constant formant frequency (1955, Fig. 5).

phonemes required small constrictions, /u/ possibly more so than /i/. For /a/, however, while the small constriction is essential for some spectra, the effect of wider constrictions is to extend the range of constriction locations up to the velum ($4 < d_o < 10$ cms.) and to increase mouth-openings to the maximum. These are quite conceivable articulations for for the vowel qualities [a] and [æ] (cf. Fig. 3). The place of articulation and mouth-opening can be summarized as follows:

	/a/	/u/	/i/
distance above the glottis	5-8 cms.	7-10 cms.	8-11 cms.
region	pharyngeal uvular	uvular velar	(velar) palatal
mouth-opening	moderate very large	small	moderate large

The constrictions for /i/ may seem unusually far back. Possible explanations for this are (i) that the point of reference, the glottis, is raised for [i] [cf. § 2.5 (a)], (ii) the informant may have a longer-than-average vocal tract [cf. § 2.5 (d)], and (iii) a slightly wider degree of constriction for /i/ than the minimum, intermediate between 0.3 cm^2 and 1.1 cm^2, would give a location higher up the palate (Fig. 5a shows that increasing A_o has the effect of shifting the [i] constriction nearer the opening).

(d) Fig. 5 b shows the corresponding articulations for the pharyngeal environments. The degree of constriction would appear to be even more critical here. When $A_o > 0.3$ cm^2, the /u/ spectra become impossible, and the /a/ spectra cannot be generated when $A_o > 1.1$ cm^2. The /i/ spectra have very similar articulations for $A_o = 0.3$ cm^2 and $A_o = 1.1$ cm^2, but at $A_o = 2.0$ cm^2 the constriction would go deep into the pharynx. Otherwise, generally smaller degrees of constriction seem to be necessary in this environment than in the non-pharyngeal environment. The place of articulation and mouth-opening can be summarized as follows:

	/a/	/u/	/i/
distance above the glottis	4-5 cms.	5-8 cms.	6-8 cms.
region	low-pharyngeal	pharyngeal uvular	uvular
mouth-opening	moderate large	small	moderate

This means that the place of constriction has been displaced 2 - 3 cms. towards the glottis, in the pharyngeal environments, relative to the non-pharyngeal environments. The displacement along the vocal tract is probably a little greater since the larynx is itself falling back.

4.1.2 Stressed vowels in continuous speech

(a) Fig. 2b shows that the spectra used in stressed non-pharyngeal environments were nearer the centre of the spectral space than those in the single word utterances. The spectra fill out the whole central area, but there is only insignificant overlapping. In the pharyngeal environments (Fig. 2a) there is considerable overlapping of phonemes. The broken lines on Fig. 1e enclose one isolated rendering of /a/ - the remainder were concentrated to the area within the unbroken line.

(b) Fig. 4 gives the frequencies F_{1o}, F_{2o} and F_{3o} of stressed vowels in continuous speech, ranked by ascending F_{1o}. As in Fig. 3, F_{1o} is higher in the pharyngeal environments than in the non-pharyngeal environments, for any one phoneme. F_{2o} was still lower for [ɨ] than for [i], but F_{3o} was not consistently lower (as it was in Fig. 3). There was only a slight difference between the allophones of /u/. But the [o] allophone of /u/ was hardly spectrally distinct from the [ɨ] allophone of /i/ – in the cases where overlapping of F_{1o} and F_{2o} has been observed, there was hardly any contrastive power in F_{3o}.

(c) Fig. 6 a gives the articulatory contours for the stressed vowels in non-pharyngeal environments, for the same three degrees of constriction as in Fig. 5. These spectra can all be generated with constrictions up to $A_o = 1.1$ cm^2, which is a more generous limit than was the case for the single word utterances, § 4.1.1 (c). Much of the spectral area of /i/ is cut off at $A_o = 2.0$ cm^2. As was the case in the single word utterances, the /u/ spectra would seem to require improbably low pharyngeal constrictions when $A_o > 0.3$ cm^2. On the other hand, the gestures for /i/ and /a/ spectra at wider constrictions are plausible – higher up the palate for /i/ and towards the velum and back of the palate for /a/. The mouth-openings are much the same at each degree of constriction. For two degrees of constriction, the articulations can be summarized as follows:

(i) $A_o = 0.3$ cm^2	/a/	/u/	/i/
distance above the glottis	5–8 cms.	7–10 cms.	8–11 cms.
region	pharyngeal uvular	uvular velar	(velar) palatal
mouth-opening	moderate large	small	moderate

(ii) $A_o = 1.1$ cm^2	/a/	/u/	/i/
distance above the glottis	5–10 cms.		10–13 cms.
region	pharyngeal velar		palatal

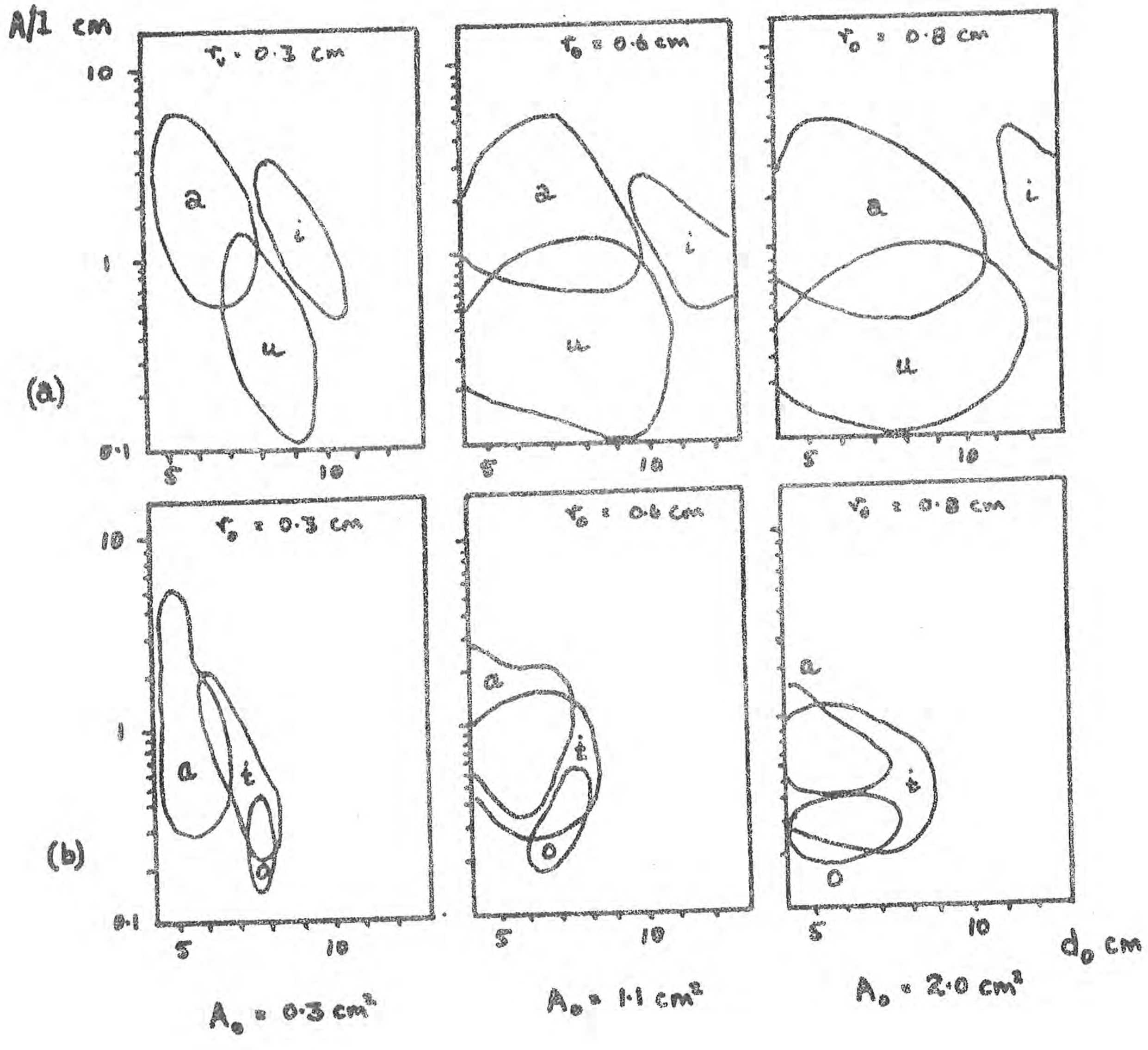

Figure 6. Contours of articulation for the informant's stressed vowel spectra in continuous speech: (a) non-pharyngeal environments, and (b) pharyngeal environments, for three different degrees of constriction.

These are much the same articulations as were found above for the single word utterances. The main differences are that mouth-openin gs were more moderate in the continuous speech (smaller for /i/ and /a/, often larger for /u/), and that slightly larger degrees of constriction can apparently be tolerated for the continuous speech spectra.

(d) Fig. 6b shows the corresponding articulations for the pharyngeal environments. The overlapping of phoneme areas is equally evident here. The spectra that do not overlap, and which consequently still contrast require the smallest degree of constriction. At larger degrees of constriction, virtually only the overlapping spectra can be generated. For contrasting spectra, the place of articulation and mouth-opening can be summarized as follows:

	/a/	/u/	/i/
distance above the glottis	4–6 cms.	7–8 cms.	6–8 cmc.
region	low-pharyngeal	uvular	uvular
mouth-opening	moderately small	small	moderately small
	moderately large		

4.1.3 Weak vowels in continuous speech

Figs. 1c and 1f show that there was considerable overlapping of the three phonemes in weak syllables in both environments. Comparison of the two charts shows that the spectra of weak vowels in pharyngeal environments are still displaced to a separate area, with generally higher F_{1o} and lower F_{2o} than those in non-pharyngeal environments. Spectral contrasts are largely neutralized, but it would be an over-simplification to say that each phoneme has one weak allophone [ə] in non-pharyngeal environments and another [ɔ] in pharyngeal environments. Fig. 2 (c,f) reveals some semblance of a system, even though it is largely confused by overlapping.

4.2 Vowel reduction

4.2.1 Spectral contrasts

The F_{1o}/F_{2o} areas of the stressed and weak vowels in continuous speech have already been seen at Fig. 2 (b, c, e, f). The focal point for vowel reduction in non-pharyngeal environments was not in the centre (towards say a neutral spectrum of 500, 1500, 2500 ... etc. Hz) but higher up towards a spectrum of 350, 1250 Hz. Many of the weak vowels, whatever the underlying phoneme, did in fact sound like [ʊ] or [o]. The areas for weak /i/ and /a/ extend from this focus of vowel reduction towards the respective stressed areas. The weak pharyngeal allophones had lower F_{1o} than the corresponding strong renderings.

4.2.2 Inferred articulations

(a) Fig 7a gives the contours of articulation for the area of complete overlapping of the weak vowels in non-pharyngeal environments (Fig. 2c). This is the area where vowels are completely reduced and distinctions abandoned. Constrictions would be located 7-10 cms. above the glottis, or roughly from the uvula to the velum with the smallest degree of constriction, $A_o = 0.3$ cm^2. With wider degrees of constriction, a larger range of constriction locations becomes necessary to generate all the spectra in the defined area. When $A_o = 2.0$ cm^2 these spectra are theoretically just possible if constrictions are located from 5 to 12 cms. above the glottis – i.e. utilizing virtually the whole vocal tract. If constrictions are

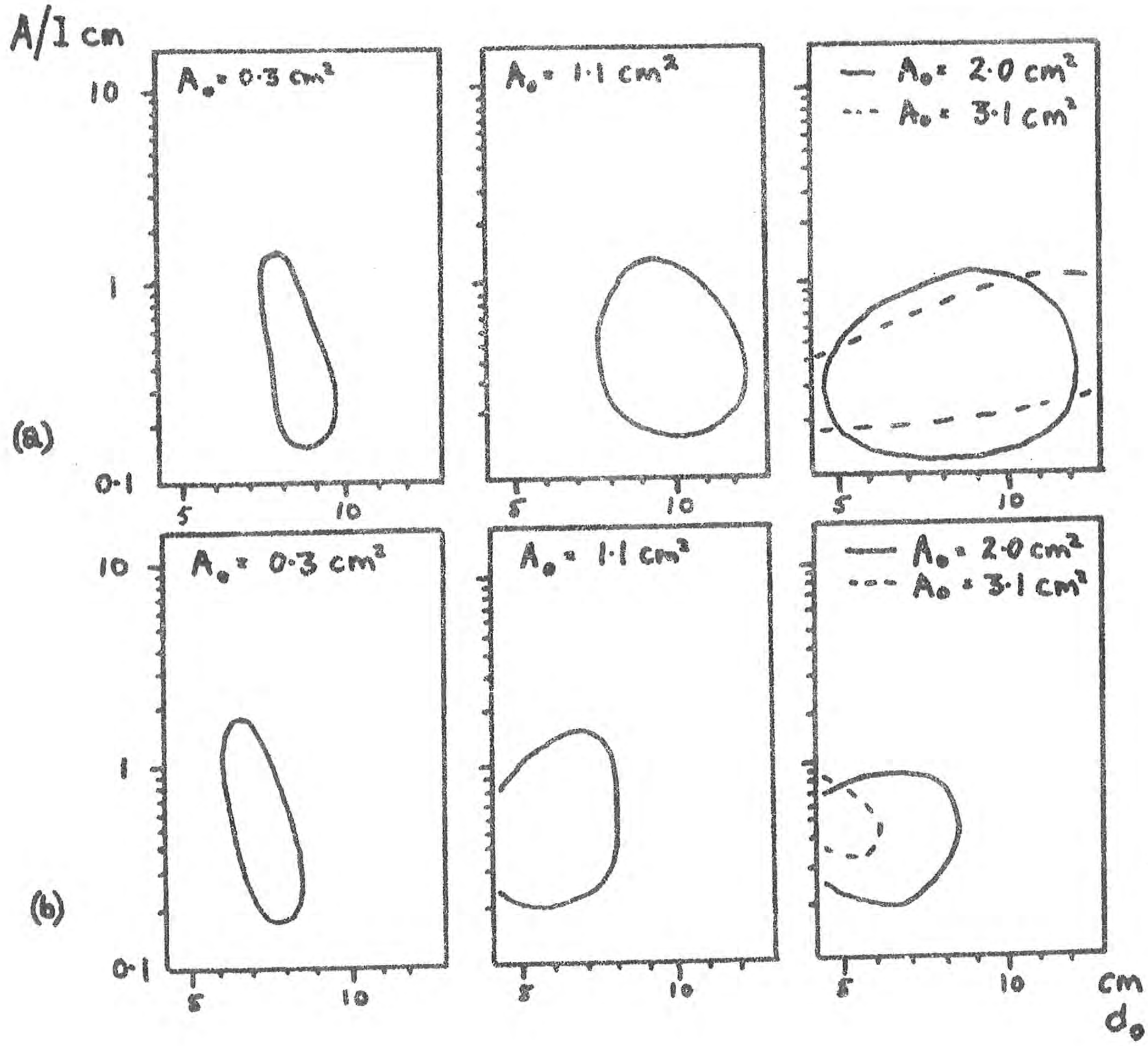

Figure 7. Contours of articulation for the informant's weak vowel spectra that were common to all three phonemes [cf. Fig. 2 (c, f)]: (a) non-pharyngeal environments, and (b) pharyngeal environments, for four degrees of constriction.

even wider, some of the spectra are impossible to generate. There are thus two limiting situations - either (i) constrictions located in all parts of the tract but with cross-section areas up to 1.5 - 2.0 cm^2, or (ii) centralized constrictions located in the velar region with small cross-section areas.

The necessary mouth-openings vary little between the degrees of constriction quoted ($0.1 < A/l < 1.5$ cm), but the upper limit is lower than for stressed vowels. The mouth-opening tended to be smaller for weak vowels than for stressed vowels.

(b) For pharyngeal environments, Fig. 7b shows that the constriction, when very small, is located about 6 - 8 cms. above the glottis, or near the uvula (somewhat lower than for the non-pharyngeal environments). For wider constrictions, the extra range of d_o is only downwards into the pharynx - there is no extension upwards into the palate. Further, some of the spectra are cut off when $A_o > 1.0$ cm^2.

(c) This comparison not only indicates that the tongue constrictions of fully reduced vowels were deeper in the pharynx before the pharyngeal consonants, but also that there was less freedom for constriction size - in pharyngeal environments A_o must be smaller than in non-pharyngeal environments. It is also clear that many of the fully reduced weak vowel spectra could not be generated in a resonator approximating the uniform tube (in Stevens and House's version of the model, the uniform tube has r_o = 1.2 cm., corresponding to A_o = 4.5 cm^2).

4.2.3 <u>Correlation between F_{1o} and F_{2o}</u>

(a) In a sample of English continuous speech (description forthcoming) it was found that there was a fairly good correlation between F_{1o} and F_{2o}

for different renderings of a phoneme in a homogeneous environment. The regressions for different phonemes were focussed on the speaker's schwa spectra and appeared to indicate the paths of reduction for phonemes in a given environment. It is unfortunately difficult to find a sufficient number of renderings in a purely homogeneous environment in the present WG Eskimo sample of continuous speech, with only 250 syllables to choose from. However it did prove possible to extract a small set of syllables - weak and strong - that excluded labial, palatal, pharyngeal and lateral environments - i.e. a mixture of dental and velar environments remained. A further condition imposed on the selection was that these syllables should faithfully reproduce the underlying forms (phonetic syllables such as those given as examples of syllable contraction in § 2.2 (and Fig. 1) can contain features from a number of underlying syllables and are therefore open to several sources of contamination).

(b) Fig. 8a shows the number of renderings, the product-moment correlation coefficient between F_{1o} and F_{2o}, and the regression of F_{1o} on F_{2o} for each of the phonemes.* These regressions can be compared with the areas of full variation in all environments at Fig. 2 (a-c).

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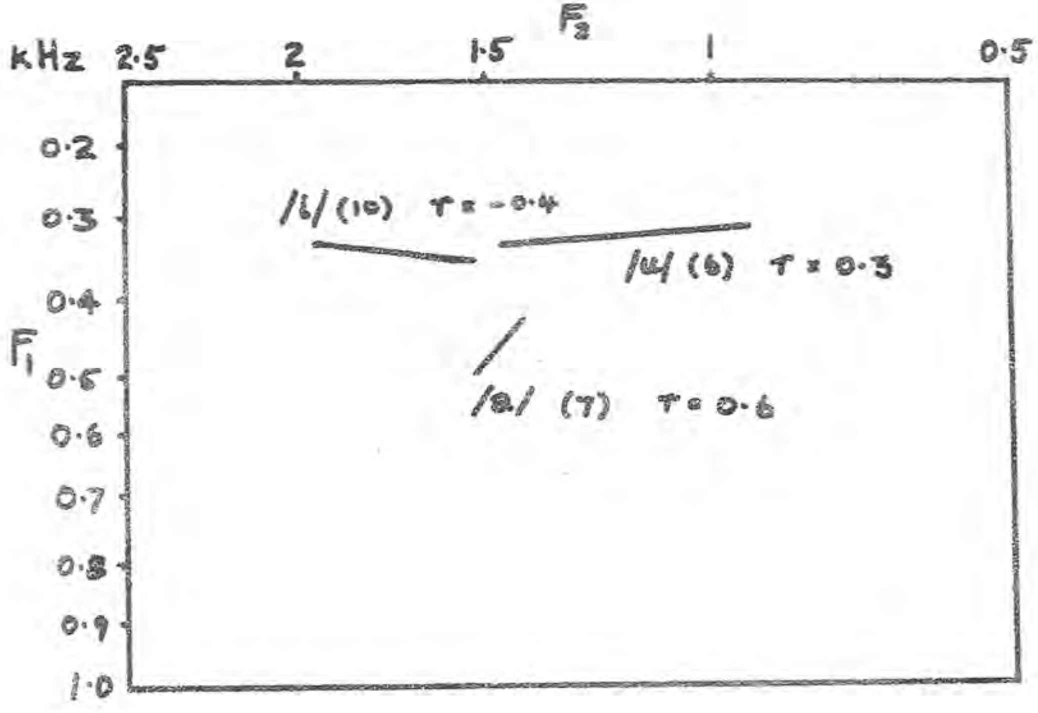
* The correlations and regressions given at Fig. 8a must be accepted with some caution because they are based on such small samples of vowels. A t-test gives the following significance levels (p) for these correlation coefficients (r) and sample sizes:

	/i/	/a/	/u/
vowels	10	7	6
r	-0.4	+0.6	+0.3
p	15 %	8 %	30 %

Nevertheless, they do follow the tendency revealed in the much larger sample of English continuous speech referred to above.



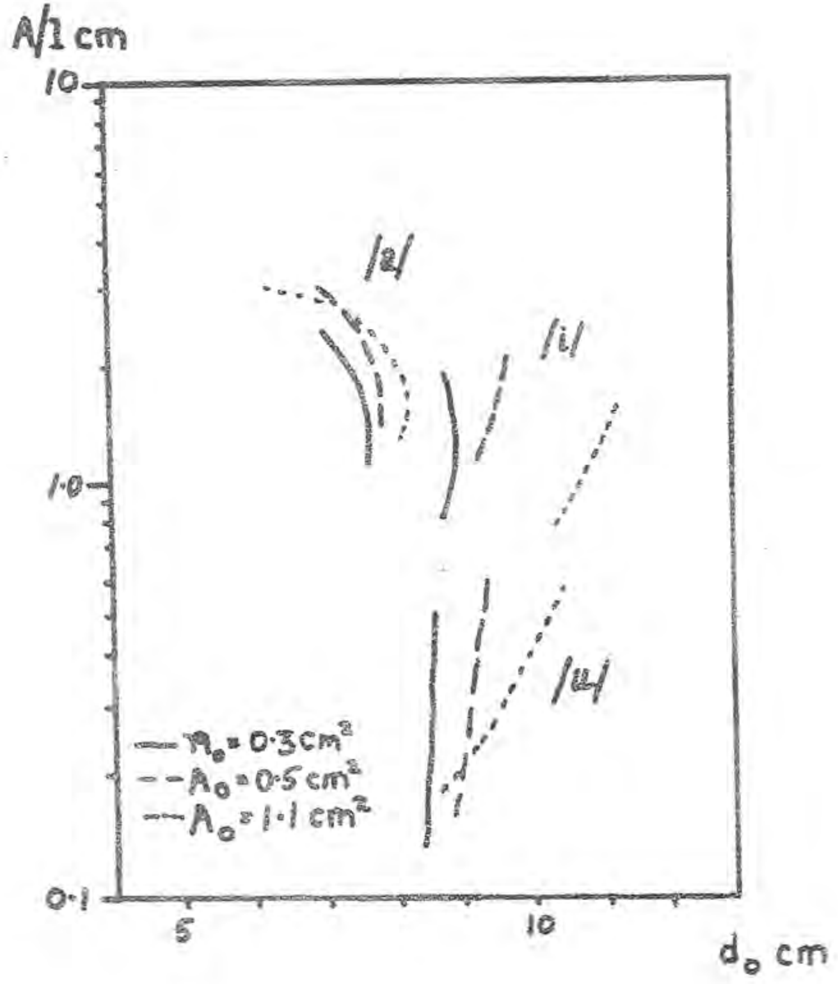


Figure 8. (a) The correlation between F_{1o} and F_{2o} in vowels (excluding labial, lateral, palatal and pharyngeal environments), and the regression of F_{1o} on F_{2o} for these vowels. (b) The articulatory contours of the spectra along the regression lines.

(c) Fig. 8b shows the articulatory contours for spectra along the regression lines, for three degrees of constriction. Considering each parameter independently, we can investigate articulatory centralization corresponding to the spectral centralization along the regression lines.

(i) The main modification to the resonator configurations concerns the mouth-opening parameter A/l. For all three phonemes, at any degree of constriction quoted, the centralization of spectra along the regression lines was associated with clear centralization of the mouth-opening to less extreme positions, falling to smaller than usual for /i/ and /a/ (to about A/l = 1.0 cm., possibly related to failure to open the mandible) and rising to wider than usual for /u/ (to about A/l = 0.7 cm., possibly related to failure to round the lips).

(ii) Little variation of the place of constriction would be necessary at each degree of constriction - except that there appears to be a slight centralizing movement of the place at the largest degree of constriction quoted (most pronounced for /a/).

(iii) All the spectra under consideration can be generated with $A_o \leq 1.1$ cm^2, and the main effect of varying the degree up to this size is to shift the constrictions of all phonemes higher up the vocal tract. In addition, as already observed, there is the appearance of some slight centralization of the place of constriction at larger degrees of constriction. But this apparent centralization is false since the range of constriction locations is larger when A_o is large ($6 < d_o < 11$ cm. for $A_o = 1.1$ cm^2) than when it is small ($7 < d_o < 9$ cm. for $A_o = 0.3$ cm^2).

The regression lines mark only the beginning of vowel reduction - they cover the stressed vowel areas and the distinctive parts of the weak vowel areas (Fig. 2 (b, c). If the /i/ and /a/ regression lines are produced towards a spectrum of 350, 1250 Hz [the centre of the overlapping area on

Fig. 2c, discussed at § 4.2.2(a)], the three-parameter model indicates even further centralization of the mouth-opening around A/l = 0.7 cm. and now also a definite centralizing shift of constriction locations towards the velum.

(d) The following reconstruction of the articulatory correlates of spectral reduction is tentatively proposed:

(i) For the beginning of the spectral centralization, from the periphery and half-way in to the centre, the movement of the lips and mandible are gradually restricted to the middle range of mouth openings. A_o remains small.

(ii) For the remainder of the path to the centre with complete loss of spectral distinctions, there is continued narrowing of the range of mouth-openings. In addition, there is either (i) some gradual centralization of the constriction location towards the velum while the cross-section area remains small, or, (ii) the cross-section area increases and the constrictions are scattered all along the vocal tract as the configuration approaches the uniform tube. Intuitively, I prefer the former alternative. This can only be speculation, but the matter could be settled by cine-radiographic investigation of successive vocal tract states during the vowels of continuous speech.

4.3 A pharyngeal vowel allophone rule

4.3.1 Articulations

(a) Non-pharyngeal environments

/a/ - a pharyngeal constriction and large mouth-opening. In some non-pharyngeal environments, /a/ spectra have been found requiring velar or slightly palatal constrictions. This [æ] allophone will be disregarded now since the investigation has not aimed at describing allophonic alternation within the non-pharyngeal environments. The basic constrictions of /a/ are below the velum, i.e. pharyngeal.

/i/ – a palatal constriction and moderate or larger mouth-opening.

/u/ – a velar constriction and a small mouth-opening.

(b) Pharyngeal environments

/a/ – a pharyngeal (especially low pharyngeal) constriction and large mouth-opening.

/i/ – a pharyngeal (especially uvular) constriction and moderate or larger mouth-opening.

/u/ – a pharyngeal (especially uvular) constriction and small mouth-opening.

4.3.2 A feature framework based on the three-parameter model

(a) Traditionally, vowel articulations are described according to the position of the dorsal hump in a quadrilateral relative to the roof of the mouth, ignoring pharyngeal constrictions. This is only indirectly, and not always predictably, related to the actual configuration of the vocal cavities (cf. Fant 1960: § 2.33). In particular, it is difficult to fit "uvularization" into a framework that does not otherwise take into account the pharyngeal cavity. However, vowel articulations can be handled in terms of the three-parameter model, as has been done in preceding sections of this paper. This provides better correspondence between the articulatory and acoustic levels of description, and takes full account of the pharynx. An added advantage of this approach is that the same place features are used for both vowels and consonants. Such a scheme will be described in greater detail in a forthcoming article, but its application to the W.G. Eskimo allophones will be outlined here.

(b) Place features. The vocal tract can be divided into three main regions with regard to the speech functions of its vowel output – the pharyngeal part, the velar part and the palatal part. These regions correspond to the inferred places of articulation of the three vowel phonemes. Radiographic evidence for the same tripartite division of the vocal tract has been given by Lindblom and Sundberg (1969, 1971), who found three basic families of tongue articulations for Swedish vowels. Two features, palatal and pharyngeal, can be combined in a binary system to denote the three regions:

+palatal	-palatal -pharyngeal	+pharyngeal

For the allophones in the pharyngeal environments, it is necessary to subdivide the pharyngeal cavity into an upper part (uvular, for /i/ and /u/) and a lower part (below the uvula, for /a/), according to § 4.3.1(b). The feature uvular makes this division.

(c) Mouth-opening features. A distinguishing feature of /u/ is the small mouth-opening ratio A/l associated with lip-rounding, while non-labial /i/ and /a/ have larger ratios, the dividing value being approximately A/l = 0.7 cm. (cf. Fig. 5a). This difference will be denoted labial. Further, the range of mouth-openings was larger for /a/ than for /i/, corresponding to the traditional features of "open" and "close", or "low" and "high". This difference will be denoted open. Combining the two features labial and open, three basic degrees of mouth-opening are obtained:

+labial	-labial -open	+open

4.3.3 Distinctive features of W.G. vowels

(a) Non-pharyngeal environments. A minimum specification of distinctions is as follows: there are three vowel phonemes, one palatal (/i/) and two non-palatal (one labial, /u/, and one non-labial, /a/). This gives the following scheme (/i/ being redundantly non-labial):

	+ lab	− lab
pal +		i
pal −	u	a

(I)

Fig. 9a shows the spectra that can be generated within the limits of these distinctions. Line A–A' divides the spectral space into an area generated with palatal constrictions and an area generated with non-palatal constrictions. Line B–B' divides the spectral space into an area generated with lip-rounding and an area without lip-rounding. These lines have been plotted as follows:

(i) Line A–A' represents the spectra for d_o = 10 cms. (the palatal/velar boundary) and the full range of mouth-openings. The degree of constriction is taken to be a function of mouth-opening in so far as the latter is produced by jaw movements. The cross-section area A_o has therefore been increased in step with A/l, from A/l = 0.1 cm. and A_o = 0.3 cm^2 at A to A/l = 20 cms. and A_o = 3.1 cm^2 at A'.

(ii) Line B–B' represents the spectra for A/l = 0.7 cm. (the inferred boundary between labial and non-labial mouth-openings, Figs. 5a and 8b) and all places of constriction ($4 < d_o < 13$ cms.). Degrees of constriction have been chosen that are similar to the Russian vowel data quoted in § 2.5 from Fant (1960) – 0.5 cm^2 for a close palatal vowel and 1.1 cm^2 for a close non-palatal vowel (i.e. r_o values 0.4 cm. and 0.6 cm. respectively on Stevens and House's charts).

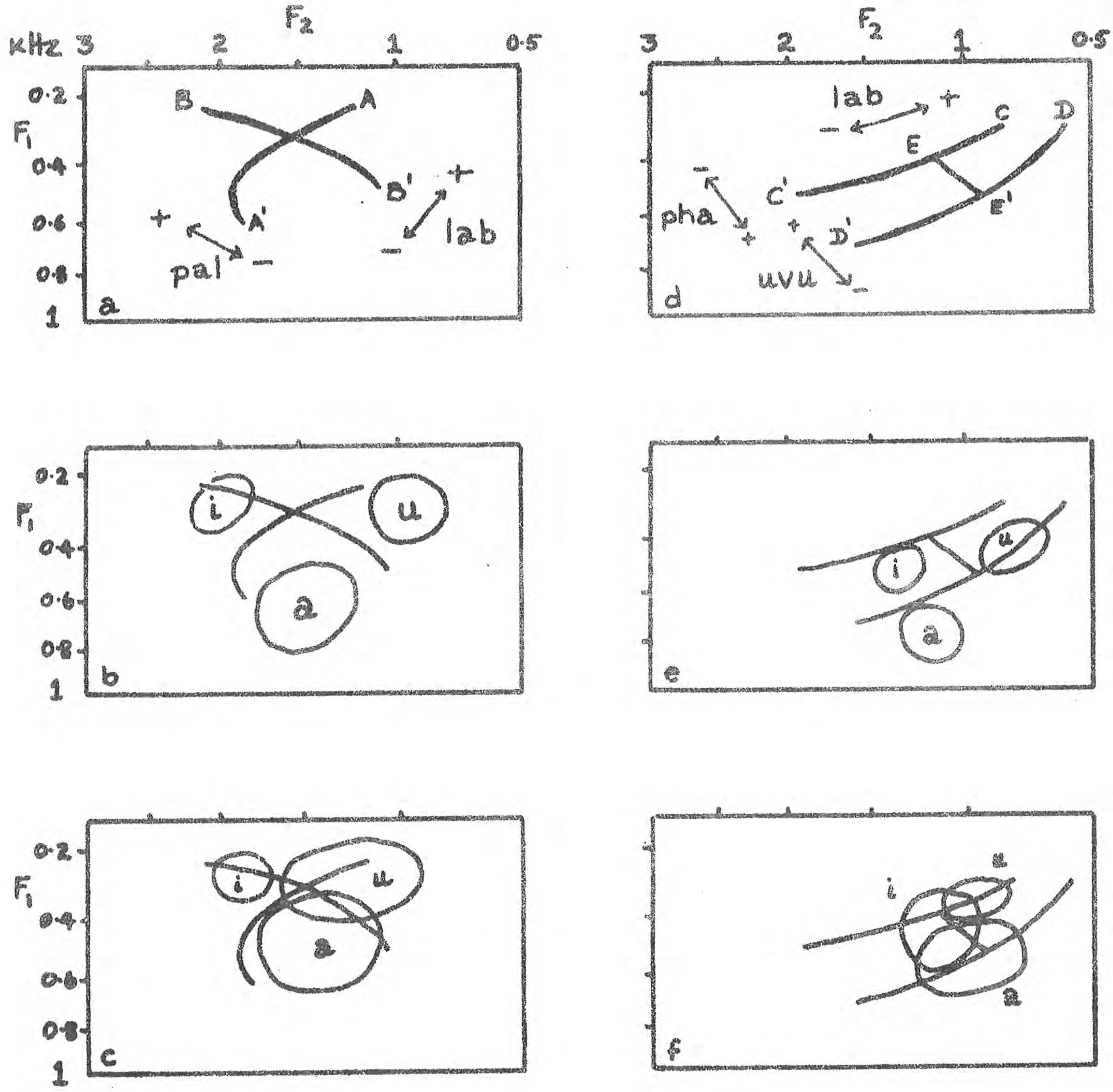


Figure 9. Acoustic correlates of distinctive features (a, d) compared with spectra observed in stressed vowels in carefully pronounced words (b, e) and continuous speech (c, f) in non-pharyngeal (a, b, c) and pharyngeal (d, e, f) environments.

Fig. 9 (b, c) shows the spectral areas of stressed vowels from Fig. 2 (a, b) superimposed on these contrasting areas.

(b) Pharyngeal environments. In the pharyngeal environments, distinctions are maintained by contrasting a low-pharyngeal (non-uvular) vowel (/a/) and two uvular vowels (one labial, /u/, and one non-labial, /i/). Fig. 9d shows the spectra that can be generated within the limits set by these distinctions. The line C-C' marks the pharyngo/velar boundary. The line D-D' divides the pharyngeal spectra into an area generated with uvular constrictions and an area generated with constrictions below the uvula. The line E-E' divides the spectral space into an area generated with lip-rounding and an area generated without lip-rounding. These lines have been plotted as follows:

(i) Line C-C' represents the spectra for d_o = 8 cms. and a small range of mouth-openings (as inferred from the informant's spectra). The degree of constriction has been set very small with small mouth-openings (A_o = 0.3 cm^2 and A/l = 0.1 cm. at C), and slightly larger with non-labial mouth-openings (A_o = 1.1 cm^2 for $A/l >$ 0.7 cm.). A/l = 10 cms. at C'.

(ii) Line D-D' represents the spectra for d_o = 6 cms. The other two parameters, A/l and A_o, have been set as for C-C'.

(iii) Line E-E' represents the spectra for A/l = 0.7 cm. in the pharyngeal area. A_o has been set at 0.5 cm^2 (it was inferred from the informant's spectra that A_o was probably smaller in pharyngeal environments).

Fig. 9 (e,f) shows the spectral areas of stressed vowels from Fig. 2 (d, e) superimposed on the contrasting areas.

(c) Full feature specifications. A complete redundant specification, according to § 4.3.1 (a) and using the features outlined in § 4.3.2, is as follows:

	/a/	/i/	/u/
palatal	−	+	−
labial	−	−	+
pharyngeal	+	−	−
open	+	−	−

(II)

and in pharyngeal environments according to § 4.3.1 (b):

	/a/	/i/	/u/
palatal	−	−	−
labial	−	−	+
pharyngeal	+	+	+
open	+	−	−
uvular	−	+	+

(III)

4.3.4 The pharyngeal allophone rule

This rule transforms the feature matrix (II) into (III) before pharyngeal consonants.

(a) Vowels assume the same place of constriction as the following consonant:

$$\begin{bmatrix} +\text{syl} \\ -\text{cns} \end{bmatrix} \longrightarrow [+\text{pha}] \;/\; \underline{\quad\quad} \begin{bmatrix} +\text{cns} \\ +\text{pha} \end{bmatrix} \qquad \text{(IV)}$$

(b) The place of articulation in (IV) must be adjusted to give the exact location of the constriction - at the uvula for /i/ and /u/, below the uvula for /a/. A suitable solution would be an alpha-rule, where the sign of the feature [uvular] is determined by some characteristic distinguishing /a/ from /i, u/. There are several possibilities:

(i) /a/ is <u>neither</u> palatal nor labial, while /i/ and /u/ are <u>either</u> palatal or labial. A rule based on this difference is tricky to formulate, but one possibility is the following unorthodox adaptation of the alpha-environment convention (Harms 1968:71):

$$\alpha \left\langle \begin{bmatrix} -\text{pal} \\ -\text{lab} \end{bmatrix} \right\rangle \longrightarrow [-\alpha\,\text{uvu}] \qquad \text{(V)}$$

(ii) /a/ is redundantly [+pharyngeal] prior to the transformation, cf. (II) above, while /i/ and /u/ are [-pharyngeal]. This gives

$$[\alpha\text{pha}] \longrightarrow [-\alpha\text{uvu}] \qquad \text{(VI)}$$

(iii) /a/ is redundantly [+open], cf. (II) and (III) above, while /i/ and /u/ are [-open]. This gives:

$$[\alpha\text{opn}] \longrightarrow [-\alpha\text{uvu}] \qquad \text{(VII)}$$

Solutions (VI) and (VII) are much simpler than (V), nor do they require any new convention for expansion. Which of (VI) and (VII) is to be preferred? It is possible that there is a universal relationship between the openness of a back vowel and the lowness of its constriction in the pharynx. If so, a rule based on (VII) would not only generate the desired output but would also express a general phonetic fact. For a complete rule, (IV) and (VII) have been combined:

$$\begin{bmatrix} +\text{syl} \\ -\text{cns} \\ \alpha\text{opn} \end{bmatrix} \longrightarrow \begin{bmatrix} +\text{pha} \\ -\alpha\text{uvu} \end{bmatrix} \Big/ \underline{\qquad} \begin{bmatrix} +\text{cns} \\ +\text{pha} \end{bmatrix} \qquad \text{(VIII)}$$

4.3.5 <u>Consonant adjustment</u>

It has previously been inferred that the pharyngeal vowel allophones probably had fairly small degrees of constriction. This means that the tongue bulge would be very close to the posterior pharyngeal wall. The constriction for /a/ is lower than that for /i/ or /u/. It is a reasonable question to wonder whether (i) the consonant constriction following /a/ will also occur low in the pharynx opposite the bulge (a tongue movement of a few millimetres, possibly a continuation of the same muscular effort that is depressing and retracting the tongue for the vowel), or (ii) whether the consonant constriction following /a/ would be higher up, in the uvular region, according to the standard description of these consonants as uvulars, (meaning more complicated muscular activity involving relaxation of the low vowel constriction andcreation of a new bulge a few centimetres higher up). Assimilation of the consonant to the place of articulation of the vowel, according to the first alternative, is not improbable. The very grave quality of the informant's pharyngeal consonants has already been remarked on in this paper. Some further indication is given by the inferred constriction locations for formant transition terminal spectra in the following words:

word	syllable	F_{1t}, F_{2t}	inferred d_o
aqigsseq	aq-	800, 1200 Hz	5 cms
aqo	aq-	625, 1000 Hz	6 cms
arqa	arq-	750, 1150 Hz	5 cms
qajaq	-jaq	750, 1125 Hz	5 cms
ikeq	-keq	575, 1075 Hz	6.5 cms
eqeq	eq-	500, 1000 Hz	7 cms
	-qeq	500, 1000 Hz	7 cms
neqe	neq-	450, 1050 Hz	7.5 cms.

A very small degree of constriction has been assumed, the constriction being minimal the moment before full consonantal obstruction. The inferred consonant locations are lower after /a/ (d_o 5-6 cms.) than after /i/ (d_o 6-7 cms.). A pharyngeal consonant adjustment rule assimilating the consonant constriction to the vowel constriction, might be as follows:

$$\begin{bmatrix} +\text{cns} \\ +\text{pha} \end{bmatrix} \longrightarrow [\alpha\text{uvu}] \Big/ \begin{bmatrix} +\text{pha} \\ \alpha\text{uvu} \end{bmatrix} \text{———} \qquad \text{(IX)}$$

giving lower consonant constrictions after /a/. This is the extreme opposite of the rival view, that the /k–q/ opposition is a palatal vs. velar contrast rather than velar vs. uvular. The above interpretation of the acoustic data not only suggests that /q/ and /ʁ/ are sub-velar, but also that the place of articulation may occur anywhere in the pharyngeal cavity – at or below the uvula – depending on the preceding vowel. The evidence for this may seem slender, being based on a small sample of speech from one informant, but the point could be settled by reference to radiographs.

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