SPECTRAL AND DURATIONAL PROPERTIES OF VOWELS IN KUNWINJKU

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ABSTRACT

In this paper we investigate the spectral properties of vowels in a Northern Australian language, Kunwinjku. The language illustrates typical vowel dispersion patterns of other languages of the region, and of 5-vowel languages in general. The spectral properties of vowels suggest a system of sufficient dispersion, with phonemic close vowels being realized in the close/mid-close region of the vowel space and with a general anchoring of the system by an open central vowel. Vowel height also interacts with vowel segment duration, with open vowels being generally longer than relatively close vowels.

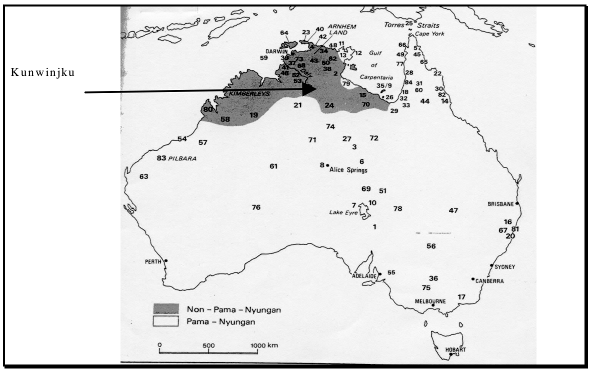
Keywords: vowel inventories, adaptive dispersion, Euclidean distance

1. INTRODUCTION

Dispersion theory [1,2], predicts that vowel contrasts in languages are essentially systemic and relational, not absolute or local. Dispersion theory (DT), or adaptive dispersion, when applied to vowel inventories of languages, suggests that each vowel acts as a repeller in a dynamical system. This is usually cited as the reason why three vowel systems tend to consist of /i/ , /a/, /u/, and five vowel systems tend to consist of /i/ , /e/, /a/, /o/, and /u/. The original hypothesis of DT suggested that vowels are maximally dispersed through the vowel system, although this hypothesis has been modified to suggest that vowels may be sufficiently, rather than maximally dispersed. Articulatory economy counterbalances the perceptual demands for a contrast.

More than 50% of Australian indigenous languages have triangular vowel spaces, whereas only about 9% have inventories consisting of five vowels [1]. Two earlier studies of Northern Australian languages [3] [4] found that rather than illustrating maximum dispersion relative to size of vowel inventory, the acoustic vowel spaces of the four languages investigated (Burarra, Gun-djehmi Mayali, Dalabon, and Kayardild), tend to be "compact" compared to languages with large vowel inventories like English or Swedish, for example, thus illustrating the principle of sufficient dispersion, as opposed to maximum dispersion. Inventories tend to be triangular in shape, anchored with a low central vowel.

Figure 1: A map of Australia showing where Kunwinjku is spoken



The language under investigation in the current study is Kunwinjku, a member of the Pama-Nyungan language grouping of Australian languages and a member of the Gunwinyguan language family. There are approximately one thousand speakers of the language and it is one of the handful of "healthy" indigenous languages that is still being acquired by children as a first language. Figure 1 shows approximately where the language is spoken in the Northern Territory of Australia. Like many Australian languages, Kunwinjku has a relatively rich range of place of articulation contrasts within the stop and nasal series, but has a relatively small phonemic vowel inventory (Table 1). Much of the interest in the phonetics and phonology of Australian languages has focused on the unusual characteristics of the consonant inventories (i.e. the general lack of a manner contrast between stops and fricatives) with very few acoustic phonetic studies of vowels.

The principle aims of the current investigation were to quantify the spectral patterns (F1 and F2) of the vowels of a group of Kunwinjku speakers, and to investigate male/female differences in vowel production. An additional aim was to see whether acoustic patterns of vowels conform to prevailing theories of dispersion. The study was also based on a prosodically controlled experimental corpus unlike previous studies [3,4], which were largely based on isolated wordlists or connected discourse.

2. METHOD AND MATERIALS

2.1 Speakers

The Kunwinjku data were recorded during two field trips July 2005, and between June and August 2006. The first set of recordings was made by the second and third authors in Jabiru in the Northern Territory (N.T.), Australia in July 2005. An additional corpus was recorded at Mamardawerre, an outstation of Kunbarlanja in Arnhem Land N.T. by the second author in 2006.

Table 1 Phonemic inventory- Kunwinjku [5]

	Peripheral		Apico-		Lamino Palatal	Glottal
	Bilab.	Vel.	Alveolar	Retroflex		
Oral Stop (lenis)	p	k	t	ʈ	c	ʔ
Oral Stop (fortis)	pː	kː	tː	ʈː	cː	
Nasal	m	ŋ	n	ɳ	ɲ	
Lateral			l	ɭ		
Rhotic			r	ɹ (ɻ)		
Glide	w				j	

	Front	Central	Back
High	i		u
Mid	e		o
Low		a	

The recordings of three females and three males were analysed in this experiment. Words containing the five vowels of Kunwinjku were chosen from a wordlist prepared by the third author in consultation with a linguist who is familiar with the language. Where possible, the words were placed in two prosodically controlled carrier phrases so that the target words would attract semantic focus and an intonational pitch accent. In most tokens the initial syllable of the focused word was accented.

An example of the speech material is shown below. The words in bold font show two of the tokens that were analysed in this study. The experimental materials are written using the practical orthography that has been developed for the language

(1) **bobo** ngarri-yime
['popo]
' I say 'bobo'

(2) yun yime **bobo** yimen **djobbo.**
['popo] ['copːo]

'don't say 'bobo' say 'djobbo'

2.2 Recording and Analysis procedure

All recordings of the Kunwinjku speakers were carried out in the field, using a Sony ECM-MS957 Electret Condenser microphone and recorded onto a Marantz PMD690 Portable Flash recorder. The .wav files were then transferred to a lap top computer for acoustic analysis.

Vowel segments were annotated using the system of vowel symbols shown in Table 1. The label files were then converted into EMU (ESPS) format at the Phonetics Laboratory at The University of Melbourne. The files were annotated at the word, syllable, phonemic and phonetic levels. F1 ,F2, and F3 values were extracted at the .5 midpoint of all labeled vowels using EMU [6]. Euclidean distances were calculated to compare the vowel space dimensions for female and male speakers. The centroid of each speaker's vowel space and Euclidean distances of each vowel to the centroid were calculated. Separate analyses were conducted for accented and unaccented vowels. Vowel duration was also measured to see whether close vowels tend to be shorter than longer vowels which is generally claimed to be a phonetic universal [7], and to see if there were any effects of accent.

3. RESULTS

Figures 2 and 3 show two ellipse plots of the F1/F2 vowel spaces under focal accented conditions for two speakers from the corpus. Speaker BN is female, and Speaker IB is male. Each ellipse accounts for 90% of the vowel tokens and the label is positioned at the centroid of each ellipse. The vowel space is relatively compressed, with "close" vowels realized as less close [ɪ] or even raised [e], and the open vowel realized as open central [ɐ]. There is a degree of overlap between the ellipses for back vowels and the mid-low front and central vowels. This is most likely due to contextual effects. For example speaker, as shown in Fig. 3, IB tends to produce lower F1/F2 values for /o/ in the vicinity of bilabial consonants. Moreover lower F1 and higher F2 values of /a/ are produced in the vicinity of laminal palatals, for example. All speakers show similar vowel dispersion patterns. There was no significant effect of accent on F1/F2 values across the corpus in keeping with earlier studies of other varieties of this language [3], although there was greater spread of F1/F2 values in unaccented syllables.

Figure 2 F1/F2 ellipse plot of vowels produced in accented contexts by speaker BN (female)

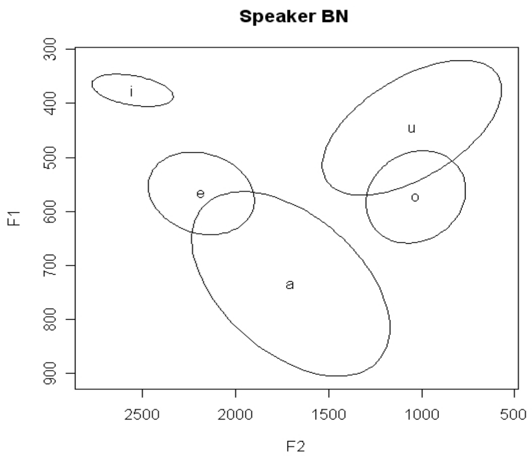


Table 2 lists mean (centroid) F1/F2 values for accented and unaccented male and female speakers for vowel tokens measured in this study. The Euclidean distances were calculated between the vowel centroids and the overall vowel space centroid for males and females separately. The results of this analysis are summarized in the boxplots of Figure 4. For both males and females, each vowel can be distinguished on the basis of the distance from mean value of the each vowel centroid to the centroid of the overall vowel space. All differences were statistically significant ($p<0.001$), with the notable exception of /o/ and /u/ for both male and female speakers. This is clearly illustrated in Figures 2 and 3 where there is overlap between the ellipses for the two vowels. As a general rule /o/ tends to vary more than /u/ throughout the corpus, although the degree of overlap varies from speaker to speaker. Figure 4 also shows that with the exception of /o/, for each vowel, the female vowel space is expanded relative to the male vowel space (/i/ $t=2.99$;$p<0.05$: /e/ $t=2.04$, $p<0.05$: /a/ $t=3.39$, $p<0.001$:, /u/ $t=3.32$, $p<0.01$).

Figure 3. F1/F2 ellipse plot of vowels produced in accented contexts by speaker IB (male)

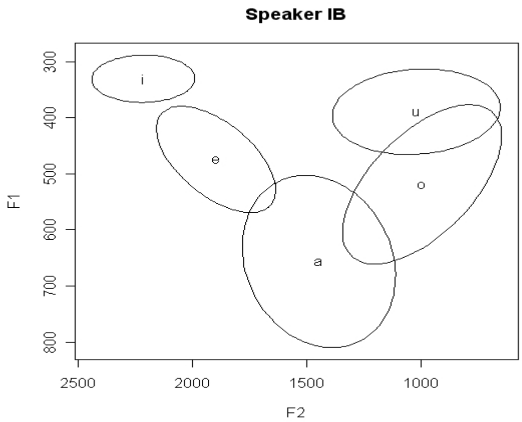


Table 2 Mean Formant frequencies (F1 and F2) for vowels across the corpus

	Male			Female		
	F1	F2	n	F1	F2	n
i	339	2151	139	369	2367	97
e	477	1909	84	593	21601	52
a	611	1471	324	682	1582	223
o	478	1050	113	551	1079	102
u	389	1079	155	436	1086	96

Figure 4. Boxplots of the Euclidean distances to the centroid (Hz) for Female and Male speakers

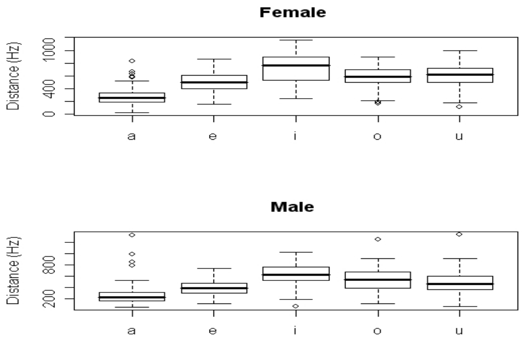


Table 3 summarizes the results of the duration analysis. There was no significant effect of accent although vowel duration appears to correlate more or less with vowel height in these data. For example, the relatively close vowels /i u/ are shorter than the open vowel /a/ for both male and female speakers although the mean differences are only of the order of 20-25 ms so possibly below the Just Noticeable Difference (Males: $t=4.77$; $p<0.0001$: Females:$t=3.72$, $p<0.01$). Moreover there is a correlation between F1/F2 of /a/ and vowel duration irrespective of accent for some speakers, suggesting that for this vowel, there was a simple correlation between 'undershoot' and vowel duration. This requires further investigation, however.

Table 3. Means and standard deviation values for vowels in ms.

	Males		Females	
/i/	85	30	90	39
/e/	95	37	107	62
/a/	112	46	104	49
/o/	122	55	112	48
/u/	97	45	87	57

4. DISCUSSION AND CONCLUSIONS

The acoustic analysis of Kunwinjku vowels presented in this paper suggests that the vowel space is compact and anchored by a low central vowel. Similar findings have been reported for a range of related Northern Australian languages [3,4]. The average female vowel space is also slightly more expanded that the average male vowel space. However, there is also evidence of wide variation in vowel target realizations, largely due to contextual effects (neighbouring) segments. While there was no apparent effect of prosodic focus when vowels associated with a pitch accent were compared to adjacent vowels, this does not necessarily mean that focus has no influence on vowel formant or acoustic duration values. It has been suggested that the entire word can show effects of accentuation.

A "place of articulation imperative" may operate in the consonant system of Australian languages, with a concomitant strong tendency for vowels to coarticulate with neighbouring consonants [8]. Our results lend some preliminary support to this hypothesis. It has also been suggested in earlier work [3] that there may be a relatively straightforward relationship between acoustic duration and target undershoot in vowels in these languages. Preliminary results reveal that F1 and F2 of open vowels in the focused word, correlates with vowel duration although this requires more investigation. Close vowels are shorter than open vowels following a universal pattern [7.In summary, the acoustic analysis presented here suggests that a principle of sufficient dispersion is operating in the vowel system of Kunwinjku like its close neighbours Dalabon and Burarra [3,4], and other languages with small vowel systems [2].

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