The Effects of Prosodic Context and Word Position on Gupapuyngu Vowels

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Abstract

This paper presents an acoustical analysis of vowels in a Northern Australian language, Gupapuyngu, in order to investigate whether vowels in CVCV words differ according to prosodic prominence and word position. It is shown that back vowels are produced with a narrower constriction when prosodically prominent and word-initial. However, in general, vowels tend not to be hyperarticulated under conditions of word-initial prosodic prominence. These results are interpreted in terms of perceptual distinctiveness and articulatory strengthening.

Index Terms: Australian, Gupapuyngu, acoustics, vowel

1. Introduction

There are few acoustic prosodic analyses of Australian Aboriginal languages, e.g., [1] [2]. In this study, we present acoustic vowel data from Gupapuyngu, a previously unexamined language spoken in north-eastern Arnhem Land in Northern Australia. It has twenty-three phonemic consonants with six place of articulation contrasts and a glottal stop and three phonemic vowel qualities with a length distinction. This number of consonant contrasts is maximal in Australian languages. The particular focus in this paper is to investigate the effects of prosodic context and word position on vowels in $CV_1.CV_2$ Gupapuyngu words. There are three aims. The first is to determine whether a given vowel differs in formant frequencies according to prosodic prominence and position within the Gupapuyngu word. The second is to quantify prosodic/positional effects on vowel variability. The third is to quantify such effects on vowel space dispersion. These aims are based on three earlier findings in non-Australian languages: (a) vowels are associated with more extreme F1 and F2 means when prosodically prominent [3] [4] [5] [6], (b) standard deviations are larger and (c) Euclidean distances are smaller when the vowel is prosodically weak [2] [6] [7].

In the Central Australian language, Arrernte, into which there have been many recent experimental investigations (e.g., [8] [9]), there is some evidence for older speakers that the low central vowel is associated with a higher F1 when stressed [8]. With respect to recent experimental investigations into Northern Australian languages, a strong effect of prosodic context has not been found on vowels in the F2 x F1 plane. Fletcher and Butcher [10] found that close vowels produced by a female speaker of Kayardild, which, like Gupapuyngu, has three vowels and a length distinction, tended not to show effects of prosodic context but rather of vowel length (or at least an interaction between accentuation and length). In an analysis of vowel variability and Euclidean distances in a five vowel language of Northern Australia, Kunwinjku (a dialect of Bininj Gun-Wok), Fletcher *et al.* [11] did not find a consistent overall effect of prosodic prominence on vowel centroid values except on variability, which was greater in unaccented vowels. We would expect similar findings in Gupapuyngu.

2. Methodology

2.1. Corpus

The corpus comprises $CV_1.CV_2$ words (Gupapuyngu words typically comprise two or three syllables) in citation form produced by three adult female Gupapuyngu speakers (AM, BT, EG) at a comfortable rate. The speech material was collected and digitised by Andrew Butcher, Flinders University, South Australia. The difficulties in collecting speech material in the Australian context are well known; hence only three speakers were available. Following Tabain [9] and Tabain and Breen [8], only female speakers were considered in order to avoid the issue of speaker normalisation. Recordings were digitised at a sampling rate of 22.05 kHz and with 16-bit resolution. Segments were identified and labelled using the acoustic waveform and wideband spectrograms in EMU [12]. A fundamental frequency signal was also extracted using the accompanying tracking tool (tkassp/f0ana). On the basis of the intonational analysis (which assumed that the vowel carrying a sharp F0 rise to a peak somewhere in or around the syllable rhyme was accentually prominent), vowels were identified as being prominent or not prominent. In the $CV_1.CV_2$ words, such as <gapu> /ˈgapu/, V_1 is prosodically prominent (associated with regular non-final lexical stress) and V_2 is both prosodically weak and word-final. V_1 and V_2 are compared in order to identify the effects of both prosodic prominence and word position on F1 and F2 frequencies in the vowel. There is a total of 556 tokens in the analysis. The number of tokens per speaker and vowel category is given in Table 1 per V_1/V_2 condition, e.g., the entry '61/99' for /a/ (AM) indicates 61 /a/ tokens in V_1 and 99 /a/ tokens in V_2. Long vowels are restricted to V_1. Word-initial and -medial consonants were not controlled for place of articulation.

Table 1. *Number of tokens ($CV_1.CV_2$ words) according to V_1/V_2 condition.*

	a	a:	i	i:	u	u:	Total
AM	61/ 99	39/0	24/ 42	17/0	43/ 70	27/0	211/211
BT	64/ 122	47/0	24/ 51	21/0	47/ 74	44/0	247/247
EG	27/ 60	21/0	0/15	12/0	20/ 23	18/0	98/98
Tot-al	152/ 281	107/ 0	48/ 108	50/0	110/ 167	89/0	

2.2. Acoustic Analysis

F1 and F2 values were measured at the vowel midpoint. Formant frequencies were plotted in the F2 x F1 plane with ellipses with radii of 2.447747 standard deviations (CI=0.95). Euclidean distances were utilised as a measure of vowel space expansion [13].

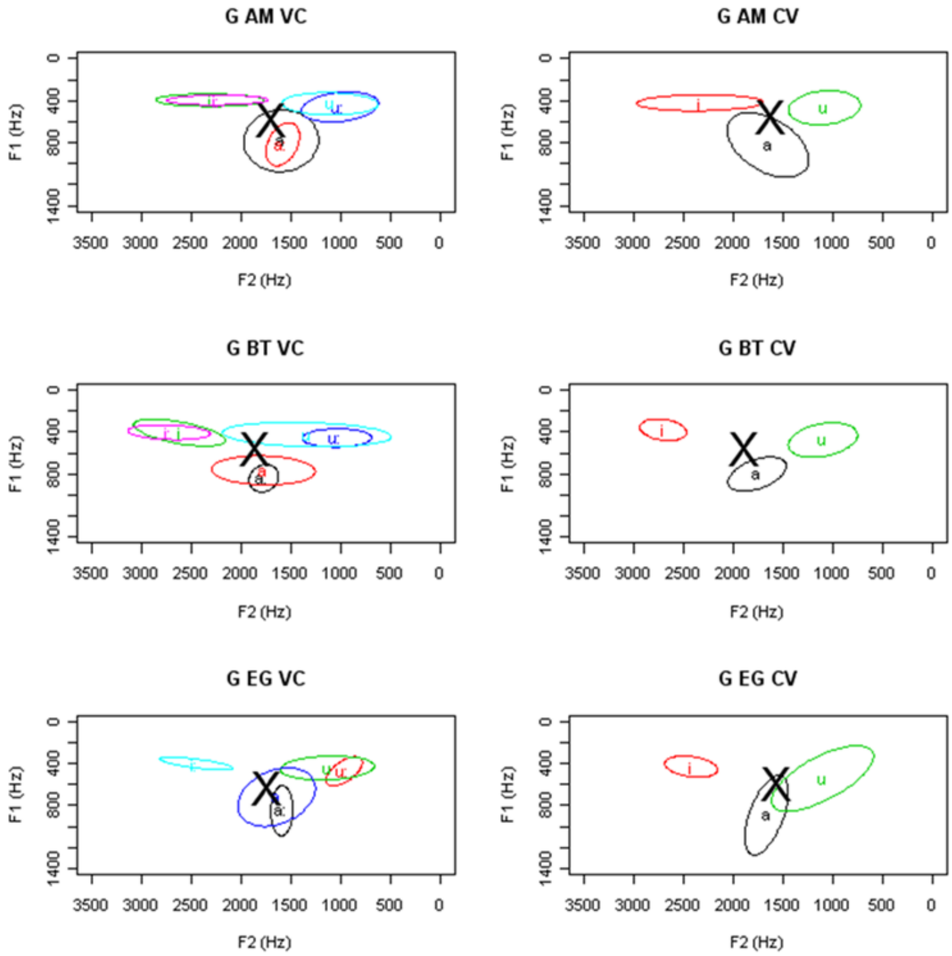

Figure 1: *Gupapuyngu vowels in the F2 x F1 plane for* V_1 *(noted as VC) (left) and* V_2 *(noted as CV) (right) conditions in CVCV words (CI=0.95).*

3. Results

3.1. Phonetic quality

Figure 1 presents an F2 x F1 plot of vowel realisations with standard deviations in V_1 (left) and V_2 (right) contexts per speaker. In V_1, vowel ellipses are well separated for speakers AM (upper) and BT (middle graph). Across speakers, long vowel centroids tend to be more peripheral than short vowel centroids (with the exception of the /i i:/ pair for AM, perhaps due to small sample sizes). In V_2, vowel ellipses tend to be well separated. In both V_1 and V_2, non-front vowels overlap for EG (lower graph), most likely due to word-medial consonant effects.

Welch-corrected t-tests with Bonferroni correction were run per vowel quality, speaker and formant to compare V_1 and V_2 (β=0.0167). In /a/, F1 frequencies are lower in V_1 than in V_2 (AM, t(128)=-2.53, p<0.0167; BT, t(127)=-4.58, p<0.0001; EG, t(65)=-6.37, p<0.0001). For EG, F2 frequencies are also lower in V_1 (t(65)=-6.37, p<0.0001) whereas for AM and BT, comparisons in F2 are non-significant (AM, t(127)=-1.99, p=0.04; BT, t(86)=1.1, p=0.27). In sum, in /a/, the constriction is less open (or 'low') in V_1 than in V_2 and for EG, the constriction is also relatively retracted in V_1.

In /i/, for AM, F1 is lower in V_1, indicating a relatively close vowel (t(57)=-3.84, p<0.0005) whereas for BT, F1 is higher in V_1, indicating a relatively open vowel (t(38.5)=2.64, p=0.018 (approaching β). In F2, comparisons are non-significant (AM, t(56)=-0.12, p=0.9; BT, t(28)=-1.76, p=0.09). For EG, there are insufficient observations. In sum, in /i/, F1 shows inter-speaker variability in the direction of significance. F2 comparisons are non-significant.

Finally, in /u/, F1 is lower in V_1 than in V_2 (AM, t(109)=-3.34, p<0.005; BT, t(116)=-4.59, p<0.0001; EG, t(28.5)=-3.55, p<0.005), *i.e.*, /u/ is associated with a narrower constriction in V_1, indicating a relatively close vowel. In F2,

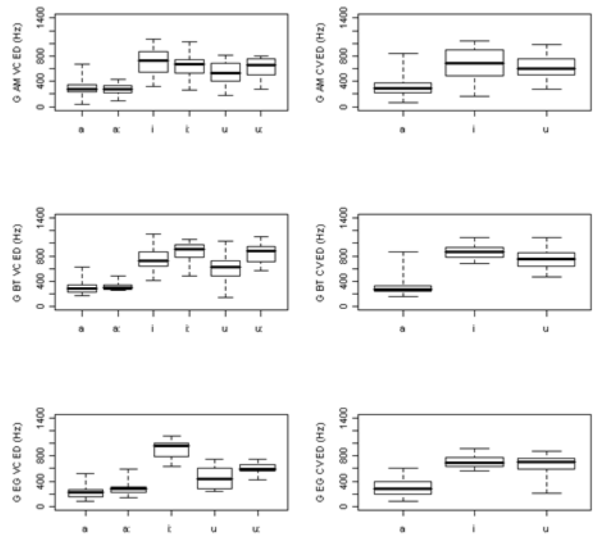

Figure 2: *Boxplots of Gupapuyngu Euclidean distances to the centroid (Hz) for V_1 (noted as VC) (left) and V_2 (noted as CV) (right) vowels in CVCV words.*

speakers vary; for BT, F2 is higher in V_1 ($t(54)=4.99$, $p<0.0001$), indicating a relatively fronted constriction and for EG, F2 is lower in V_1 ($t(28.5)=-3.5$, $p<0.005$), indicating a backed constriction. For AM, comparisons are non-significant ($t(68)=1.03$, $p=0.31$).

3.2. Variability

Acoustic variability in vowels has been shown in Figure 1. Inspection of vowel ellipses suggests that variability in close vowels tends to affect F2 rather than F1, which could indicate that these vowels are specified more for height than anteriority. The considerable F1 variability in V_2 /u/ noted for EG could be associated with a relatively low sample size.

In order to identify prosodic/positional effects on standard deviations, paired t-tests were modified to resemble the standard Levene test for homogeneity of variances whereby the mean value of each condition is subtracted from each (short vowel) value in that condition and the resulting absolute values are tested (where $\alpha= 0.05$) [9]. When vowel categories are collapsed, standard deviations tend not to differ according to prosodic/positional condition. However, for AM, in F2, standard deviations are larger in V_2 ($t(2)=-9.5529$, $p<0.05$), indicating that more variability exists in the prosodically weak, word-final vowel. All other comparisons are non-significant.

3.3. Dispersion

Figure 2 shows that in both V_1 and V_2 the non-central vowels are associated with larger Euclidean distances. In V_1, AM (upper graph) produces /a a:/ with low values at 311 and 299 Hz, respectively. /i i:/ are most distant from the grand centroid (the centre of the vowel space) at 700 and 677 Hz, respectively, indicating fairly close vowels. /u/ is intermediate at 570 Hz, while /u:/ is closer to /i i:/ at 653 Hz. The vowels then separate into two main groups of central and non-central vowels. For BT (middle graph), /a a:/ are closest to the grand centroid at 326 and 317 Hz, respectively. /u/ is somewhat low at 609 Hz, indicating a close-mid and central-back vowel, whilst /u:/ is much further from the grand centroid at 834 Hz, and clusters with /i i:/ with regard to distances at 771 and 817 Hz, respectively. For EG (lower graph), /a/ is closest to the grand centroid at 219 Hz and /a:/ is also quite close at 281 Hz. /u u:/ are intermediate at 441 and 660 Hz, respectively; the long vowel being more peripheral. /i:/ is furthest from the grand centroid at 907 Hz, indicating a relatively close and front vowel. The vowels then form three 'groups': /a a:/, /u u:/, and /i/.

In V_2, there is a clear anchoring of the vowel space by the low central vowel. For AM (upper graph), /a/ is closest to the grand centroid at 315 Hz, and the close vowels, /i u/, are further from the centroid at 672 and 619 Hz, respectively. These vowels therefore form two groups: central and non-central. For BT (middle graph), /a/ is again closest to the grand centroid, at 287 Hz, but in this case, /i/ is furthest at 906 Hz and /u/ is intermediate at 697 Hz. There is a roughly even spacing between the three vowels on this measure. For EG (lower graph), the vowels form two groups of central and non-central vowels; /a/ is closest to the grand centroid at 306 Hz, /i/ is furthest at 710 Hz, and /u/ is slightly less distant at 650 Hz.

In order to compare dispersion in the vowel space across conditions, the nonparametric Wilcoxon rank sum test with continuity correction was applied to paired samples. Results reveal that Euclidean distances do not differ according to prosodic/positional condition (AM, $V=9987$, $p=0.18$; BT, $V=15791$, $p=0.67$; EG, $V=2221$, $p=0.47$), which indicates a lack of vowel space expansion in V_1.

4. Discussion

Trends in the results relating to prosodic context and word position are summarised in Table 2.

Table 2. *Summary of statistical results.*

Dependent variable	Result
F1 frequency	F1 is lower in /a u/ in V_1. Inter-speaker variation in /i/.
F2 frequency	Tendency towards no effect in /i a/. Inter-speaker variation in /u/.
Standard Dev.	Tendency towards no effect.
Euclid. Dist.	No effect.

4.1. Phonetic quality

Overall, it can be said that /i/ tends to be produced with a narrower (and fronter) constriction than /u/. However, both appear to be close-mid rather than fully close vowels. /a/ is realised as a low central vowel, which may be retracted towards the pharynx. Contrary to the claim (see e.g., [6]) that vowels are associated with more extreme F1 and F2 means when prosodically prominent and a more general hypothesis of overall sonority expansion related to degree of accentual prominence, the speakers appear to produce more open non-front vowels in the prosodically weak, word-final position, perhaps under conditions of final lengthening (see e.g., [2] [10] [14]). This result is inconsistent with a previous finding for older speakers of Central Arrernte that the low central vowel has a higher F1 and is therefore more open when stressed [8]. /i/ tends not to show effects of prosodic condition (see [10]) and /a/ tends not to show prosodic/positional effects in F2, however the results for EG suggest a retraction of the constriction of both non-front vowels in the word-initial prosodically prominent condition. /u/ is produced with a narrower constriction when prosodically prominent and word-initial. In F2, while AM does not show an effect of prosodic/positional condition on /u/, BT shows a fronted /u/ in the word-initial prosodically prominent condition. Long (word-initial, prosodically prominent) vowels tend to be more peripheral than short vowels, as was found for low vowels in Kayardild [10].

4.2. Variability

It was hypothesised that variability at the vowel midpoint is greater when the vowel is prosodically weak. However, in the majority of cases we investigated, the effects of prosodic/positional condition on variability are insignificant. Nevertheless, for AM, F2 variability is greater when the vowel is weak (and word-final) in agreement with previously reported results for Kunwinjku [11].

4.3. Dispersion

A central aim of our investigation was to determine whether Euclidean distances are smaller for the prosodically weak vowel, V_2, than for V_1. Results reported in this paper indicate that prosodic and word positional effects on Euclidean distances are not significant, *i.e.*, acoustic vowel spaces are not significantly more dispersed when vowels are prosodically prominent (see e.g., [11]), perhaps because it is the consonant immediately following the prominent vowel that is hyperarticulated (as shown by Butcher and Harrington [15] for Warlpiri) and/or because of the effects of word-final pre-boundary lengthening (see [10]).

Given a general compactness and some non-front vowel overlap, it may be concluded that vowels are not widely dispersed within the available phonetic space. Gupapuyngu appears to display minimal distinctiveness in conformity with other Australian languages such as Warlpiri, Burarra, Dalabon, Bininj Gun-wok, Kayardild and Kunwinjku [10] [11] [16].

5. Conclusions

In the present study, vowels tend not to be ‘hyperarticulated’ or made more peripheral under conditions of word-initial prosodic prominence. However, there is inter-speaker variation that should be taken into account, in particular, in the effects of prosody and word position on /i/ with regard to height and on /u/ with regard to anteriority. Moreover, multiple non-prosodic factors such as the distribution of adjacent consonants are likely to affect vowel variability and dispersion [17]. It has been argued [7] that localised hyperarticulation, specifically, greater peripherality, in accented syllables enhances vocalic perceptual distinctions. Therefore, our findings suggest that the maintenance of perceptual distinctions between the large number of place of articulation contrasts in Gupapuyngu is prioritised over the maintenance of perceptual distinctions between vowels [18]. Future work will extend this study to several other Australian languages in order to investigate whether the size of vowel and consonant inventories affects the distribution and magnitude of variability of vowels in acoustic vowel spaces.

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7. References

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