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Central vowels in Kamu and Larrakia

Mitchell Browne, Mark Harvey, Michael Proctor and Robert Mailhammer

Macquarie University, University of Newcastle, Macquarie University and Western Sydney University

ABSTRACT
The vowel inventories of Kamu and Larrakia each consist of peripheral /i/-/u/-/e/-/a/-/o/ and another non-low vowel that has not been phonetically characterized. Descriptions of similar six-vowel systems in Western Top End languages offer inconsistent accounts of the non-peripheral vowel, but no instrumental analysis has yet been conducted. Acoustic and phonological analysis reveals that the sixth vowel is best characterized as /ʉ/ in Kamu and /ɨ/ in Larrakia. Height and backness are the critical phonetic properties that differentiate the non-peripheral vowel from the other vowel phonemes in each language. These results enhance our understanding of the structure and properties of higher cardinality vowel systems in Australian languages, and the typology of six-vowel systems more generally.

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1. Introduction

The vowel systems of Australian languages show limited variation. Nearly all vowel inventories involve /a/-/i/-/u/ and most of the variation between individual language inventories lies in the presence vs absence of either or both of the mid vowels /e, o/ (Busby, 1980; Fletcher & Butcher, 2014; Round, 2023). Beyond the variation involving the mid vowels, Round (2023, p. 102) notes that "the presence or absence of non-low central vowels such as /ə, ɨ/" is an important parameter in variation and therefore an important factor in the typological analysis of Australian vowel systems.

In this paper, we expand the database for the evaluation of phonetic, phonological and typological analyses by examining two languages, Kamu and Larrakia, whose vowel inventories include a non-low vowel that contrasts with both /i/ and /u/. To date there has been no systematic phonetic analysis of the vowel inventory of either language. These two languages form part of a contiguous block of six languages in the Western Top End (Map 1), whose inventories include a similar vowel (Table 1).

In his survey of the languages of the Daly River region, which includes all the languages in Table 1 other than Larrakia,[1] Tryon (1974) uses the symbol <ö> to represent this

CONTACT Mitchell Browne mitchell.browne@mq.edu.au

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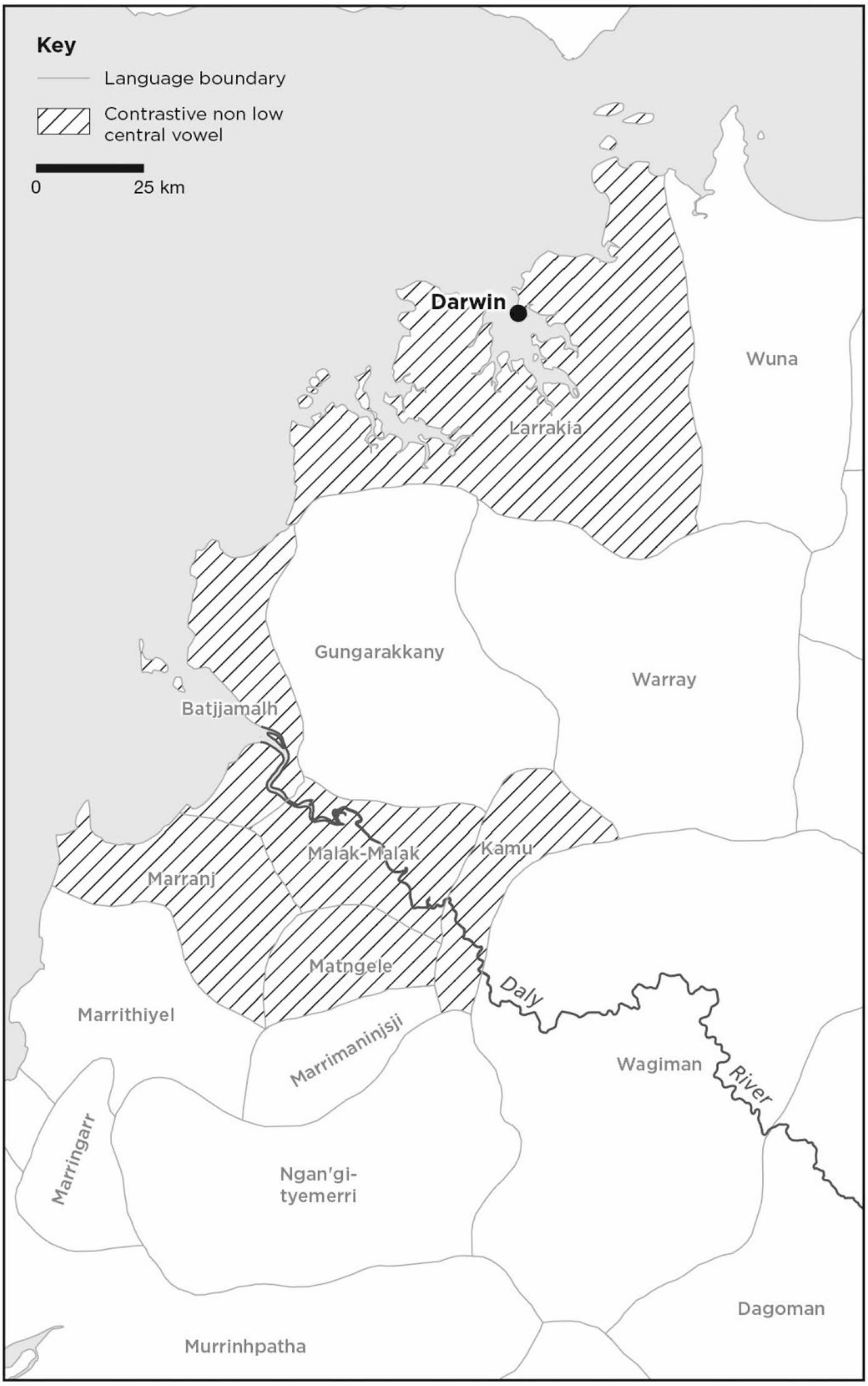
[1]Tryon (1974, p. 95) includes Marri Tjevin in the set of languages with an <ö> vowel. However, none of the subsequent fieldwork with Marri Tjevin speakers reports this vowel (John Mansfield p.c.). Marri Tjevin forms part of a dialect grouping including Marrithiyel, Marridan and Marri Amu, and there is very limited variation between the four varieties (Green, 1989, pp. 8–9). Marrithiyel is the most extensively described variety, and it does not have an <ö> vowel. Consequently, we do not include Marri Tjevin in the areal grouping of languages with a similar vowel.



Map 1 Western Top End languages with a non-low vowel contrasting with /i, u/

Table 1 Western Top End languages with a non-low vowel contrasting with /i, e/

Language	Known dialects
Bachamal	Bachamal (also known as Wadjiginy), PunguPungu
Kamu	
Larrakia	
MalakMalak	MalakMalak, Tyeraity
Marranj	Emmi, Marranunggu, Mendhe
Matngele	

phoneme, suggesting a mid-front rounded vowel. However, across the materials on these languages, there is considerable variation in the descriptions and representations of these non-peripheral vowels (Table 2). Notably, these descriptions are not founded on quantitative analysis.

The phonetic characteristics associated with these different representations vary considerably, most importantly in backness, height and rounding (Table 3).

There is evidently some uncertainty about the phonetic and phonological characterization of these vowels in these languages. In this study, we examine the vowel systems of Kamu and Larrakia to clarify their phonetic properties. We undertake a quantitative analysis of Kamu and Larrakia to determine how these vowels are best described, and how they pattern with respect to the other vowels in each language. The results have implications for the phonological structure of Australian languages with larger vowel inventories. We seek to answer two primary research questions:

(1) What are the acoustic properties of the Kamu and Larrakia vowel systems?
(2) What phonetic properties best describe the contrastive features of these systems?

To investigate these research questions, we first review previous analyses of central vowels in Australian languages (§2) and provide background information on Kamu and

Table 2 Descriptions of [-back, -low] vowels in languages of the Western Top End

Language	Representation	Description in source materials
Bachamal	ø	front, rounded (Ford, 1990, pp. 35–39)
Emmi	ɵ	close-mid, central, rounded (Ford, 2011, pp. 35–39)
Larrakia	ʉ, ɵ	centralized (Capell, 1984, pp. 56–57)
MalakMalak	ö	mid, close, retracted, front, unrounded (Birk, 1976, pp. 10–12)
Kamu	ö, oe	unrounded, resembling [ʊ] (Harvey, 1989, p. 22)
Marranunggu	œ	mid, central, neutral (Tryon, 1970, p. 6)

Table 3 Phonetic characterization of vowel representations in Table 2

Symbol	Backness	Height	Rounding
ɨ	central	high	unrounded
ʉ	central	high	rounded
ɵ	central	high-mid	rounded
ə	central	mid	unrounded
ø	front	high-mid	rounded
œ	front	low-mid	rounded

Larrakia (§3). Section 4 explains the methods used in this study, and results are presented in §5. Section 6 discusses the findings with particular reference to the phonological characterization of the vowel systems of these languages and how best to represent the vowel phonemes.

2. Quantitative research on central vowels in Australian languages

Research into phonemically contrastive non-low central vowels in Australian languages has been limited. Quantitative phonetic studies have been conducted in four languages: Central Arrernte (Tabain & Breen, 2011), Dalabon (Fletcher & Butcher, 2002, 2003), Kaytetye (Harvey et al., 2023) and Wunambal (Loakes et al., 2015).

2.1 Central Arrernte

Tabain and Breen (2011, pp. 69–70) propose that Central Arrernte has a three-vowel system /i/-/ə/-/a/. Acoustic phonetic analysis of data from four speakers revealed that /ə/ was higher than /a/ and characterized by greater variation in realization. Because /i/ is considered a marginal phoneme, the /i/–/ə/ opposition was not analyzed, so it is not clear exactly how the non-low vowels are phonetically differentiated in Central Arrernte.

2.2 Dalabon

Fletcher and Butcher (2002, 2003) demonstrate that there are six distinct vowels /i, e, a, o, u, ɨ/ in conservative varieties of Dalabon. The sixth vowel /ɨ/ is realized at a high, central position in the F1–F2 plane in all prosodic contexts. Phrase-finally, high back /u/ merges with /ɨ/, and this merger is complete for some Dalabon speakers who use a five-vowel inventory /i, e, a, o, u/.

2.3 Kaytetye

Harvey et al. (2023) propose that Kaytetye has a four-vowel inventory /i, a, ə, u/. The non-low central vowel is produced with considerable allophony, but is described as /ə/ because all realizations are clustered in the middle of the F1–F2 acoustic plane, central to the /i–u/ continuum and higher than /a/.

2.4 Wunambal

Loakes et al. (2015) examine data from three male speakers of the northern dialects of Wunambal, which use a six-vowel system /i, e, a, o, u, ɨ/. Realizations of /ɨ/ were consistently central, but varied in height from mid [ə] to high [ɨ] across words and speakers.

These studies provide important insights into the phonetic properties of non-low central vowels in Australian languages, and the ways that they pattern within different vowel systems. In each language, this additional vowel is central, but variable in height. However, an important property for the phonetic and phonological characterization of these central vowels which has not been addressed systematically in these studies is rounding.

3. Kamu and Larrakia

3.1 Language background

Kamu (ISO-639-3 xmu) is an Eastern Daly Non-Pama-Nyungan language associated with the area between the Daly River Crossing and the upper Reynolds River. Larrakia (ISO-639-3 lrg) is a Non-Pama-Nyungan language spoken in the Darwin area.

Neither Kamu nor Larrakia were spoken regularly after World War 2, and no first-language speakers of either language remain. Consequently, the materials available on both languages are limited. The Kamu data come from recordings made with a first-language speaker, Elsie O'Brien, in 1989–1992 (Harvey, 1989). The Larrakia data come from recordings made with a first-language speaker, Topsy Secretary, in the 1990s (Harvey, n.d.). Appendix 1 provides a brief grammatical overview of the two languages.

Both sets of recordings formed part of community-led language documentation and description projects. The Dak Milng Corporation has facilitated and managed ongoing Kamu community input into Kamu language revitalization programmes. Larrakia Nation Aboriginal Corporation and the Larrakia Development Corporation have facilitated and managed ongoing Larrakia community input into Larrakia language revitalization programmes. The Kamu language project was managed through the University of Newcastle (Ethics approval H-2022-0293). The Larrakia language project was managed by Larrakia Nation Aboriginal Corporation.

Kamu resources include a lexicon of approximately 900 roots and materials covering basic morphological and syntactic structures. For Larrakia, a lexicon of approximately 650 roots and materials provides a limited coverage of the basic morphological and syntactic structures. The limitations of the Larrakia materials are such that it is not possible to evaluate all potential analyses of these materials. We discuss situations where these limitations bear on analyses presented in this paper.

Previous work on Kamu has focused on basic linguistic description (Harvey, 1989; Tryon, 1974, pp. 62–69) and historical relations (Harvey, 2003a, 2003b). Previous work on Larrakia has focused on basic linguistic description (Capell, 1984; Harvey, n.d.), the kinship terminology (Harvey, 2023) and historical linguistics (Black, 2016).

3.2 Kamu and Larrakia vowel phonologies

Kamu has a six-vowel inventory, including five peripheral vowels /i, e, a, o, u/ whose phonemic status is demonstrated and phonetic properties are described in Harvey (1989). The sixth vowel – represented as V because its phonetic properties and representation are the points at issue – is attested in at least 40 lexical items in the Kamu lexicon, including two grammatical morphemes: the pronominal prefix allomorph /pV-/ '3 Augmented Subject'; and the verb root /wVʎe/ which appears only as an auxiliary. Minimal and subminimal pairs illustrating the contrast between V and the other five vowels of Kamu are illustrated in (1):

(1) Kamu minimal pairs illustrating vowel contrasts

/V/ vs. /i/	/pVn/	'black plum'	/pin/	'holey'
/V/ vs. /e/	/wVrVr/	'leaf'	/werer/	'to spoil'
/V/ vs. /a/	/tVt/	'to sit'	/tat/	'to die'
/V/ vs. /o/	/ŋŋVr/	'nail, shell'	/ŋŋor/	'to sharpen'
/V/ vs. /u/	/tVn/	'to thunder'	/tun/	'moon'

Larrakia also has a six-vowel inventory, including the same five peripheral vowels /i, e, a, o, u/ (Harvey, n.d.). The sixth vowel V is attested in at least 55 lexical items in the Larrakia lexicon, including in the grammatical morpheme /gVlV/ 'not'. Minimal and subminimal pairs illustrating the contrast between V and the other five vowels of Larrakia are illustrated in (2):

(2) Larrakia near-minimal pairs illustrating vowel contrasts

/V/ vs. /i/	ˈtVtVt	'to tie up'	ˈtitit-ma	'peewee-III'
/V/ vs. /e/	ˈpVlppVl	'to nod'	ˈpelppe-la	'stone-II'
/V/ vs. /a/	ˈmVr-ma	'lung-III'	ˈmar-ma	'boat-III'
/V/ vs. /o/	mVˈmVlkkiŋ	'full up'	mi-ˈn-olkka	'III-MIN-lots'
/V/ vs. /u/	ˈpVlppVl	'to nod'	ˈpulppu-la	'passionfruit-II'

Larrakia also distinguishes length in the low vowel, but because long /aː/ is attested in only a few roots, this phonemic contrast is marginal. The /a/–/e/ contrast is problematic. Phonetically, [æ] realizations are very common and difficult to distinguish from [ɛ] realizations; however, it appears that there is a phonemic opposition in which [æ] is an allophone of /a/ and [ɛ] an allophone of /e/ (Harvey, n.d.). This is one issue where more extensive materials would inform a better supported analysis.

In both Kamu and Larrakia, /o/ is a quantitatively marginal vowel. In both languages, it is found only in lexical roots and usually in the syllable bearing primary stress. However, the diachronies of /o/ appear to be distinct between the two languages. In Kamu, /o/ is almost certainly a recent innovation introduced through loans from Wagiman and Warray, which border on Kamu to the north and east. In both Wagiman and Warray, /o/ is quantitatively well attested. By contrast, in Larrakia, the /o/ vowel appears in roots in closed paradigms and appears to be of some antiquity.

The prosodic structure of Kamu resembles that of many other Australian languages (Harvey, 1989), and appears to be governed by the two principles (3) and (4) (Baker, 2014, pp. 153–160; Dixon, 2002, pp. 557–558; Fletcher & Butcher, 2014, pp. 113–115):

(3) All polysyllabic morphemes have a (metrical) prosodic prominence aligned with their left boundary.
(4) All lexical morphemes have a (metrical) prosodic prominence aligned with their left boundary.

Consequently, the only morphemes which lack a prosodic prominence in Kamu are grammatical morphemes which are not polysyllabic. Prosodic prominences of this kind in Australian languages are usually analyzed as stress prominences (Baker, 2014, pp. 153–160).

Under this approach, stress placement is predictable in Kamu, so we do not indicate metrical structure in the Kamu data. In Larrakia, the principles in (3) and (4) account for most stress placements. However, there is a substantial minority of cases where stress placement does not align with the left boundary. The stress placements in these cases do not appear to be fully phonologically predictable.

4. Methods

4.1 Source materials and database construction

The original audio materials for Kamu and Larrakia were recorded on audio cassette in comparatively quiet environments. The Kamu audio was recorded in 1989–1992 and the Larrakia audio was recorded in the 1990s. Audio data were digitized and transcripts aligned in ELAN (Max Planck Institute for Psycholinguistics, The Language Archive, 2025). Lexical items in which each of the six vowels /i, e, a, o, u, V/ appears in tonic position were identified in each dataset, from which word forms appearing with high frequency within the overall digital audio and text corpus were selected for Kamu (Appendix 2) and Larrakia (Appendix 3). Tokens of each word form were extracted manually from the corpus and compiled to create a database of each language for analysis. Because the digitized data were acquired in sub-optimal acoustic recording conditions more than 30 years prior to this analysis, complementary methods of analysis and data validation were developed to extract the most robust metrics appropriate for the goals of the study from as much data as possible.

4.2 Formant analysis

Acoustic boundaries of target vowels were manually located by inspecting time aligned speech waveforms and spectrograms in Praat ($F_{max} = 6{,}000$ kHz, Gaussian windows, Window width = 5 ms, Dynamic range = 70 dB) (Boersma, 2001). Duration, pitch and formant trajectories were tracked over each vowel interval using a Praat script adapted from García (2017). Four formants were tracked using 14-order LPC analysis of overlapping 30 ms windows with a time step of 10 ms, up to a ceiling of 4,600 kHz. Although formant tracking parameters were dynamically optimized for each dataset, intrinsically low signal-to-noise ratios resulted in less consistent tracking – of higher formants in particular – for some tokens. To reduce errors arising from automatic formant mis-tracking, fundamental frequency and formant estimates (F1–F4) were calculated from the mean values of the formant trajectories over the central 30 ms of the total vowel duration.

4.3 Data validation

Formant estimates extracted from all tokens of each vowel were compiled in R (R Core Team, 2024). Outliers were successively removed from the analysis dataset using two methods:

(i) Tokens with a third formant frequency beyond two standard deviations from mean F3 for each category were removed.
(ii) Distributions of first and second formant frequencies in the remaining tokens were analyzed to identify extreme acoustic outliers. Mean F1 and mean F2 were calculated

for each vowel category. The Mahalanobis distance in the acoustic plane of each exemplar to the category mean was calculated using the nipnTK package (Myatt & Guevarra, 2020). Distances for each token were compared against a chi-square distribution (two degrees of freedom), and tokens where the chi-square statistic of the Mahalanobis distance was less than 0.05 were removed.

An example of a token removed in the data validation is given in Figure 1. This token was excluded because the estimated mean F1 (1,063 Hz) and F2 (2,189 Hz) values exceed acceptable limits from the means for that vowel category (i.e. the chi-square statistic of the Mahalanobis distance was less than 0.05). Inaccuracies in automatic formant tracking in this token and others excluded from the analysis dataset according to these criteria are primarily due to the low SNR of the digitized recordings.

After validation and filtering of the original dataset using these methods, 1,449 Kamu vowel tokens and 841 Larrakia vowel tokens remained for analysis (Table 4).

4.4 Statistical modelling

Statistical modelling was conducted to examine relationships between formant frequencies and phonemic identity. In order to investigate the acoustic distribution of vowels in

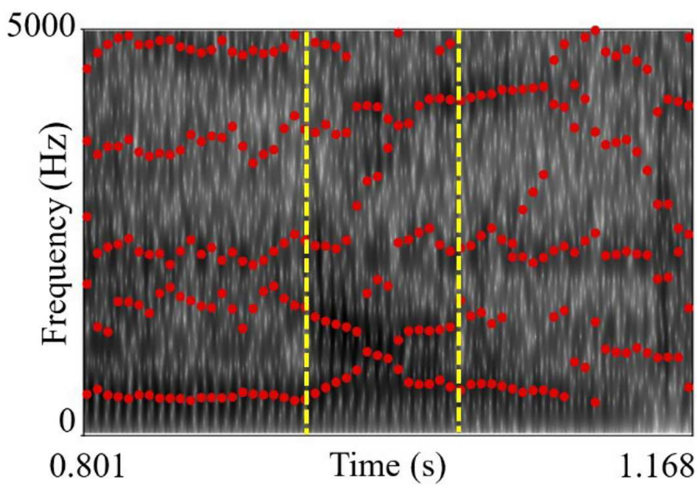


Figure 1 Spectrogram of example /u/ token excluded from analysis. Vertical dashed lines demarcate initial and final vowel boundaries; superimposed red dots indicate automatically-tracked formant trajectories

Table 4 Number of vowel tokens analyzed (excluded)

Vowel	Kamu		Larrakia	
/i/	272	(35)	81	(9)
/e/	289	(32)	150	(18)
/a/	269	(40)	234	(24)
/o/	187	(24)	93	(9)
/u/	256	(27)	143	(14)
/V/	176	(22)	140	(17)
Total	1,449	(180)	841	(91)

each language, we examined distributions of formants. Vowel height was analyzed using F1, and vowel backness was analyzed using F2 frequencies. For rounding, we consider two measures: F3 and F3−F2, the latter of which is typically the most robust acoustic correlate of rounding in vowels (Stevens, 2000). Each of these measures was analyzed using linear mixed-effects models (LMM) in R (Bates et al., 2015; Kuznetsova et al., 2017). Specifically, vowel token formant frequencies (5) and durations (6) were modelled as a function of phonemic category with random effects of word:

(5) $F_i \sim \text{Vowel} + (1|\text{Word})$
(6) $\text{Dur} \sim \text{Vowel} + (1|\text{Word})$

LMMs were estimated using REML and the *nloptwrap* optimizer. The 95% confidence intervals and *p*-values were computed using Wald *t*-distribution approximations.

5. Results

5.1 Acoustic vowel distributions

First and second formant frequencies of the 1,449 Kamu vowel tokens are plotted in the acoustic vowel space shown in Figure 2. Formant frequencies of the 841 Larrakia

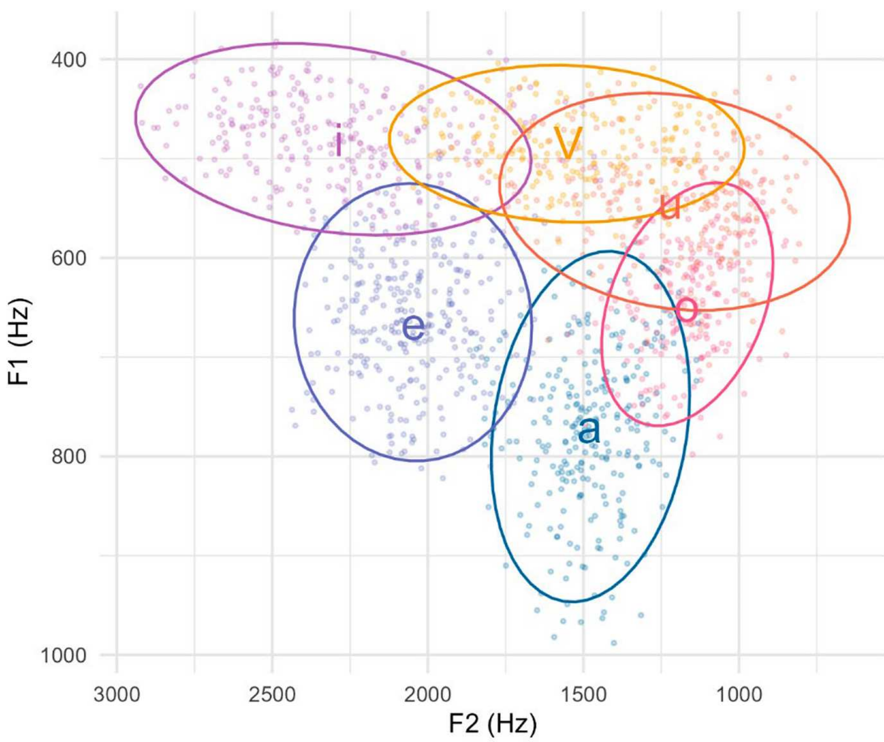


Figure 2 Distribution of Kamu vowels in the F2–F1 plane. Ellipses centred on mean formant frequencies delimit 95% confidence intervals

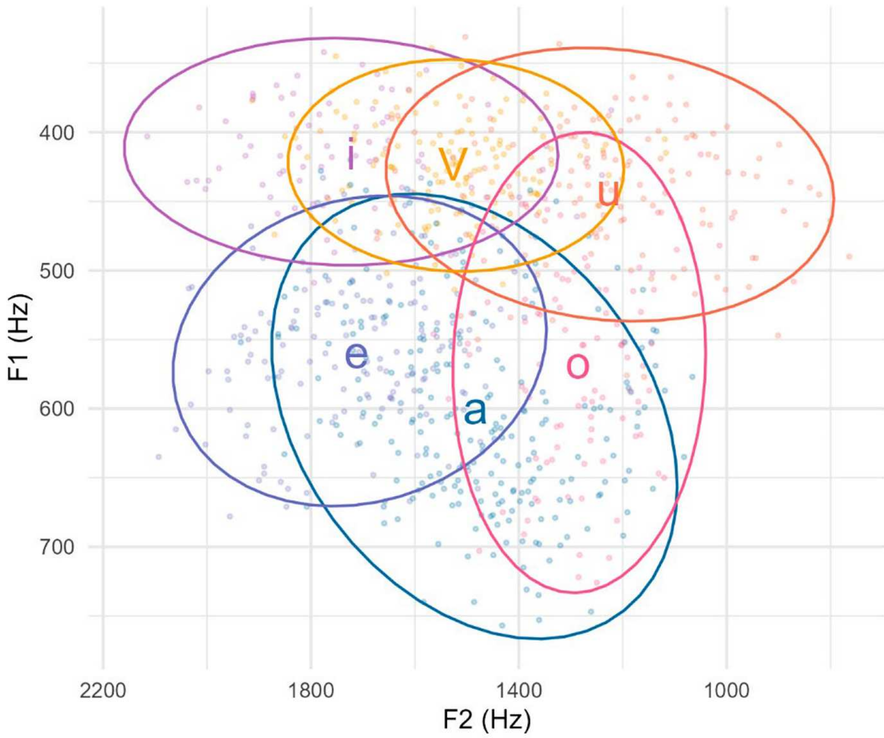


Figure 3 Distribution of Larrakia vowels in F2–F1 plane. Ellipses centred on mean formant frequencies delimit 95% confidence intervals

vowel tokens are plotted in Figure 3. Ellipses delimiting 95% confidence intervals are centred on mean F1 and F2 frequencies for each vowel phoneme. Mean formant frequencies for the six Kamu and Larrakia vowels are summarized in Tables 5 and 6, respectively.

5.2 Vowel duration

Boxplots showing the distribution of duration for each vowel type are given in Figure 4 (Kamu) and Figure 5 (Larrakia). In Kamu, V is longer than /i/ ($\beta = 24$ ms; $t(1{,}410) = 3.4$; $p < 0.01$) and /u/ ($\beta = 16$ ms; $t(1{,}410) = 2.3$; $p = 0.02$), but does not differ significantly in duration from /a, e, o/. In Larrakia, V is shorter than /o/ ($\beta = 29$ ms; $t(833) = 3.0$; $p = 0.003$), but does not differ significantly in duration from any other vowels.

Table 5 Formant frequencies of Kamu vowels

Vowel	Mean (Hz)			Median (Hz)			Std. Deviation (Hz)		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
/i/	481	2,287	3,103	478	2,293	3,121	44	296	293
/e/	666	2,046	2,937	667	2,055	2,901	64	175	326
/a/	770	1,480	2,984	766	1,484	2,998	83	148	302
/o/	648	1,167	3,019	645	1,165	3,042	56	131	257
/u/	544	1,221	2,921	540	1,154	2,952	52	255	263
V	484	1,549	3,064	486	1,566	3,070	36	248	195

Table 6 Formant frequencies of Larrakia vowels

Vowel	Mean (Hz)			Median (Hz)			Std. Deviation (Hz)		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
/i/	415	1,723	2,616	417	1,765	2,599	36	196	196
/e/	559	1,712	2,681	558	1,692	2,674	52	160	161
/a/	599	1,483	2,627	608	1,486	2,638	73	179	188
/o/	566	1,286	2,699	554	1,279	2,714	75	113	197
/u/	441	1,227	2,560	438	1,231	2,564	46	199	146
V	423	1,526	2,627	423	1,519	2,626	35	151	155

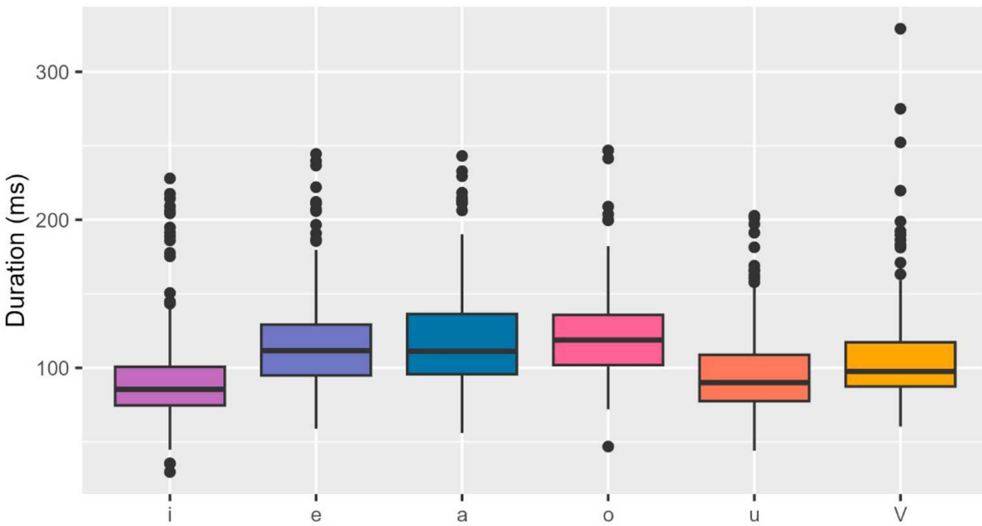


Figure 4 Boxplots of duration (ms) for the six vowel phonemes of Kamu

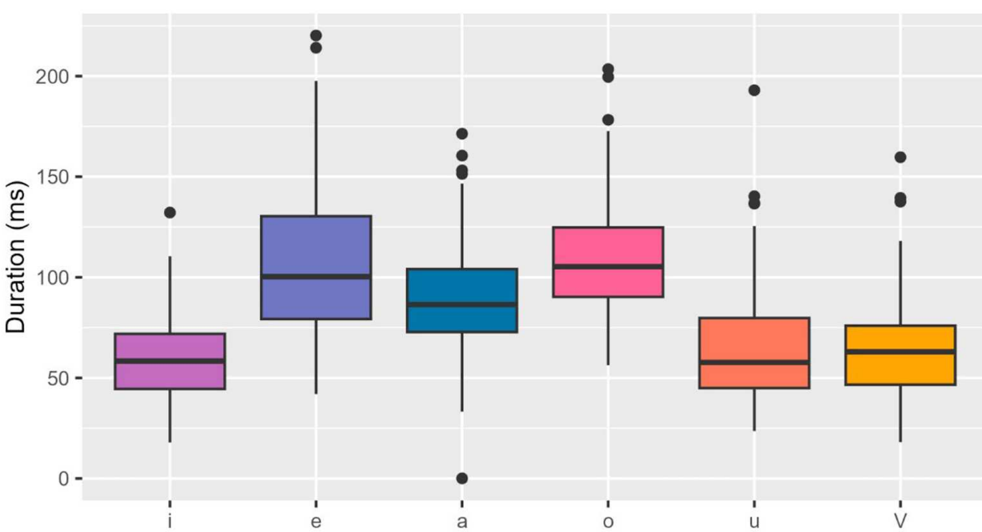


Figure 5 Boxplots of duration (ms) for the six vowel phonemes of Larrakia

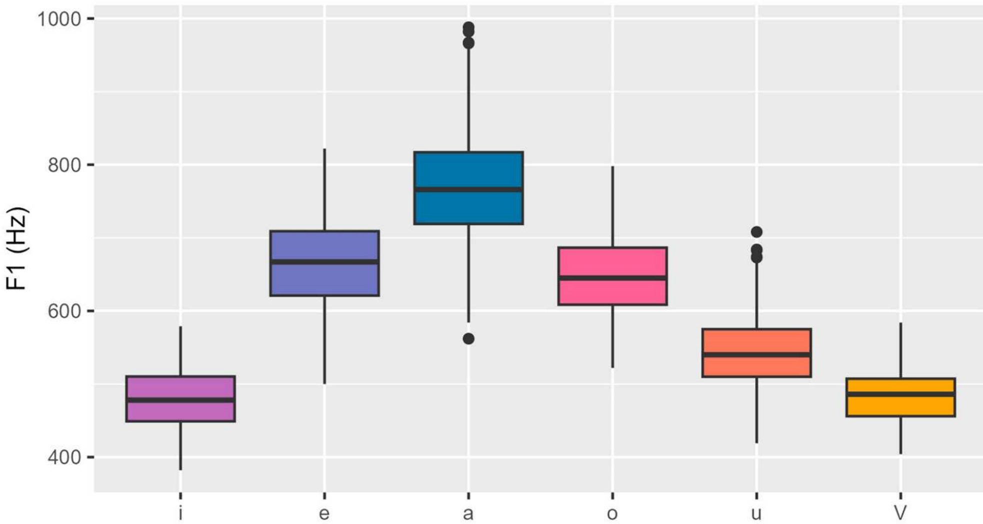


Figure 6 Boxplots of F1 (Hz) for the six vowel phonemes of Kamu

5.3 Vowel height

We analyzed the vertical organization of vowels in each language by modelling the relationship between F1 and vowel category. Boxplots of F1 for Kamu (Figure 6) reveal that /i-u-V/ are produced with the lowest first formant frequencies. A linear mixed model of F1 by phoneme with Word as a random effect found no significant difference between V and /i/, but F1 differences between V and all other vowels (Table 7).

Boxplots of F1 for Larrakia (Figure 7) reveal that /i-u-V/ are produced with the lowest first formant frequencies. A linear mixed model of F1 by phoneme with Word as a random effect found no significant difference between V, /i/ and /u/, but F1 differences between V and all other vowels (Table 7).

5.4 Vowel backness

We analyzed the horizontal organization of vowels in each language by modelling the relationship between F2 and vowel category. Boxplots of F2 for Kamu (Figure 8) reveal

Table 7 LMM results: F1 by phoneme

	Parameter	beta	SE	*df*	*t*	*p*	
Kamu	Intercept (V)	485.7	8.1	137.2	59.9	<0.001	***
	/i/	1.9	10.8	124.0	0.2	0.860	
	/e/	182.3	10.9	113.7	16.7	<0.001	***
	/a/	285.8	10.7	122.6	26.6	<0.001	***
	/o/	161.3	11.5	123.6	14.0	<0.001	***
	/u/	57.7	10.8	124.0	5.5	<0.001	***
Larrakia	Intercept (V)	428.8	17.6	48.1	24.3	<0.001	***
	/i/	−16.4	26.8	45.9	−0.61	0.547	
	/e/	137.9	30.0	39.3	4.59	<0.001	***
	/a/	158.3	22.6	43.1	7.01	<0.001	***
	/o/	127.9	19.7	52.9	6.49	<0.001	***
	/u/	22.1	23.2	47.2	0.95	0.345	

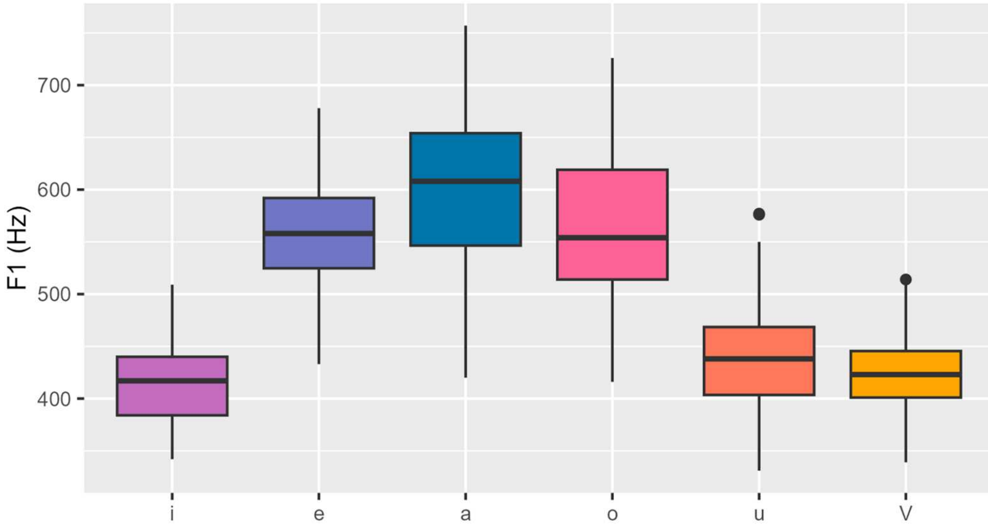


Figure 7 Boxplots of F1 (Hz) for the six vowel phonemes of Larrakia

Table 8 LMM results: F2 by phoneme

	Parameter	beta	SE	df	t	p	
Kamu	Intercept (V)	1,507.0	38.6	139.1	39.0	<0.001	***
	/a/	−19.8	52.4	126.9	−0.4	0.706	
	/i/	738.7	51.8	134.0	14.3	<0.001	***
	/e/	537.7	54.2	121.0	9.9	<0.001	***
	/o/	−355.1	56.1	128.4	−6.3	<0.001	***
	/u/	−338.6	52.7	128.8	−6.4	<0.001	***
Larrakia	Intercept (V)	1,473.1	46.2	59.3	31.9	<0.001	***
	/a/	−12.3	58.8	52.8	−0.2	0.834	
	/i/	254.9	69.9	56.5	3.6	<0.001	***
	/e/	233.3	77.8	47.5	3.0	0.004	**
	/o/	−193.5	51.9	66.6	−3.7	<0.001	***
	/u/	−242.6	60.7	58.5	−4.0	<0.001	***

that /i-e/ are produced with the highest F2, /o-u/ have the lowest F2, and /V-a/ are produced with second formant frequencies intermediate to those of the other vowels. A linear mixed model of F2 by phoneme with Word as a random effect found V to be significantly more backed than /i/ and /e/, significantly less backed than /o/ and /u/, with no significant difference in backness between /a/ and V (Table 8).

Similarly in Larrakia, /i-e/ are produced with the highest F2, followed by /V-a/, and then /u-o/ which have the lowest F2 (Figure 9). A linear mixed model of F2 by phoneme with Word as a random effect found V to be significantly more backed than /i/ and /e/, significantly less backed than /o/ and /u/, with no significant difference in backness between /a/ and V (Table 8).

5.5 Vowel rounding

We analyzed vowel rounding in each language using two methods: by modelling the relationship between F3 and vowel category; and by modelling the relationship of the F3–F2 differential and vowel category. Boxplots of F3 for Kamu high vowels (Figure 10

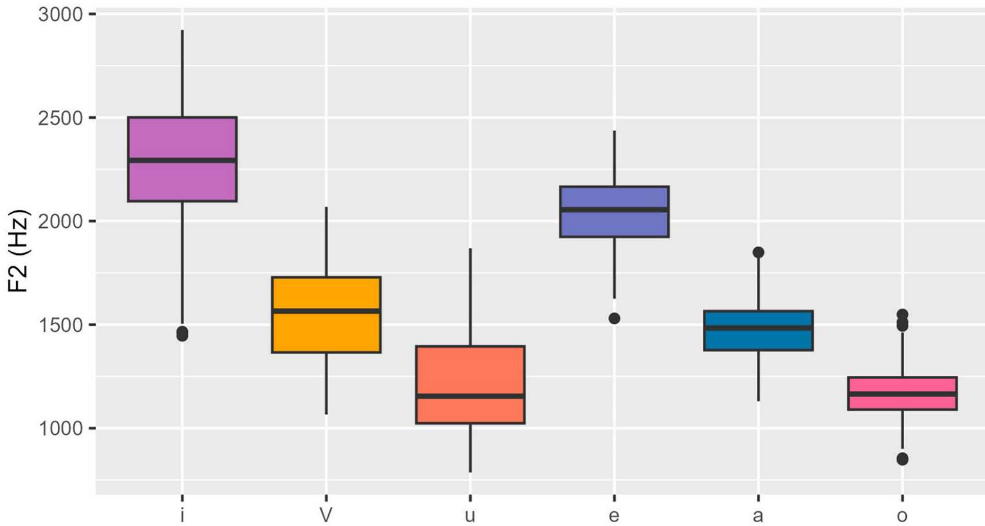


Figure 8 Boxplots of F2 (Hz) for the six vowels of Kamu

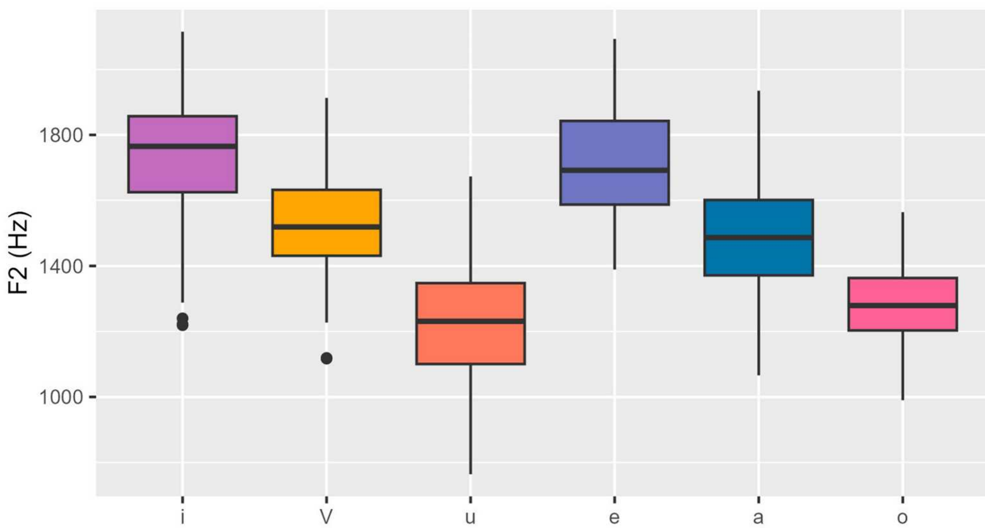


Figure 9 Boxplots of F2 (Hz) for the six vowels of Larrakia

left) reveal a lowered third formant frequency for /u/, relative to /i-V/, and a lower F3–F2 difference for /i/, relative to /V-u/ (Figure 10 right).

Boxplots of F3 for Larrakia high vowels (Figure 11 left) reveal little difference between third formant frequencies for /i-V-u/. The F3–F2 frequency difference for V is intermediate to /i-u/ (Figure 11 right).

For Kamu, a linear mixed model of F3 by phoneme with Word as a random effect found /u/ to be significantly lower, but no significant difference in F3 between V and /i/ (Table 9). A linear mixed model of F3–F2 by phoneme with Word as a random effect found V to be significantly higher than /i/ and marginally higher than /u/ (Table 10).

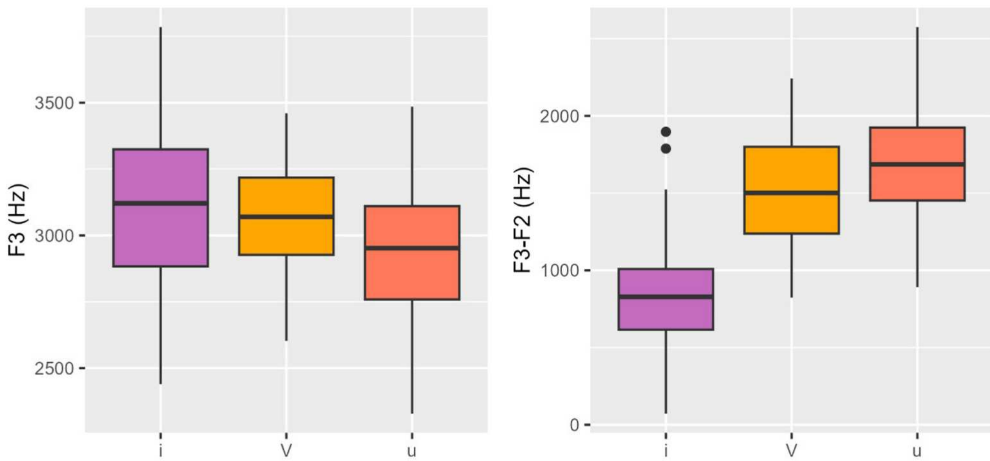


Figure 10 Boxplots of F3 (Hz) (left) and F3–F2 (Hz) (right): Kamu high vowels

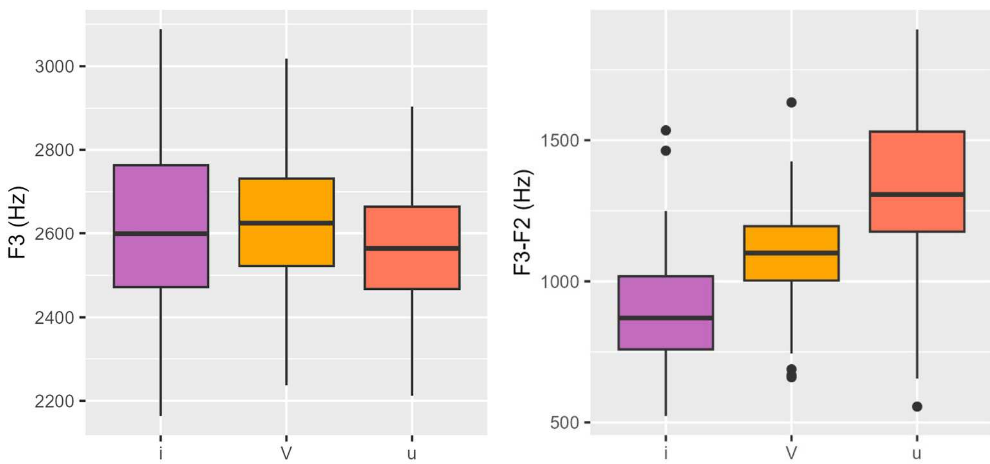


Figure 11 Boxplots of F3 (Hz) (left) and F3–F2 (Hz) (right): Larrakia high vowels

Table 9 LMM results: F3 by phoneme

	Parameter	beta	SE	*df*	*t*	*p*	
Kamu	Intercept (V)	3,095.4	33.3	129.1	92.9	<0.001	***
	/i/	−5.6	44.0	121.0	−0.1	0.900	
	/e/	−151.4	44.0	105.9	−3.5	<0.001	***
	/a/	−118.1	43.6	116.7	−2.7	0.008	**
	/o/	−89.2	46.8	117.1	−1.9	0.059	.
	/u/	−184.3	44.0	117.5	−4.2	<0.001	***
Larrakia	Intercept (V)	2,589.5	34.7	23.9	74.6	<0.001	***
	/i/	50.0	52.0	23.0	1.0	0.347	
	/e/	99.9	54.8	17.4	1.8	0.085	
	/a/	38.1	43.0	21.3	0.9	0.385	
	/o/	100.7	40.7	32.4	2.5	0.019	*
	/u/	−24.8	45.7	24.7	−0.5	0.592	

Table 10 LMM results: F3–F2 by phoneme

	Parameter	beta	SE	df	t	p	
Kamu	Intercept (V)	1,596.1	49.2	134.0	32.4	<0.001	***
	/i/	−755.4	65.6	127.6	−11.5	<0.001	***
	/e/	−691.5	67.3	111.9	−10.3	<0.001	***
	/a/	−110.6	65.6	120.0	−1.7	0.095	
	/o/	249.9	70.5	121.1	3.5	<0.001	***
	/u/	126.3	66.2	121.6	1.9	0.059	.
Larrakia	Intercept (V)	1,099.2	56.1	42.6	19.6	<0.001	***
	/i/	−181.9	84.7	40.5	−2.1	0.038	*
	/e/	−112.9	92.7	32.9	−1.2	0.232	
	/a/	65.2	70.8	37.6	0.9	0.363	
	/o/	305.7	63.8	50.1	4.8	<0.001	***
	/u/	234.3	73.8	42.5	3.2	0.003	**

For Larrakia, a linear mixed model of F3 by phoneme with Word as a random effect found no significant differences in third formant frequency between high vowels (Table 9). A linear mixed model of F3−F2 by phoneme with Word as a random effect found V to be significantly higher than both /i/and /u/ (Table 10). Mid vowels also differ in rounding in both languages: F3−F2 for /o/ is significantly higher than /e/ in both Kamu ($\beta = 941$ Hz) and Larrakia ($\beta = 419$ Hz) (Table 10).

6. Discussion

6.1 Segmental oppositions and typological characterization

These data provide clear insights into the acoustic distribution of vowels in Kamu and Larrakia, and the relative positioning of the sixth vowel in each language. Formant analysis reveals a clear three-way distinction in backness in each language, with a pair of front vowels /i-e/, a pair of back vowels /u-o/ and another pair of central vowels /V-a/ characterized by intermediate F2 frequencies. The vowels in each pair differ in F1 frequency, characteristic of horizontally-organized six-vowel systems consisting of three degrees of backness with a height contrast at each degree.

This can be succinctly captured using three contrastive features, [front], [back] and [high], shown in Table 11 for Kamu and Larrakia, which reflects the acoustic distribution found by the data for F1 and F2 in both languages.

Typologically, six-vowel systems organized with similar geometries are relatively common (Crothers, 1978). The majority of the 71 languages in the UPSID database (Maddieson, 1991) that use six vowel phonemes conform to this same basic structure: five symmetrically-distributed peripheral vowels plus a sixth central vowel, most commonly /ə/ followed by /ɨ/ (Schwartz et al., 1997). Less commonly, five peripheral vowels are accompanied by a sixth vowel contrasting primarily in rounding, e.g. {/y/, /ø/, /ɤ/, /ɯ/}. Acoustic analysis of these Kamu and Larrakia data demonstrate that the sixth vowel is

Table 11 Vowel inventory of Kamu and Larrakia

	[+front] [−back]	[−front] [−back]	[−front] [+back]
[+high]	i	V	u
[−high]	e	a	o

neither /ə/ nor co-located with any of the other peripheral vowels in either language, but produced at the same height as and central to /i/ and /u/. Therefore, the vowel inventories of both languages consist of five symmetrical peripheral vowels and a high central vowel. In the taxonomy of Schwartz et al. (1997), this inventory type is classified structurally as ɨπ_5, an arrangement attested in eight of the 60 six-vowel inventories analyzed. Languages using vowel systems with a similar structure include Teduray (Austronesian: Blust, 1992), Wanano (Eastern Tukano: Stenzel, 2013) and Tol (Hokan: Fleming & Dennis, 1977).

6.2 Rounding

While backness and height distinctions suffice to describe the Kamu and Larrakia vowel inventories, rounding must also be considered, as analyses of Australian vowel phonologies have proposed that only height and rounding are phonologically active, omitting the need for backness as a contrastive feature (Breen, 2001, p. 48; Harvey & Mailhammer, 2024, pp. 83–90). In both Kamu and Larrakia, rounding is contrastive for the other [−low] vowels and so an analysis utilizing height and rounding would also be sufficient for both Kamu and Larrakia, if V were excluded from consideration: the five-way /i, e, a, o, u/ opposition can be analyzed using either [back, high, low] or [high, low, round]. However, since V is clearly [+high], the most succinct phonological analysis will make use of backness features.

The acoustic data do not provide a clear characterization of rounding for V in either language. In Kamu, F3 differs from /u/ but not from /i/, while F3−F2 differs more from /i/. These data suggest that V may be realized with different degrees of labialization depending on context, lexical item, register and other factors. Nevertheless, because F3−F2 is typically the most robust acoustic correlate of rounding in vowels (Stevens, 2000), the data suggest that most of the vowels in the Kamu dataset are realized with some degree of labial protrusion, i.e. [ʉ].

We can also briefly consider non-acoustic evidence for rounding. When conducting fieldwork on Kamu, the second author – a speaker of Australian English – frequently confounded V with /u/, but not with /i/, which also suggests that V is realized with some degree of rounding, consistent with the characterization as /ʉ/. However, when asked to illustrate the difference between the high vowels, the consultant Elsie sometimes produced hyperarticulated realizations of V with observable lip spreading, which would be more consistent with a characterization of V as [ɨ].

The Larrakia acoustic data are particularly inconclusive about rounding, as F3−F2 frequencies for V pattern between /i/ and /u/ and differ significantly from both peripheral high vowels; however, the F3−F2 differential for V is closer to that of the high front vowel /i/ than the high back vowel /u/ (Table 10). In summary, both languages appear to exhibit variable labialization in the articulation of V. In Kamu, the evidence suggests that V involves some degree of lip protrusion; whereas in Larrakia the evidence is less conclusive, but suggests that V patterns more closely with the acoustic correlates of lip spreading.

6.3 Phonological characterization and representation

Our analysis suggests that backness and height features are sufficient to describe the Kamu and Larrakia vowel inventories. Additionally, incorporating [round] into this phonological system decreases the feature economy by introducing gaps into the paradigms (Clements, 2003). If V is specified as [-back, -front, +high] in Kamu and Larrakia, this raises interesting questions about phonemic representation, as the only available IPA symbols for a vowel of this quality are /ɨ/ and /ʉ/, which are both inherently specified for rounding.

Following general principles of aligning phonological representation as closely as possible with phonetic form, we represent Kamu V as /ʉ/, given that the most common acoustic realization involves some rounding. Following the same general principles, we represent Larrakia V as /ɨ/, given that the most common acoustic realization involves minimal rounding. However, though the phonetic ranges of V in Kamu and Larrakia differ sufficiently to motivate distinct IPA representations, in neither language do the overall acoustic and articulatory data suggest that V has a clear characterization with respect to rounding. Indeed, these data suggest that V is variably realized with allophony in the range [ɨ–ʉ]. The difference in representation follows from the limitations of the IPA orthography and not from a difference in phonological specification between the two languages. Rather, the available evidence supports the Kamu and Larrakia V vowels as having identical phonological specifications.

7. Conclusion

Acoustic and phonological analysis of the vowels of Kamu and Larrakia has revealed that both languages use a six-vowel system involving three backness distinctions, with height contrasts at each place. Formant analysis demonstrates that the non-low central vowel in each language shares the same height as /i/ and /u/ but differs in backness from each. The vowel inventory of each language is organized into a typologically common structure for six-vowel systems, which can be described using only backness and height features. Phonetic correlates of rounding for the high central vowel are inconclusive in both languages, suggesting that rounding may not be phonologically specified; nevertheless, based on the data available, the most appropriate representation of the non-low central vowel in Kamu is /ʉ/ and in Larrakia is /ɨ/.

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Notes on contributors

Mitchell Browne is a Macquarie University Research Fellow. He primarily works with speakers in Tennant Creek on the description and documentation of central Australian languages. His recent research spans phonetics, phonology and morphology.

Mark Harvey is a Conjoint Associate Professor in Linguistics at the University of Newcastle. He has worked with speakers of Australian languages in the Darwin region since 1980. His research interests include historical linguistics, kinship, ethnobiology, indigenous spatial heritage, phonetics, phonology and morphosyntax. He has published extensively across this range of interests.

Michael Proctor is Associate Professor at Macquarie University. He investigates speech production and perception, and phonological organization in human language. He uses MRI, articulography, ultrasound, eye-tracking and other methods to investigate how speech sounds are made and processed, and how language is acquired and used by adults, children, second language learners and disordered populations.

Robert Mailhammer is Professor of Linguistics at Western Sydney University. He studies what makes languages diversify, how they become different and their connections to the histories of their speakers.

Data availability statement

The language data that support the findings of this study are openly available in Paradisec. Kamu: https://dx.doi.org/10.26278/G9WV-WS33; Larrakia: https://dx.doi.org/10.26278/ht1p-6884.

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ORCID

Mitchell Browne http://orcid.org/0000-0001-7623-8179
Mark Harvey http://orcid.org/0000-0001-9901-9921
Michael Proctor http://orcid.org/0000-0002-3083-6859
Robert Mailhammer http://orcid.org/0000-0003-0628-9813

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