Vowel Duration beyond Contrastive Length in Djambarrpuyŋu

Kathleen Jepson[1,2], Rasmus Puggaard-Rode[2]

[1]University of Queensland; [2]Institute of Phonetics and Speech Processing, LMU Munich

k.jepson@uq.edu.au; r.puggaard@phonetik.uni-muenchen.de

Abstract

Djambarrpuyŋu has contrastive vowel length only in word-initial syllables; long vowels are twice as long as short vowels. Little is known, however, about vowel duration outside of this position. Vowel duration can be affected by various other factors including syllable structure, number of syllables in the word, and proximity to prosodic boundaries, topics that require further investigation in Djambarrpuyŋu. This paper aims to describe the durational patterns of vowels, beyond contrastive length, to enhance our understanding of vowel duration and factors that affect it in Djambarrpuyŋu, and to contribute to our cross-linguistic understanding of segment duration.

Index Terms: vowels, duration, syllable structure, polysyllabic shortening, final lengthening, vowel length, Djambarrpuyŋu

1. Introduction

Djambarrpuyŋu has contrastive vowel length, but only in word-initial syllables [1]. This is the proposed location of primary stress, which is fixed (see Section 1.1). Long vowels are, on average, twice as long as short vowels with duration values of ~200 ms and ~100 ms respectively [2]. However, little is known about the durational characteristics beyond these word-initial, stressed vowels, and a more nuanced understanding of the effect of other factors on vowel duration awaits further investigation. Non-contrastive vowels, which have not been investigated acoustically, are typically transcribed using a plain vowel symbol, categorising them in this way as short vowels, although it is not known if they actually pattern with short vowels in terms of their durational characteristics.

Across languages, it is understood that vowel duration can be affected by a number of factors such as syllable structure [3], number of syllables in the word [4, 5], and proximity to prosodic domain boundaries [6, 7]. The aim of this paper is to deepen our understanding of Djambarrpuyŋu vowels, including non-contrastive vowels, and in doing so to contribute to what is known about the durational characteristics of non-contrastive vowels in a language with a length contrast, a topic which is not well-understood. Specifically, we investigate the effects of syllable structure on vowel duration, effects of polysyllabic shortening across contrastive and non-contrastive vowels, and durational modification due to proximity to the word-final boundary.

The cross-linguistic literature and expectations for the effects of these factors in Djambarrpuyŋu are discussed in Sections 1.2–1.4. Djambarrpuyngu is introduced further in Section 1.1.

1.1. The Djambarrpuyŋu language

Djambarrpuyŋu, a Pama-Nyungan language spoken by ~4,000 people in northeast Arnhem Land [8], is described as having six contrastive vowels /ɪ ɪː ɐ ɐː ʊ ʊː/ [1]. While it is simplest to describe contrastive length as being restricted to word-initial (i.e., stressed) syllables, long vowels can occur in word-medial position in compounds when the second compound member has a long vowel in the initial syllable, for example, *yaŋara'-märrma'* /ˈjɐ.ŋɐ.ɹɐʔ.mɐː.r.mɐʔ/ "twins" (lit. "lower leg two") [1]. However, long vowels are proposed to be shortened in the second morpheme of reduplicated stems, for example, *yolŋu'-yulŋu* /ˈjʊː.l.ŋʊʔ.jʊl.ŋʊ/ "people". In the current analysis, vowels at the beginning of the second morpheme in compounds are coded as being either short or long, and these are considered "medial" with respect to their position within the word. Vowels in the word-initial syllable are coded as either short or long, vowels elsewhere within the word are coded as non-contrastive.

Like many Australian languages, Djambarrpuyŋu has relatively free word order, and is a highly agglutinating, exclusively suffixing language [1]. Syllables take the form CV(C)(C)(ʔ), where C represents a consonant and V represents a vowel. Syllable onsets are always a single consonant, codas can be more complex, glottal stops only occur syllable-finally.

Acoustic and perceptual investigations have examined vowel length in disyllabic words, including the effect of syllable structure [2]. The effect of final lengthening on consonants has also been considered [9]. Details of the findings are discussed in the following sections.

1.2. Effect of syllable structure

A common pattern observed cross-linguistically is for vowels in closed syllables such as CVC to be phonetically shorter than in open syllables such as CV [3]. This effect has been reported to occur in languages that have contrastive vowel length such as Dutch [10, 11], Arabic [12-14], and Malayalam [12], as well as those which do not such as Italian [15, 16]. In Dutch for example, short vowels are 82 ms in open syllables and 51 ms in closed syllables, and long vowels are 178 ms in open syllables and 124 ms in closed syllables [11].

The effect of syllable structure on vowel duration in disyllabic Djambarrpuyŋu words is reported in [2]. Closed syllables did affect the duration of vowels; however, long vowels were affected to a greater extent than short vowels. Long vowels in closed syllables are approximately three quarters the duration of long vowels in open syllables. Therefore, the ratio between short and long vowels is altered from ~1:2 in open syllables to 1:1.5 in closed syllables.

It is not yet known what effect syllable structure has on non-contrastive vowels in Djambarrpuyŋu, though it is expected that non-contrastive vowels behave in a similar way to short vowels, and that closed syllable vowel shortening results in only slightly shorter non-contrastive vowels.

1.3. Effect of polysyllabic shortening

Polysyllabic shortening is a mechanism whereby syllable duration, especially that of primary stressed syllables in accented words, is negatively correlated with the number of

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syllables in the word [4, 5, 17-19]. [4] examined the effect of polysyllabic shortening in English. They observed polysyllabic shortening is stronger for accented words than unaccented words irrespective of location of main stress. In German it has similarly been found that stressed vowels in accented words show an effect of polysyllabic shortening [5]. The effect was observed for tense vowels but not lax vowels, resulting in a smaller difference in duration between the two categories. Polysyllabic shortening is reported to not occur in some languages, however. For example, the number of syllables in a word has no consistent effect on segment duration in Finnish [20].

Based on the cross-linguistic literature, polysyllabic shortening is expected to be observed in Djambarrpuyŋu across vowel categories and positions. However, long vowels are expected to be affected to a greater degree than short vowels in stressed position, and short vowels would in turn be affected to a greater extent than non-contrastive vowels, which do not occur in stressed position. It is expected that long vowels in open and closed syllables could be affected differently by polysyllabic shortening. Using the current data set it is not possible to compare accented versus unaccented words, so additional effects due to accentuation awaits further investigation.

1.4. Effect of final lengthening

Domain-final lengthening is the phonetic lengthening of segments due to proximity to a prosodic constituent boundary, and is often found to affect syllable rimes, that is, syllable-final vowel-consonant sequences [6, 7].

For English, [21] report that final lengthening affects word-final rimes, and also main stress syllable rimes of phrase-final words. That is, domain-final lengthening was found to affect non-final stressed segments in domain-final words. In Dutch, word-final consonants as well as the preceding vowel are found to be affected by being in utterance-final position, with consonants, not vowels, contributing the majority of the durational difference between syllables across positions [22].

Most research has focused on higher-level prosodic constituent boundaries such as the Intonational Phrase (IP), and the varying degrees of lengthening corresponding to different levels of the prosodic hierarchy; lower level boundaries (e.g., Prosodic Word) result in a small degree of lengthening, with increases in lengthening for higher-level constituent boundaries (e.g., IP, Utterance) [21].

IP-final lengthening of vowels is anecdotally reported to occur in Djambarrpuyŋu [23]. Further, consonants have been found to be lengthened when adjacent to a prosodic phrase boundary in Djambarrpuyŋu, with nasals followed by a break being ~ 55 ms longer than when not [9]. However, in this paper, we are concerned primarily with the domain of the word and focus on the effect of lengthening in final versus non-final syllables. Considering only non-contrastive vowels, we hypothesise that vowels in word-final syllables are longer than vowels elsewhere within the word, and that syllable structure minimally affects the effect of final lengthening.

2. Methods

2.1. Participants

Eight Djambarrpuyŋu speakers (five women, three men) were recorded in Milingimbi, northeast Arnhem Land, Northern Territory, Australia. All participants were familiar with related language varieties, other Aboriginal languages, and Australian English. Participants were paid for their time.

2.2. Materials and recordings

A wordlist was compiled making use of grammatical [1] and dictionary resources [24]. Words included all vowels, had varying morphological structure including compounds and reduplicated forms, and were between one and eight syllables in length. A total of 8,995 vowels are examined in the analysis, the distribution of these is presented in Table 1. Note that vowels from monosyllabic words are included in Table 1 and Figures for interest, but are not included in the statistical analyses.

The wordlist items were elicited in three frame sentences in which the target word was syntactically in utterance-initial, -medial, or -final position. The items in the wordlist were discussed with each speaker before the recording session. In the recording session, each item was presented verbally in English, Djambarrpuyŋu, or through an explanation in English. Speakers said each item in the three frame sentences once. Sentence frame is not examined in detail in this paper, nor was the occurrence of a pause following the target word (i.e., a proxy for a prosodic constituent boundary), though it is acknowledged that proximity to higher-level prosodic boundaries would affect vowel duration, and this will be explored imminently.

Audio data were collected using a Zoom H6 digital recorder and Countryman H6 headset microphone with a hypercardioid pattern directional capsule covered with a windshield. Recordings were made at 24 bit bit-depth and a 48 kHz sample rate. Recording sessions primarily took place sitting inside a house, with over-head fans and air-conditioning units turned off, or outside in the shade or on a veranda.

Table 1. *Summary of the data presented by vowel length category, position within the word, and structure of the syllable counting vowel tokens, and by number of syllables in the word counting word tokens.*

Vowel	*V n*	Pos. in word	*V n*
long	732	*initial*	2838
short	2237	*medial*	3294
non-contr.	6026	*final*	2838
		mono	25
Syll. structure	*V n*	Sylls. in word	*W n*
open	6380	*1*	25
closed	2615	*2*	1554
		3	383
		4	214
		5	355
		6	255
		7	53
		8	24

2.3. Data processing and acoustic measures

Utterance segmentation and transcription were conducted in Praat [25] using a modified Djambarrpuyŋu orthography. Data were forced aligned on two separate occasions and two slightly differing methods were used. For the first set of data, the Munich Automatic Segmentation System [26] implemented in R [27] was employed, using a modified SAMPA (language-independent) parameter definition. For the second set of data, the web-based Munich Automatic Segmentation System [28] was employed, using the language-independent model. All segmentation was manually corrected in Praat using waveform and spectral information.

An Emu SDMS database was created using the emuR package in R [29]. The database was queried in R using the emuR suite of commands. Durational values were extracted for all vowels along with other relevant information.

2.4. Analysis

Linear mixed-effects regression models were fitted to test the predictions made in Sections 1.2–1.4, using the lme4 library [30] in R. Two separate models were fitted. Visualisations were created using the ggplot2 package in R [31].

Since syllable structure and polysyllabic shortening potentially interact, we fitted a model with vowel duration as the dependent variable, predicted from a three-way interaction between syllable structure (*open* or *closed*), phonological vowel length (*long*, *short*, or *non-contrastive*), and number of syllables (numeric, between 2–8). The model includes uncorrelated random by-speaker slopes for syllable structure and phonological vowel length, and random by-item intercepts; models with more elaborate random effects structures failed to converge, and the random effects structure was pruned to remove by-speaker slopes with very low predicted variance. The data for this model does not include vowels in final syllables ($n = 6132$).

A separate model tested the effects of final lengthening. This model also had vowel duration as the dependent variable, predicted from a two-way interaction between syllable finality (a binary variable), and syllable structure. The model included random by-speaker slopes for both syllable finality and syllable structure (but not their interaction), and random by-item intercepts. The random effects structure was pruned as in the previous model. The data for this model only includes non-contrastive vowels, as vowels with contrastive length never appear word-finally ($n = 6026$).

Individual comparisons of interacting variables are obtained using the emmeans [32] library in R, which reports Bonferroni-corrected p-values. Due to the large number of comparisons, only selected ones are reported here. p-values < 0.05 are considered statistically significant.

3. Results

Figures 1 and 2 present the data in different organisations that relate to the statistical analyses, although the figures present all data, including that which was excluded from the statistical models. Fig. 1 shows vowel duration (ms) by position within the word (*initial*, *medial*, *final*, *monosyllabic*) and phonological length category of the vowel (*short*, *long*, *non-contrastive*), coloured by syllable structure (*open*, *closed*). Vowels in monosyllabic words could arguably be considered either initial or final vowels, and so are their own category in the plots for descriptive information for the reader. Fig. 2 shows the number of syllables per word (1-8) by phonological length category, coloured by syllable structure.

3.1. Syllable structure

The effect of syllable structure can be observed in both Figures 1 and 2. As has previously been reported [2, 33], we found that long vowels are shorter in closed syllables (yellow) than open syllables (blue), while the duration of short and non-contrastive vowels is not affected to a considerable degree by syllable structure. The effect for the long vowel data is observed in the location of the peaks in the distribution in the facet representing initial long vowels in Fig. 1 and long vowels in disyllabic words in Fig. 2. The statistical analysis finds that open long vowels are

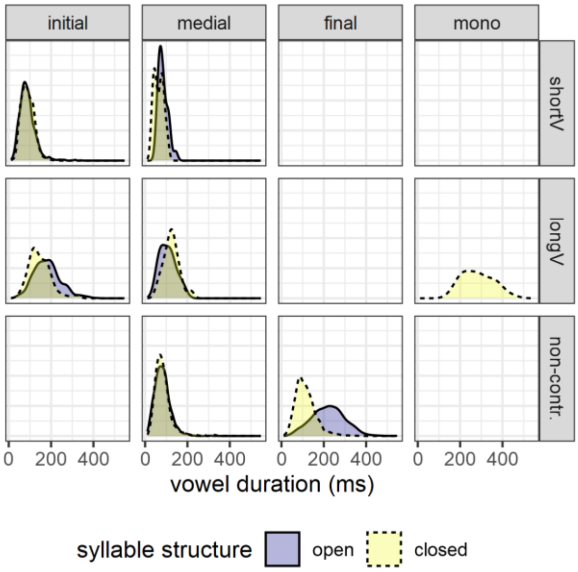

Figure 1: *Duration of vowels by position within the word and length category, coloured by whether the syllable was open or closed.*

an estimated 17 ms (95% CI = [7, 27]) longer than closed long vowels; this difference is significant with $p < 0.001$. Syllable structure does not significantly affect the duration of short and non-contrastive vowels. The effect of syllable structure on vowels in word-final syllables is discussed in Section 3.3.

3.2. Polysyllabic shortening

Fig. 2 shows the effect of number of syllables in the word on vowel duration. Considering short vowels first, there is little change in duration across words of different lengths in open or closed syllables; they are usually in the range of 100 ms. Next, considering long vowels, there is less data, but overall what can be observed is that vowel durations in open syllables (blue) become shorter, and more similar to vowels in closed syllables (yellow). Lastly, non-contrastive vowels in 3–8 syllable words show the same pattern as short vowels. That is, the duration values across word lengths and syllable structures are nearly identical, and hover around 100 ms. Non-contrastive vowels in disyllabic words are considered more in Section 3.3; these vowels are necessarily in word-final syllables.

The statistical analysis predicts that with the addition of each subsequent syllable, short vowels shorten by -5.6 ms, 95% CI = [-3.8, -7.3]. The effect of increasing syllable count does not significantly differ between short and non-contrastive vowels, nor does syllable structure significantly affect polysyllabic shortening in short and non-contrastive vowels. In long vowels in open syllables, there is a stronger effect of polysyllabic shortening, with a predicted decrease in duration for each added syllable of -9.3 ms, 95% CI = [-2.3, -16.3], and the effect is much stronger in long vowels in closed syllables, with a predicted decrease of -24.3 ms (95% CI = [-21.1, -27.5]) for each added syllable.

3.3. Final lengthening

In this study, all vowels that are word-final are non-contrastive, so, as mentioned above, the analysis only considers non-contrastive vowels across word positions.

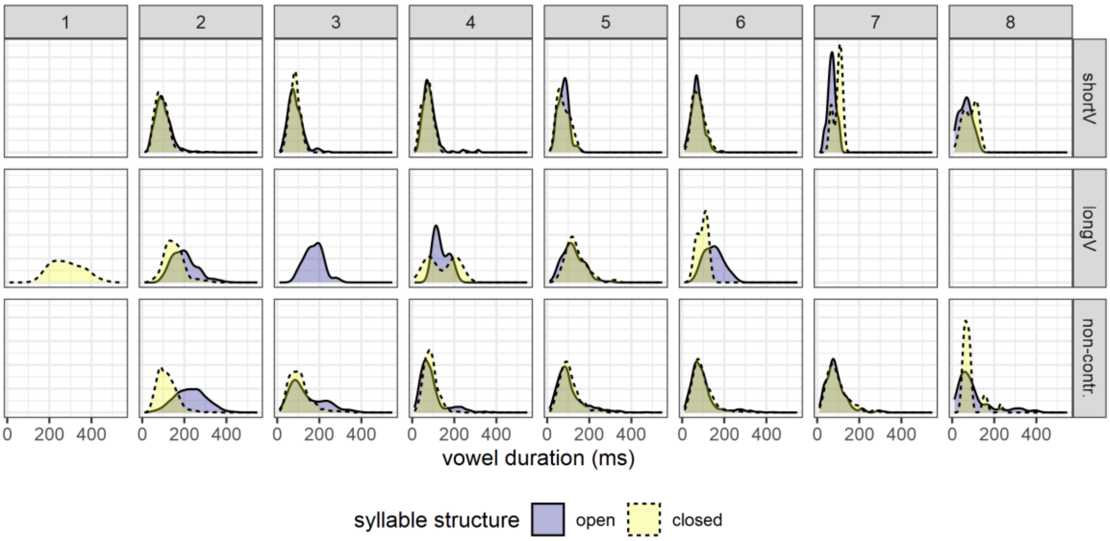

Figure 2: *Duration of vowels by the number of syllables in the word (1-8) and length category, coloured by whether the syllable was open or closed.*

The bottom row of Fig. 1 represents the data in this analysis. As can be seen, for medial (i.e., the non-final category) vowels, duration values for vowels in closed and open syllables are nearly identical; this was supported in the analysis of syllable structure, presented in Section 3.1. In word-final position, only vowels in open syllables appear to show a lengthening effect, contrary to the hypothesis that syllable structure would have little effect on vowel duration. The figure clearly shows that vowels in open syllables (blue) are longer than vowels in closed syllables (yellow) in final position.

The statistical analysis supports this, predicting that vowels in word-final open syllables are significantly longer than all other vowels by over 100 ms, $p < 0.001$.

4. Discussion and conclusions

This paper provides an overview of vowel duration in Djambarrpuyŋu and the effects of factors that are frequently found to affect vowel duration. Contrastive vowel length was considered, but oft neglected non-contrastive vowels were also examined with respect to the effect of syllable structure, polysyllabicity, and final lengthening.

For syllable structure, previous findings were replicated across words of varying lengths. Long vowels are affected by syllable structure to a greater degree than short vowels, with vowels in closed syllables shorter than those in open syllables. The hypothesis that non-contrastive vowels pattern with short vowels and show minimal effect of syllable structure was generally supported. Data for long vowels in longer words is sparse, but overall, we observe the expected effect of syllable structure across words of different lengths. A next step could be investigating the effect of different codas to understand if more complex codas result in different degrees of shortening. For now, no differentiation was made between codas in terms of how many consonants they contained, nor consonant manner.

Long vowels were affected by polysyllabic shortening to a greater degree than short vowels and non-contrastive vowels. Further, long vowels in open syllables were affected to the greatest degree with each additional syllable. On the whole, short vowels (in stressed position) did not appear to be affected to a greater degree than non-contrastive vowels. This suggests that polysyllabic shortening selectively applies to stressed vowels, as also found in German [5].

Regarding final lengthening, it was hypothesised that word-final vowels would be longer than non-contrastive vowels elsewhere in the word, and that syllable structure would not affect the duration. Word-final position did result in longer duration values. However, this was due wholly to vowels in open syllables; vowels in closed syllables were only minimally lengthened in final position. Taken together with findings from [9], this suggests that final lengthening may only be observed on absolute final segments. Exploring the effect of different prosodic constituent boundaries on vowel duration remains for future research.

Some other interesting findings emerged that were not explicitly examined. In this dataset, monosyllabic words always contain long vowels and are closed syllables. These vowels are the longest in the dataset overall. This is at once expected, but also surprising in light of other findings. We might expect long duration values because 1) these are long vowels, 2) there can be no effect of polysyllabic shortening. Further, word-final position resulted in significantly longer duration for non-contrastive vowels. However, being in a closed syllable resulted in a near total reduction of the effect of final position for non-contrastive vowels. Inclusion of monosyllabic words without codas is required to better understand these durational patterns.

Incidentally, we can also see in Fig. 1 that medial long vowels (i.e., long vowels in the second member of a compound), are considerably shorter than initial long vowels. This presents an opportunity for further exploration of the duration of these vowels, and reconsidering the phonological representation of vowels in compounds.

Overall, it appears that durationally, non-contrastive vowels pattern with short vowels, with similar effects of syllable structure and polysyllabicity. Non-contrastive vowels in word-final position, however, are in the range of duration values observed for long vowels. Syllable structure affects both long vowels and word-final non-contrastive vowels in a similar way, but long vowels in closed monosyllabic words remain long in duration. This study illustrates how multiple factors that affect vowel duration can operate simultaneously and differently on vowels, and disentangling these factors is important in fully understanding a language’s durational patterns.

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