

Prosodically Conditioned Consonant Duration in Djambarrpuyŋu

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Abstract

Cross-linguistically, segments typically lengthen because of proximity to prosodic events such as intonational phrase or phonological phrase boundaries, a phrasal accent, or due to lexical stress. Australian Indigenous languages have been claimed to operate somewhat differently in terms of prosodically conditioned consonant lengthening and strengthening. Consonants have been found to lengthen after a vowel bearing a phrasal pitch accent. It is further claimed that this post-tonic position is a position of prosodic strength in Australian languages. In this study, we investigate the effects of proximity to a phrasal pitch accent and prosodic constituent boundaries on the duration of stop and nasal consonants in words of varying lengths in Djambarrpuyŋu, an Australian Indigenous language spoken in northeast Arnhem Land, Northern Territory, Australia. Our results suggest that the post-tonic consonant position does not condition longer consonant duration compared with other word-medial consonants, with one exception: Intervocalic post-tonic consonants in disyllabic words are significantly longer than consonants elsewhere. Word-initial position did not condition longer consonant duration than word-medial position. Further, initial consonants in higher-level prosodic domains were had shorter consonant duration compared with domain-medial word-initial consonants. By contrast, domain-final lengthening was observed in our data, with word-final nasals preceding a pause found to be significantly longer than all other consonants. Taken together, these findings for Djambarrpuyŋu suggest that, unlike other Australian languages, post-tonic lengthening is not a cue to prosodic prominence, whereas prosodic domain-initial and -final duration patterns of consonants are like those that have been observed in other languages of the world.

Keywords

consonants, duration, prosodic prominence, prosodic boundaries, Australian languages

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Introduction

Prosodically conditioned lengthening (“temporal expansion”) of segments has been found to occur cross-linguistically, along with prosodically conditioned strengthening (“spatial expansion”; see e.g., Cho, 2015 for an overview). Segments typically lengthen as a result of proximity to intonational phrase or phonological phrase boundaries, a phrasal accent, or due to lexical stress in many languages (Keating, 2006). In this study, the effects of prosodic domain boundaries, and accentual prominence on consonant duration are investigated in an Australian Indigenous language, Djambarrpuyju.

Durational variation is a common correlate of prosodic prominence in a wide range of languages (Turk, 2012). For example, speakers of many varieties of English produce longer segments in lexically stressed syllables and post-lexically accented syllables (e.g., Beckman & Edwards, 1994; Turk, 2012; Turk & White, 1999). Phrasal accent or prominence is often observed to affect syllable onset duration, as well as that of the nucleus, with less effect on codas (Turk, 2014). However, it has also been found that the effects of accentuation can extend beyond the syllable it is metrically or phonologically associated with. For example, segments in a word that receives a post-lexical pitch accent may be somewhat longer compared with segment durations in the same word when unaccented. This is found in Finnish where the range of accentual lengthening effects extended from the word onset position to the first segment of the fourth syllable in the word, and affected each segment in between (Suomi, 2007). Phrasal prominence and stress-related lengthening can also affect multiple discontinuous segments. As Turk and Dimitrova (2007) showed in English, four-syllable words there are multiple optional sites of accentually conditioned lengthening: the word-initial primary stressed syllable, the secondary stressed syllable, and the final syllable. In Dutch, accented words are longer than unaccented words, and this overall lengthening is achieved through an increase in each segment’s duration (Eefting, 1991). Cho and Keating (2009) also found for English that the effect of accent is not limited to a single syllable, but rather is realized across the whole word, with consonants in word-initial secondary-stressed syllables affected by being in an accented word in a similar way to primary-stressed syllables. Likewise, domain-final lengthening has been found to affect non-final stressed syllables in English words (Cho, 2016; Turk & Shattuck-Hufnagel, 2007).

In terms of prosodic structure and domain boundaries, effects of duration are seen cross-linguistically in domain-initial (post-boundary) strengthening, as well as domain-final (pre-boundary) lengthening. “Domain” here refers to a prosodic constituent such as a word, or higher-level constituent such as intonational phrase or utterance. The effects of the domain-initial position have been said to be restricted to the first segment, with these segments seen to be longer than elsewhere (see e.g., Keating, 2006; Turk, 2012). For example, Voice Onset Time is found to be longer for stops in domain-initial versus medial position in a Korean (Cho & Jun, 2000; Keating, Cho, Fougeron, & Hsu, 2004), nasal duration domain-initially is longer than domain-medially in English (Cho & Keating, 2001; Fougeron & Keating, 1997), and in French, /n/ is found to have longer duration in word and accentual phrase-initial positions (Keating et al., 2004), whereas domain-final lengthening is often found to affect syllable rhymes (that is, the syllable-final vowel-consonant sequence), and has a larger range of effect, either spreading across a number of segments, or multiple unconnected lengthening sites (see e.g., Turk & Shattuck-Hufnagel, 2007). Further, domain-initial and domain-final lengthening have been shown to distinguish a number of levels of prosodic constituent boundaries through differing degrees of durational adjustment. Domain boundaries distinguished by lengthening is seen, for example, in French (Fougeron, 2001), English (Fougeron & Keating, 1997), and Korean (Cho & Keating, 2001).

Although initial strengthening at the left edge of a prosodic unit (a prosodic word, or an intonational phrase, for example) has been considered to be restricted strictly to the initial segment, initial strengthening, like domain-final lengthening, has been found to extend beyond the initial segment. For example, Cho and Keating (2009) in their investigation of effects of proximity to prosodic boundaries, lexical stress and phrasal accent on articulatory and acoustic characteristics in English /ne/ and /te/ syllables, conclude that the initial boundary effect is not strictly local to the initial consonant—proximity to the initial boundary also affects the following vowel—and acoustic duration alone does not reliably vary due to initial position. Similarly, in Korean, syllables beyond the initial syllable show strengthening when words are in phrase-initial position (Cho, 2016).

A further factor relevant in the study of segment duration is the number of syllables in the word. Polysyllabic shortening is a mechanism whereby syllable duration, especially that of primary stressed syllables in accented words, is negatively correlated with the number of syllables in the word but tends to be less evident in longer words (Crystal & House, 1990; Siddins, Harrington, Kleber, & Reubold, 2013; Turk, 2012; Turk & Shattuck-Hufnagel, 2000; White & Turk, 2010).

As the number of studies of typologically diverse languages grows, it is becoming apparent that there is variation in how prominence- and boundary-related lengthening are manifested cross-linguistically. Cho (2015) surveys a range of studies of preboundary lengthening across a range of languages, including Finnish, Italian, Korean, and Japanese, and concludes that there are language-specific durational lengthening patterns. For example, in Japanese the final mora constitutes the domain of phrase-final lengthening (Shepherd, 2008), whereas Hebrew phrase-final disyllabic words constitute the domain of pre-boundary lengthening (Berkovits, 1993). It is similarly found in Northern Finnish that final lengthening is observed up to the initial syllable of phrase-final disyllabic words (Nakai, Kunnari, Turk, Suomi, & Ylitalo, 2009). Cho (2015) concludes that it is important to consider durational patterns across typologically different languages, as cross-linguistic differences help us determine what is language-specific or universal about boundary-related prosodic strengthening. This sentiment also rings true for prominence-related strengthening, and hence we aim to add to what is known in these areas.

2 Prosodic Lengthening Effects in Australian Languages

The effects of prosodic prominence and prosodic boundaries on segment and syllable duration in Australian Indigenous languages have been explored in only a handful of studies to date (e.g., Bishop, 2002; Butcher & Harrington, 2003; Fletcher & Evans, 2002; Fletcher, Evans, & Round, 2002; Fletcher, Stoakes, Loakes, & Singer, 2015; Pentland, 2004; Tabain & Butcher, 2015). Australian languages are traditionally described as “stress” languages with no use of lexical tone (Dixon, 2002; Evans, 1996; Goedemans, 2010). They have also been described as “fixed accent” languages but with alternating rhythm (see also Baker, 2014).

In the majority of the world’s languages for which there are quantitative phonetic analyses of stress and prominence, vowels are traditionally considered to be the locus of prominence-related lengthening (see e.g., Cho, 2016; Turk, 2012 for overviews). By contrast, in Australian languages, vowels associated with an accentually prominent or lexically stressed syllable do not consistently lengthen compared to unaccented vowels. Evidence of stressed or accentual vowel lengthening has been found in Arrernte, a Pama-Nyungan language of Central Australia (Tabain, 2016); Pitjantjatjara, a Pama-Nyungan language of Central Australia (Tabain, Fletcher, & Butcher, 2014); and in varieties of Bininj Kunwok and Dalabon, two non-Pama-Nyungan languages spoken in Northern Australia (Fletcher & Evans, 2002), but not in Mawng, a non-Pama-Nyungan language of Northern Australia (Fletcher et al., 2015); Warlpiri a Pama-Nyungan language of central Australia (Pentland, 2004); nor in preliminary studies of Djambarrpuyju (Jepson, Fletcher, &

Stoakes, 2016), the language under investigation in this paper, or the closely related variety Guypapuyŋu (Graetzer, Fletcher, & Hajek, 2016). There is also contrastive vowel length in some of these languages (Pitjantjatjara, Warlpiri, Djambarrpuyŋu, and Gupapuyŋu). Therefore, there is a possibility that due to duration being used contrastively in the phonological system, this parameter is not used; or used only minimally, to realize stress contrasts (see Berinsein, 1979). Gordon (1997) argues that, for Estonian, there are limits to which a single phonetic parameter can serve multiple prosodic functions, referring specifically to Estonian consonant onset duration in stressed syllable and domain-initial positions. However, in some of the studies mentioned above, and in an overview of studies of acoustic cues to stress by Lunden, Campbell, Hutchens, and Kalivoda (2017), it is not always the case that a parameter is excluded from being used to cue stress or phrasal prominence because of use elsewhere in the system, and that durational variation attributed to these aspects of prosodic structure can occur without obscuring phonemic contrasts of the same parameter.

It has been claimed that Australian languages operate somewhat differently from stress languages like English or German in that consonants contribute to the durational marking of prominence rather than vowels (e.g., Butcher, 2006). In particular, the position of prosodic strength appears to be the *post-tonic* position. Specifically, prominence effects are manifested on the consonant *after* the vowel that bears a tonic stress (i.e., a phrasal pitch accent), irrespective of whether the consonant is affiliated with the tonic syllable or not. In the phonological literature, a rule of gemination of consonants following stressed short vowels is often proposed, resulting in consonants in the post-tonic position being analyzed as ambisyllabic (see Baker, 2014). Butcher (2006) refers to this prominence-related lengthening as *post-tonic* or *medial strengthening*, and discusses a range of related phenomena that have shaped this proposed prosodic trait in Australian languages. For example, Australian languages neutralize coronal contrasts in word-initial position (Dixon, 2002)—the full range of contrasts is often restricted to C0 or intercontinuant position.

This tendency for preserving or enhancing the place information of consonants in medial contexts has been termed the “Place of Articulation Imperative” by Butcher (2006). It also relates to debates around syllable typology and phonotactics in Australian languages. With very few exceptions, the maximum coda in Australian languages is more complex than the maximum onset: thus, many Australian languages contrast homorganic and heterorganic clusters in the coda but have only singleton consonants in the onset (Baker, 2014; Dixon, 2002; Evans, 1996). This is quite different from English or other mainstream European languages, where onsets tend to be privileged (Hooper, 1976). Butcher (2006) also refers to the well-known tendency of many languages (approximately a third) to show “initial-dropping,” whereby the initial consonant or even syllable of words has been lost (see also Blevins, 2001; Dixon, 2002). This has led to a suggestion that the unit of articulatory planning in some Australian languages could be a vowel-consonant (VC) rather than the universally assumed consonant-vowel (CV) sequence (see e.g., Tabain, 2016 for a good discussion). Subsequent experimental work on Arrernte (e.g., Tabain, 2016; Tabain, Butcher, & Breen, 2004) has shown little evidence of a CV or a VC preference with regard to magnitudes of coarticulation or hyperarticulation of stop burst features, for example. Furthermore, segmental timing patterns of Arrernte CV versus VC sequences under stress favor a CV planning unit (Tabain, 2016). The Yolngu languages including Djambarrpuyŋu show little evidence of initial-dropping but show similar phonotactic patterns to a range of other Australian languages (see Section 3.1).

The situation is therefore somewhat complex with regard to post-tonic lengthening because it is found across a range of languages that have never been analyzed as having an underlying VC syllable. In Warlpiri, stops following primary stressed vowels are lengthened in words that are in utterance-initial position (Pentland, 2004). Nasals do not show an effect of post-tonic position in

Pentland's study, though are found to be lengthened in post-tonic position in heterorganic clusters in an electropalatography study by Fletcher, Loakes, and Butcher (2008). An EMA (electro-magnetic articulography) study of Warlpiri also shows there is a greater degree of tongue raising of post-tonic /j/ in target words that are focused, suggesting articulatory strengthening and localized hyperarticulation in this context (Butcher & Harrington, 2003).

Somewhat differently to Warlpiri, in Mawng, sonorants have a longer mean duration after an accentually prominent vowel—82 ms compared with 68 ms after a non-prominent vowel (Fletcher et al., 2015). By contrast there is minimal lengthening of accented (i.e., tonic) versus unaccented vowels. Fletcher et al. (2015) suggest that the lengthening of the sonorant boosts the sonority of the entire vowel + sonorant sequence, similarly enhancing the prominence-lending pitch movement associated with accented syllable. They conclude that the post-tonic sonorant in Mawng forms part of the entire accentual gesture. A similar pattern is observed in studies of Bininj Kunwok, in which post-tonic nasals in C1 position of a heterorganic consonant cluster are longer than nasals in following consonants (C2), intervocalic (C0), and word-initial (positions (Fletcher & Butcher, 2014; Fletcher, Butcher, Loakes, & Stoakes, 2010).

This “lengthening and strengthening” of post-tonic consonants appears to serve dual purposes of signaling prosodic prominence on the one hand and maintaining and possibly enhancing paradigmatic consonant contrasts on the other. The nature of the sound systems of most Australian languages is such that there are at least five places of articulation for stops and nasals, thus, through their lengthening, contrasts may be better maintained. The strengthening and lengthening of these intervocalic or intercontinuant consonants is also associated with the cueing of phrasal prominence in some of the languages as discussed above, although further research is needed to see whether these patterns hold across other Australian languages for all classes of consonants. Further, there may be some domain-initial effects in some Australian languages; albeit, not duration-related. Tabain and Butcher (2015) showed for Pitjantjatjara that despite neutralization of the phonemic alveolar and retroflex contrast for stops in word-initial position—which is a location where primary lexical stress and word-initial position coincide—this position does affect the center of gravity of stop bursts for the neutralized apical such that it is higher in word-initial position than both of the non-neutralized counterparts in non-initial position. Furthermore, burst duration is also longer for /p, k, c/ in word-initial position than elsewhere, showing two prosodic effects: domain-initial and stress-related strengthening.

In the following sections we outline some of the linguistic and phonological features of Djambarrpuyŋu before presenting the data and methods used to investigate prosodically conditioned consonant lengthening of nasals and stops in Djambarrpuyŋu.

3 The Djambarrpuyŋu Language

Djambarrpuyŋu is one of 40–60 clans in a large socio-cultural and linguistic bloc in north-east Arnhem Land, Northern Territory, Australia. Linguistic affiliation in Arnhem Land is complex, and contributes to linking an individual to a clan, areas of land, and ceremonial practices. Traditional linguistic practices have changed since the 1920s when missions were started throughout Arnhem Land, and they are continuing to change. Today, a language variety referred to as “Djambarrpuyŋu” is spoken as a primary language of communication by 24,300 people (Australian Bureau of Statistics, 2016) in a number of communities in north-east Arnhem Land. It is therefore assumed that Djambarrpuyŋu is a lingua franca, or koine of the area (Wilkinson, 2012), with people recognized as speakers of Djambarrpuyŋu living hundreds of kilometers westwards from the traditional language affiliation land areas, and identifying as belonging to clans with which other language varieties are traditionally associated.

Table 1. Consonant phoneme inventory of Djambarrpuyŋu.

	Bilabial	Alveolar (apico)	Dental (lamino)	Retroflex/ Post-alveolar	Palatal (lamino)	Velar	Glottal
Lenis	p ~ b (b)	t ~ d (d)	ɬ ~ ɗ (dh)	ʈ ~ ɖ (d)	c ~ ɟ (dj)	k ~ g (g)	ʔ (')
Fortis	p: (p)	t: (t)	ɬ: (th)	ʈ: (t)	c: (tj)	k: (k)	
Nasal	m (m)	n (n)	ɳ (nh)	ɳ (t)	ɲ (ny)	ŋ (ŋ)	
Lateral		l (l)		ɭ (t)			
Rhotic		r (rr)		ɻ (r)			
Glide	w (w)				j (y)		

Parenthesized italics are used for orthographic conventions.

Linguistically, Djambarrpuyŋu is analyzed as being in the Dhuwal/Dhuwala group of the Southern branch of the Yolngu subgroup of the Pama-Nyungan language family. Languages in the Pama-Nyungan language family are associated with being exclusively suffixing morphologically. This is typologically distinct from the language families that neighbor the Yolngu subgroup, which allow prefixing. Djambarrpuyŋu is a highly agglutinating language, and word order is relatively free (Wilkinson, 2012). The Southern Yolngu branch is divided into three subgroups; the Dhuwal/Dhuwala group having the most member varieties. The words “dhuwal” and “dhuwala” are shared proximal demonstratives meaning “this” or “here.” A feature of languages in the Dhuwal branch is final vowel deletion, which occurs in the majority of case-marking suffixes, some pronouns, and some demonstratives. It is observed in the language grouping terms (and demonstratives) Dhuwal versus Dhuwala.

The grammatical structure of Djambarrpuyŋu has been documented by Wilkinson (1991, 2012). However, there is little phonetic research into the Djambarrpuyŋu language to date, though there has been extensive phonetic analysis of Gupapuyŋu, a closely related variety which is also spoken throughout north-east Arnhem Land (see e.g., Graetzer, 2012; Graetzer et al., 2016; Graetzer, Hajek, & Fletcher, 2012).

3.1 Phoneme Inventory, Stress, and Phonotactics

The consonant phoneme inventory of Djambarrpuyŋu is presented in Table 1 and the vowels in Table 2, based on Wilkinson (2012). Orthographic conventions are included in the tables in parenthesized italics below the phonemic representation.

There are 25 phonemic consonants in the Djambarrpuyŋu inventory. Six places of articulation for stops, and nasals, as well as two glides, two rhotics, and two lateral approximants. There are two series of stops that are generally described as being fortis and lenis. The stop contrast is highly restricted in where it can occur phonotactically. The stop series are contrastive only in intercontinuant morpheme internal position, and are neutralized word-initially, word-finally, and following nasals and stops. The characterization of the stop series has impressionistically been related to duration (fortis stops having longer duration), the possibility of voicing (for lenis stops), and

Table 2. Vowel phoneme inventory of Djambarrpuyŋu.

	Front		Back	
Close	ɪ (i)	ɪː (e)	ʊ (u)	ʊː (o)
Open		e (a)	eː (ā)	

Parenthesized italics are used for orthographic conventions.

patterns of lenition (of lenis stops). Processes of lenition of the lenis stop series to semivowels, or approximants, occur in fast, and natural speech in Djambarrpuyŋu (Wilkinson, 2012).

There are six contrastive vowels in Djambarrpuyŋu: a three-way quality distinction, and contrastive vowel length. Vowel length is contrastive only in the initial syllable of words and long vowels are less frequent overall in the language. Jepson and Stoakes (2015) also showed that consonants after phonemically short vowels have longer duration than consonants after phonemically long vowels. As is the case throughout the Australian Indigenous languages (see e.g., Butcher, 2006), the vowel space is compressed and centralized relative to the cardinal vowels, as is also observed in the closely-related variety Gupapuyŋu (e.g., Graetzer et al., 2016).

In Djambarrpuyŋu, syllables are minimally CV and can maximally be CVCC? (Wilkinson, 2012). On top of positional restrictions for contrastive vowel length (word-initial syllables) and the stop series (contrastive in intercontinuant position), there are also distributional differences by place of articulation. For example, dental consonants do not occur in syllable-final position, except when a dental nasal occurs in an intersyllabic homorganic cluster with a dental stop. And further, alveolar consonants are uncommon, particularly in word-initial position.

In the analysis of syllable structure above, all syllables are consonant-initial, ensuring that for an intersyllabic consonant cluster, consonants in the first consonant position (C1) in the cluster are coda to the initial syllable, and the following consonant (C2) is traditionally analyzed as being onset to the following syllable. This is important for the present study because it means that a singleton consonant following the first vowel in the word forms the onset to the second syllable, although as discussed previously, there are ongoing debates with regard to the status of the syllable and underlying syllable structure in current phonological analyses of Australian languages. Medial consonant clusters can occur within a morpheme and across morpheme boundaries.¹ We are primarily concerned with clusters that span two syllables intramorphemically.

Djambarrpuyŋu, like all previously described Australian languages, is classified as having lexical stress. Stress in Djambarrpuyŋu is largely predictable (Wilkinson, 2012).² Primary, or main stress occurs on the initial syllable of a word. Secondary stress is assigned to the initial syllable of subsequent “stress groups.” Stress groups consist of two or three syllables and are treated as the structural core to the metrical structure system in the Yolŋu languages. As is found to be the case for many Australian languages, stress assignment in Djambarrpuyŋu (after Wilkinson, 2012) is affected by morpheme boundaries with the initial syllable of suffixing morphemes analyzed as attracting a secondary lexical prominence.³ The initial syllable of words is further defined as the tonic syllable. It is the potential location of a major pitch movement associated with phrasal accent or prominence (Jepson, forthcoming).

Acoustic cues to word-level and phrasal prominence in Djambarrpuyŋu have only just started to be investigated (see e.g., Jepson, forthcoming; Jepson et al., 2016). A preliminary investigation suggests that prosodic prominence does not affect the formant characteristics of vowels, nor are vowels lengthened in primary stressed versus unstressed syllables. Other effects of word-level

prominence on a segment's articulation and acoustic characteristics have not yet been explored in Djambarrpuyŋu, though Graetzer, Fletcher, and Hajek (2015) provide detailed results into consonant-vowel coarticulation in the closely related language variety Gupapuyŋu.

4 Study Aims

The aim of this study is to investigate the effects of prosodic prominence and phrasing on consonant duration in Djambarrpuyŋu. It remains to be seen how phrasal prominence, and proximity to the left or right edge of major prosodic constituents (determined by the presence of a pause and post-lexical pitch patterns) affect the duration of consonants in this Indigenous Australian language. Specifically, we ask whether consonants in the post-tonic position (i.e., consonants occurring after an accented vowel, determined by the association of a prominence lending tonal event) are longer than comparable consonants elsewhere within the accented word.

As has been found for other Australian languages, we hypothesize that consonant duration will be longer in post-tonic position compared to consonants in other prosodic contexts. However, because earlier work by Jepson and Stoakes (2015) found that post-tonic consonants are the locus of another phonetic durational contrast prompted by segmental features—compensatory lengthening of consonants due to the phonological length of the preceding vowel—we anticipate that a durational difference may be minimized due to this compensatory timing effect. It remains to be seen whether Djambarrpuyŋu displays a similar pattern to Warlpiri where obstruents are primarily affected, or whether it is more like Mawng and Bininj-Kunwok where sonorants exhibit more post-tonic lengthening than obstruents, when a singleton and in clusters.

Regarding constituent-edge effects, it is further hypothesized that word-final consonants may also be lengthened at a higher-level prosodic boundary. Given the absence of initial lengthening in other Australian languages (see Section 2), we do not predict that word-initial consonants will be longer than consonants in other positions within the word, despite consonants being the onset of a main stressed (and tonic) syllable, as well as being phonological word-initial and potentially, in the initial position of a higher-level prosodic domain.

Because of the nature of the data—all words are accented—we do not compare accented versus unaccented consonants in this paper. Therefore, we do not compare edge consonants from accented words with those from unaccented words. These remain for future investigations.

5 Method

5.1 Speakers

Eight speakers (five women, i.e., D.B., H.G., H.M., M.G., and N.B., and three men, i.e., G.M., J.G., and S.M., of mean age = 46.5 years, age range = 32–68 years) who have all lived in Milingimbi for the majority of their lives, provided the recordings for analysis. All speakers identified as speaking Djambarrpuyŋu, though had knowledge of a number of other Yolngu and non-Yolngu traditional Indigenous Australian languages as well as Australian English. Speaker participants were recruited by the first author and were compensated for their time participating in the recording sessions.

5.2 Corpus

A corpus of Djambarrpuyŋu utterances was constructed through elicitation of a wordlist in three frame sentences to investigate aspects of segments and word-level prosody in Djambarrpuyŋu.

Table 3. Examples of the three frame sentences that vary the placement of the target word within the utterance.

(a)	Raŋanŋaniŋ	napurr	ŋuli	bitjan	waŋa.	Utterance-initial position
	flatfish	lpl.excl	usually	like.this	talk	
	“‘Flatfish’ is how we usually say it.”					
(b)	Napurr	ŋuli	waŋa	raŋanŋaniŋ	bitjan.	Utterance-medial position
	lpl.excl	usually	talk	flatfish	like.this	
	“We usually say ‘flatfish’ in this way.”					
(c)	Napurr	ŋuli	bitjan	waŋa	raŋanŋaniŋ.	Utterance-final position
	lpl.excl	usually	like.this	talk	flatfish	
	“We usually say it like this: ‘flatfish’.”					

(a) Utterance-initial position; (b) utterance-medial position; (c) utterance-final position.

Wilkinson’s Djambarrpuyŋu grammar (1991, 2012), the Online Yolngu Dictionary (Greatorex, 2014), Beulah Lowe’s Gupapuyŋu dictionary (Lowe, 2004, 2014) **[AQ: 1]**, and resources from the Yolngu Matha learning course run by Charles Darwin University were drawn on to create the wordlist. The wordlist contained a number of words with sonorant segments to allow for the investigation of post-lexical pitch patterns but there was also a large number of words that contained stops. Items varied in segmental, phonotactic, and morphological structure. In total, the wordlist contained **?140** items. From that corpus, a curated dataset was constructed for analysis of positional effects on the duration of consonants, specifically nasals and stops (further details of the experimental materials, below, in Section 5.5).

5.3 Elicitation and Recording Procedure

The wordlist was discussed with individual speakers before recording the experimental materials. In the recording session, each item was presented verbally in English, Djambarrpuyŋu, or through an explanation in English. Prompting by the researcher was adopted for consistency across speakers, who had differing levels of literacy. Speakers said each item in three frame sentences once. The three frame sentences were constructed in consultation with Paula Madiwirr, a senior teacher at Milingimbi Community Education Center and were designed to place the target word in utterance-initial, utterance-medial, and utterance-final positions. Examples are presented below, in Table 3, with the token of interest in bold font.

Audio recordings were conducted in Milingimbi, a community of **?1,100** people in north-east Arnhem Land, Northern Territory, Australia, by the first author. Recordings were made using a Countryman headset microphone with a hypercardioid pattern directional capsule covered by a wind shield and were of 24-bit bit-depth (16-bit bit-depth for analysis) and 48-kHz sample rate. Recording sessions were conducted inside a house with overhead fans and air-conditioning unit turned off. Speakers were seated either at a wooden table facing parallel to a wall, or on a sofa. Exceptions to this standard are speaker S.M., who was seated on a secluded veranda facing away from the house, and speaker G.M., who was sitting under a tree and subsequently on a veranda.

5.4 Data Preparation and Acoustic Analysis

For construction of the full corpus, all utterances were transcribed and segmented in PRAAT (Boersma & Weenink, 2017) using a modified Djambarrpuyŋu orthography. Transcriptions were then converted to SAMPA (Wells, 1997). Segmentation of data of four speakers was force-aligned

using the Munich Automatic Segmentation System (Schiel, Draxler, & Harrington, 2011) in R (R Core Team, 2016) using a modified SAMPA (language-independent) parameter definition that included acoustic models for retroflex plosives, laterals, and nasals. For the remaining four speakers' data, the web-based Munich Automatic Segmentation System (Kisler, Reichel, & Schiel, 2017) was used to force align consonant and vowel segmentation using the language-independent model, which now includes acoustic models for retroflex, dental, and palatal places of articulation, trained on various Australian languages including Yolŋu Matha varieties Gupapuyŋu and Djambarrpuyŋu.⁴ All segmentation was manually corrected in PRAAT using waveform and spectral information.

Duration of nasals /m, n, ŋ, ɲ, ŋ/. Nasals were segmented with reference to wide-band spectrograms and corresponding waveforms. The interval from the onset to the offset of the nasal energy (i.e., nasal murmur) visible in the spectrogram as lower amplitude was measured. The nasal energy in the spectrum coincided with the lower amplitude in the waveform. For word-initial post-pausal nasals, the initial boundary was placed at the commencement of nasal energy visible in the lower portions of the spectrogram. For word-final pre-pausal nasals, the final boundary was placed at the cessation of voicing, determined by consulting the waveform and the spectrogram.

Duration of stops /p, b, t, d, t̪, d̪, c, ʃ, t̪, d̪, k, g/. Stops were segmented with reference to wide-band spectrograms and corresponding waveforms. The occlusion and release phases of stops were measured together. For intervocalic stops, duration was measured from the initial boundary, placed where there was a marked drop in energy, and cessation of voicing, to the final boundary, which was placed where there was a marked increase in energy and the voicing of the following segment commenced. If a stop was the first member of a cluster in which the following member was also a stop, the final boundary for the first consonant was placed at the mid-point of the overall closure duration visible in the spectrogram and waveform. For word-initial stop initial boundaries, a number of approaches were taken, depending on whether or not there was a preceding pause, and whether the stop was phonetically voiced, voiceless, or lenited to a glide or fricative. If the stop was post-pausal and phonetically voiced, the boundary was placed at the commencement of voicing visible in the lower portion of the spectrogram and also visible in the waveform. If the stop was post-pausal and phonetically voiceless, the initial boundary was placed 60 ms before the stop burst, which was identified by a marked peak in the waveform and a dark vertical bar in the spectrogram. If the stop was not preceded by a pause, and was not lenited, the initial boundary was placed in the same manner as for intervocalic stops. If the stop was not preceded by a pause, and was lenited, the initial boundary was placed at the mid-point of the formant change and where the drop in energy commenced, visible in the spectrogram. Word-final pre-pausal stop final boundaries were placed after the stop release, or, if there was no release visible in the spectrogram or waveform, then a boundary was placed 60 ms after the commencement of the closure period. Word-final non-pre-pausal stop boundaries were placed in the same manner as intervocalic stops, or stops preceding another stop, depending on the following segment.

5.5 Experimental Materials

A summary of the consonant data, separated by consonant category and position within the word, is provided in Table 3. Nasals and stops in word-initial, word-final, intervocalic, and first member in a biconsonantal, intersyllabic cluster positions are investigated in this study. Only nasals in clusters are considered in the statistical analysis. While fortis stops in clusters are presented in the summary of the data in Table 3, below, there were insufficient data for an analysis of fortis stops in clusters (i.e., $n = 31, 7$). Lenis stops are not investigated in this paper due to limited numbers of tokens. Note, the lenis symbol is used for word-initial stops orthographically and in phonological transcriptions, but those stops are non-contrastive. This is also the case for word-final stops that are

Table 4. Summary of data in the Djambarrpuyu dataset consonant category and position in word.

	Nasal <i>n</i>	Fortis <i>n</i>	Stop <i>n</i> ^a
Word-initial	681		604
Post-tonic intervocalic	370	477	
Post-tonic C1 of cluster	204	31	
Elsewhere intervocalic	942	271	
Elsewhere C1 of cluster	109	7	
Word-final	522		73

Open cells indicate a position-by-consonant-category combination that does not occur.

^aThese stops are, according to previous phonological analysis, non-contrastive.

C1 = first consonant; elsewhere = word-medially.

orthographically the fortis symbol. Further, due to position restrictions of the stop contrast, only comparison of nasals across all (non-cluster) positions was possible.

A hierarchically associated Emu database was created for the full corpus using the emuR package in R (Winkelmann, Jaensch, Cassidy, & Harrington, 2016). The database was queried in R using the emuR suite of commands, resulting in a dataset containing word-initial nasals and stops, intervocalic nasals and fortis stops, first-member of a consonant cluster nasals, and word-final nasals and stops. Those segments of interest were extracted from wordlist items of two to six syllables in length; this comprises 136 lexical items. Wordlist items included nouns, verbs, and pronouns. Further, only words with phonemically short vowels were included. The dataset for analysis included 4,291 consonants in total, comprised of 2,828 nasals and 1,463 stops (see Table 4). Durational values were extracted for all segments of interest using the dur() function from the emuR package. Additional information regarding the number of syllables in the word, the existence of a pause before and/or after the target word, identity of the speaker, identity of the target word itself, and position of the target word within the utterance, was also extracted and included in the data frame for analysis. The combined (C1+C2) duration of clusters was included for the investigation of consonants in clusters.

There are two further important aspects to these data. Firstly, all target words were in information focus due to the nature of the task and were realized with a post-lexical tonal event—usually a peak in fundamental frequency—associated near the left word edge regardless of sentence frame position. There were no cases of de-accentuation in any sentence position. This means that we cannot investigate what effect presence or absence of accentuation may have over a whole word. Secondly, in the corpus, we found pauses were often inserted before or after the target word, irrespective of where they occurred in the sentence frame. A frame-initial word may be followed by a pause, for example. Understanding these pauses to indicate a prosodic domain boundary, the frame-initial word may prosodically be both domain-initial and domain-final (Turk, 2012; Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992). This also applies for frame-final words, and frame-medial words. The distribution of tokens that were either preceded or followed by pauses, or neither, is summarized in Table 5, below.

5.6 Statistical Analysis

Linear mixed-effects models were used to statistically model and test the data. Statistical analysis was performed in R using the lmer() function from the lmerTest package (Kuznetsova, Bruun Brockhoff, & Haubo Bojesen Christensen, 2016). The step() function from the lmerTest package

Table 5. Distribution of Djambarrpuyŋu tokens arranged by frame sentence position and presence or absence of a pause.

	pause X ... (before) <i>n</i>	X pause ... (after) <i>n</i>	pause X pause (both) <i>n</i>	...X... (neither) <i>n</i>
Initial frame	662	0	810	0
Medial frame	194	247	538	336
Final frame	0	748	756	0

“X” = the target word; “pause” = locations of the pause in relation to the target word; “...” = non-pause (i.e., segmental content of another word) in relation to the target word; before = left of the word; after = right of the word; both = on both sides; neither = no pause on either side.

was used in model selection, and *f*-values are reported from its output. Bonferroni-corrected post-hoc significance (*p*-) values for individual comparisons were obtained using the `ph.step()` function (Harrington, 2017). *P* values < 0.05 are considered significant.

Position (“position”) within the word is operationally defined with four categories: word-initial, post-tonic, word-final, and elsewhere (i.e., not initial, post-tonic, nor word-final). Consonant category (“category”) is coded as a binary distinction in all comparisons, as either nasal and fortis stop, or nasal and non-contrastive stop (i.e., neutralized context). While the data were originally elicited in frame sentences, exploration of the data indicated that the existence of a pause before or after the target word reveals more about the data, and in the step output frame, as a factor, it would be removed. Therefore, the effect of a pause is investigated. The presence of a pause (“pause”) before and/or after a target word is defined with four categories: pause on neither side (neither); pause on both sides (both); pause before the target word (before); pause after the target word (after). These are reduced to a binary opposition when investigating word-initial and word-final consonants (pause vs. segment). Number of syllables in the word (“syllnum”) was also investigated as an effect; words were two to six syllables in length. “Cluster” was included in the comparison of intervocalic and first member of a cluster nasals and has two levels: first member of a cluster (C1) and intervocalic (C0). “Speaker” includes the individuals who participated in the study. “Word” includes individual lexical items as recorded in the wordlist. The duration of the second members of consonant clusters, irrespective of consonant category, is included in the analysis of C1 duration (“post.seg.dur”).

In total, six models are presented here to examine different factors in subsets of the data. These models include one for nasals and fortis stops in intervocalic positions, nasals in C1 position in clusters, word-medial nasals intervocalically versus in clusters, nasals in all (non-cluster) positions, word-initial nasals and stops, and word-final nasals and stops. Full models can be found in the Appendix. Below are the final models.

For the analysis of the duration of intervocalic consonants, the following model was used:

$$\text{duration} \sim \text{position} + \text{category} + \text{pause} + \text{syllnum} \\ + \text{position:category} + (1 + \text{position} \mid \text{speaker}) + (1 \mid \text{word})$$

Position (post-tonic, non-post-tonic/elsewhere), consonant category (nasal, fortis stop), presence of a pause (before, after, both, neither), and number of syllables in the word (2–6) were included as fixed effects with an interaction between position and consonant category. Random effects included random intercepts for speaker, and word, as well as by-speaker random intercepts for the effect of position.

For the analysis of the duration of nasals in clusters, the following model was used:

$$\text{duration} \sim \text{position} + \text{pause} + \text{syllnum} \\ + (1 + \text{post.seg.dur} \mid \text{speaker}) + (1 \mid \text{word})$$

The model included the fixed factors of position, presence of a pause, and number of syllables in the word as random effects; and there were intercepts for speaker and word and by-speaker random slopes for the effect of the duration of the following segment. Note, no interactions were included in this model as they were not retained in the model provided in the step function output.

For the comparison of intervocalic nasals and nasals in the C1 position of consonant clusters, the following model was used:

$$\text{duration} \sim \text{cluster} + \text{pause} + \text{syllnum} + \text{cluster:syllnum} \\ + (1 + \text{position} \mid \text{speaker}) + (1 \mid \text{word}).$$

The model included as fixed factors whether the segment was in a cluster or not, the presence of a pause, and number of syllables in the word, as well as an interaction between cluster information and the number of syllables in the word. Random effects included random intercepts for speaker, and word, as well as by-speaker random slopes for the effect of position.

To investigate the duration of nasal singleton consonants in all positions, the following model was used:

$$\text{duration} \sim \text{position} + \text{pause} + \text{syllnum} + \text{position:pause} \\ + (1 + \text{position} \mid \text{speaker}) + (1 \mid \text{word})$$

Position, presence of a pause, and number of syllables in the word are included as fixed effect with an interaction between position and presence of a pause. Random effects included intercepts for speaker and word and by-speaker random slopes for the effect of position.

For the analysis of the effect of a pause on the duration of word-initial nasals and stops, a separate model was used. Stops are not contrastive in the word-initial position, and thus a larger model including fortis stops in the intervocalic positions would not be a motivated comparison. The final model for the investigation of word-initial consonants was:

$$\text{duration} \sim \text{pause} + \text{syllnum} + (1 + \text{pause} + \text{category} \mid \text{speaker}) + (1 \mid \text{word})$$

Presence of a preceding pause and number of syllables in the word were included as fixed factors. As random effects, the model included intercepts for speaker and word, and by-speaker random slopes for the effect of a pause, and consonant category. Note, consonant category was removed from the model due to a non-significant effect result in the step output.

Finally, to investigate the effect of the presence of a pause on the duration of word-final consonants, the following model was used:

$$\text{duration} \sim \text{pause} + \text{category} + \text{syllnum} + \text{category:pause} (1 \mid \text{speaker})$$

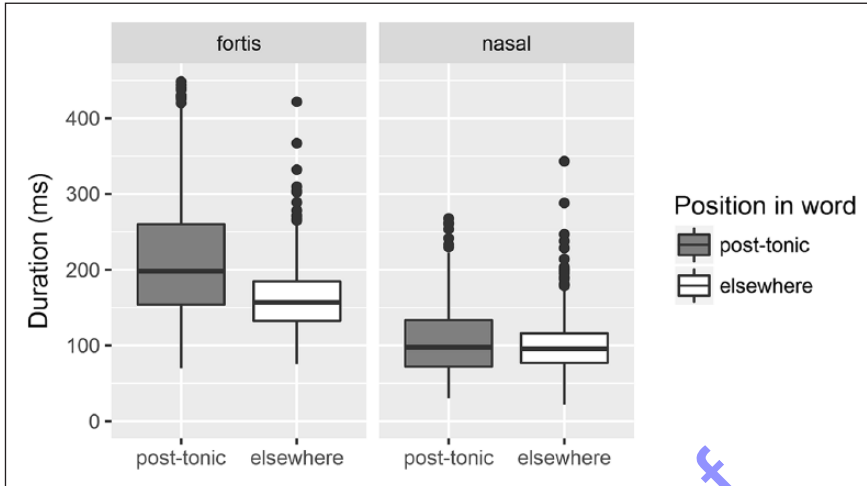


Figure 1. Duration values of nasals and fortis stops in intervocalic post-tonic (colored gray) and intervocalic elsewhere (colored white) position with the word. ms = milliseconds.

Presence of a pause, consonant category, and number of syllables in the word were included as fixed effects with an interaction between the pause and consonant category, and the model also included random intercepts for speaker. Note, random intercepts for word was removed from the model in step.

6 Results

As there are position restrictions on where the stop contrast can occur in Djambarrpuyu phonotactically (see Section 3.1), consonants in this section are referred to according to their manner of articulation; for example, “nasal” or “stop,” when presenting data from positions where the stops are non-contrastive. In positions where the stop contrast occurs, the stop in the series is mentioned; for example, “fortis.”

Results are presented firstly for intervocalic consonants, followed by the results from the analysis of nasals in clusters, then a specific analysis of singleton nasals across all positions, and the section is concluded with the results from the analysis of consonants at word-boundaries.

6.1 Duration of Singleton Consonants (Nasals and Fortis Stops) within Words

Figure 1 shows the distribution of duration values for fortis stops and nasals in intervocalic post-tonic position and in non-post-tonic intervocalic position. Table 6 presents the comparisons from the statistical analysis of word-medial singleton consonants. There is a significant effect of consonant category on consonant duration, $F(1, 894) = 807.15, p < 0.001$, such that fortis stops are an estimated $78 \text{ ms} \pm 3 \text{ ms}, p < 0.001$, longer than nasals. In Figure 1, it appears that post-tonic fortis stops have longer duration than their non-post-tonic medial counterparts. Position approached significance as an effect on the duration of consonants, $F(1, 10) = 4.63, p = 0.057$, but with a trend in the opposite direction than hypothesized. Further investigation into the discrepancy between the Figure 1 and the statistical comparisons by position presented in Table 6 revealed that the duration

Table 6. Results of statistical comparisons for intervocalic word-medial (post-tonic and elsewhere) fortis stop and nasal consonants ($n = 2,060$).

Comparison	Estimated difference (ms)	Standard error (ms)	p-value
<i>Position</i>			
Elsewhere ~ ptonic	15.7	7.3	
<i>Category</i>			
Fortis ~ nasal	77.7	2.7	<0.001
<i>Word length</i>			
2 ~ 3	71.3	7.1	<0.001
2 ~ 4	99.0	7.6	<0.001
2 ~ 5	97.7	6.3	<0.001
2 ~ 6	103.1	6.3	<0.001
3 ~ 4	27.7	7.8	0.014
3 ~ 5	26.5	6.5	0.002
3 ~ 6	31.8	6.5	<0.001
4 ~ 5	-1.3	6.8	
4 ~ 6	4	6.9	
5 ~ 6	5.3	5	
<i>Pause</i>			
Before ~ after	-10.2	2.9	0.0072
Before ~ both	-14	2.6	<0.001
Before ~ neither	1.6	3.8	
After ~ both	-3.7	2.5	
After ~ neither	11.8	3.7	0.038
Both ~ neither	15.6	3.6	<0.001
<i>Position:category</i>			
E. fortis ~ P.T. fortis	8.7	8.1	
E. fortis ~ E. nasal	70.7	3.5	<0.001
E. fortis ~ P.T. nasal	93.4	8	<0.001
P.T. fortis ~ E. nasal	62.1	7.6	<0.001
P.T. fortis ~ P.T. nasal	84.7	4.6	<0.001
E. nasal ~ P.T. nasal	22.7	7.7	0.28

Position comparison of intervocalic post-tonic consonants (ptonic) and intervocalic consonants word-medially (elsewhere); words of differing number of syllables (2–6); presence of a pause, to the left of the word (before), to the right of the word (after), on both sides (both), or no pause on either side (neither); and an interaction between consonant category (fortis; nasal), and position in the word (E.; P.T.).

ms = millisecond; elsewhere = word-medially; ptonic = post-tonic; E. = elsewhere; before = left of the word; after = right of the word; neither = no pause on either side; both = on both sides; P.T. = post-tonic.

of the post-tonic consonant category as a whole was strongly influenced by the number of syllables in the word, $F(4, 123) = 78.37, p < 0.001$. In Figure 2, post-tonic consonants in disyllabic words are plotted separately from post-tonic consonants in words of longer lengths, and consonants in non-tonic medial positions. Comparisons between consonants from words of differing lengths are included in Table 6 and show all comparisons are significant for consonants in two-syllable words. Therefore, the appearance of longer duration values of consonants in post-tonic position is due in part to the effects of word length. Recall that the non-post-tonic medial position consonants are from words of three or more syllables in length.

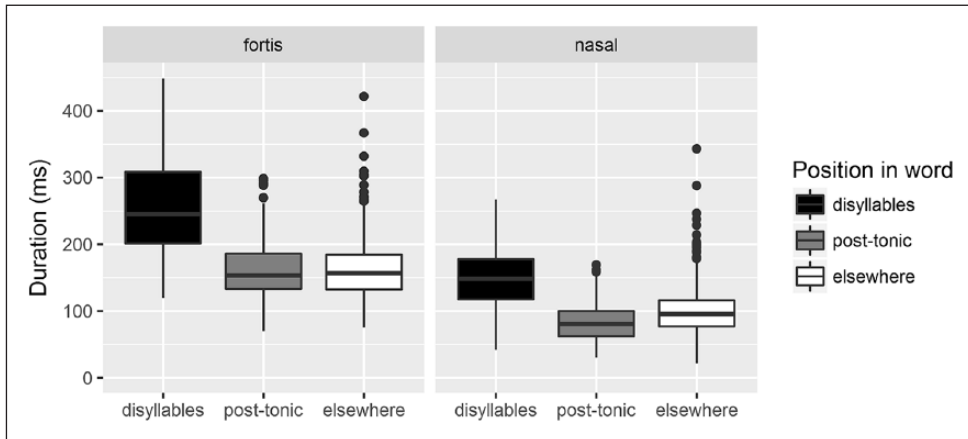


Figure 2. Duration values of nasals and fortis stops in intervocalic post-tonic position in disyllabic words (colored black) as well as intervocalic post-tonic (colored gray) and intervocalic elsewhere (colored white) position with words of three to six syllables in length.
ms = milliseconds.

There also appears to be an effect of a word's proximity to pauses, and therefore higher-level prosodic boundaries, for all consonants irrespective of position category $F(3, 1,998) = 12.75$, $p < 0.001$. Consonants in words that are followed by a pause (i.e., there is a following prosodic phrase boundary) have longer duration than consonants in words not followed by a pause, irrespective of whether there is a pause preceding the word or not. However, the effect is small (i.e., < 16 ms in all cases).

The interaction between position and consonant category was significant, $F(1, 717) = 5.52$, $p = 0.019$. However, the comparisons of interest (i.e., post-tonic fortis stops vs. elsewhere fortis stops, post-tonic nasals vs. elsewhere nasals) did not add to our understanding of the effect of position on consonant duration, as the results were reflected in the overall effects of position and category independently.

6.2 Duration of Nasals in Clusters

Figure 3 plots the duration of the initial nasal in clusters according to proximity to the tonic vowel (here also referred to as "post-tonic" for ease of comparison with intervocalic consonants). Table 7 presents the comparisons from the statistical analysis of nasals in the first position of consonant clusters. There are only a small number of tokens in the fortis C1 category (see summary in Table 3, above) so these were not included in this analysis. Position in the word has a significant, albeit small, effect on the duration of consonants $F(1, 255) = 9.87$, $p = 0.0019$, such that C1 nasals in the elsewhere position have longer duration than their post-tonic counterparts by an estimate $23 \text{ ms} \pm 7 \text{ ms}$, $p = 0.002$. Likewise, presence of a pause on either side of the word had a small effect on consonant duration irrespective of word-internal position $F(3, 288) = 4.32$, $p = 0.0053$. As for the singleton analysis, the number of syllables in a word had an effect on consonants irrespective of word-internal position $F(4, 43) = 2.6$ $p = 0.049$. The individual comparisons, however, showed that the consonants in two-syllable words were not significantly different from consonants in words of other lengths. A proportional analysis of the relative contribution of C1 to overall cluster duration showed that C1 consonants in post-tonic position constituted 760% (mean) of the duration

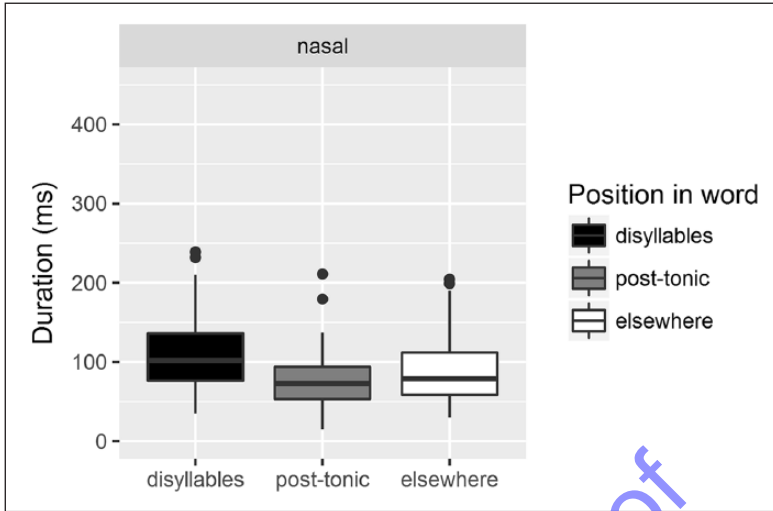


Figure 3. Duration of nasals as the first member of a consonant cluster (C₁) in post-tonic position in disyllabic words (colored black) as well as C₁ post-tonic (colored gray) and C₁ elsewhere (colored white) position within words of three to six syllables in length. ms = milliseconds.

Table 7. Results of statistical comparisons for C₁ nasals in consonant clusters ($n = 313$).

Comparison	Estimated difference (ms)	Standard error (ms)	<i>p</i> -value
Position			
Elsewhere ~ ptonic	23	7.3	0.032
Syllnum			
2 ~ 3	18.5	15	
2 ~ 4	31.7	14.9	0.659
2 ~ 5	31.4	13.7	0.453
2 ~ 6	43.2	14.4	0.075
3 ~ 4	13.2	16.4	
3 ~ 5	12.9	15.6	
3 ~ 6	24.7	16.5	
4 ~ 5	-0.3	13.9	
4 ~ 6	11.5	15.7	
5 ~ 6	11.8	14.4	
Pause			
Before ~ after	1.8	5.2	
Before ~ both	-10.8	4.6	0.32
Before ~ neither	3.4	6.8	
After ~ both	-12.5	4.2	0.051
After ~ neither	1.6	6.5	
Both ~ neither	14.2	6.2	0.39

Position comparison of post-tonic C₁ nasals and C₁ nasals word-medially; words of differing number of syllables (2–6); presence of a pause, to the left of the word, to the right of the word, on both sides, or no pause on either side. ms = millisecond; elsewhere = word-medially; ptonic = post-tonic; Syllnum = number of syllables in the word; before = left of the word; after = right of the word; both = on both sides; neither = no pause on either side.

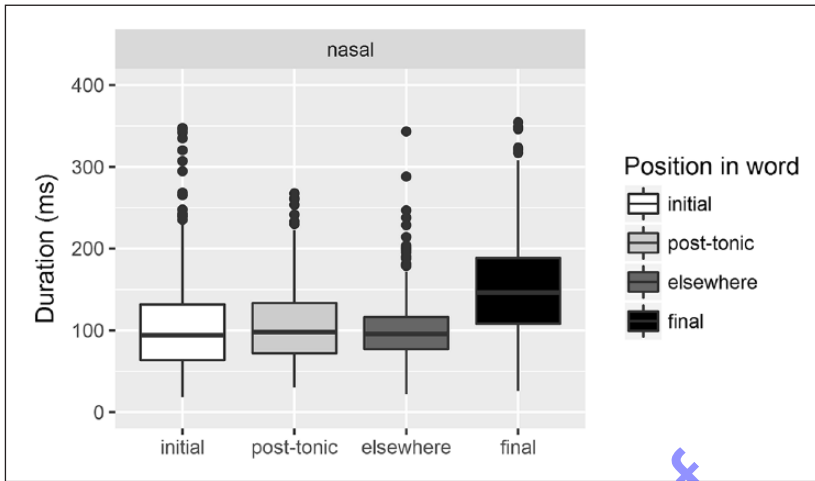


Figure 4. Duration values (ms) of singleton nasals in word-initial (colored white), intervocalic post-tonic (colored light gray), intervocalic elsewhere (colored dark gray), and word-final (colored black) positions within the word.
ms = milliseconds.

of the entire consonant cluster, and C1 consonants in non-post-tonic medial clusters constituted 256% (mean) of the duration of the entire consonant cluster. This has not yet been investigated statistically. Nevertheless, it suggests that the contribution of C1 consonants to the duration of the entire consonant cluster is similar for clusters in both word-medial positions.

An additional comparison between nasals when the first member of a consonant clusters versus intervocalic nasals showed that there was a significant effect of being in a cluster, $F(1, 445) = 13.28$, $p < 0.001$, with nasals in clusters being an estimated $11 \text{ ms} \pm 3 \text{ ms}$, $p = 0.019$ shorter than intervocalic nasals. Further, position in the word was removed as a factor from the model, as it did not have an effect on the duration of these consonants.

6.3 Word-Initial and Word-Final Consonants

As nasal consonants are the only consonants in our investigation that occur in all word positions, the results of a series of analyses investigating those consonants is presented here. Position within the word has a significant effect on the duration of nasals $F(3, 14) = 15.87$, $p < 0.001$, such that word-final nasals are longer than nasals in all other positions. This is shown in Figure 4, which plots the duration values of nasals in word-initial, post-tonic, elsewhere, and word-final positions. Table 8 presents the comparisons from the statistical analysis of singleton nasals. All comparisons with nasals in the word-final category are found to be significant, whereas all other comparisons were not significant. In other words, neither post-tonic (as seen above) nor word-initial position are significant predictors of longer nasal duration in these data. Number of syllables in the word also had a significant effect on consonant duration $F(4, 176) = 8.58$, $p < 0.001$. The presence of a pause was also a significant effect on consonant duration, $F(3, 2,401) = 58.31$, $p < 0.001$, as was the interaction between position and the presence of a pause, $F(9, 1,755) = 26.96$, $p < 0.001$. This is investigated further for word-initial and -final consonants, below.

We now consider the influence of higher-level prosodic domain boundaries through the presence or absence of pause on word-initial and word-final consonant duration. We were interested to

Table 8. Results of statistical comparisons for singleton nasals ($n = 2,515$).

Comparison	Estimated difference (ms)	Standard error (ms)	<i>p</i> -value
Position			
Final ~ initial	24.1	7.5	0.008
Final ~ elsewhere	31.9	5.2	<0.001
Final ~ ptonic	29	6.6	<0.001
Initial ~ elsewhere	7.9	8.9	0.4
Initial ~ ptonic	5	7.5	0.52
Elsewhere ~ ptonic	-2.9	5.3	0.59
Pause			
Before ~ after	-33.2	2.6	<0.001
Before ~ both	-24.7	2.4	<0.001
Before ~ neither	-21.3	3.5	<0.001
After ~ both	8.5	2.3	<0.001
After ~ neither	11.9	3.4	<0.001
Both ~ neither	3.4	3.4	0.31
Syllnum			
2 ~ 3	15.9	4.6	<0.001
2 ~ 4	18.1	5.2	<0.001
2 ~ 5	19.4	4.3	<0.001
2 ~ 6	24	4.5	<0.001
3 ~ 4	2.2	5.9	0.71
3 ~ 5	3.5	5	0.49
3 ~ 6	8.1	5.5	0.11
4 ~ 5	1.3	5.3	0.81
4 ~ 6	5.9	5.4	0.27
5 ~ 6	4.7	4.1	0.25

Position comparison of consonants in word-initial, post-tonic, word-medially, and word-final positions; presence of a pause, to the left of the word, to the right of the word, on both sides, or no pause on either side; words of differing number of syllables (2–6). The comparisons from the interaction between position and presence of a pause are not included.

ms = millisecond; final = word-final; initial = word-initial; elsewhere = word-medially; ptonic = post-tonic; before = left of the word; after = right of the word; neither = no pause on either side; both = on both sides; Syllnum = number of syllables in the word.

see if a pause before a word had an effect on the duration of word-initial consonants. It is assumed that if there is a preceding pause, the consonant is domain-initial at a higher prosodic level, as well as word-initial so we were interested to see whether higher-level prosodic domain-initial position has an effect on consonant duration. For this analysis, we investigated both nasal and neutralized stop consonants.

Figure 5 plots word-initial nasals and stops depending on whether or not the word is preceded by a pause. Table 9 presents the comparisons from the statistical analysis of word-initial consonants. Phrasal context (determined by the presence of a pause) has a significant effect on the duration of a word-initial consonant, $F(1, 7) = 18.1$, $p = 0.0033$, regardless of consonant category, which, as mentioned above (see Section 5.6), was not included in the final model based on the output from the step function. Specifically, consonants that occur in word-initial position after a pause (i.e., prosodic phrase-initial) are shorter than word-initial consonants that are not preceded by a pause by an estimated $41 \text{ ms} \pm 9.64 \text{ ms}$, $p = 0.003$. In other words, initial consonants that are

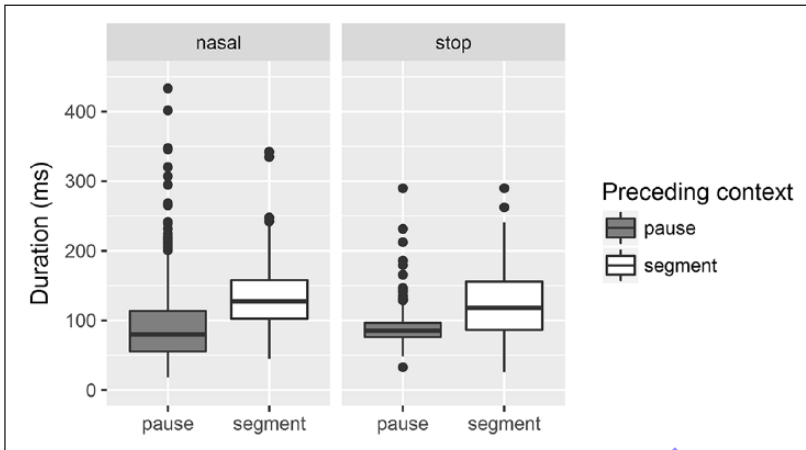


Figure 5. Duration values of word-initial nasals and stops where there is a preceding pause (colored gray) or no pause (colored white), and thus a segment of the preceding word. ms = milliseconds.

Table 9. Results of statistical comparisons for nasals and neutralized stops in word-initial position ($n = 1,285$).

Comparison	Estimated difference (ms)	Standard error (ms)	<i>p</i> -value
Pause			
Pause ~ segment	-41.0	9.6	0.036
Syllnum			
2 ~ 3	9.3	4.2	0.31
2 ~ 4	7.8	5.5	
2 ~ 5	5.9	4.7	
2 ~ 6	13.6	4.8	0.055
3 ~ 4	-1.5	6.1	
3 ~ 5	-3.4	5.4	
3 ~ 6	4.3	5.4	
4 ~ 5	-1.9	6.4	
4 ~ 6	5.8	6.5	
5 ~ 6	7.7	5.7	

Presence of a pause before the word-initial consonant (pause) or not (segment); words of differing number of syllables (2-6).

ms = millisecond; Syllnum = number of syllables in the word.

domain-medial are significantly longer than their domain-initial counterparts. Number of syllables in the word, again, had a significant, though small, effect on consonant duration, $F(4, 113) = 2.71$, $p = 0.038$. No individual comparisons for word length reached significance.

Regarding word-final consonants, it was shown in Figure 4 that nasals in word-final position are significantly longer than word-initial or word-medial (intervocalic post-tonic or elsewhere) nasals. The interaction between proximity to a boundary marked by a pause and word-final position is further considered for both neutralized stops and nasals here. Figure 6 shows the duration values of stops and nasals in word-final position plotted separately by the presence or absence of a following

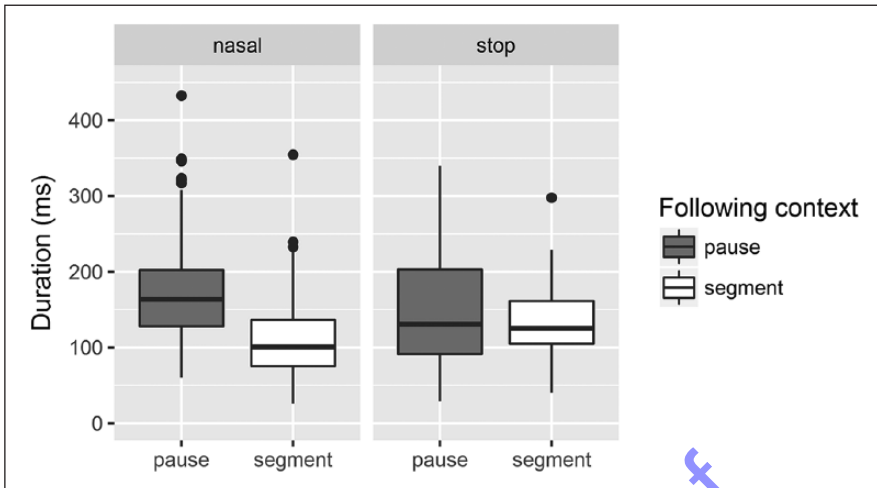


Figure 6. Duration values of word-final nasals and stops where there is a following pause (colored gray) or no pause (colored white), and thus a segment of the following word. ms = milliseconds.

pause. Table 10 presents the comparisons from the statistical analysis of word-final consonants. There is considerable variation in the duration values of word-final stops followed by a pause. The presence of a following pause had an effect on consonant duration, $F(1, 595) = 15.1, p < 0.001$. Number of syllables in the word, again, had an effect on consonant duration, $F(1, 581) = 3.19, p < 0.013$. Manner did not have a significant effect on the duration of these word-final consonants, $F(1, 590) = 1.6, p = 0.21$. However, the interaction between manner and presence of a following pause was significant, $F(1, 488) = 7.3, p = 0.007$, which showed that nasals and stops are effected differently by the presence of a following pause. Word-final nasals followed by a pause have longer duration than word-final nasals, which are followed by another word by an estimated $55 \text{ ms} \pm 6 \text{ ms}, p < 0.001$. There is no significant duration difference between word-final stops, $p = 1$.

7 Discussion

This investigation into prosodically conditioned consonant lengthening has provided some insightful results on the effects of prosodic boundaries and prominence on the duration of singleton consonants and consonants in clusters in Djambarrpuyŋu. We made three predictions: Firstly, that post-tonic consonants will have longer duration than other word-medial consonants, secondly, that we will observe an effect of domain-final lengthening when a word-final consonant is followed by a pause, and lastly, that we will not find an effect of domain-initial lengthening similar to other Australian languages. Below we summarize and discuss the findings of each analysis and consider their broader implications.

Our prediction that there would be post-tonic lengthening of consonants in Djambarrpuyŋu was not supported by these data except in the case of disyllabic tokens (e.g., Figure 2; see word length comparisons in Table 6). Rather, there was a more general tendency for intervocalic nasals in non-post-tonic position to be marginally longer than their post-tonic counterparts. This was also observed for nasals in the C1 position in consonant clusters (see Figure 3). This is in contrast to previous studies of other Australian languages, including Mawng and Bininj Kunwok, where nasals tended to lengthen in post-tonic position compared to other word-medial positions (Fletcher

Table 10. Results of statistical comparisons for word-final nasals and neutralized stops ($n = 595$).

Comparison	Estimated difference (ms)	Standard error (ms)	p -value
Pause			
Pause ~ segment	33	8.5	0.0018
Category			
Nasal ~ stop	-10.5	8.4	
Syllnum			
2 ~ 3	8	8.2	
2 ~ 4	24.4	7.2	0.14
2 ~ 5	-7.1	12.1	
2 ~ 6	4.5	14.1	
3 ~ 4	16.4	10.2	
3 ~ 5	-15.2	14	
3 ~ 6	-3.6	15.7	
4 ~ 5	-31.5	13.4	0.35
4 ~ 6	-19.9	15.1	
5 ~ 6	11.6	17.6	
Category:pause			
N. pause ~ N. segment	55.1	6.1	<0.001
N. pause ~ S. pause	11.6	8.9	
N. pause ~ S. segment	22.5	13.8	
N. segment ~ S. pause	-43.5	9.7	<0.001
N. segment ~ S. segment	-32.6	14	0.36
S. pause ~ S. segment	10.9	15.5	

Presence of a pause after the consonant (pause), or not (segment); category of the consonant (nasal; stop); words of differing number of syllables (2–6); interaction between consonant category (nasal; stop) and presence of a pause after the segment (pause) or not (segment).

ms = millisecond; Syllnum = number of syllables in the word; N. = nasal; S. = stop.

et al., 2010, 2015). It was also argued in previous studies that the sonority of these segments could be enhanced through lengthening, and generally contribute to the entire phrasal accentual prominence gesture, which is also typically associated with a strong rising pitch movement throughout the initial segmental sequence of a phrase. Rather a different pattern of consonant duration patterning is found in our study. Unlike earlier studies, we factored word length into the analysis of post-tonic lengthening. While we observed longer post-tonic consonants in disyllabic words, the effects were not evident at all in longer words. It should also be noted that in one of the earlier studies of Warlpiri (Butcher & Harrington, 2003), the effects appeared strongest in *focused* disyllable tokens that were compared with unfocused counterparts. However, we did not compare consonants following the first vowel of a word when the word was accented (and hence the consonant would be post-tonic) with consonants in the same position in unaccented words. It should also be pointed out that reported duration differences associated with this effect are not typically large in magnitude.

Furthermore, across Australian languages, the post-tonic position is the first position within a word where it is possible for all consonant contrasts to be realized. This includes stop series and all coronal consonants.⁵ Therefore, it appears that the relevant phonological contrasts of Djambarrpuyngu signal this to be a prominent position in the language in some sense (see discussion in Keating, 2006). The lengthening of these consonants may have served to enhance these consonant contrasts,

as well as encode prosodic prominence. However, our data do not concur with previous findings for other Australian languages that lengthening the post-tonic consonant is an additional cue to prosodic strength in Djambarrpuyŋu alongside prominence-lending pitch movements associated with the tonic vowel (see Butcher, 2006; Cho, 2016).

Word-initial position did not have an effect on consonant duration in these data. We found that the duration of nasals had comparable duration values to those in the word-medial positions. This result suggests that the word-initial consonant is not a site of temporal expansion, unlike other languages (see Cho, 2015; Fletcher, 2010), although further acoustic and additional articulatory investigations might tell a more complex story of “strength” (see, e.g., Keating et al., 2004 on English, Korean, French, and Taiwanese; Tabain & Butcher, 2015 on Pitjantjatjara). The effect of a higher-level prosodic domain boundary on word-initial consonant duration was investigated through comparing word-initial consonants, which were preceded by a pause with those that were not preceded by pause. We showed that consonants—both nasals and neutralized stops—when not preceded by a pause had longer duration than segments that were. That is, being in the initial position of a higher-level prosodic domain did not appear to condition lengthening of word-initial consonants, but rather shortened them. Similar findings have been reported for French (Fougeron, 2001) and English (Cho & Keating, 2009). Our results resonate with Cho and Keating (2009) findings for English nasal /n/ in particular, which was found to not show an effect of proximity to an initial boundary overall, but it was discovered to have *shorter* duration in utterance-initial position compared with utterance-medial position when the word was accented. Cho and Keating’s findings for /t/, however were markedly different, such that Voice Onset Time was longer for utterance-initial stops, when *unaccented*. This highlights again that it may prove quite fruitful in the future to investigate unaccented words regarding domain-initial lengthening, to assess whether there is a further durational effect of accentuation, or an interaction between proximity to a boundary and accentuation in Djambarrpuyŋu.

Word-final position appeared to have an effect on the duration of word-final consonants particularly when consonants were also in final position of a higher-level prosodic domain. Nasals in word-final position preceding a pause were significantly longer than nasals in all other positions, including word-initially, word-medially, and word-finally, not preceding a pause. This was predicted, as the phenomenon of domain-final lengthening is more or less universally attested (see Cho, 2016 for discussion), and the word-final consonant or syllable rhyme is often found to show this effect (Turk, 2012; Turk & Shattuck-Hufnagel, 2007).

Taken together, these data suggest that Djambarrpuyŋu speakers are able to encode prosodic domain boundaries in different ways through insertion of a pause or through segment lengthening, and that these operate distinctly at the left versus the right domain edges. Left-dislocation is an important strategy for marking information structure prominence in many Australian languages (Simpson & Mushin, 2008), and this may further condition domain-final lengthening of word-final consonants. Prepausal lengthening has certainly been observed in vowels in previous analyses of Australian languages (e.g., Bishop, 2002; Fletcher & Evans, 2002) and the results shown here suggest that this is also apparent in prepausal word-final consonants in Djambarrpuyŋu. Therefore, in the present study, lengthening of consonants at the right boundary of words that occur before a pause may increase the sense of junction at the domain-final boundary. Without an articulatory investigation, we cannot be sure whether the shorter duration values observed for word-initial segments following a pause is due to a shorter articulation of the segment, or a delay in voicing resuming or beginning after the pause (Fougeron, 2001). In general, a deeper investigation is required. It would include taking into account speech rate and tempo, which were not examined here. Comparing word-initial and word-final consonants with their counterparts from *unaccented* words (or, at least, non-focused words) would also enhance the analysis. Further, it would also be

interesting to investigate the articulatory correlates of consonants in different word and utterance positions to ascertain if there is additional strengthening in terms of gestural magnitude as was found for Pitjantjatjara (Tabain & Butcher, 2015) and Warlpiri (Butcher & Harrington, 2003).

Returning to post-tonic consonants, there are a number of interesting implications of the results reported in this study. Firstly, as mentioned previously, intervocalic post-tonic consonants in disyllabic words are indeed significantly longer than all other word-medial consonants. There is a statistical trend for consonants in other positions in two-syllable words to also have longer duration than their counterparts in longer words, but individual comparisons do not show an effect of the same magnitude, if at all (see word length comparisons in Tables 6–10). Therefore, it may be that polysyllabic shortening is affecting the duration of post-tonic consonants in longer words, and that this is why we observe longer duration values for intervocalic post-tonic consonants in disyllabic words, and not in words of more syllables (see e.g., White & Turk, 2010). Nevertheless, the observed duration differences between words of different syllable length highlights the value in working with a wide range of data in terms of word length and word structure. Secondly, these results have noteworthy implications for the analysis of the relationship between consonant duration and phonemic vowel length in Djambarrpuyngu. Previously, it has been reported that consonants lengthen after phonemically short vowels in word-initial syllables (see Jepson & Stoakes, 2015). The findings presented here suggest that the relationship is better described as consonants being shortened after phonemically long vowels. That is, the post-tonic consonants analyzed in this study follow phonemically short vowels, and thus are the longest consonants that occur in that post-tonic position. Yet they have similar duration values to other word-medial consonants. Therefore, post-tonic consonants following phonemically long vowels would have shorter duration values than consonants elsewhere within the word.

These findings tell us more about the possible scope of phonetic realization of prosodic prominence and effects of prosodic boundaries, and how competing phonologically motivated goals—for example, phoneme distinctions, and metrical structure—are negotiated. On the topic of phonemic distinctions, it may be that post-tonic consonants are already overloaded in terms of the functions of durational differences. The duration of these consonants correlates inversely with the phonemic length of the preceding vowel, and the language contrasts long and short stops, realized primarily by closure duration. Therefore, it is possible that the functional load of duration to encode these aspects of the language means there are reduced lengthening effects associated with prominence (see Berinsein, 1979).

In future work, it would be insightful to manipulate the information structure of the utterance frames. Tokens in this study were realized with information focus regardless of utterance position, so the effect that phrasal prominence or accentuation may have on a whole word is not able to be teased apart from other conditioning factors at this stage. Nor can the combined effects of proximity to a boundary and accentuation be separated in these data. It is important to note that even outside of this prominent information structure position, it may also be the case that accentual prominence is obligatory on nouns in Djambarrpuyngu, as found in Mawng (Fletcher, Singer, & Loakes, 2012), so we may not expect to find patterns of deaccentuation akin to languages like English. Further research could also involve an investigation into individual speakers to ascertain if all individuals use similar lengthening strategies for encoding boundaries and prosodic prominence. Cross-linguistically, individuals have been found to have different patterns of lengthening and strengthening (see Cho & Keating, 2001, 2009; Fougeron, 2001), so a next step could include a closer exploration of interspeaker differences, now we have a better understanding of how consonant duration interacts with prominence and domain-boundaries in Djambarrpuyngu.

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Notes

1. There are 14 possibilities for intramorphemic two-member consonant clusters: nasal + nasal; nasal + stop; stop + nasal; stop + stop; stop + semi-vowel; lateral + nasal; lateral + stop; lateral + semivowel; rhotic + nasal; rhotic + stop; rhotic + semivowel; semivowel + nasal; semivowel + stop; semivowel + semivowel. Further possibilities are observed intermorphemically.
2. In her grammar, Wilkinson (1991, 2012) follows the approach of Wood (1978) and Waters (1979) in their analyses of stress in Gaalpu and Djinang, respectively. These are two (relatively) distantly related languages in the Yolngu subgroup.
3. Further, word-final syllables are generally treated as extrametrical for stress assignment. This means word-final syllables are not stressed unless the word is monosyllabic, the word is a compound and the second member is monosyllabic, or if a monosyllabic form is reduplicated. In the latter two cases, this may also result in stress falling on adjacent syllables.
4. "Yolju Matha" refers to language spoken by Yolngu, and linguistically includes a reduced number of languages in the Yolngu subgroup.
5. Due to distributional difference in the stop series, and the rarity of lenis stops in contrastive positions in the dataset used in the present study, it is not possible to delve further into how prosodic position may affect fortis and lenis stops differently at this stage, using our current dataset.

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Appendix

Full models for each analysis that were used with the step() function (Kuznetsova et al., 2016) are included below.

Intervocalic Consonants

$$\text{duration} \sim \text{position} * \text{category} * \text{pause} + \text{syllnum} + \text{pause:syllnum} \\ + (1 + \text{position} \mid \text{speaker}) + (1 \mid \text{word})$$

Nasals in Clusters

$$\text{duration} \sim \text{position} + \text{pause} + \text{syllnum} + \text{post.seg.dur} \\ + \text{position:syllnum} + \text{position:post.seg.dur} + \text{syllnum:post.seg.dur} \\ + (1 + \text{position} + \text{post.seg.dur} \mid \text{speaker}) + (1 \mid \text{word})$$

Nasals in Clusters versus Intervocalically

$$\text{duration} \sim \text{position} * \text{cluster} * \text{pause} + \text{syllnum} \\ + (1 + \text{position} \mid \text{speaker}) + (1 \mid \text{word})$$

Singleton Nasals in All Position within the Word

$$\text{duration} \sim \text{position} + \text{pause} + \text{syllnum} + \text{position:pause} \\ + \text{pause:syllnum} + (1 + \text{position} \mid \text{speaker}) + (1 \mid \text{word})$$

Word-Initial Consonants

duration ~ pause + category + syllnum + pause:syllnum
+ syllnum:category + (1 + pause + syllnum + category | speaker) + (1 | word)

Word-Final Consonants

duration ~ pause + category + syllnum + pause:category
+ (1 + pause + category | speaker) + (1 | word)

Uncorrected Proof