Consonantal coarticulation resistance in vowel-consonant-vowel sequences in two Australian languages

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Abstract

Formant two distribution for Arrernte and Burarra, two Australian languages, at V^1-offset and V^2-onset in V^1CV^2 sequences reveals that phonemic voiceless plosive consonants differ in coarticulation resistance such that labial consonants are least resistant and palatal consonants are most resistant. While the two languages display slightly dissimilar patterns of resistance, they share a strong tendency towards greater variation in V^1-offset, suggesting that the effects of coarticulation resistance are strongest immediately after intervocalic consonants in these languages.

1. Introduction

This paper reports on a quantitative, acoustic phonetic study of consonantal coarticulation resistance in vowel-consonant-vowel sequences in two Australian aboriginal languages: Arrernte and Burarra.

Coarticulation is the articulatory or acoustic influence of one consonant or vowel on another, and is known to occur universally. Coarticulation resistance may be defined as the extent to which some segment resists the influences of a neighbouring segment or segments. Coarticulatory resistance is found in three main contexts. Firstly, it is found when resistance prevents the confounding of paradigmatic contrasts by heightening phonetic clarity. Secondly, it is found when articulatory strengthening of segments is induced by prosody or pragmatics, where articulatory strengthening is defined as 'an increase in the spatio-temporal magnitude of gestures' (Cho, 2004, 142). When induced by prosody, articulatory strengthening delimits the edges of prosodic constituents such that, in general, strengthening is greater at constituent onsets than offsets (called "domain-initial strengthening"), and is greater at onsets of higher prosodic constituents than lower ones (see e.g. Fougeron & Keating, 1997). Finally, coarticulatory resistance is found when segments are inherently strong articulatorily. This claim is supported by Recasens (1985). According to Recasens, coarticulatory resistance is positively correlated with large degrees of dorsopalatal contact, i.e. contact between the upper surface of the tongue and the palate, the formation of a double place of articulation, as in a palatovelar consonant, and tongue-body-tongue-tip "coupling" (i.e. interaction) (105). In other words, on this view, resistance for a given segment may vary according to whether or not, and the extent to which, a given segment shares articulators with one or more adjacent segments.

The main research goal of the current study was to determine whether phonemic consonants differ in coarticulation resistance in the speech of speakers of Arrernte and Burarra. It is profitable to examine coarticulation resistance in these languages for two main reasons: one, because coarticulation resistance in one or more Australian languages has not previously been the subject of any instrumental phonetic study, and two, because the consonant inventories of Australian languages have many places of articulation (in turn, because the need to preserve distinctions between multiple places of articulations is likely to relate to coarticulation resistance, see e.g. Cho, 2004; Butcher, 2006, chap. 12; see above).

Based on earlier work, consistent differences in coarticulation resistance are expected, such that labial consonants will be least resistant, alveolar consonants of intermediate resistance, and palatal consonants most resistant. This prediction is based on our knowledge of universals and our knowledge of related languages such as Yanyuwa and Yindjibarndi (see e.g. Recasens, 1985; Tabain & Butcher, 1999). Tabain & Butcher (1999), using the locus equation metric for measuring coarticulation, found for Yanyuwa and Yindjibarndi that velar and labial stops (e.g. /k/ and /p/) are most highly coarticulated, and laminals (e.g. /c/) least coarticulated, with apical consonants (e.g. /t/) coarticulated to an intermediate degree.

The way in which the main research goal is attained is by determining whether formant two (F2) distribution for V^1-offsets and V^2-onsets in V^1CV^2 (vowel-consonant-vowel) sequences, where C is /p, t, tr, c, k/ ('tr' representing an oral voiceless retroflex plosive), is consistently related to consonant identity. The justification is that larger ranges at V^1-offset or V^2-onset indicate a lesser degree of lingual constraint, and thus lower coarticulation resistance in the intervocalic consonant (Recasens, 1985, 103), given that consonants with low coarticulatory resistance are known to exert weaker influence on adjacent vowels (see e.g. Recasens, 1987).

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2. Methods and Materials

The two languages addressed in this study are Arrernte and Burarra. Arrernte is principally spoken near Alice Springs in the Northern Territory. It is an Arandic, Pama-Nyungan language, which has twenty-seven phonemic consonants and two non-marginal and two marginal phonemic vowels (Breen & Dobson, 2005). The majority of Arrernte's consonantal phonemes can be phonetically realised as labialised or non-labialised consonants. Phonemic inventories are set out in tables 1 and 2 (after Breen & Dobson, 2005).

Burarra is principally spoken in Arnhem Land, approximately five-hundred kilometres east of Darwin. It is a non-Pama-Nyungan language, which has twenty-one phonemic consonants and five phonemic vowels (Glasgow, 1981, p.65). See table 3 (after Glasgow, 1981).

The consonants chosen for this study are categorised by Butcher (2004) as fortis consonants, where "fortis" indicates greater intra-oral peak pressure and stricture duration than in "lenis" counterparts. One fortis/lenis pair is, for example, /p/ and /b/. Phonemic vowels are shown in table 4 (after Glasgow, 1981).

	bilabial	dental	(apico-) alveolar	apico-postalveolar /retroflex	(lamino-) palatal	(dorso-) velar
plosive	p	t̪	t	ʈ	c	k
nasal	m	n̪	n	ɳ	ɲ	ŋ
pre-stopped nasal	ᵖm	ᵗ̪n̪	ᵗn	ᵗɳ	ᶜɲ	ᵏŋ
trill			r			
fricative						ɣ
approximant	w			ɻ	j	
lateral approximant		l̪	l	ɭ	ʎ	

Table 1: Arrernte: phonemic inventory of consonants

	Front	Central	Back
Close	i		u
Mid		ə	
Open		a	

Table 2: Arrernte: phonemic inventory of vowels (where close vowels are marginal)

	bilabial	(apico-) alveolar	apico-postalveolar /retroflex	(lamino-) palatal	(dorso-) velar
plosive	p b	t d	ʈ ɖ	c ɟ	k g
nasal	m		ɳ	ɲ	ŋ
trill		r			
approximant			ɻ	j	
lateral approximant		l	ɭ		

Table 3: Burarra: phonemic inventory of consonants

	Front	Central	Back
Close	i		u
Open-Mid	ɛ		
Open		ɐ	ɒ

Table 4: Burarra: phonemic inventory of vowels

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The corpus consists of approximately one-thousand words from Arrernte and Burarra elicited from four speakers. The corpus was collected and digitised by Professor Andrew Butcher. Tokens were extracted from the corpus using Praat version 4.3.12 (Boersma & Weenink, 2005; Copyright 1992-1998, Summer Institute of Linguistics). Table 5 shows the number of tokens per consonant, language, and speaker.

		Consonant					
Language	Speaker	p	t	tr	c	k	Number of available tokens
Burarra	1 (DP)	18	7	6	18	22	287
	2 (KF)	4	2	6	3	9	86
	SUBTOTAL	22	9	12	21	31	373
Arrernte	3 (MM)	27	12	24	20	48	276
	4 (VD)	27	16	31	23	57	322
	SUBTOTAL	54	28	55	43	105	598
TOTAL		76	35	67	64	236	971

Table 5: Number of tokens per consonant, language, and speaker

The extracted tokens are labelled using the EMU Speech Database System Version 2.0.1 (Copyright 1998, SHLRC, Macquarie University) (see e.g. Cassidy & Harrington, 2004, 1). Labelling in EMU involves segmentation and duration estimation based on acoustic waveform and broadband spectrographic information. See Figure 1. The strategy for spectrographic segmentation in EMU used in this study is as follows: vowel-consonant-vowel sequences are picked out for analysis when consonants are /p,t,tr,c,k/. Intervocalic consonants are chosen on account of neutralisation in these languages (see e.g. Capell, 1967). Vowel offset boundaries, when vowels precede these plosives, are placed at the offset of regular periodicity in the waveform, and vowel onset boundaries, when vowels follow these plosives, are placed at the onset of regular periodicity. Formant values (F2) were extracted at measurement points using EMU(R Version 2.1.1) and statistical analyses were performed. Variation between speakers of the same language was found to be insignificant; hence separate plots were generated for each consonant, for each language.

The resistance of a consonant to coarticulation is here averaged across vowel environments. The uneven distribution of vowel types cannot be discounted as a confounding factor, on account of the small size of the current corpus not permitting empirical verification of invariant resistance across vowel contexts (see e.g. Recasens & Espinosa, 2006; c.f. e.g. Carre, 1998).

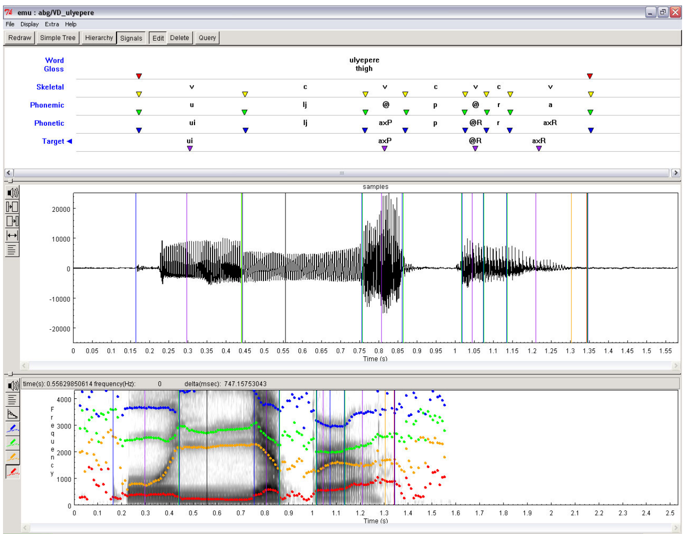

Figure 1: The EMU signal display

3. Results

Figures 2 to 6 plot F2 V^1-onset values and F2 V^2-offset values in adjacent boxes for /p,t,tr,c,k/ across vowel environments. Separate plots are shown for the two languages.

Figure 2 plots values for /p/. For Arrernte speakers (shown in the left plot), V^1-offsets and V^2-onsets differ so markedly that medians (indicated by notches) do not overlap. The "notch non-overlap" in the boxplots provides strong evidence for weak consonantal coarticulation resistance.

For Burarra speakers (shown in the right plot), V^1-offsets and V^2-onsets differ somewhat but less so. Observe that the range of onset values is rather large, and highly similar across groups, but that offset values are less variable, and are different in frequency but hardly in range between groups. The smaller range at V^2-onset suggests that the acoustic effects of coarticulation resistance are greater at V^2-onset than at V^1-offset for /p/, for both languages.

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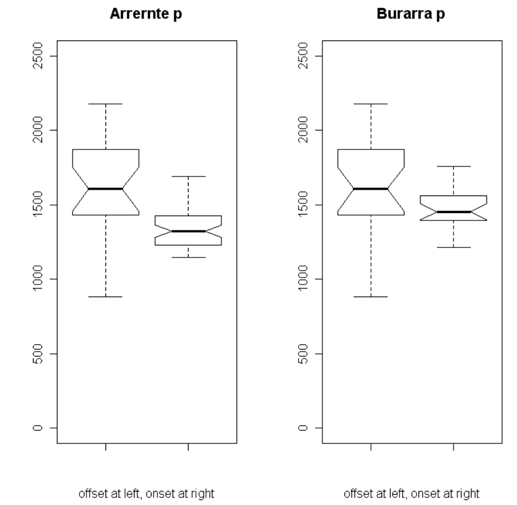

Figure 2: Boxplots for V^1 offset and V^2 onset for /V^1pV^2/ for both languages

Consider boxplots for /t/ (Figure 3). Observe that V^1-offset and V^2-onset ranges are much greater for /t/ in Arrernte (in the left plot) than in Burarra (in the right plot), which suggests that /t/ is less coarticulation resistant in Arrernte than Burarra. Again, V^2-onset ranges are smaller than offset ranges (for both languages), suggesting that the coarticulatory resistance effects between consonant and adjacent vowel(s) are larger at V^2-onset than elsewhere.

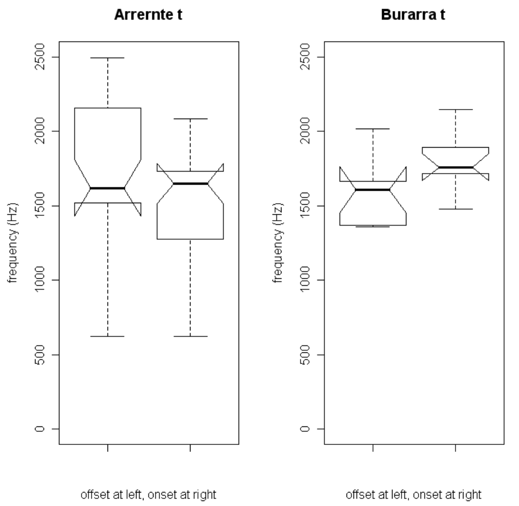

Figure 3: Boxplots for V^1 offset and V^2 onset per group for /V^1tV^2/ for both languages

Turning to /tr/ in Figure 4, compare the very large range of offset values for Arrernte (left plot), to the very limited range of onset values for Arrernte (left plot). The same contrast between offset and onset ranges is seen for Burarra (right plot), but on a smaller scale. These results suggest that /tr/ is somewhat coarticulation resistant. Again, the smaller range at V2 onset suggests that the acoustic effects of coarticulation resistance are greater at V2-onset than elsewhere.

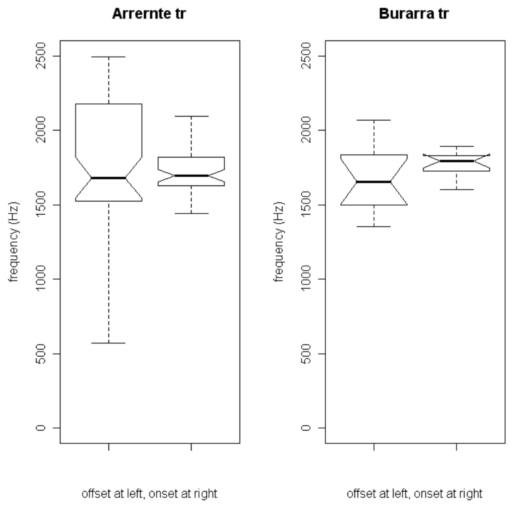

Figure 4: Boxplots for V^1 offset and V^2 onset for /V^1trV^2/ for both languages

With respect to /c/ and /k/ (Figures 5 and 6), observe that ranges are relatively small for /c/, especially for Burarra (right plot) and only slightly larger for /k/ in Arrernte. Furthermore, for /c/, ranges are more similar across V^1-offset and V^2-onset than for previous consonants, although the V^1-offset range is very slightly larger for both languages. For /k/ in Burarra (right plot) the V^2-onset range (not including the whiskers) is larger. /k/ ranges are of moderate size for Burarra. Finally, across all results, only for /k/ in Burarra is the offset range not greater than the onset range.

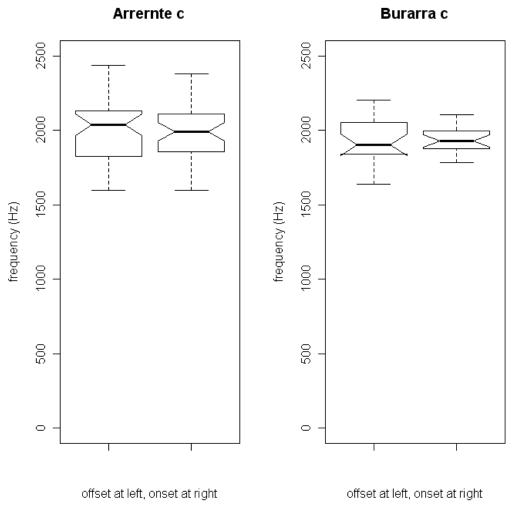

Figure 5: Boxplots for V^1 offset and V^2 onset for /V^1cV^2/ for both languages

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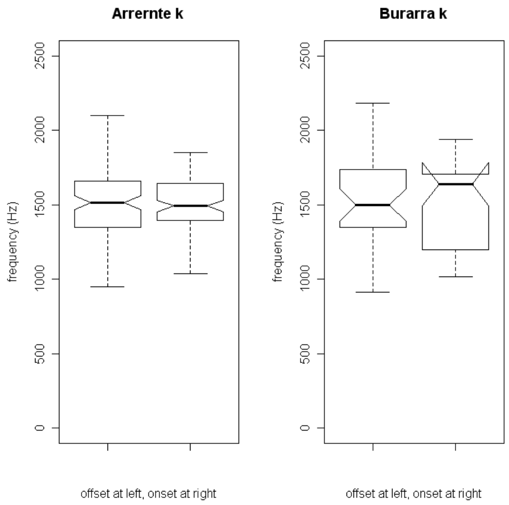

Figure 6: Boxplots for V^1 offset and V^2 onset for /V^1kV^2/ for both languages

4. Discussion

As stated, greater variation, or larger range, at vowel offset or onset is taken to indicate lower coarticulation resistance. In general, the largest range occurs for /p/, as in previous studies (e.g. Tabain & Butcher, 1999, 338). For /p/ for Arrernte speakers, V^1-offsets and V^2-onsets differ markedly, indicating low resistance. A probable explanation is that labial consonants such as /p/ do not involve lingual activity that would conflict with a gesture or gestures for the transconsonantal vowels (e.g. Recasens, 1999, chap. 16).

Moderate coarticulation resistance is present for /t/ for Burarra speakers while weak coarticulation resistance is present for /t/ for Arrernte speakers.

Results for /tr/ suggest that it is somewhat coarticulation resistant - possibly because of an inability to both raise and curl back the tongue front to execute the consonant, and adjust the height of the tongue dorsum to coarticulate with adjacent vowels (see Recasens, 1999, chap. 16). The majority of the effects of this resistance is clearly realised immediately after the consonant, rather than before, given that ranges are very much smaller for V^2-onset than V^1-offset.

Ranges are small for /c/, and V^1-offset and V^2-onset ranges are highly similar for /c/ for both groups, indicating very high coarticulation resistance for this consonant. Even so, V^1-offset ranges are slightly larger, suggesting that V^2-onset range is more tightly controlled (at least for this consonant). In Arrernte, offset and onset ranges are similar for /k/, and V^1-offset ranges are slightly larger than V^2-onset ranges. Ranges are more restricted (i.e. smaller) for Arrernte speakers than for Burarra speakers. /k/ appears to be highly coarticulation resistant in Arrernte, and moderately resistant in Burarra. These results suggest that /c/ is highly coarticulation resistant, or in other words, that articulatory gestures for /c/ are tightly controlled. The finding of high resistance for /k/ in Arrernte does not accord with results for Yanyuwa and Yindjibarndi (Tabain & Butcher, 1999).

The findings for labial, velar and palatal consonants are readily explained - the production of labial consonants does not require use of the tongue body, so there is no articulatory conflict between intervocalic consonant and vowels, whereas velar and palatal consonants require 'use of the tongue body in conflict with the production of vowels, thereby restricting vowel-to-vowel coarticulation' (Magen, 1997, 188). /c/ is both a close and front constriction, which places significant constraints on the tongue (see Recasens, 1999, chap. 16), whereas /k/ is produced with the tongue dorsum, which is relatively slow-moving (85). The finding of high resistance in Arrernte for /k/ indicates that there are no distinct palatovelar or dorsovelar allophones of /k/ in Arrernte as have been hypothesised for some other languages (such as English, see e.g. Recasens, 1985, 103; Butcher & Tabain, 2004).

Results for this experiment show clear and consistent effects of coarticulation resistance differences between phonemic consonants. In addition, a very strong tendency for greater variation in V^1-offset than V^2-onset indicates that the effects of coarticulation resistance on transconsonantal vowels are greatest immediately after the consonant in these languages.

Highly similar V^1-offset and V^2-onset ranges were found for /c/ in both Burarra and Arrernte, and for /k/ in Arrernte. One possible interpretation of these results relates articulatory strengthening to an important issue in Australian languages - the status of the syllable. For /c/ in both languages, and for /k/ in Arrernte, spectral cues to consonant identity appear to be very nearly as tightly controlled in vowel to consonant transitions as in consonant to vowel transitions. This finding might provide some evidence against the articulatory strengthening one might hypothesise for syllable-initial segments in a language for which the syllable is a relevant prosodic parameter, given Fujimura's suggestion that syllable-initial, word-initial, and phrase-initial positions seem to be 'generally characterised by more "forceful" articulatory gestures' (1990, 232). Fougeron and Keating make this link between coarticulatory resistance, articulatory strengthening, and prosodic-domain edges (1997, 3737).

Overall, the results showed a general tendency for a greater range of values at V^1-offset than V^2-onset in both languages. Given that strengthening effects are thought to be strongest at domain-initial position, and not at domain-medial or domain-final position (see e.g. Fougeron & Keating, 1997), one might speculate that these results support the VC syllable-type for these languages, rather than the CV syllable-type. However, there are some possible confounding factors, including the need to preserve paradigmatic contrasts, progressive effects due to sluggish articulators, and the low rank of the relevant prosodic domain (given that strengthening effects tend to be greater when delimiting higher ranking prosodic domains, see e.g. Beckman & Pierrehumbert, 1986; Fougeron & Keating, 1997).

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5. Conclusions

This paper contributes to an understanding of coarticulation by examining consonantal coarticulation resistance in two Australian languages. As predicted, the results provide evidence for a relationship between consonant identity and variability in V^1-offsets and V^2-onsets in V^1CV^2 sequences, and by extension between consonant identity and coarticulation resistance. On the basis of these results, it would appear profitable to extend the current study to better investigate, firstly, the relationship between coarticulation resistance and phonemic inventory, and secondly, the relationships between coarticulation resistance, articulatory strengthening, and prosodic-domain edges, in the two relevant languages.

6. Acknowledgements

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