# Coarticulation in CV sequences: Locus Equation data

Simone Graetzer

University of Melbourne, Royal Parade, Parkville Victoria, 3010 Melbourne, Australia
n.graetzer@pgrad.unimelb.edu.au

The aim of the study was to compare the magnitude of anticipatory coarticulation of oral voiceless plosives by following vowels in four Australian languages: Arrernte, Burarra, Gupapuyngu, and Warlpiri. The corpus consisted of approximately nine hundred isolated real words spoken by eight female adult speakers of the four languages. Locus equations were calculated for intervocalic consonants /p, c, t, ʈ, k/ and all following vowels in consonant-vowel sequences. Measurement points were 0.1 and 0.5 into the vowel. There was a general tendency towards relatively highly coarticulated velar plosives, moderately coarticulated retroflex and alveolar plosives, and weakly coarticulated palatal plosives. Results were variable for bilabial plosives. These results are for the most part in accordance with findings for other Australian languages.

# 1 Background

Languages are known to differ both qualitatively and quantitatively in their implementation of the process of coarticulation. One of the factors known to interact with coarticulation is language-particular phonological structure. If a phonemic inventory has a large number of places of articulation, then we might anticipate that coarticulation would be reduced in order to preserve perceptual contrasts. Additionally, there may be a relationship between possessing a large number of consonantal contrasts and possessing a small vowel system. This pattern of place rich consonant inventories and small vowel inventories is found in the Australian languages considered in this paper. There is a need to preserve perceptual contrasts between consonants according to the "place of articulation imperative" [2], therefore the possession of a large number of phonemic consonants may be associated with greater vocalic variation. In this way, the need to maintain perceptual contrasts between vowels favours a smaller vowel inventory.

A language possessing a smaller consonant or vowel inventory might be expected to tolerate greater variability in consonant/vowel production. However, it does not necessarily exhibit greater variability because of intervening factors [12]; both the magnitude and the organisation of coarticulation may be determined by the identity of the segment, prosodic variables including stress and timing patterns [10], and language-specific phonological processes such as consonant and vowel harmony. Segments may be inherently resistant to coarticulation because the articulatory gestures associated with the segment place a high level of constraint on the tongue dorsum, e.g., because of large degrees of dorsopalatal contact (i.e., contact between the upper surface of the tongue and the palate), and/or because of the formation of a double place of articulation, as in a palatovelar consonant [4, 14].

The phrase "anticipatory consonant-vowel coarticulation" refers to the influence of a vowel or vowels on a consonant within a consonant-vowel (CV) sequence. The magnitude of anticipatory CV coarticulation can be measured using a locus equation. The locus equation, formulated by Lindblom [9], is a linear regression metric. In the present study, the locus equation is employed as means of determining the magnitude of formant two (F2) coarticulation in a consonant as a function of the following vowels. The locus equation slope value varies between 0 and 1; a slope of 0 indicates minimal coarticulation of the consonantal locus (or F2 onset of the vowel in the CV sequence), and a slope of 1, maximal coarticulation, i.e., that the consonantal locus is strongly affected by the following vowel contexts. Krull first claimed a relationship between LE slope and degree of anticipatory coarticulation between the consonant and the vowel in a CV sequence [7].

Locus equation slopes are known to exceed one for Australian languages, especially for velar consonants [16]. Tabain and Butcher found for the Pama-Nyungan languages, Yanyuwa and Yindjibarndi, that peripherals (e.g., /p/ and /k/) possess higher slope values, and laminals (e.g., /c/) possess lowest slope values, with slope values of apical consonants (e.g. /t/) of an intermediate size [16].

## 1.1 Arrernte, Burarra, Gupapuyngu, and Warlpiri

Arrernte, Gupapuyngu, and Warlpiri belong to the Pama-Nyungan family, whereas Burarra is a non-Pama-Nyungan language.

Arrernte is a member of the Arandic subgroup of the Pama-Nyungan family. It has an oral (voiceless) plosive series with six places of articulation: bilabial, dental, apico-alveolar, apico-postalveolar or retroflex, lamino-palatal, and dorso-velar [1]. The number of phonemic vowels is uncertain. The four vowel analysis used in this paper is consistent with Breen and Dobson [1]. Two marginal and two non-marginal vowels are posited; the marginal vowels, /i/ and /u/, are low in frequency and are relatively restricted in distribution, and the two non-marginal vowels, /a/ and /ə/, are not.

Burarra is a member of the Burarran subgroup of the Maningrida family. The oral plosive series has five places of articulation: bilabial, apico-alveolar, apico-postalveolar or retroflex, lamino-palatal, and dorso-velar [6]. The oral plosive series has a fortis lenis contrast: the fortis plosives (e.g., /p/) are associated with greater intra-oral peak pressure and stricture duration than their lenis counterparts (e.g., /b/). The fortis consonants are here classified as voiceless for the purpose of comparison. Burarra possesses five phonemic vowels: /i, ɛ, a, ɒ,u/.

Gupapuyngu is a member of the Yolngu subgroup of Pama-Nyungan. It has seven places of articulation in the oral plosive series - bilabial, dental, apico-alveolar, apico-postalveolar or retroflex, lamino-palatal, dorso-velar, and glottal - and a voicing distinction [11]. The vowel series has three qualities and a length distinction: /i, i:, a, a:, u, u:/.

Finally, Warlpiri is a member of the Ngarga subgroup of Pama-Nyungan. It has five place contrasts in the oral (voiceless) plosive series: bilabial, apico-alveolar, apico-postalveolar or retroflex, lamino-palatal, and dorso-velar [13]. Like Gupapuyngu, the vowel series has three qualities and a length distinction: /i, i:, a, a:, u, u:/. Warlpiri displays vowel harmony.

## 1.2 Goals of present study

The primary aim of the study is to compare the magnitude of anticipatory coarticulation of word-medial oral voiceless plosives by the following vowels in the isolated real words of eight speakers of four Australian languages: Arrernte, Burarra, Gupapuyngu, and Warlpiri. The metric employed to measure the magnitude is the locus equation, and in particular, the locus equation slope value. A single slope value is generated per consonant, per speaker.

This aim is important because previous experimental studies of Australian languages have made a number of claims about coarticulatory processes in these languages. Moreover, Australian languages are rather unusual with regard to universals of speech production concerning segment inventories. The consonant inventories of Australian languages have many places of articulation, especially coronal places, and as discussed, the need to preserve distinctions between multiple places of articulation is likely to relate to coarticulation and coarticulation resistance [2].

In agreement with evidence reported so far, we would expect that the slope values should decrease in the order /p/>/k/>/t/>/ʈ/>/c/. Additionally, we would expect the slope values to be meaningfully related to both articulatory specifications for the consonant and the size and crowdedness of consonant inventories. A language with a larger number of places of articulation might be expected to require a more precise articulation of these consonants, and therefore to exhibit less coarticulation of these consonants by vowels [12]. Additionally, speakers of a language possessing two very similarly articulated but phonemically contrasting consonants might be expected to strengthen the articulatory gestures of the these consonants for better perceptual differentiation, thus reducing the magnitude of coarticulation.

# 2 Method

Two speakers were recorded for each of four languages: Arrernte, Burarra, Gupapuyngu, and Warlpiri. The corpus was collected and digitised at a 20Hz sampling rate by Andrew Butcher of Flinders University. The eight speakers (MM, VD, DP, KF, AM, BT, BP, KR) produced isolated real words, and typically produced three tokens of each type. Prosodically, each token displays post-lexical (or phrasal) prosodic prominence. A total number of 938 tokens were analysed.

Tokens were extracted from the original recordings using Praat version 4.3.12. EMU Speech Database System Version 1.9 was used for mark-up and analysis. F2 data was collected for all VCV sequences in which C is one of /p/, /c/, /t/, /ʈ/, or /k/. This set of consonants is the largest set of oral plosives shared by the four languages. The VCV context is chosen because only in this context, or word-medially, are all consonants in contrast (i.e., not neutralised) in these languages. Additionally, it removes from consideration the confounding variable of articulatory strengthening; consonants in word-initial position may undergo articulatory strengthening (which involves, for example, increased dorsopalatal contact) and thus become more resistant to coarticulation [5, 15].

In EMU, broadband spectrograms were generated using a view range of 0-5000Hz and a bandwidth of 300Hz. Time-aligned waveforms were also generated. In the signal view, each token was annotated with hierarchical word, phonemic, and phonetic labels. Segment boundaries were identified. Segmentation criteria based on inspection of spectrograms and waveforms were as follows: the intervals for plosives were marked from the offset of periodicity in the preceding vowel to the offset of the burst. The onsets of the vowels are marked at the onset of periodicity, and the offsets at the offset of periodicity. F2 was automatically tracked in EMU and the tracking was manually corrected when necessary. The two measurement points were the vowel onset, which is cut at 0.1 into the second vowel, and the midpoint, at 0.5. F2 values at the two measurement points were extracted from EMU into R (a clone of SPLUS) using the R-based interface. In R, locus equations were generated using the EMU-R library “locus” function for each of the five consonants per speaker. An individual speaker’s tokens of the relevant consonant appearing immediately before all phonemic vowels was plotted, and a line-of-best-fit was calculated (dependent variable: F2 at vowel-onset (consonant release), independent variable: F2 at vowel-midpoint). A second line was used to fit outliers. The steepness of the line-of-best-fit is the slope value (or coefficient). The locus function in R also generates the y-intercept.

A multivariate ANOVA (or MANOVA; independent variables: consonant, speaker, language group; dependent variable: slope value) and Pearson’s product-moment correlations per language group (independent variable: speaker; dependent variable, slope value) were then run in R to identify where the significant differences between consonants, speakers, and language groups lay. A set of point and line plots of locus equation slope values per consonant, speaker, and language group were also generated in R to provide a good graphical representation of all of the slope values.

The corpus comprises tokens spoken by female speakers only, meaning that normalization for sex is unnecessary. The inclusion of both stressed and unstressed vowels cannot be excluded as a confounding factor [10]. Vowel harmony and the fortis lenis contrast are not considered in this experiment.

# 3 Results

This section reports results for the locus equation tests.

For Arrernte speaker MM, /k/ is highest at 0.61, /t/ and /ʈ/ are low to mid at 0.42 and 0.31 respectively, /p/ is low at 0.24, and /c/ is lowest at 0.1. See Table 1.

For Arrernte speaker VD, /c/ is highest at 0.84, /t/ and /ʈ/ are mid to high at 0.61 and 0.5 respectively, /k/ is low at 0.28, and /p/ is lowest at 0.17. Considering Arrernte speakers as a whole, /t/ and /ʈ/ tend to be mid, and /p/ low, however speakers differ substantially for /c/ and /k/.

For Burarra speaker DP, /t/ and /k/ are highest at 0.54 and 0.5 respectively, /c/ is mid at 0.43, /ʈ/ is low at 0.3, and /p/ is lowest at 0.19. For Burarra speaker KF, /k/ and /t/ are relatively high at 0.56 and 0.52 respectively, /p/ is low to mid at 0.36, and /c/ and /ʈ/ are lowest at 0.12 and 0.03 respectively. For Burarra speakers as a group, /t/ and /k/

| | Language | Speaker | Slope | y-int | n |
|---|---|---|---|---|---|
| p | G | AM | 0.78 | 414 | 29 |
| | | BT | 0.95 | 248 | 28 |
| | W | BP | 0.6 | 702 | 21 |
| | | KR | 0.62 | 681 | 31 |
| | A | MM | 0.24 | 1248 | 27 |
| | | VD | 0.17 | 1318 | 27 |
| | B | DP | 0.19 | 1259 | 37 |
| | | KF | 0.36 | 1045 | 28 |
| t | G | AM | 0.77 | 390 | 16 |
| | | BT | 0.31 | 1299 | 16 |
| | W | BP | 0.45 | 907 | 19 |
| | | KR | 0.45 | 910 | 18 |
| | A | MM | 0.42 | 1006 | 12 |
| | | VD | 0.61 | 676 | 15 |
| | B | DP | 0.54 | 701 | 19 |
| | | KF | 0.52 | 812 | 14 |
| ʈ | G | AM | 0.85 | 152 | 10 |
| | | BT | 0.74 | 588 | 8 |
| | W | BP | 0.6 | 712 | 21 |
| | | KR | 0.55 | 738 | 18 |
| | A | MM | 0.31 | 1191 | 24 |
| | | VD | 0.5 | 833 | 31 |
| | B | DP | 0.3 | 1076 | 17 |
| | | KF | 0.03 | 0 | 18 |
| c | G | AM | 0.57 | 627 | 14 |
| | | BT | 0.22 | 1541 | 6 |
| | W | BP | 0.34 | 1353 | 10 |
| | | KR | 0.32 | 1170 | 17 |
| | A | MM | 0.1 | 1502 | 20 |
| | | VD | 0.84 | 70.2 | 23 |
| | B | DP | 0.43 | 874 | 24 |
| | | KF | 0.12 | 1518 | 20 |
| k | G | AM | 0.85 | 145 | 12 |
| | | BT | 0.6 | 773 | 68 |
| | W | BP | 0.65 | 693 | 33 |
| | | KR | 0.62 | 572 | 39 |
| | A | MM | 0.61 | 693 | 49 |
| | | VD | 0.28 | 1218 | 57 |
| | B | DP | 0.5 | 741 | 34 |
| | | KF | 0.56 | 696 | 35 |

Table 1 LE slopes (“Slope”) and y-intercepts (“y-int.”) per speaker and the number of tokens analysed (“n”)

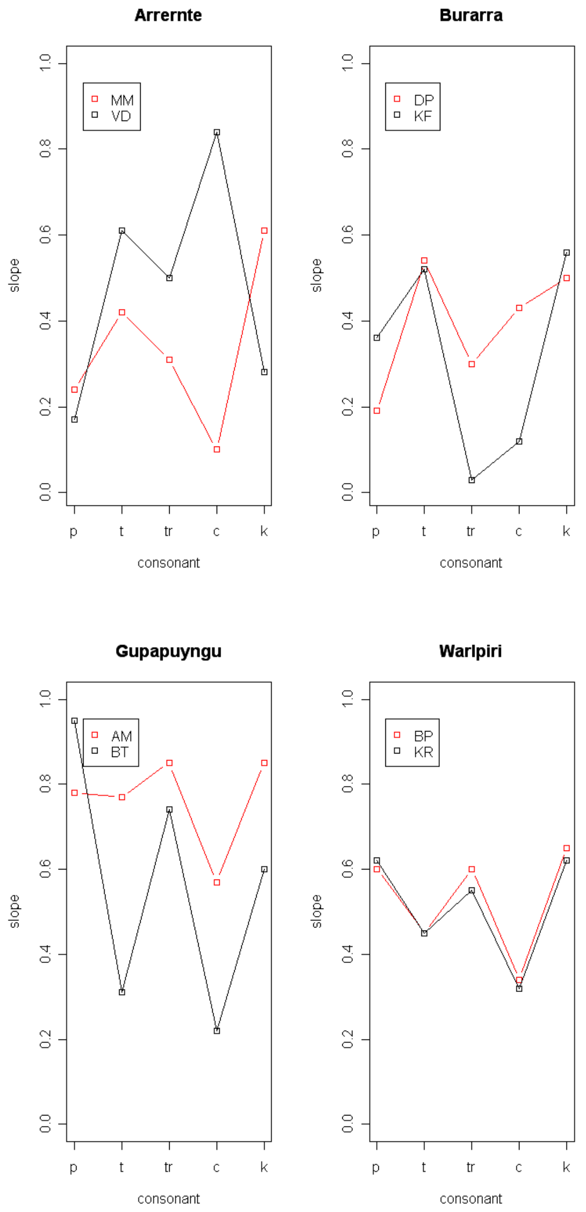


Fig.1 Plots of LE slope values per consonant, speaker, and language (where “/tr/” represents the voiceless oral retroflex plosive)

tend to be high, and /ʈ/, /c/ and /p/ tend to be low to mid. These results are relatively low.

For Gupapuyngu speaker AM, /ʈ/ and /k/ are highest at 0.85, /p/ and /t/ are mid to high at 0.78 and 0.77 respectively, and /c/ is lowest at 0.57. These results are relatively high. For Gupapuyngu speaker BT, /p/ is highest at 0.95, /ʈ/ is mid to high at 0.74, /k/ is mid at 0.6, /t/ is low at 0.31, and /c/ is lowest at 0.22. For Gupapuyngu speakers as a whole, /ʈ/, /k/, and /p/ tend to be high, /t/ mid, and /c/ lowest.

For Warlpiri speaker BP, /k/ is highest at 0.65, /p/ and /ʈ/ are mid to high at 0.6, /t/ is mid at 0.45, and /c/ is lowest at 0.34. For Warlpiri speaker KR, /p/ and /k/ are highest at 0.62, /ʈ/ and /t/ are mid at 0.55 and 0.45 respectively, and /c/ is lowest at 0.32. Finally, considering Warlpiri speakers as a whole, /k/ and /p/ tend to be high, /t/ and /ʈ/ mid, and /c/ low.

Except for /k/ for Arrernte speakers MM and VD, the results reveal a consistent and interesting pattern: slope value trends are similar across speakers within each language group. See Fig. 1. For example, for both MM and VD, the slope value for /p/ is lower than the one for /t/, and the slope value for /t/ is higher than the one for /ʈ/. The slope values are clearly seen to be most similar for the Warlpiri speakers.

A MANOVA yielded a significant slope value x language group interaction ($F(3,28)=4.8$, $p<0.01$) but a non-significant slope value x consonant interaction ($F(4,28)=1.2$, $p<0.5$) and slope value x speaker interaction ($F(4,28)=1.1$, $p<0.4$). Pearson's product-moment correlation tests indicated a strong and significant correlation between Warlpiri speakers BP and KR ($r>9.9$, $p<0.005$), and a moderate but insignificant correlation between other speakers of each language ($r=+/-0.5$, $p=0.4$ for MM and VD (Arrernte) and for DP and KF (Burarra), and $r=0.6$, $p=0.2$ for AM and BT (Gupapuyngu)).

# 4 Discussion

An articulatory interpretation for the acoustic data will be presented in this section. An interpretation based on the phonemic inventories of the four languages will also be presented.

In the present study, the results for /p/ are variable; it is weakly coarticulated for Arrernte and Burarra speakers, and strongly coarticulated for Gupapuyngu and Warlpiri speakers. Importantly, Tabain and Butcher found a high magnitude of coarticulation for labial stops in Yanyuwa and Yindjibarndi [16]. Labials tend to be less resistant to coarticulation than lingual consonants because they lack obvious articulatory constraints; the lip-rounding gesture does not intervene with tongue-body activity. In Arrernte and Burarra then, /p/ may not have merely a phonetic labial specification but may also be specified for lingual position, perhaps to ensure that aerodynamic requirements are met for the occurrence of the burst and the avoidance of turbulence noise in the transition into the following vowel [3].

Alveolars such as the alveolar plosive, /t/, tend to display less coarticulatory variability than labials, but more than palatals [16]. This is true for the speakers of Gupapuyngu (AM, BT) and Warlpiri (BP, KR) in this data. The rather high slope values for Arrernte and Burarra speakers cannot be related to the number of phonemic contrasts in the anterior region of the palate, as Arrernte and Gupapuyngu, but not Burarra, have the higher number of contrasting articulations in the region. Perhaps there is a stronger requirement in Arrernte and Burarra for the tongue to maintain an airtight seal for the stop closure, minimising the amount of anticipatory coarticulation that can be made [10].

The apico-postalveolar plosive, /ʈ/, is low to mid for MM (Arrernte) and KF (Burarra), mid for KR (Warlpiri), and mid to high for VD (Arrernte), AM and BT (Gupapuyngu), and BP (Warlpiri). There is a relatively strong need to ensure perceptual differentiation because of the large size of the consonant inventories, and the retroflex is a somewhat constrained articulation (the speaker must raise and curl back the tongue front to execute the consonant). On the other hand, these plosives are *apico*-postalveolar and are therefore associated with a less retroflexed (and therefore constrained) tongue shape than for the sub-apical retroflex. The vowel inventories are fairly small, hence we would expect a fair amount of allowance for coarticulation of the vowels by the (e.g., retroflex) consonants. Specifically, retroflex consonants tend to coarticulate preceding vowels more than following ones [8]. This is probably because the tongue tip is curled back to execute the consonant during the latter part of the vowel, and then quickly returns to a straightened position during the latter part of the consonant closure phase [8]. It might be hypothesised that the number of coronal (i.e., dental, alveolar, and postalveolar) contrasts (two for Burarra and Gupapuyngu, and three for Arrernte and Warlpiri) might induce similarities in the magnitude of coarticulation for the coronal consonants /t/ and /ʈ/, such that Arrernte and Warlpiri show less coarticulation. However, this hypothesis does not appear to be supported. Perhaps the variation in the number of places is not large enough to precipitate clear differences in the magnitude of coarticulation.

Spectrograms indicate that /c/ is fricated or affricated in these languages more strongly and frequently than the other voiceless plosives examined in this paper. According to Ladefoged and Maddieson, if a language has both an apical and a laminal plosive, the laminal consonant is likely to be more affricated, as is the case here [8]. For Gupapuyngu and Warlpiri speakers, /c/ is most weakly coarticulated. With one exception (Arrernte speaker, VD), Arrernte and Burarra speakers also exhibit weak coarticulation for the palatal. The finding of weak coarticulation for /c/ is expected. This consonant is associated with a high degree of articulatory constraint; palatals require that the tongue dorsum be both raised and fronted, allowing little dorsum variability. The scenario for speaker VD is more complex. A possible articulatory explanation of VD's exceptionally high slope value is that the speaker has unusual difficulty forming a closure at the hard palate (e.g., because of a highly domed palate shape), and hence there is less dorsopalatal contact. This would reduce the consonant's resistance to coarticulation [15].

In this study we see a moderate to high magnitude of coarticulation for the velars. All but two speakers (Arrernte speaker VD and Gupapuyngu speaker BT) display a high level of coarticulation. For BT, the consonant is moderately coarticulated. The mechanico-inertial constraints associated with velars do not prevent anticipatory effects; a highly coarticulated /k/ may indicate allophonic variation for front and back vowel contexts, i.e., there may be a palatovelar constriction in front vowel contexts and a velar constriction in back vowel contexts. The velar stop can behave in this way because the active articulator is the tongue dorsum, and this articulator is used in vowel production. Therefore the effect of adjacent vowels on the velar stop is that the location of the constriction changes to allow for front/back contrasts in the vowels [8]. Allophonic variation in velars for front and back vowel contexts was also found by Tabain and Butcher for Yanyuwa and Yindjibarndi [16]. This raises the issue of possible perceptual confusion between the palato-velar allophone and the lamino-palatal phoneme, /c/. The distinction between the two may be maintained because /c/ exhibits a more anterior closure location than front /k/. According to Recasens and Espinosa, /c/ 'does not seem to require a front place of articulation to avoid merging with the velar phoneme /k/' [15]. The distinction may be enhanced by a difference in manner: as earlier mentioned, the /c/ tends to be more fricated or affricated than /k/. Nonetheless, it is arguable that the need to maintain the distinction between /c/ and the front allophone of /k/ might cause /c/ to be more resistant to variability in the place of articulation, i.e., more weakly coarticulated [15].

Language groups were shown to differ significantly according to slope value in a MANOVA. The non-significant findings for the independent variables consonant and speaker may be the result of the small number of tokens (i.e., slope values) for each condition. Additionally, results presented by Tabain and Butcher found poor separation of coronal stops for languages with more than one [16]. The languages considered in this paper contain either two (Burarra and Warlpiri) or three (Arrernte and Gupapuyngu). Poor separation of coronal stops is then quite possibly an intervening factor in the MANOVA. Another is that retroflexion mainly affects the higher formants, and not F2, hence we would not expect the retroflexes to be well separated.

Slope values for Warlpiri were seen to be unusually consistent (see Fig. 1), and in fact, Pearson's correlation tests indicated a strong and significant correlation between Warlpiri speakers (but not between other speakers).

Broadly speaking, the consonants considered here are articulated with the same moving articulator and articulatory target region across languages. It may be finer articulatory specifications that are causing language differences, such as specifications of degree of dorsopalatal contact. Phonemic inventories are another possible factor. We have already considered how the number of coronal place distinctions might lead to differences in the magnitude of coarticulation. If we were to consider the number of places in the entire oral plosive series, we would then predict that Arrernte and Gupapuyngu would display less coarticulation than the other languages. This hypothesis is not supported. Perhaps the single additional (non-glottal) place in Arrernte and Gupapuyngu is not sufficient to create the predicted difference in magnitude of coarticulation.

# 5 Conclusion

The present paper was concerned with anticipatory consonant-vowel coarticulation in eight speakers of Arrernte, Burarra, Gupapuyngu, and Warlpiri. Results obtained using the locus equation metric displayed a general tendency towards relatively highly coarticulated velar plosives, moderately coarticulated retroflex and alveolar plosives, and weakly coarticulated palatal plosives. The slope values for the bilabial plosives were variable. These results were compared with the study of Yanyuwa and Yindjibarndi by Tabain and Butcher [16]. Results for non-bilabial consonants were seen to be consistent.

# Acknowledgments

I would like to thank the eight language speakers. I am grateful to Janet Fletcher and John Hajek for advice and support and to Andrew Butcher for the use of the corpus.

# References

[1] G. Breen, V. Dobson, "Central Arrernte", *Journal of the International Phonetic Association* 35(2), 249-254 (2005)

[2] A. R. Butcher, "Australian Aboriginal languages: consonant-salient phonologies and the 'place-of-articulation imperative'", in *Speech Production: Models, Phonetic Processes and Techniques*, edited by J. M. Harrington (Psychology Press, New York) (2006)

[3] O. Engstrand, "Articulatory coordination in selected VCV utterances: A means-end view", *Reports from Uppsala University, Department of Linguistics (RUUL)* 10 (1983)

[4] E. Farnetani, "Labial coarticulation", in *Coarticulation. Theory, data and techniques* , edited by W. J. Hardcastle and N. Hewlett, 144-163 (Cambridge: Cambridge University Press) (1999)

[5] C. Fougeron, P. A. Keating, "Articulatory strengthening at edges of prosodic domains", *J. Acoust. Soc. Am.* 101(6), 3728-3740 (1997)

[6] K. Glasgow, "Burarra phonemes", in *Work papers of SIL-AAB, series A*, edited by B. Waters (S. I. L., Darwin) (1981)

[7] D. Krull, "Second formant locus patterns as a measure of consonant-vowel coarticulation", *Phonetic Experimental Research at the Institute of Linguistics. University of Stockholm* (PERILUS) 5, 43-61 (1987)

[8] P. Ladefoged, I. Maddieson, *The Sounds of the World's Languages* (Oxford, Blackwell) (1996)

[9] B. Lindblom, "Spectrographic study of vowel reduction", *J. Acoust. Soc. Am.* 37(5), 783 (1963)

[10] B. Lindblom, A. Agwuele, H. M. Sussman, E. E. Cortes, "The effect of emphatic stress on consonant vowel coarticulation", *J. Acoust. Soc. Am.* 121(6), 3802-3813 (2007)

[11] B. Lowe, *Alphabet and Pronunciation [Gupapuyngu]*. Galiwinku, N.T.: Galiwinku Adult Education Centre (1975)

[12] S. Manuel, "Cross-language studies: relating language-particular coarticulation to other language-particular facts" in *The Handbook of Phonetic Sciences*, edited by W. J. Hardcastle and J. Laver, 179-198 (Oxford: Blackwell Publishers; Blackwell Handbooks in Linguistics, 5) (1999)

[13] D. Nash, *Topics in Warlpiri Grammar* (PhD thesis, MIT) (1980)

[14] D. Recasens, "Coarticulatory patterns and degrees of coarticulatory resistance in Catalan CV sequences", *Language and Speech* 28, 97-114 (1985)

[15] D. Recasens, A. Espinosa, "Articulatory, positional and contextual characteristics of palatal consonants: Evidence from Majorcan Catalan", *Journal of Phonetics* 34, 295-318 (2005)

[16] M. Tabain, A. Butcher, "Stop consonants in Yanyuwa and Yindjibarndi: locus equation data", *Journal of Phonetics* 27, 333-357 (1999)