# Coarticulation in nasal and lateral clusters in Warlpiri

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## Abstract

Indigenous Australian languages are said to show remarkable stability in $C_1C_2$ sequences with no evidence of assimilation of place of articulation. An EPG corpus of Warlpiri was examined to test the extent of spatio-temporal modification in a series of nasal and lateral/oral stop clusters that differed in place of articulation. There was evidence of limited anticipatory coarticulation in nasal clusters. Laminal palatal sonorants also exerted the strongest carryover coarticulatory effects on the following consonant although place contrasts were maintained showing that the extent of coarticulation (both spatially and temporally) is somewhat constrained by the phonological structures of the language.

**Index Terms**: coarticulation, consonants, speech production

## 1. Introduction

Previous articulatory research on $C_{1\#}C_2$ sequences in languages like English has shown that the first consonant is overlapped somewhat by $C_2$ particularly if the latter is alveolar, whereas there is less temporal overlap in syllable initial clusters (e.g [1] [2]). It is also common for the coronal nasal in words like "income" to assimilate to the following velar. By contrast, Australian languages are said to show remarkable stability in $C_1C_2$ sequences where $C_1$ is coronal and $C_2$ is non-coronal as in /nk/ sequences [e.g. 3]. In Warlpiri, the language under investigation in this paper, the word /ˈjinka/ "sorcerer" is pronounced as [ˈji**ngɐ**] and not [ˈji**ŋgɐ**], even in connected speech. Two reasons have generally been proposed for the lack of strong anticipatory assimilation in Australian languages a) the need to maintain place of coarticulation contrasts in all medial environments, and b) the dominance of syllable coda over syllable onset position [3, 6].

In an electropalatographic study of alveolar assimilation in connected Southern British English speech, partial assimilation and residual traces of apical gestures were found in sequences like "handgun", suggesting as others had previously, that anticipatory coarticulation is highly gradient (e.g. reported in [4]). In other words there is a degree of "gestural hiding" although this can vary according to speaking rate, for example. Furthermore, it appears that English listeners can detect whether or not a segment is a "true" velar.

In Warlpiri (or in any Australian language for that matter), it remains to be seen whether there is any quantitative evidence of partial spatial coarticulation of coronal (alveolar, postalveolar) sonorants to following heterorganic stops, for example. The temporal extent of any gestural overlap also remains to be investigated in either anticipatory or carryover directions. This will be the subject of a later study. Carryover coarticulatory effects are mostly due to bio-mechanical inertia, whereas anticipatory effects require a degree of pre-programming (e.g. [5]). A particular focus of this study is the coarticulatory behaviour of heterorganic sequences that contain a laminal-palatal consonant. Previous studies of Catalan show that palatals produce strong carryover coarticulatory effects on following phonetic material ([5]). One might hypothesize, therefore, that if there is limited spatial modification due to gestural overlap in the anticipatory direction in Warlpiri, there may be more spatial modification in the carryover direction due largely to biomechanical effects.

## 2. Method and Materials

### 2.1. Speaker and Language Materials

One female speaker of Warlpiri participated in this experiment. Warlpiri is spoken in the Northern Territory of Australia (Figure 1) and has around 3000 speakers.

Figure 1: *Map of Australia showing where Warlpiri is spoken*

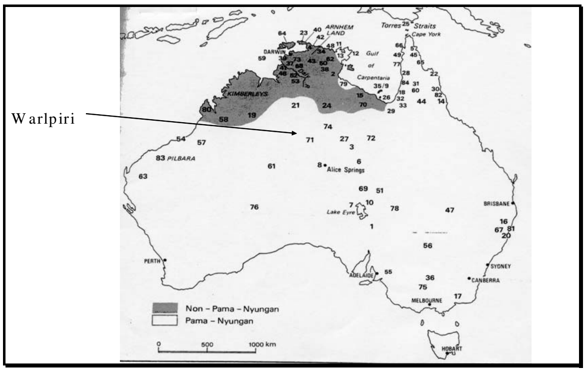



Table 1 shows the consonant and vowel inventory of Warlpiri, after [7]. It is typical of many Australian languages in that there is a single stop series, no fricative series, and a rich inventory of sonorants and place of articulation contrasts, and relatively few vowel contrasts. Some of the stop contrasts (e.g. amongst the coronal set) are neutralized word initially, but all are realized intervocalically.

10.21437/Interspeech.2008-19

Table 1. *Consonant and Vowel Inventory for Warlpiri*

| | *Consonants* | | | | |
|---|---|---|---|---|---|
| | **peripheral** | | **apical** | | **laminal** |
| | *labial* | *velar* | *alveolar* | *postalv* | *alveopalatal* |
| stops | p | k | t | ʈ | c |
| nasals | m | ŋ | n | ɳ | ɲ |
| laterals | | | l | ɭ | ʎ |
| rhotics | | | ɾ | ɽ | |
| glides | w | | | ɹ | j |
| | | | *Vowels* | | |
| | | | front | back | |
| high | | | ɪ ɪː | ʊ ʊː | |
| low | | | ɐ ɐː | | |

Warlpiri has a CV(C) syllable structure, with the optional coda being a sonorant. This optional coda is only allowed syllable finally and word medially. Most words are minimally CVCV and one or two consonants can occur intervocalically, but consonants do not occur word-finally. Consonant clusters can be heterorganic or homorganic. Certain clusters are not contrastive in all environments, e.g. /nc/ versus /ɲc/ is neutralized in low vowel environments as are apical alveolar - apical postalveolar (retroflex) sequences. This is actually recognized in the practical orthography and nasal+palatal stop sequences are often written as "nj". Accentual prominence is generally on the initial syllable. For this experiment, a wordlist containing singleton and all permissible consonant contrasts was prepared by the third author. The heterorganic and homorganic clusters recorded in this experiment include the sequences listed below:

/nt nc nk/ /lt lc lk /

/ɳʈ ɳk/ /ɭʈ ɭc ɭk/

/ɲc ɲk/ /ʎk/

/ŋk

Only a subset of these were analysed in this paper. These include the alveolar nasal and lateral + stop sequences, and the palatal nasal and lateral + stop. All tokens were inserted in one of three carrier phrases (shown in both practical orthography and IPA) with the token highlighted in bold font:

Mayi **kinki**.
[mɐjɪ **'kɪngɪ]**
"*don't know devil*"

**Kinki** wangkaya.
[ **'kɪngɪ** wɐŋgɐjɐ]
"*Say devil*"

Panu **kinki**.
[pɐnʊ **'kɪngɪ**]
"*many devil*".

## 2.2. Recording and Analysis procedure

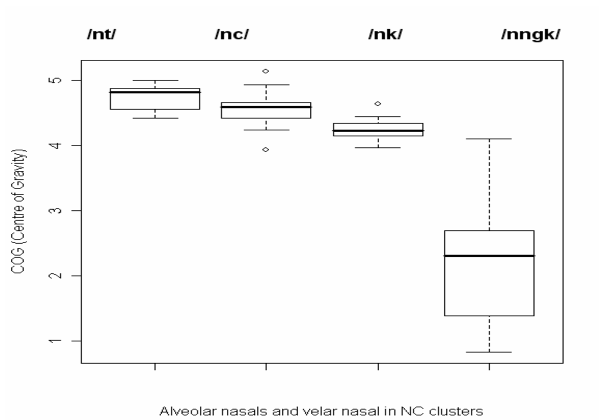
Recordings took place on two separate occasions in Alice Springs, Northern Territory, and were carried out by the third author. Electropalatographic data were acquired using the Reading Electropalatograph (version 3) with Articulate Assistant (version 2). Acoustic data were recorded simultaneously at 22Khz.. The EPG data were recorded at a sampling rate of 100 Hz. Segmental labelling was carried out using the acoustic waveform, spectrogram and EPG window in the EMU Speech Database System [8]. The onset and offset of nasal and lateral segments was used to locate the boundary of these segments (i.e. at the onset and offset of central contact on the palate). There were between 25 and 31 instances for each nasal+stop and lateral+stop heterorganic sequences. A range of data reduction procedures were performed within EMU-R. For each nasal/lateral stop cluster, the COG (centre of gravity: the main concentration of electrode activation), AI (Anteriority Index – degree of contact in the first five rows), and DI (Dorsal Index – degree of contact in the last three rows) were calculated for nasals, laterals and following stops. The EPG indices were derived for the entire segment and also at the .5 midpoint. A total of

# 3. Results

## 3.1. Anticipatory coarticulation in coronal/dorsal sequences

Figure 2 summarizes the COG (Centre of Gravity) results for nasal+stop sequences where the nasal is apico-alveolar. The COG is measured at the midpoint of the nasal consonant. The velar homorganic nasal cluster /ŋk/ is included for ease of comparison. Higher values on the y-axis correlate with degree of anteriority of the place of articulation.

Figure 2: *Box plots showing a simplified distribution of the EPG COG values for two heterorganic and two homorganic clusters in Warlpiri – the black line indicates median values. "nngk" is practical orthography for the /ŋk/ cluster..*

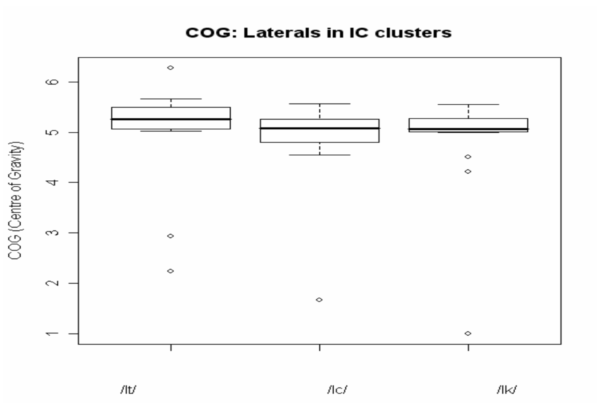



For the COG measure, here is a significant main effect of place of articulation of C2 on the alveolar nasal in alveolar nasal stop clusters (COG: df (2,71), F=13.35, p<0.0001), but AI differences do not approach significance. Based on the

COG measure, alveolar nasals retract slightly in the environment of a following palatal, and are further retracted when followed by a velar stop. While significant, the actual adjustments to linguopalatal contact are relatively small and it is also quite clear from Figure 2, that the /n/ in /nk/ clusters is quite distinct from the velar nasal in the homorganic velar clusters.

Figure 3 presents a somewhat different picture for the alveolar lateral clusters. Unlike the nasals, the differences in linguopalatal contact at the segment midpoint are not significant for any of the measures apart from DI (df(2,93), F=4.37, p<0.01). There is, however, a degree of variation in the /l/ preceding velars and to a lesser extent, palatals, that is not apparent in the homorganic clusters, which is probably due to surrounding vowel context. The outliers in Figure 3 also show cases of possible lenition where insufficient contact was registered during the lateral, hence the very low COG values for a handful of tokens. This will be explored further in a later study.

Figure 3: *Box plots showing the distribution of EPG COG values for alveolar laterals in a homorganic and two heterorganic lateral stop clusters in Warlpiri*




## 3.2. Carryover coarticulation - heterorganic clusters

Figure 4 shows the EPG DI values for /k/ preceded by different types of lateral sonorants. Lower values on the y-axis correspond to a more posterior place of articulation. Linguopalatal contact for the /k/ is somewhat further forward on the palate in /ʎk/ clusters (represented in practical orthography as "lyk") compared to /lk/ and /ɭk/ (represented in practical orthography as "rlk") clusters(df(2,70) F=22.37, p<0.0001). COG values are also significantly different (df (2,70),F=15.82, p<0.0001). This suggests a carryover coarticulatory effect of the palatal lateral /ʎ/ on the following velar. Posthoc t.tests also confirm that there is no difference between either DI or COG for /k/ in retroflex and alveolar velar clusters (p>0.05). There is actually a high degree of variation in the realization of the velar stops in this corpus, mainly due to the very back velars (frequently uvular) produced in back and low vowel contexts by this speaker. Full contact is not often achieved along the back row of the palate. However, linguopalatal contact in the posterior portion of the EPG palate is typically registered in the context of close front vowels. Figure 5 shows grayscale images of average tongue palate contact for velar stops in two words (averaged across 8 –-10 repetitions), /milki/ [mɪlkɪ] and /jilyki/ [cɪːʎkɪ], from the corpus, averaged at 10ms and 30ms time points from the acoustic onset of the stop. Greater contact in the dorsal region is clearly visible due to influence of the preceding palatal lateral in /jilyki/ [cɪːʎkɪ] (bottom panel Fig. 5). Less contact is evident in the alveolar velar cluster (top panel Fig. 5). Figure 6 presents a similar picture for DI values associated with velar stops in nasal - velar clusters. Once again, lower values correspond to a more posterior place of articulation. There is a significant effect of place of articulation on the EPG DI (df(2,65), F=13.61, p<.0001) and on the EPG COG index (df(2,65), F=8.48, p<0.0001). Velar stops that follow palatal nasals are less back than those in either aloveolar or retroflex clusters suggesting carryover coarticulatory effects of the palatal nasal on the place of articulation of the stop.

Figure 4. *Box plots showing the distribution of EPG DI values for /k/ in: alveolar, retroflex and palatal lateral/ velar stop clusters*

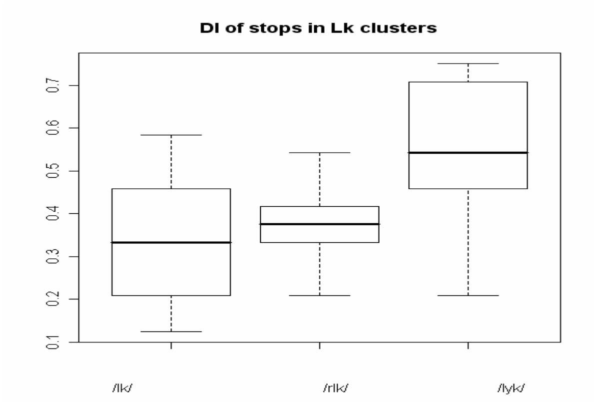



Figure 5. *Greyscale images of average tongue-palate contact for "milki" vs "jilyki"*

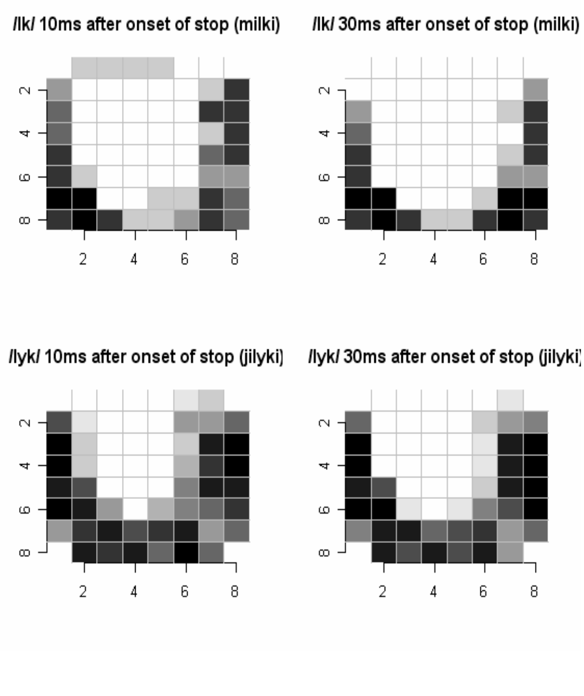


Figure 6. *Box plots showing the distribution of EPG DI values for /k/ in different nasal-velar stop clusters*

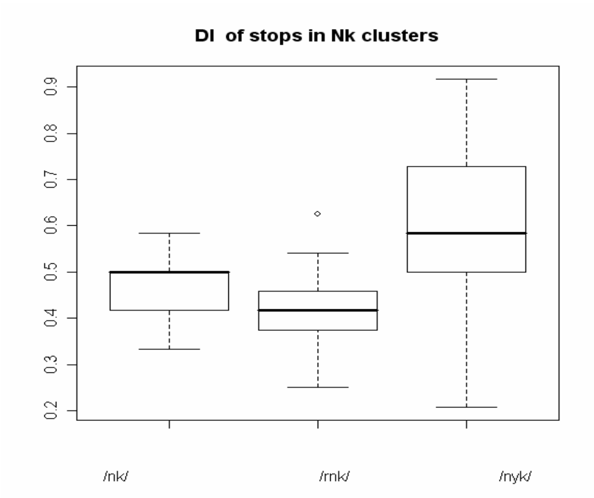
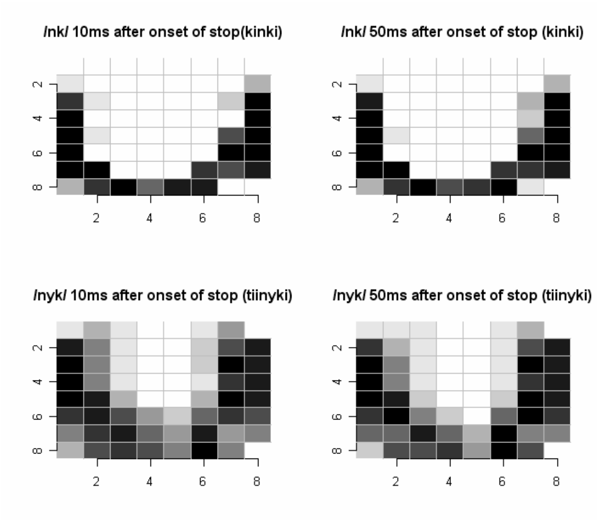



Figure 7 shows grayscale images of average tongue palate contact for two words containing nasal velar clusters at 10 ms and 50 ms time points during the velar stop. A similar pattern is evident to that observed in Figure 5. There is more linguopalatal contact in the posterior section of the palate for the velar stop in "tiinyki" versus "kinki" in more or less identical vowel environments. One can also see clear effects of the preceding palatal nasal along the sides of the palate in "tiinyki". However in all cases the velar stop is still "velar" and never approaches a palatal place of articulation (recall that palatals in Warlpiri are laminal alveopalatal rather than dorso-palatal).

Figure 7. *Greyscale images of average tongue-palate contact for "kinki" vs "tiinyki"*




# 4. Discussion and Conclusion

Our results suggest there is some evidence of anticipatory coarticulation of $C_2$ on $C_1$ in clusters in Warlpiri, although the extent of spatial modification is quite constrained, supporting previous descriptions of assimilation, or the lack thereof, in this language [e.g. 3]. The place of articulation of apico-alveolar and lamino-palatal nasals retracts slightly when followed by a velar stop, although the extent of spatial accommodation is minimal compared to similar sequences in languages like English, for example (e.g. [4, 6]). Nevertheless this speaker totally elided the nasal stop in one or two cases, suggesting a more complex picture that merits further investigation. There is however, no such effect on alveolar laterals in lateral-stop clusters, thus supporting earlier claims that the "place of articulation imperative" may be operating in this language [e.g. 3, 6]. Conversely, there is evidence that lamino-palatals exert a strong carryover coarticulatory effect on the velar stop in nasal-velar stop and lateral-velar stop clusters, suggesting that Warlpiri is similar to Catalan in that palatals are highly resistant consonants to coarticulatory effects from neighbouring segments, and are more likely to effect following phonetic material (e.g.[5]). We are in the process of examining the temporal extent of co-production in all clusters in our corpus, including homorganic sequences. Nevertheless, our results so far tend to support the notion that anticipatory coarticulatory affects are somewhat "planned", or at least accommodate to phonological constraints which intervene to limit the extent of place of articulation modification in consonant clusters in Warlpiri.

# 5. Acknowledgements


We would like to thank our language speaker, Bess Price Nungarrayi. This research was supported by an Australian Research Council Discovery Grant to Janet Fletcher and Andrew Butcher.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