# A spectral analysis of laterals in three Central Australian languages.

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## Abstract

This study presents dental, alveolar, retroflex and palatal lateral /l̪ l ɭ ʎ/ data from three Central Australian languages: Arrernte, Pitjantjatjara and Warlpiri. We examine spectral tilt and spectral moments. Results suggest that Centre of Gravity and Standard Deviation (1st and 2nd spectral moments) are sufficient to characterize the four places of articulation. The retroflex has a concentration of energy at slightly lower frequencies than the alveolar, while the palatal has a concentration of energy at higher frequencies. The dental is characterized by a more even spread of energy. We discuss the possibility of spectral cues to place of articulation across manners of articulation.

**Index Terms**: lateral consonants, spectral moments, Australian languages.

## 1. Introduction

### 1.1. Acoustics of laterals

Acoustic phonetic studies of laterals have mainly focused on the alveolar lateral, which is the most common lateral in the languages of the world [1, 2, 3]. In the present study, we examine three additional laterals: the dental /l̪/ 'lh', the retroflex /ɭ/ 'rl', and the palatal /ʎ/ 'ly', with data taken from three Central Australian languages (Arrernte, Pitjantjatjara and Warlpiri).

In a previous paper [4], we found average formant values for these various laterals at: 374, 1616, 2832 and 3801 Hz for the alveolar /l/; 318, 1683, 2829 and 3996 Hz for the dental /l̪/ 'lh'; 363, 1664, 2756 and 3666 Hz for the retroflex /ɭ/ 'rl'; and 339, 2093, 2891 and 4001Hz for the palatal /ʎ/ 'ly'. These average values are plotted in Figure 1. It can be seen that the largest gap is between F1 and F2: this implies an anti-resonance at a much lower frequency than has previously been estimated [1, 2]. In relation to the alveolar lateral, the dental has a lower F1 and a higher F4; the retroflex has lower F3 and F4 and slightly higher F2; and the palatal has lower F1 and higher F2, F3 and F4.

In the present study, we seek to determine if the laterals can be characterized in terms of spectral measures more usually applied in the analysis of turbulent sounds or of laryngeal properties – namely, spectral tilt and spectral moments. These measures capture gross characteristics of the spectrum as may be encoded by the human auditory system [5]. Spectral tilt is an estimate of the slope of the spectrum, capturing the drop-off in energy across a selected frequency range – as a result, it also gives an indication of the relative amount of high- vs. low-frequency energy in the range. The four spectral moments are Centre of Gravity (CoG), Standard Deviation (SD), Skewness and Kurtosis (see [5] for further detail). We chose to examine these more gross spectral measures due to the fact that very large differences in calculated formants are observed across speakers of the same language [2]. Thus, although broad formant patterns may be observed across large groups of speakers such as in the present study, it may be that gross spectral measures are more accurate at capturing the identity of lateral place. In addition, gross spectral measures are able to capture differences in the relative intensity of various formants, a factor which is of great relevance for a class of sounds characterized by the presence of an anti-resonance in the spectrum.

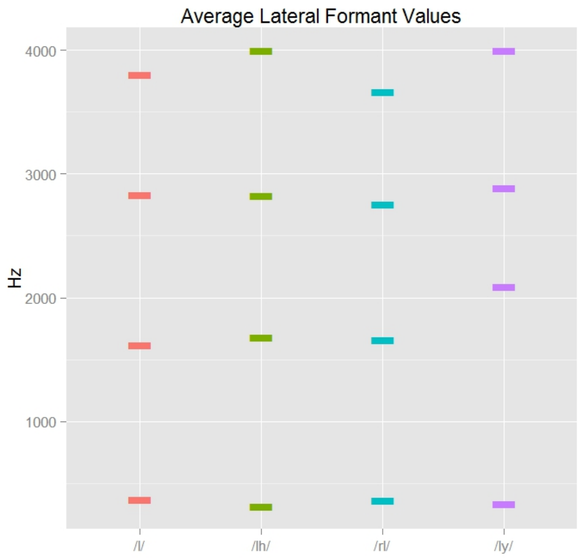



Figure 1: *Average formant values for four lateral places of articulation.*

### 1.2. Coronal consonants in Australian Aboriginal languages

Australian Aboriginal languages are known for their relatively large number of coronal place contrasts [6]: most languages have either three or four coronal places of articulation. In any given language, the multiple coronal places of articulation typically extend across the oral stop, nasal and lateral series. A four-place system includes two apical consonants (i.e. produced with the tongue tip), which are alveolar and "retroflex" (i.e. postalveolar) in place of articulation; and two lateral consonants (i.e. produced with the tongue blade, which in practice often involves both the tip and part of the tongue body), which are dental and (alveo-)palatal in place of articulation. Central Arrernte (henceforth simply Arrernte), one of the languages studied here, is a language with a four-place contrast – namely lamino-dental, apico-alveolar, apico-postalveolar (retroflex) and lamino-(alveo)palatal. The other two languages studied here – Pitjantjatjara and Warlpiri – have three coronal places of articulation. Relative to Arrernte, they lack the lamino-dental place of articulation. Hence, the lateral inventory for Arrernte is /l̪ l ɭ ʎ/, and the inventory for Pitjantjatjara and Warlpiri is /l ɭ ʎ/.

Arrernte, Pitjantjatjara and Warlpiri are all languages of Central Australia. Each language has a few thousand speakers, and all are still being learned by infants. Pitjantjatjara is more accurately described as a dialect of the greater Western Desert Language, which occupies about one sixth of the main Australian continent.

## 2. Method

Data are presented for 21 speakers from the three different Central Australian languages: seven speakers of Arrernte, nine speakers of Pitjantjatjara and five speakers of Warlpiri. Four of the Arrernte speakers, six of the Pitjantjatjara speakers, and all of the Warlpiri speakers were recorded to cassette tape in a quiet room in their home communities in about 1990 by author AB. One Arrernte speaker was recorded to reel-to-reel tape by author GB at the CAAMA radio studio in Alice Springs in the early 1980s; and two Arrernte speakers and three Pitjantjatjara speakers were recorded by author MT in professional-grade recording studios direct to computer (at Macquarie University in 2004 for Arrernte, and at La Trobe University in 2010 for Pitjantjatjara). All of the speakers are female, with the exception of one male speaker for each language. No speaker-normalization was carried out for these data.

Stimuli consisted of single words which were repeated by the speaker three times in a row (or twice in a row in the case of the Arrernte speaker from the 1980s). Although laterals may occur as the first element of a consonant cluster in all three languages, for the present study we selected only tokens which were word-initial, word-final, or inter-vocalic. It should be noted that only Arrernte allows word-final (non-palatal) laterals phonemically (however this is relatively rare, and phonetically a schwa is likely to be appended word-finally). It should also be noted that in all three languages, the contrast between the alveolar and the retroflex (which are both apical) is neutralized in initial position – in the figures below, this neutralized initial apical is represented with a capital 'L'. However, this neutralized apical is not included in subsequent statistical analyses (see below), partly because the issue of neutralization is beyond the scope of this paper, and partly because initial observations suggested that the neutralized apical showed much greater variation across languages than did the non-neutralized laterals.

Pitjantjatjara and Warlpiri have a clear 3-vowel system /i, a, u/. Although Arrernte may be described as having a 3-vowel system /i, a, ə/, the high vowel /i/ has very low lexical frequency and very low functional load, and is therefore ignored in the present study - see [7, 8] for discussion of the complexities of the Arrernte vowel system. Pitjantjatjara and Warlpiri have an additional length contrast on the three vowels, but this length contrast is likewise of very low lexical frequency/functional load, and is also ignored in the present study.

Spectral analyses of the data were based on a 20 ms Hamming windowed Fast Fourier Transform (FFT), centred at the temporal midpoint of the lateral. Moments and tilt were calculated in the frequency range 1-5 kHz.

Linear Mixed Effects models were used to examine the spectral results using the lme() function of the *nlme* package in R [9]. This function also estimates t- and p-values. Language, Speaker, Preceding vowel and Following vowel were included as random factors in the model, with the fixed factor Lateral. As noted above, the initial neutralized apical /L/ was excluded from these analyses. In addition, the retroflex lateral /ɭ/ (written 'rl') from Arrernte was also excluded from these analyses – this is due to the tendency for this sound to be produced as a sequence of palatal glide plus alveolar in certain environments – for instance, the word *arlenge* 'a long way away' might be pronounced [ɛjləŋə] instead of [əɭəŋə]. This is most likely due to the proximity of F2 and F3 for both of these consonants, the spectral prominence being lower in the case of retroflexes and higher in the case of palatals. Table 1 gives the number of tokens used in the present study.

Table 1. <u>Number of tokens.</u> *Note that shaded cells denote tokens that are include in the figures, but not included in the LME analyses. The number after each language name denotes number of speakers. Note that in this and subsequent tables and figures, 'lh' denotes the dental lateral /l̪/, 'rl' denotes the retroflex lateral /ɭ/, and 'ly' denotes the palatal lateral /ʎ/. Capital letter 'L' denotes the neutralized apical lateral found in initial position.*

| Language | L | l | rl | lh | ly | Total |
|---|---|---|---|---|---|---|
| **Arrernte (7)** | 11 | 235 | 105 | 102 | 49 | 502 |
| **Pitjantjatjara (9)** | 169 | 543 | 501 | - | 187 | 1400 |
| **Warlpiri (5)** | 91 | 194 | 291 | - | 165 | 741 |

## 3. Results

Figure 2 shows sample FFT spectra from the current database. These data are from the digital studio recordings and therefore show the spectral range up to 10 kHz. It can be seen that both the dental 'lh' (light blue) and the palatal 'ly' (dark blue) have a relatively large amount of energy above 5 kHz, which is not captured in the present spectral analyses.

Figure 3 shows plots of means and 95% confidence intervals for spectral tilt and for the four spectral moments, as measured in the present study. Table 2 gives LME results for these various measures. In the first column, a reference mean value is given for the alveolar lateral /l/; subsequent columns give LME results for comparison between the reference alveolar lateral, and the dental, retroflex and palatal laterals respectively. Each cell gives the difference between the means of the reference lateral and the comparison lateral, followed by the standard error of the difference in means, and then the t- and p-values. The reader is reminded that the initial neutralized apical is not included in these LME results, and nor are the retroflex lateral data from the Arrernte speakers. However, Figures 2 and 3 do include these data.

It can be seen that most of the lateral places of articulation are well separated based on spectral tilt, with the retroflex 'rl' having a lower tilt value than the alveolar, and the two laminals 'lh' (dental) and 'ly' (palatal) having higher tilt values. However, it is not clear that the two laminals can be well separated from each other based on tilt alone, since both seem to have relatively higher energy in higher parts of the spectrum, compared to the apicals. Interestingly, the CoG results almost exactly mirror the tilt results.

The Standard Deviation results, by contrast, show a different pattern. Here, the dental 'lh' is significantly different from the other three laterals, in that is has a much higher Standard Deviation. The results for Skewness show a higher value for the retroflex 'rl'; curiously, LME results also show a significantly lower value for the palatal 'ly', but not for the dental 'lh'. We believe this is explained by the fact that the Arrernte /l/ has a much lower Skewness value than in the other languages (individual language results are not shown here for lack of space), and since this is the only language that contains the dental 'lh', the LME results reflect this.

Finally, the Kurtosis results are somewhat similar to the SD results in that the dental 'lh' once again stands out from the other three laterals, this time with a much lower value, suggesting a much more "short and fat" (platykurtic) spectrum. In addition, the retroflex 'rl' has a higher value than the alveolar 'l'.

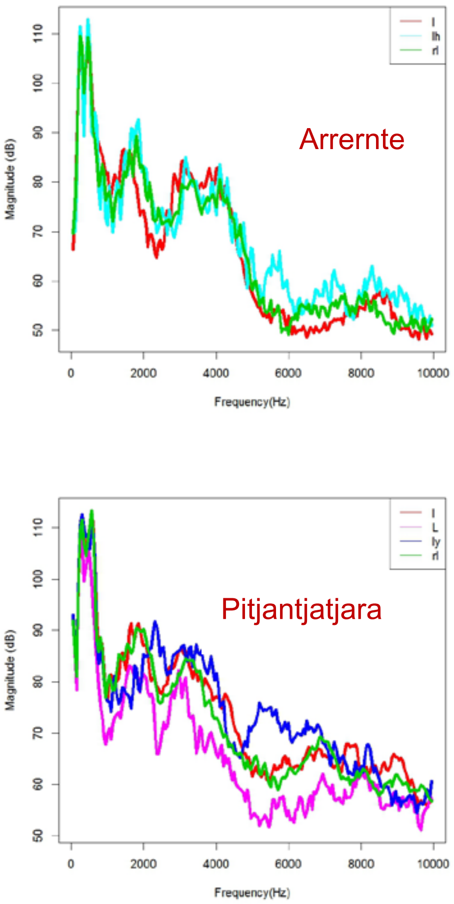
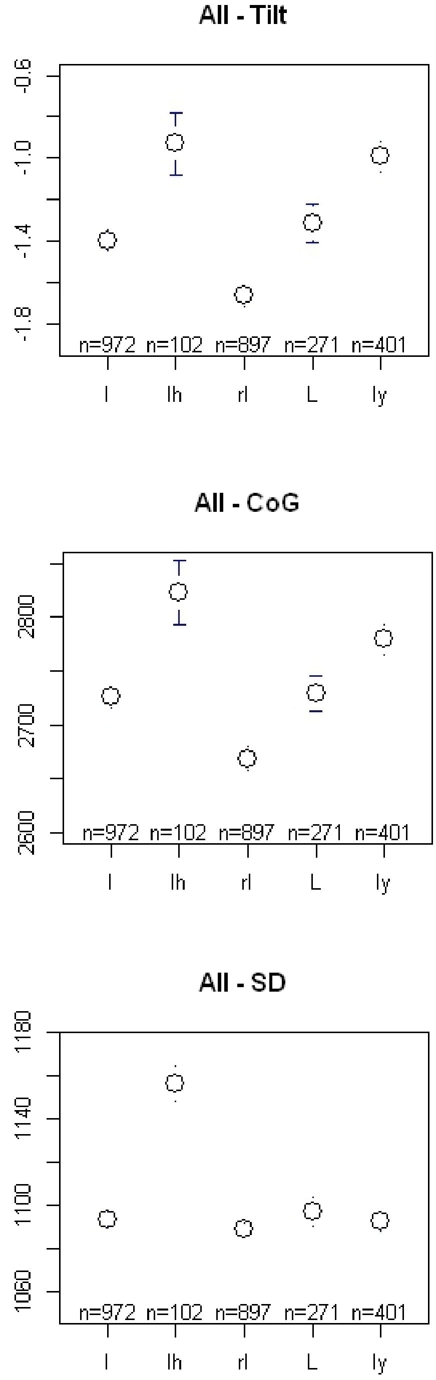
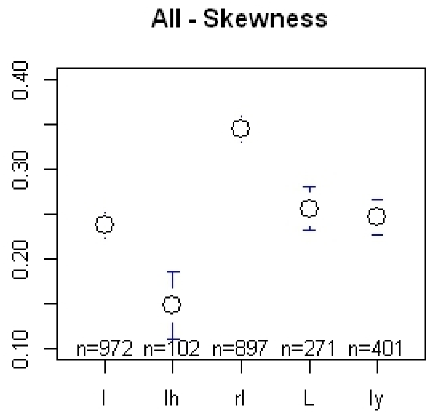



Figure 2: *Sample lateral FFT spectra – data are from two female speakers of Arrernte, and three female speakers of Pitjantjatjara.*





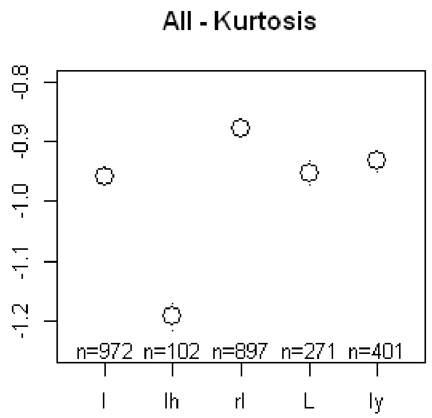




Figure 3: *Spectral tilt and spectral moments as returned by FFT at the temporal midpoint of the lateral – data for all speakers combined. Note that CoG and SD are in Hertz.*

Table 2. *LME results. Note that shaded cells denote results that do not reach significance at $p < 0.01$.*

| d.f.=2034 | /l/ | vs. /lh/ | vs. /rl/ | vs. /ly/ |
|---|---|---|---|---|
| Tilt | -1.50 | 0.23<br>SE = 0.069<br>t = 3.41<br>p < 0.0001 | -0.15<br>SE = 0.030<br>t = -5.25<br>p = 0.0006 | 0.65<br>SE = 0.033<br>t = 19.25<br>p < 0.0001 |
| CoG (Hz) | 2706 | 45<br>SE = 13.7<br>t = 3.28<br>p = 0.0011 | -34<br>SE = 6.0<br>t = -5.80<br>p < 0.0001 | 99<br>SE = 6.7<br>t = 14.73<br>p < 0.0001 |
| SD (Hz) | 1100 | 41<br>SE = 5.5<br>t = 7.42<br>p < 0.0001 | -5<br>SE = 2.4<br>t = -2.26<br>p = 0.0234 | -6<br>SE = 2.7<br>t = -2.15<br>p = 0.0315 |
| Skewness | 0.26 | 0.01<br>SE = 0.018<br>t = 1.07<br>p = 0.2805 | 0.06<br>SE = 0.007<br>t = 7.87<br>p < 0.0001 | -0.06<br>SE = 0.008<br>t = -7.19<br>p < 0.0001 |
| Kurtosis | -0.96 | -0.11<br>SE = 0.022<br>t = -5.18<br>p < 0.0001 | 0.06<br>SE = 0.010<br>t = 6.38<br>p < 0.0001 | -0.00<br>SE = 0.011<br>t = -0.28<br>p = 0.7748 |

## 4. Discussion

The current results show that the four lateral places of articulation can be characterized using just two gross spectral measures: Centre of Gravity and Standard Deviation. The retroflex has a lower CoG value than the alveolar 'l', while the two laminals 'lh' and 'ly' (dental and palatal) have higher values. The two laminals are in their turn separated by the second spectral moment, Standard Deviation, with the dental having a much greater value on this measure than any other lateral place of articulation. The tilt, skewness and kurtosis data are redundant.

These results are strikingly similar to results for stop burst spectra for Arrernte, as presented in [10]. This suggests that there may be gross spectral cues to stop place of articulation that are common across manners of articulation. More precisely, the retroflex has a concentration of energy at slightly lower frequencies than the alveolar, while the palatal has a concentration of energy at much higher frequencies. The dental is characterized by a more even spread of energy across the spectrum. It remains to be seen if this characterization can be applied to the nasal class as well.

## 5. Acknowledgements

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