A SPECTRAL ANALYSIS OF STOP BURSTS IN PITJANTJATJARA

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ABSTRACT

This study examines stop burst spectra for the three coronal stops of Pitjantjatjara: /t/, /ʈ/ and /c/. It is shown that the two apical consonants /t/ and /ʈ/ have a broad, high-energy spectral peak in the region of 1-5 kHz, with the drop-off in energy occurring at a lower frequency for /ʈ/ as compared to /t/. The laminal /c/ has a much flatter spectrum in comparison to the apicals.

However, greater differences emerge when vowel context is considered: whereas both of the apicals show a significant downward shift in spectral peak when preceding /u/, only the retroflex /ʈ/ is also affected in the context of /i/, with a narrowing of the spectral peak in comparison to the /a/ context. The lamino-alveo-palatal /c/ is by far the most affected by a following /u/, with a narrow, high-energy spectral peak around 3 kHz in this vowel context, compared to a much flatter spectrum in the context of /i/ and /a/.

Keywords: Australian languages, stop bursts, spectral moments, spectral tilt, coronal contrasts

1. INTRODUCTION

Pitjantjatjara is spoken in Central Australia, and is a dialect of the greater Western Desert language. It has about 2000 speakers, for most of whom English is a second language. Phonetically speaking, it is notable for its five places of articulation, with three coronal places of articulation: alveolar, "retroflex" (both apical), and alveo-palatal (laminal). Although the three-way coronal contrast exists for stops, nasals and laterals, in this study we focus only on stops, exploring the spectral properties of the stop burst for /t/, /ʈ/ and /c/.

2. METHOD

Three female speakers of Pitjantjatjara were recorded at La Trobe University's recording studios in February 2010. The acoustic data were recorded with a Neumann U87 microphone placed at a slight angle about 15-20 cm from the speaker's mouth. The microphone was connected into a Soundcraft GB8 mixer, and then onto the computer via a Pro Tools 003 system. The sample rate was 44.1 kHz with 16 bits per sample, and the recordings were in mono. The speakers read a list of words which was designed to illustrate the sounds of Pitjantjatjara in different positions in the word (i.e. word initial and medial – note that word-final consonants are not permitted in Pitjantjatjara), and in different vowel contexts (i.e. preceding the three vowels of the language, /a, i, u/). Acoustic data were labelled by paid labellers using standard labelling criteria (c.f. Harrington & Cassidy [4]) using the EMU speech software package (http://emu.sourceforge.net/). It should be noted that labelling was based on the orthography of the language (Goddard [3]): in practice, this meant that apicals were labelled as alveolar or retroflex according to their dictionary entry, rather than according to the labeller's perception of the sound.

Table 1: Number of tokens for each coronal stop for each speaker, and for all speakers combined. Number of tokens is also listed separately for each following vowel context.

		CC	HB	KW	All
/t/		**73**	**74**	**73**	**220**
	a	22	17	19	58
	i	35	42	36	113
	u	16	15	18	49
/ʈ/		**47**	**51**	**65**	**163**
	a	20	24	23	67
	i	18	15	24	57
	u	9	12	18	39
/c/		**102**	**101**	**98**	**301**
	a	63	57	56	176
	i	24	23	21	68
	u	15	21	21	57
Total		**222**	**226**	**236**	**684**
	a	105	98	98	301
	i	77	80	81	238
	u	40	48	57	145

As already mentioned, only the coronal stop data will be presented here. For the purposes of the current study, only word-initial or intervocalic stops were selected for analysis (i.e. no clusters). The numbers of tokens are given in Table 1.

Spectral analyses of the data were based on a 10 ms Hamming-windowed Fast Fourier Transform, centred at the stop release. The spectral data were analysed using the first and second spectral moments (Forrest, Weismer, Milenkovic & Dougall [2]) and spectral tilt (a regression on the amplitude values as a function of frequency, as returned by the FFT). Spectral moments and spectral tilt were calculated for the frequency range 1-6 kHz, based on an initial visual inspection of the spectra and on the comparable analyses presented in [6] for Central Arrernte.

For the three measures analysed here (1st spectral moment, 2nd spectral moment, and spectral tilt), an ANOVA was conducted for the factor consonant (/t/, /ʈ/ or /c/), and for the interaction between consonant and following vowel (/a/, /i/ and /u/). Data were combined across speakers because initial analyses did not suggest any consistent effects of speaker across the different measures. Significance was set at 0.05 for the main test, and Bonferroni-corrected to 0.017 for the posthoc tests. Equal variances were not assumed for the posthoc tests, with a Welch (or Satterthwaite) approximation to the degrees of freedom applied. The R statistical package [5] was used for all statistical tests.

3. RESULTS

Figure 1 shows FFT spectra of the three coronal consonants averaged across all speakers and across all vowel contexts (top left panel). It can be seen that the apicals (written "t" for the alveolar /t/ and and "tt" for the retroflex /ʈ/) have noticeably more energy in the spectral range up to about 5 kHz than does the lamino-alveo-palatal /c/ (written "ty"), whereas the opposite is true for the spectral range above 5 kHz. The spectral peak that drops off sharply at about 4-5 kHz for the apicals occurs at a lower frequency for the retroflex than for the alveolar – this parallels results presented for Central Arrernte in [6]. Figure 1 also shows FFT spectra of the three coronal consonants separately according to vowel context (remaining three panels): here it can be seen that the spectral peak for the apicals /t/ and /ʈ/ in the context of /u/ occurs at a much lower frequency than in the context of /i/ and /a/, whereas for the lamino-alveo-palatal /c/, a very sharp and very clear peak occurs at around 3 kHz in the context of /u/ in comparison to a much flatter spectrum in the context of /i/ and /a/.

Figure 2 shows the measures spectral tilt and spectral moments collapsed across speakers and vowel contexts; and Table 2 presents the statistical significance results. It can be seen that spectral tilt in the 1-6 kHz range is not as sharp for the lamino-alveo-palatal /c/ as for the two apicals (although in all cases the tilt is negative); and the 1st spectral moment (or spectral centre-of-gravity) is higher for /c/ than for the apicals, presumably due to the sharp drop-off at around 5 kHz for the apicals. By contrast, the 2nd spectral moment (diffuseness) differentiates all three coronals, with the retroflex /ʈ/ having a lower 2nd spectral moment than the alveolar /t/ (which in turn has a lower 2nd spectral moment than /c/). This result reflects the narrower spectral peak for /ʈ/ than for /t/, and again mimics the results from Central Arrernte presented in [6].

Table 2: Results from an ANOVA on consonant and on the interaction between consonant and following vowel. Significance for the main tests is set at 0.05 and for the posthoc tests at 0.017. All main test results are significant in this table.

		d.f.	F	eta^2	Posthoc
Spectral Tilt	Cons.	2, 675	341.6	.357	c > t, ʈ
	Cons. * Vwl	6, 675	92.0	.288	t: a, i > u ʈ: i > a > u c: a, i > u
1st Moment	Cons.	2, 675	205.4	.308	c > t, ʈ
	Cons. * Vwl	6, 675	40.9	.184	t: a, i > u ʈ: i > a > u c: a, i > u
2nd Moment	Cons.	2, 675	100.6	.196	c > t > ʈ
	Cons. * Vwl	6, 675	24.7	.144	t: u > a ʈ: u > a, i c: a > i > u

We turn now to a consideration of the results according to following vowel context. It can be seen from Table 2 that spectral tilt and the 1st spectral moment once again pattern similarly, with all three consonants having the lowest spectral tilt value and the lowest 1st spectral moment value in the context of a following /u/. However, the retroflex /ʈ/ stands out from the other two consonants in that the contexts /i/ and /a/ are differentiated by these two measures: /ʈ/ in the context of /i/ has a higher spectral tilt and a higher 1st spectral moment than in the context of /a/.

Figure 1: FFT spectra collapsed across all three female speakers. Note that 'tt' = /t̪/ and 'ty' = /c/.

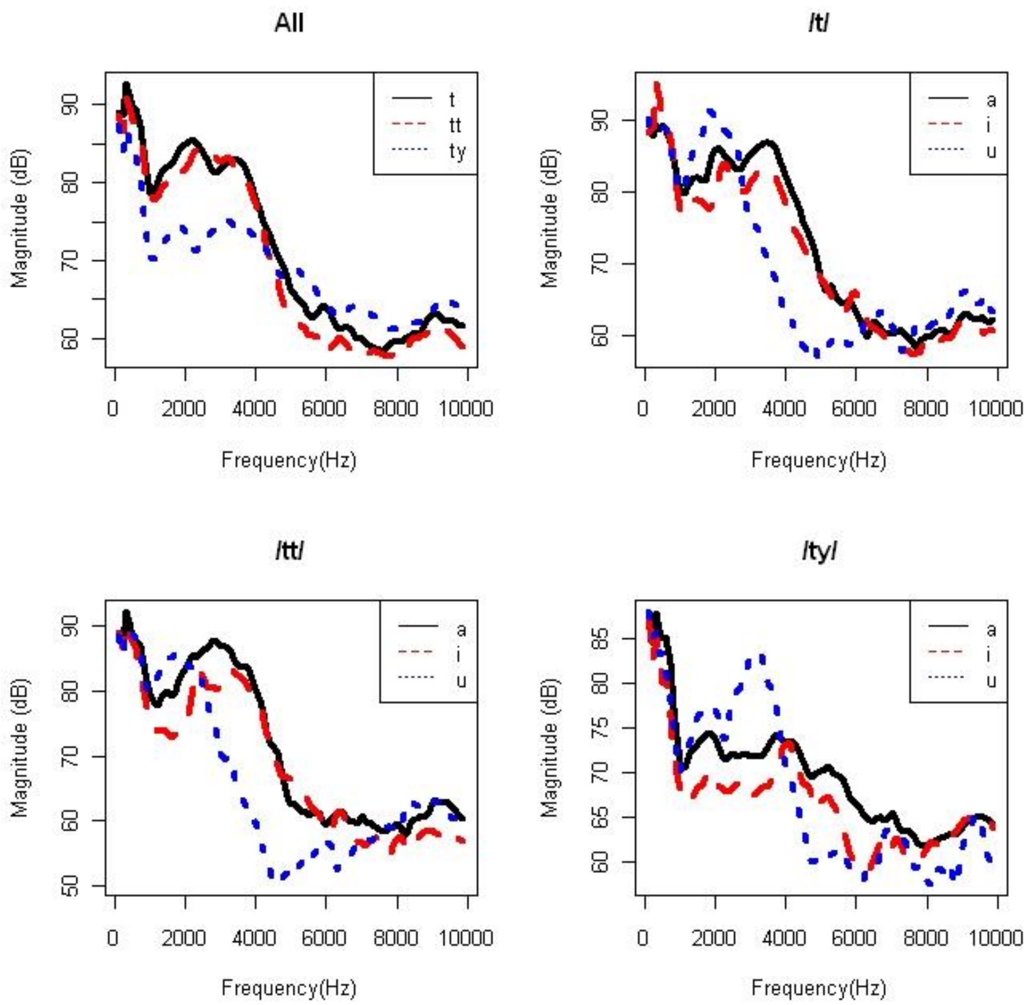
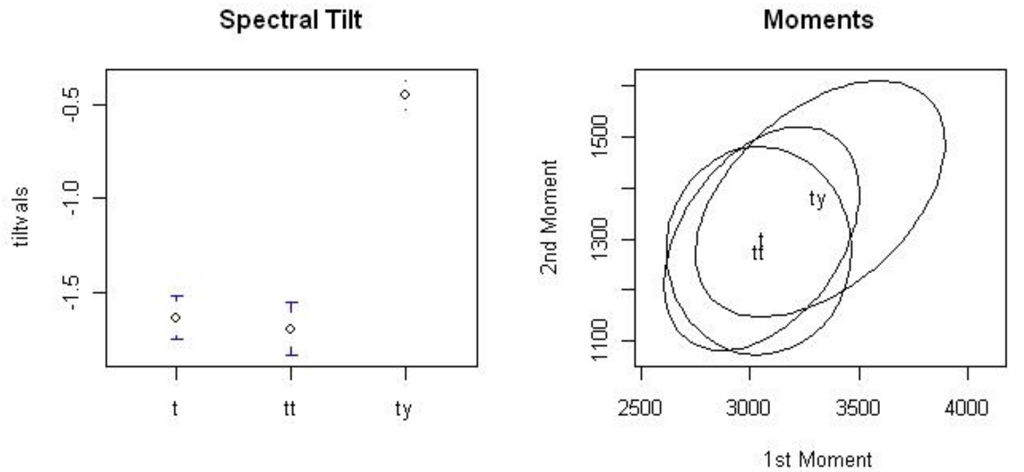


Figure 2: Results from the spectral tilt and spectral moment analyses collapsed across speakers.



By contrast, the results for the 2nd spectral moment are slightly different. Although the 2nd spectral moment is higher in the context of /u/ for both /t/ and /ʈ/ (though in the case of /t/, the /u/ context is not significantly different from the /i/ context), it is instead lower in the context of /u/ for /c/. For /c/, it is also the case that the 2nd spectral moment is lower in the context of /i/ than /a/.

4. DISCUSSION

The present results are in line with previous results for the apical contrast (alveolar vs. retroflex) presented in [6] for Central Arrernte, with the spectral peak that drops off sharply at about 4-5 kHz for these sounds occurring at a lower frequency for the retroflex than for the alveolar. This consistency of results is remarkable given that in both the present study and in [6], data were labeled according to language orthography, rather than according to the quality of the sound that was produced (in Australian languages, the contrast between apicals is not always consistent, with a given apical varying in quality even across repetitions of the same word). However, an additional insight from the present study is the observation that /ʈ/ has a greater spectral tilt and 1st spectral moment in the context of /i/ than in the context of /a/, while both /t/ and /ʈ/ are strongly affected in the context of /u/.

Where the present study results differ from the results for Central Arrernte is for the lamino-alveo-palatal sound /c/. In [6], /c/ has a narrow spectral peak around 4-5 kHz, whereas this was not the case in the present data collapsed across vowel context. However, when vowel context was taken into account, /c/ in the context of /u/ had a very clear spectral peak in precisely this frequency range (but not in the context of /i/ and /a/).

There are two factors which may be relevant here: (1) in Arrernte, /u/ is not a phoneme in the language, but only occurs allophonically when a consonant is rounded; and (2) Arrernte has an additional laminal place of articulation, the dental, with which the lamino-alveo-palatal contrasts. In fact, the flatter spectrum of the /c/ observed in the present study is somewhat reminiscent of the flatter lamino-dental spectrum presented in [6]. It is therefore possible that the differences in articulation observed between single-laminal and double-laminal Australian languages (Butcher [1]) have acoustic consequences which are yet to be explored. These questions of phoneme inventory effects on spectral properties in Australian languages remain a question for further study.

5. ACKNOWLEDGEMENTS

This work was supported by an Australian Research Council grant DP0663825 to the first author, and DP0770835 to the first author, Andy Butcher and Janet Fletcher. We would like to thank Marg Purdam, Adele Gregory, Hywel Stoakes and Anna Parsons for their help in collecting and labeling the data, and our speakers (Charmaine Coulthard, Hilda Bert and our long-time friend Kathleen Windy) for their time.

6. REFERENCES

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