Lateral acoustics and phonotactics in Australian languages*

Kathryn Flack
University of Massachusetts, Amherst

1. Lateral distribution and possible analyses

Australian languages have a large number of contrastive coronal places of articulation; three or even four coronal stops and nasals are common. Australian languages often have laterals articulated at each of these coronal places, and as such have more contrastive voiced lateral approximants than any other language group (Ladefoged and Maddieson 1996: 185). Panyjima’s four laterals represent the maximal lateral inventory; other Australian languages have all or a subset of these laterals.

(1) Panyjima phoneme inventory (Dench 1991)

<table>
<thead>
<tr>
<th></th>
<th>Labial</th>
<th>Dental</th>
<th>Apico-alveolar</th>
<th>Retroflex</th>
<th>Palatal</th>
<th>Velar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop</td>
<td>p</td>
<td>t voiced</td>
<td>t</td>
<td>t</td>
<td>c</td>
<td>k</td>
</tr>
<tr>
<td>Nasal</td>
<td>m</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>Lateral</td>
<td>l</td>
<td>l</td>
<td>l</td>
<td>l</td>
<td>l</td>
<td>l</td>
</tr>
<tr>
<td>Rhotic</td>
<td>r</td>
<td>r</td>
<td>r</td>
<td>r</td>
<td>r</td>
<td>r</td>
</tr>
<tr>
<td>Glide</td>
<td>w</td>
<td>j</td>
<td>j</td>
<td>j</td>
<td>j</td>
<td>j</td>
</tr>
</tbody>
</table>

Laterals are often subject to phonotactic restrictions which prevent them from surfacing word-initially or postconsonantly in many Australian languages, as in (2).

* Thanks to John Kingston, John McCarthy, Michael Becker, Shigeto Kawahara, Ehren Reilly, the participants in UMass Second Year Seminar and Phonology Group, and the audience at NELS 35 for suggestions and helpful discussion; also to Tim Beechey, Claire Bowern, Gavan Breen, and Rob Pensalfini for language data and advice.

© 2005 by Kathryn Flack
Kathryn Flack and Shigeto Kawahara (eds.), UMOP 31, 37-57.
Laterals: \( l \)

Word-initial: \( *l \)

Postconsonantal: \( *l \)

The appearance of laterals across these contexts is implicational: if a language allows laterals to appear postconsonantally, it allows them word-initially; if a language allows laterals word-initially, it allows them postvocally.

In current phonological theory (specifically, in Optimality Theory; Prince and Smolensky 1993), two basic approaches are commonly used for explaining phonotactic restrictions. A formal, sonority-based approach (Gouskova 2002, 2003; Smith 2002) makes crucial use of restrictions on sonority in particular segmental or prosodic contexts. A fundamentally acoustically-based framework like Licensing by Cue (Steriade 1997, 1999), on the other hand, allows the interaction of segmental acoustics and contextual acoustics to determine the environments in which particular segments appear.

These two approaches are not entirely opposed in their premises. Many “formal” constraints are grounded in articulation and/or perception, and Licensing by Cue grammaticizes perceptual scales in constraints which interact with the rest of a phonological grammar. A key difference is the directness with which the grammar refers to the physical and perceptual properties of language. Licensing by Cue claims that speakers have direct access to the relative perceptability of any segment in any context; this information is encoded in the P-map (Steriade 2001). This is used to generate hierarchies of constraints which preferentially license segments in perceptable contexts.

Formal theories of contextual licensing, e.g. positional augmentation (Smith 2002) and positional faithfulness (Beckman 1998), are also grounded in functional pressures, but these pressures act less directly than they do in Licensing by Cue. Constraints in these, more formally-oriented frameworks are simply given as primitives in a grammar, rather than being built based on knowledge of acoustic and perceptual salience. The constraints can license a particular segment (or class of segments) e.g. word-initially because that segment is easy to perceive in that context, or for additional reasons: such licensing may facilitate word boundary identification, or lexical recognition. A major goal of current work in phonology is to understand the ways in which these formal and functional mechanisms interact, and to determine the range of processes for which each type of analysis is truly explanatory.

Australian laterals are an important test of the explanatory scope of these types of analyses, as both acoustic and formal approaches appear to be likely explanations of their phonotactics. This is because the patterns of lateral phonotactics look like other phonotactic patterns that have been previously analyzed in each framework, as follows.

Lateral phonotactics bear a strong resemblance to those of other classes of segments whose distributions have been explained in terms of Licensing by Cue, e.g. retroflex segments in Australian and other languages. In a striking parallel to the lateral pattern described above, Steriade (1999) shows that if a language allows a retroflex contrast to surface postconsonantally,
the contrast also surfaces word-initially, and that all languages with word-initial retroflexion allow it postvocally as well. This is due to the fact that retroflexion is a left-anchored contrast, meaning that the primary acoustic distinction between apico-alveolar and retroflex consonants lies in the left-edge transitions from vowels preceding these segments. These cues are thus most robust when there are, in fact, vowels preceding the consonants; word-initial position facilitates identification of this contrast less well than does postvocalic position, but still better than does postconsonantal position (presumably because the preceding consonant masks cues which are available word-initially). In the Licensing by Cue framework, this hierarchy of left-anchored environments is expressed as V _ > # _ > C _. The phonotactic distribution of laterals thus strongly suggests that they might also be left-anchored, and that their asymmetrical acoustics could thus explain their phonotactics.

Formal, sonority-based analyses have also accounted for aspects of lateral phonotactics, as well as other similar patterns. Smith (2002) claims that laterals are dispreferred word-initially because, given their high sonority, they fail to attract perceptual attention to the extent that less sonorous segments do; she gives a sonority-based account of restrictions against word-initial laterals which will be described in detail in section 5. Further, the absence of high-sonority segments like laterals in postconsonantal position is a common effect of syllable-contact constraints which prefer high-sonority codas followed by (crucially) low-sonority onsets (as in Gouskova 2002, 2003, also discussed below).

The phonotactic patterns of Australian laterals, then, are interesting in that they look very similar to patterns that have been shown to follow from acoustic properties and also patterns governed by segments’ sonority properties. The goal of this paper is to determine which properties, and which style of analysis, are in fact responsible for the contextual restrictions on these laterals.

To test whether lateral phonotactics may be the result of contextual Licensing by Cue restrictions, this paper will investigate whether there is evidence of acoustic left-anchoring in laterals. This paper will also investigate the possibility of a formal, sonority-based analysis of these patterns. I will first describe an analysis of acoustic properties of Australian laterals which would likely show asymmetries which could support a Licensing by Cue explanation; this analysis does not reveal evidence of left-anchoring. I then sketch a formal, sonority-based account of lateral phonotactics. I conclude that despite the similarity between lateral phonotactics and those of other left-anchored segments, a formal account is a more appropriate explanation of these phonotactics than is an acoustically-based analysis. The absence of a connection between phonotactic restrictions and acoustic properties raises important questions about the predictive power of the Licensing by Cue framework.

2. Experimental methods

In order to test the hypothesis that Australian laterals are acoustically left-anchored, and thus that their phonotactic distribution can be explained using the Licensing by Cue framework, this study

---

1 While there have been general objections to the Licensing by Cue framework (e.g. Gerfen 2001, Howe and Pulleyblank 2001, Kingston 2002), this paper begins by assuming that the premises of Licensing by Cue are valid and asking whether lateral phonotactics could fall into its explanatory domain; questions raised by this study about the premises of this framework are addressed in section 4.
investigated acoustic properties of laterals in three languages from the central and northern Northern Territory of Australia, all of which belong to different language families. Each language has lateral phonotactics which follow the V_ > #_ > C_ hierarchy of environments.2

(3)  
  a. **Ngandi** (Arnhem Land; Heath 1978)  
      Laterals: l  
      Word-initial: l *l  
      Postconsonantal: l *l  
  
  b. **Jingulu** (Mendi; Pensalfini 1997)  
      Laterals: l  
      Word-initial: l *  
      Postconsonantal: *l *l *  
  
  c. **Warlpiri** (Pama-Nyungan; Nash 1986)  
      Laterals: l  
      Word-initial: l *l *  
      Postconsonantal: *l *l *  

While none of the data was recorded for the purpose of acoustic analysis, all was of high enough quality to make analysis possible. Jingulu and Ngandi data came from recordings made during linguistic fieldwork,3 and Warlpiri data from instructional Warlpiri-language tapes (Laughren et al. 1996). Exemplars of each lateral pronounced by a single speaker of each language and flanked on each side by /a/ were selected; tokens are listed in the appendix.

The frequency and rate of formant transitions constitute the locus of asymmetry which identifies the retroflexion contrast; visual examination of lateral spectrograms, as in the representative spectrogram in figure 1, did not reveal significant asymmetries in this measure.

![Spectrogram of [ala], from Jingulu kalara.](image)

---

2 The data in (3) shows that retroflex and palatal laterals are sometimes subject to independent restrictions, e.g. acoustically-based Licensing by Cue restrictions, in particular phonotactic positions. These restrictions against particular laterals are not the subject of the current investigation, which is instead concerned with patterns of licensing lateral manner. If any of a language’s laterals may surface in a phonotactic position, this is evidence that lateral manner is licensed in that position. The restrictions against individual laterals are discussed in Flack (2004).

3 The author and Rob Pensalfini recorded a Jingulu speaker in Ngukurr in 1998; Tim Beechey recorded a Ngandi speaker in Numbular in 2003.
Instead, this experiment proceeded following a suggestion by Stevens (1998) that there is an asymmetry in spectral amplitude at the right and left edges of laterals. Specifically, Stevens claims that there are abrupt, dramatic increases in formant amplitude during the transition from (English) laterals into following vowels, while transitions from preceding vowels into laterals show much shallower and more gradual changes in formant amplitude.

Licensing by Cue claims that such slow anticipatory changes provide listeners with more useful information than abrupt changes like those at the lateral release. Therefore, if this sort of slow anticipatory decrease in intensity were consistent and significant across tokens, it would render laterals left-anchored, and thus be the basis for a Licensing by Cue account of lateral distribution.

This study measured overall spectral energy during vowel-lateral transitions and within vowels and laterals; this should reflect not only the diminished formant amplitudes in laterals but also the acoustic zeroes between formants which characterize laterals. Lateral formants are weaker than those of vowels due to the greater closure of the oral cavity. Further, the oral configuration for a lateral includes a supralingual cavity in addition to the main oral cavity; the resonances of these two cavities cancel each other out at characteristic frequencies, resulting in frequencies at which there is a notable absence of energy – an acoustic zero. Measuring the overall spectral amplitude across transitions should provide a detailed acoustic record of the rates of the articulatory changes in both oral closure and in supralingual cavity formation which precede and follow a lateral.

The edges of each lateral and flanking vowel were identified by hand, based on predictable characteristics of the waveform. After this was accomplished, all further acoustic analysis was done using Praat (Boersma and Weeninck 1992).

The positions at which spectral amplitude measurements were taken were guided by Praat’s glottal-closure-identification function. This function identifies the point of maximum negative pressure – and thus the point at which the glottis is closed – within a acoustic and articulatory cycle. It achieves this by finding the pitch and thus the period of the signal at a given time, then labelling the absolute amplitude extremum within that period as a glottal closure. This procedure is recursively carried out across the signal, using the period at each closure to indicate the likely location of the next closure and thus defining the time window searched for an extremum. For a complete description of this algorithm, see the Praat manual (Boersma and Weeninck 1992). Spectral amplitude measurements were always calculated at the middle of a glottal pulse to ensure that comparable glottal states were measured. Amplitude measurements were taken at the following locations, in the manner described further below.

First, the temporal midpoint of the lateral was calculated, and the amplitude at the midpoint of the glottal pulse containing the middle of the lateral was measured. The position of this and the following measurements are indicated in figure 2.
Figure 2. Waveform with glottal closures (dashed vertical lines) for [ala], from Warlpiri *calangu*; spectral amplitude measurements were taken at the midpoints of the glottal pulses indicated by arrows.

Spectral amplitude was also measured at points surrounding the lateral onsets and releases as follows. After Praat calculated the edges of glottal pulses, the pulse which included portions of both the preceding vowel and the lateral was identified; the amplitude of this pulse was not measured. Instead, the amplitudes of the three pulses adjacent to this boundary pulse on either side were measured. That is, across the lateral release, amplitude measures were recorded for the final three pulses of the lateral. The next pulse, which straddles the release edge, was skipped as it represented neither lateral nor vowel uniquely; the next three pulses immediately following the beginning of the following vowel were the targets of amplitude measures as well. Six similar transition amplitude measures were recorded across the lateral onset.

Finally, the amplitude of the flanking vowels was measured. The temporal position of these measurements varied according to the length of the vowels; the target position was one which would be far enough from the lateral to be representative of the vowel rather than being part of the articulatory transition between vowel and lateral, but which would still (in a relatively long vowel) be close enough to the lateral to show some effects of coarticulation, if these are in fact present. Amplitude of a vowel preceding a lateral was thus measured at the midpoint of the glottal pulse which contained the temporal middle of the vowel, or at the midpoint of the pulse which occurred at 50 ms before the lateral – whichever pulse was closer to the beginning of the lateral. A similar measure was taken at the glottal pulse either at the middle of the following vowel or 50 ms after the end of the lateral; again, whichever pulse was closer to the end of the vowel.

In each of the locations described above, the overall spectral amplitude at that time would be measured as follows. Praat would compute a spectral slice at the desired time; this slice would
then be queried for the sum of energy present at all frequencies. The output value would be given in Pascal; this was converted to decibels by the formula in (4), where \( Pa \) is the amplitude in Pascal and \( dB \) is the corresponding amplitude in decibels.

\[
(4) \quad dB = 20 \times \log \left( \frac{Pa}{.01} \right)^{.5} \div .00002
\]

These decibel values were then converted from absolute amplitudes to differences between the energy in the nearest flanking vowel and the energy at the target location; that is, the amplitude of the middle of the preceding vowel was subtracted from the each of the amplitude measures taken across the vowel-to-lateral transition, and the amplitude of the middle of the following vowel was subtracted from each of the lateral-to-vowel transition measures; the resulting normalized measurements are discussed below. Therefore, a point with a positive normalized amplitude is louder than the middle of the flanking vowel, and a negative amplitude is one which is quieter than the flanking vowel. This normalization allowed comparisons of amplitude across tokens, as it reduced token-particular variation in terms of e.g. speaker volume or recording volume. Using the nearest flanking vowel as the reference in normalization further reduced within-token amplitude variations that could result from the location of stress with respect to the lateral; this was necessary as there was not enough data available to control for stress location and so tokens varied as to whether the preceding or following vowel, or neither, was stressed.

The amplitude measure taken at the midpoint of the lateral was compared to both the preceding and following vowels, in order to calculate the similarity – and thus coarticulation – between each of these flanking vowels and the lateral itself. These two comparisons effectively served to normalize the mid-lateral amplitude measure.

3. Results

Two major questions were investigated. First, does the preceding vowel show more coarticulation with the lateral than the following vowel, thus indicating that the lateral is are left-anchored (section 3.1)? Second, does the vocalic portion of the vowel-to-lateral transition show more acoustic characteristics of the lateral than does the vocalic portion of the lateral-to-vowel transition, further indicating that the laterals are left-anchored (section 3.2)? The basic result of these analyses is that there is no evidence of left-anchoring from the measurements taken here, in terms of either of full vowel coarticulation or of coarticulation in transitions from vowels into laterals; evidence for this conclusion follows.

3.1. Flanking vowel coarticulation

The differences between the amplitude at the middle of the lateral and the amplitudes at the midpoints of preceding and following vowels was calculated in order to measure the extent to which laterals induce coarticulation in flanking vowels. The results are as shown in figure 3, where a short bar in the graph represents a small acoustic difference; this indicates that a large amount of coarticulation is present between vowels and laterals at the given place of articulation.
Figure 3. Spectral amplitude differences between laterals and flanking vowels (with 95% CI), indicating flanking vowel coarticulation with laterals; low values indicate a high degree of coarticulation. Palatal data (n = 20) from Jingulu and Warlpiri; apico-alveolar (n = 32) and retroflex (n = 34) data from Jingulu, Warlpiri, and Ngandi.

The differences in vowel coarticulation in preceding versus following vowels are not significant at any place of articulation; this measure therefore fails to provide any evidence that laterals are acoustically left-anchored. We do see a pattern of coarticulation which fails to reach significance; however, this pattern also fails to suggest left anchoring, as follows.

Palatal and alveolar laterals tend to be more similar to following vowels than they are to preceding vowels, indicating that they induce more coarticulation in following vowels than in preceding vowels. Retroflex laterals are coarticulated with preceding vowels roughly to the same extent that alveolars are, though retroflexes are more different from, and thus less coarticulated with, following vowels than with preceding vowels.

The fact that retroflexes tend to induce a different pattern of coarticulation than do the other two laterals is likely related to the common claim that retroflexion is generally heard in preceding vowels but not in following vowels, and the observation that retroflexion is itself left-anchored. This suggests that this lack of coarticulation in following vowels (relative to that present in preceding vowels) reflects a general property of retroflex consonants rather than one of retroflex laterals in particular, and so this pattern is irrelevant to the question of whether laterals themselves are left-anchored.

If preceding vowels were generally more coarticulated with laterals than were following vowels, this could be evidence for left-anchoring in laterals; however, since it is in fact the following vowels which show greater coarticulation for two of the three places of articulation – and thus according to the Licensing by Cue principles themselves contain a greater degree of information than do preceding vowels about the laterals – this measure of vowel coarticulation fails to provide evidence that laterals are left-anchored.
3.2. Lateral edge events

Left-anchoring could also be realized in the transitions between laterals and flanking vowels. If there were a significant asymmetry between the final, lateral-adjacent portion of the preceding vowel and the initial portion of the following vowel, and if the end of the preceding vowel were more lateral-like than the beginning of the following vowel, this would be strong evidence that laterals are in fact left-anchored despite the lack of left-anchoring throughout the middles of the flanking vowels. True anticipatory coarticulation which would signal left-anchoring should cause the final portion of a pre-lateral vowel to reach (or approach) an amplitude characteristic of a lateral (approximately 3 dB less than mid-vowel amplitudes, for the laterals measured here) before the beginning of the lateral. This study found no such pattern of anticipatory coarticulation.

In the amplitude graphs in figure 4, the labeled positions of the six measurements along vowel-to-lateral transitions correspond to the six labeled measurement positions along the lateral-to-vowel transitions, where the temporal order of the second series is reversed. That is, the measure taken in the preceding vowel at the third pulse before the lateral and the measure taken in the following vowel at the third pulse after the lateral are both labeled “1”, as each is the outermost measurement taken along the given transition. Each subsequent pulse at which a measurement was taken across the transition is numbered sequentially, 2-6. I will use terms like “outermost” and “outside” in discussing positions in vowel-lateral-vowel sequences; these terms are generally symmetrical, referring to positions near both edges of the lateral unless otherwise specified; they take the middle of the lateral as their center and the edges of the lateral as the reference points. The “outermost” transition measurements are those furthest from the lateral within either vowel – the third pulse before the lateral onset and the third pulse after the lateral release. The “innermost” measurements are the third pulse after the lateral onset and the third before the lateral release. The heavy horizontal lines in these graphs represent the energy in the flanking vowels, to which other amplitude measures have been normalized; the dashed vertical lines represent the edges of the laterals. The dB measures displayed are differences between the amplitude at a given time and the amplitude of the nearest flanking vowel.

As figure 4 shows, transitions between laterals and flanking vowels are characterized by overall decreases in energy across the transitions at either edge of the laterals.
These transitions are not smooth decreases from mid-vowel amplitudes (whose normalized values are represented by the heavy horizontal lines) to lateral amplitudes; rather, the amplitude immediately outside the edge of laterals (at positions 1-3) is generally greater than the mid-vowel amplitude, indicating that laterals induce amplitude increases prior to their onsets and following their releases (see section 5 for discussion of these increases). The energy peaks outside the lateral edges are asymmetrical such that the pre-lateral increase is relatively shallow compared to the increase following the end of the lateral.

Across the edges of the laterals (between positions 3 and 4, at the dashed vertical line), the energy decreases rapidly to levels below that characteristic of the vowels. The presence and magnitude of onset versus release asymmetries in energy inside the edge of the lateral varies by place of articulation. Alveolars and palatals have less energy inside the onset than inside the release; palatals also have a more abrupt energy decrease at their onset compared to at their release. Retroflexes have similar energy levels inside both edges.

In deciding whether or not these transitions are evidence for left-anchoring, only the amplitudes of the portions of vowels immediately adjacent to lateral edges (positions 1-3) are relevant. One-way ANOVA analyses which compared onset and release amplitudes across vowel-lateral transitions at each place of articulation produced no significant difference between onsets and releases for palatal and retroflex laterals (palatal: $F(1, 18) = 2.131$, $p = .162$; retroflex: $F(1, 29) < 1$, $p = .936$). There was a significant difference between onset and release amplitudes for apico-alveolar laterals ($F(1, 31) = 6.807$, $p = .014$); however, as figure 4 indicates, this change does not seem to indicate anticipatory coarticulation but rather simply a smaller energy peak preceding a lateral onset than following its release.

These data do not show a pattern which would indicate left-anchoring, as described above. Instead, the asymmetry in alveolar lateral onset and release transitions follows from the fact that, while the amplitude peak preceding the onset of alveolar laterals is relatively similar to those preceding palatal and retroflex laterals, the peak following an alveolar release is quite a bit larger than the pre-alveolar peak (and also larger than the peaks following releases of other laterals); thus there is a significant asymmetry between the transitions flanking alveolar laterals which is not present for other places of articulation.
Repeated-measure ANOVA analyses of the changes between each sequential pair of pulses indicated that the amplitudes within the vowel (positions 1-3) and within the lateral (positions 4-6) are relatively stable and consistent – that is, there is no significant change in amplitude within these positions. The only significant amplitude change occurred between these two amplitude plateaus, where there is a significant change in amplitude across both onset and release edges of all laterals \( F(5, 11) = 39.116, \ p < .001 \). These sudden transitions between otherwise stable amplitudes are another indication that laterals are not left-anchored, as there is no evidence of gradual change across the pre-lateral portion of the preceding vowel.

4. Discussion of results

The experiment reported here has shown that laterals in Australian languages are acoustically asymmetrical in terms of their spectral amplitude; there are two primary differences in onset vs. release characteristics. First, there is a tendency for palatal and alveolar laterals to induce more coarticulation in following vowels than in preceding vowels, while retroflex laterals show the opposite pattern (figure 3). There is also a consistently greater increase in energy relative to the flanking vowel following the lateral release than there is preceding the lateral onset; this trend reaches significance in alveolar laterals (figure 4).

These asymmetries, however, do not support the hypothesis that laterals are acoustically left-anchored, and thus laterals’ implicational distribution across postvocalic, word-initial, and postconsonantal environments cannot be explained based on the acoustic properties measured here. Such an account of lateral phonotactics would depend crucially on the acoustics of vowels which precede laterals showing characteristics of laterals before a lateral onset. For example, to find evidence of this asymmetry in terms of spectral amplitude, preceding vowels should be overall more coarticulated with (i.e. have amplitudes more similar to) laterals than are following vowels; for two of the three laterals analyzed here, the opposite pattern of coarticulation emerged.

Another pattern which would support a Licensing by Cue analysis would be one in which the final portion of the vowel before the lateral onset would take on acoustic characteristics of a lateral; this was also not the case. The asymmetry in transitions before and after laterals was due to a larger increase in amplitude (relative to both the lateral and also the amplitude at the midpoint of the vowel) following a lateral than preceding the lateral, rather than due to the amplitude of the preceding vowel decreasing from vowel-like values to lateral-like values before the lateral began.

As only a single aspect of lateral acoustics was measured here, it is possible that a different acoustic property might reveal just the sort of asymmetry predicted by Licensing by Cue for left-anchored segments. It is not clear at this time, though, which alternative acoustic property might reveal such an asymmetry. As discussed in section 2, formant transitions did not appear to be a locus of asymmetry, and the measure of spectral amplitude used here captures many of the spectral changes characteristic of laterals and thus seems a natural place to find any extant asymmetry. The lack of evidence for acoustic left-anchoring found here thus does not disprove the possibility of a Licensing by Cue analysis of these patterns, though it does render it increasingly unlikely. Further, this analysis did find asymmetries in spectral amplitude changes;
when these asymmetries are interpreted within the Licensing by Cue framework, they make unexpected predictions regarding lateral phonotactics.

If anything, the amplitude asymmetries identified here suggest that laterals may be right-anchored according to Licensing by Cue. That is, following vowels more commonly show more coarticulation than do preceding vowels. The asymmetry in the amplitude peaks outside the lateral onset and release could also be interpreted to support this claim, as follows. Stevens and Blumstein (1978; Blumstein and Stevens 1979, 1980; also Delgutte (1997); cf. Walley and Carrell 1983) claim that the human perceptual apparatus is designed to attend to abrupt acoustic events whose frequency spectra uniquely and invariantly define phoneme identity. This claim is based on acoustic and perceptual experiments focusing on characteristics of the short-time spectra of release bursts following /b/, /d/, and /g/, which are shown by Stevens and Blumstein (1978) to differentiate these segments by place of articulation with 85% accuracy.

Following these premises, one could claim that the dramatic rises in amplitude which follow lateral releases capture the attention of the auditory system. While amplitude peaks occur both before and after laterals, the latter peak should attract more auditory attention. This peak is generally larger and, more importantly, represents a much larger increase in amplitude: the amplitude rise from the lateral to the post-lateral peak is generally at least 2 dB, while the rise from the vowel to the pre-lateral peak is usually less than 1 dB. Therefore the frequency characteristics of these post-lateral peaks should play a major role in identifying laterals (and possibly differentiating among them). As this aid to lateral identification lies in the vowel following a lateral, laterals should be regarded as acoustically right-anchored, if anything.

Despite the acoustic evidence suggesting that Australian laterals are right-anchored, this acoustic property does no ‘work’ in the grammar of any Australian language. That is, more information which could aid a listener in identifying a lateral lies in a post-lateral vowel than in a pre-lateral vowel. Licensing by Cue predicts that the asymmetrical presence of such information should drive a language to preferentially license e.g. laterals in contexts where this information will be available to listeners. Right-anchored segments should then be phonotactically sensitive to the segmental environment at their right edge, preferring to appear before vowels and avoiding preconsonantal positions. This, however, is never the case; laterals are never sensitive to their rightward environment, but rather are extremely restrictive in terms of which leftward contexts they will tolerate. This is evidence that these patterns should not be explained in terms of Licensing by Cue but rather using the sonority and perceptually-based analysis developed in the following section.

5. Alternative: Formal phonotactic restrictions

The absence of acoustic evidence of left-anchoring suggests that Licensing by Cue is not responsible for the phonotactic restrictions on laterals, and that a formal account will instead appropriately describe these phenomena. Such account must describe their appearance (and lack thereof) both word-initially and also postconsonantly. This section will present first Smith’s (2002) positional augmentation analysis of the word-initial restrictions, and then a syllable-contact account of the postconsonantal restrictions following Gouskova (2002, 2004). See also Flack (2004) for a more detailed discussion of these restrictions.

---

4 This claim is supported by Marlen-Wilson, Brown, and Zwitserlood (1989).
5.1. Word-initial restrictions

As described above, Australian languages like Panyjima don’t allow laterals to appear word-initially. This restriction is discussed by Smith (2002), who argues that word-initial onsets are preferentially of low sonority, as the acoustic properties of low-sonority segments maximize the perceptual salience of a word beginning and facilitate word recognition. She encodes this tendency in the sonority-based \([*\text{ONSET}/X]/\sigma_1\) constraint hierarchy in (5) and (6).

\[
(5) \quad [*\text{ONSET}/X]/\sigma_1 \quad \text{The onset of the initial syllable in a word must have sonority less than that of X.}
\]

\[
(6) \quad [*\text{ONSET/Glide}]/\sigma_1 \gg [*\text{ONSET/Stop}]/\sigma_1 \quad \uparrow \\
\text{IDENT[F]}^5
\]

Ranking IDENT[F] below \([*\text{ONSET/Lateral}]/\sigma_1\) forces low-sonority nasals and stops to appear faithfully in word-initial position, but bans initial high-sonority glides, rhotics, and (crucially) laterals, as shown in (7).

<table>
<thead>
<tr>
<th>/lana/</th>
<th>[*\text{ONSET/Lateral}]/\sigma_1</th>
<th>IDENT[F]</th>
</tr>
</thead>
<tbody>
<tr>
<td>lana</td>
<td>*†</td>
<td></td>
</tr>
<tr>
<td>tana</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

Using this sonority-based hierarchy to prevent initial laterals correctly predicts that higher-sonority segments like rhotics will be banned in languages lacking initial laterals. This prediction is borne out in Australian languages; Panyjima is typical in banning its full inventory of both laterals and rhotics in initial position.\(^6\)

\[
(8) \quad \text{Panyjima (Dench 1991)} \quad \text{Liquids: } r \ r \ l \ l \ \Lambda \quad \text{Word-initial: } *r \ *r \ *l \ *l \ *\Lambda
\]

5.2. Postconsonantal restrictions

Most Australian languages (e.g. Panyjima and Anindilyakwa) also prevent laterals from appearing postconsonantally. As Australian languages exhibit quite simple syllable shapes, without complex margins, this means that laterals do not appear as the second member of a medial coda-onset cluster. Evidence that this is a syllable contact effect, rather than simply a restriction on sequences of phonemes, is found in languages like Gooniyandi (McGregor 1990). Here, CL clusters are possible when they are word-initial (tautosyllabic), but not medial.

---

\(^5\) As this is a phonotactic effect, alternations provide no evidence about which faithfulness constraint is low-ranked and therefore fails to protect initial laterals; I use IDENT[F] here, but MAX or DEP would work as well.

\(^6\) Factorial typology predicts that glides should occasionally fail to follow the general sonority-based phonotactic patterns that other consonants do, because glides have vocalic [V-Place] features and therefore pattern somewhat like vowels (Clements 1991). Formally, this means that the ranking IDENT[V-Place] » sonority restrictions » IDENT[F] is possible, and that glides may be protected in positions where other high-sonority consonants are banned. Throughout Australian languages, this is the case: glides may generally surface word-initially and postconsonantally.
(heterosyllabic): plan.pi.ra ‘on one’s back’, but *kap.la. Laterals are therefore only banned as the second member of a coda-onset cluster, rather than simply in all postconsonantal positions.

In order to formalize this syllable contact restriction, we must define sonority values of laterals and other segments. Parker (2002) found that the sonority values given in (9) (the values shown are those for segments which occur in Australian languages) correlate with segments’ acoustic intensity; relevant earlier work on numerical sonority values includes Clements (1990), Selkirk (1984), and Steriade (1982).

(9)

<table>
<thead>
<tr>
<th>Segment</th>
<th>Sonority</th>
</tr>
</thead>
<tbody>
<tr>
<td>w</td>
<td>11</td>
</tr>
<tr>
<td>r</td>
<td>10</td>
</tr>
<tr>
<td>l l l l</td>
<td>9</td>
</tr>
<tr>
<td>r</td>
<td>8</td>
</tr>
<tr>
<td>m n n n n</td>
<td>6</td>
</tr>
<tr>
<td>p t t t c k</td>
<td>1</td>
</tr>
</tbody>
</table>

These sonority values can be used with Gouskova’s (2002, 2003) *DISTANCE X constraint hierarchy. This enforces syllable contact restrictions by preferentially licensing coda-onset clusters with steeply falling sonority contours. Constraints of the form in (10) are in the fixed ranking in (11), where a relatively high-ranked constraint like *DISTANCE +3 assigns violations to clusters like m.l, where the sonority of the onset l is three degrees higher than the sonority of the preceding coda m. Such a cluster with a steep rise in sonority is worse than a cluster like l.m, where the sonority of the coda is greater than that of the onset.

(10) *DISTANCE X The sonority difference between consonants in a heterosyllabic cluster may not be X.7

(11) steep rise — flat — steep fall

…*DIST +3 » *DIST +2 » *DIST +1 » *DIST 0 » *DIST -1 » *DIST -2 » *DIST -3 …

e.g. *m.l *l.c *l.m

The *DISTANCE constraints relevant to possible clusters in Australian languages are given in (12). Ranking *DISTANCE -2 » IDENT[F] » *DISTANCE -5 correctly predicts a lack of lateral-final clusters; this ranking can be determined based on the inventory of clusters in Australian languages, as will be described below.

(12) *DIST +8 » *DIST +3 » *DIST +1 » *DIST 0 » *DIST -1 » *DIST -2 » IDENT[F] » *DIST -5

e.g. *p.l *m.l *r.l *l.l *r.l *w.l √ n.t

IDENT[F] must outrank *DIST -5, because of the possible clusters in Panyijima (whose cluster inventory is typical of Australian languages), the worst cluster – i.e. the cluster with the

7 The *DISTANCE hierarchy is formally developed through relational alignment of the *ONSET/X and *µ/X hierarchies, which prefer low-sonority onsets and high-sonority codas, respectively; this produces a syllable-contact hierarchy which may also be characterized in terms of numeric sonority contours.
Lateral acoustics and phonotactics in Australian languages

The smallest sonority drop – is a nasal followed by a stop, as in kan.ta ‘leave it!’ The nasal has a sonority value of 6, and the stop has a sonority value of 1; the slope is therefore -5, so IDENT[F] » *DISTANCE -5 will allow this cluster to surface faithfully.

(13) /kan.ta/ IDENT[F] *DIST -5
    ➔ kan.ta *
      kal.ta *!

*DIST -4 must outrank IDENT[F], because clusters with a sonority drop of -4 (e.g. r.ŋ) never surface faithfully.

(14) /tar.ŋa/ DIST -4 IDENT[F] DIST -5
    ➔ tar.ņa *
      tar.ka *

Given this ranking *DIST -4 » IDENT[F] » *DIST -5, and the rest of the *DISTANCE hierarchy, the absence of lateral-final clusters is predicted as shown in (12). The best possible lateral-final cluster – i.e. the one with the maximal sonority drop – would be composed of a glide followed by a lateral. This would violate *DISTANCE -2, which outranks *DISTANCE -4 and therefore outranks IDENT[F]. This and all other lateral-final clusters (which would have even less optimal sonority contours) are therefore banned.

(15) /taw.la/ DIST -2 DIST -4 IDENT[F] DIST -5
    ➔ taw.la *
      taw.ta *

5.3. The implicational nature of lateral phonotactics

I have shown that the common word-initial and postconsonantal bans on laterals in Australian languages can be explained in terms of laterals’ relatively high sonority, as these phonotactic positions prefer to host low-sonority segments. The restrictions are formally encoded in sonority-based constraint hierarchies targeting initial and postconsonantal onsets; the rankings of these constraints necessary to predict the restrictions on laterals also correctly predict other phonotactic patterns found in these languages.

As noted earlier, lateral phonotactics are implicational: if laterals are licensed word-initially in a language, they also appear postvocically; if they are licensed postconsonantally, they will be licensed word-initially as well. An analysis of lateral phonotactics based on their acoustic properties, and formalized using Licensing by Cue, would inherently capture the implicational nature of the phonotactics. As shown above, however, lateral acoustics do not support such an acoustically-based analysis. Instead, as shown in this section, the lateral restrictions can be explained using the *DISTANCE and [*ONSET/X]/σ₁ constraint hierarchies.

The use of independent constraints does not inherently capture the implicational nature of the restrictions, though; it should be possible for a language to ban laterals word-initially but allow them to surface postconsonantally. Given the crosslinguistic tendencies to impose sonority-based restrictions word-initially and postconsonantally, however, as well as the
tendency towards phonological consistency within Australian languages, this accidental implicational relationship is nevertheless expected, as follows.

A small set of languages ban initial high-sonority segments: the Iglesias dialect of Campidanian Sardinian (Bolognesi 1998) and Mbabaram (Dixon 1991) ban initial rhotics, and Mongolian (Poppe 1970), Kuman (Lynch 1983), and most Australian languages (Hamilton 1996) ban all initial liquids. While such high-sonority segments are nonoptimal from a perceptual perspective in word-initial position, most of the world’s languages allow them. This means that there is a strong tendency for [*ONSET/Lateral]/σ₁ to be relatively low-ranked. In contrast, syllable-contact restrictions against coda-onset clusters without sharp sonority drops are prevalent (see Gouskova (2003) and references cited therein); this indicates that *DISTANCE constraints (which tend to prevent lateral-final clusters) tend to be relatively high-ranked cross-linguistically.

A likely functional motivation for this bias arises in the competing pressures to which word-initial position is subject. Initial segments are preferentially of low sonority in order to facilitate identification of word boundaries. However, in order to facilitate rapid word recognition, it is also important to maximize the number of segmental contrasts realized in initial position (this tendency is captured in positional faithfulness constraints; see e.g. Beckman 1998). The cross-linguistic desirability of low-sonority initial segments is often sacrificed in order to maximize initial contrasts. No similar competing pressures are relevant in medial clusters, and thus syllable-contact restrictions may apply more freely across languages.

Given these tendencies, it is not surprising to find that *DISTANCE constraints apply more frequently across Australian languages than do [*ONSET/X]/σ₁ constraints. The fact that these languages go beyond a mere tendency and are deeply consistent in allowing [*ONSET/X]/σ₁ constraints to be active (i.e. high-ranked) only if those *DISTANCE constraints which ban postconsonantally laterals are highly-ranked as well is also unsurprising, given that the phonological systems of Australian languages tend to be quite consistent (Hamilton 1996, Dixon 2002). Lateral restrictions are only one of many phonological patterns which are common across Australian languages. While individual languages vary in where laterals may appear, they adhere to a basic pattern where laterals are dispreferred word-initially, and even more strongly dispreferred postconsonantally.

6. Conclusion

The specific goal of this paper was to evaluate two possible frameworks which might provide accounts of lateral phonotactics in Australian languages; a broader goal was to examine the roles of acoustic and formal explanations in phonology. Towards the first goal, I have demonstrated that the acoustics of laterals do not explain their phonotactic distribution; that is, the Licensing by Cue framework cannot explain the contextual restrictions on laterals. I have further shown that it is possible to explain these restrictions in terms of formal constraints. As there is no similarly possible acoustic analysis, this formal analysis appears to be correct.

The study of lateral acoustics has also contributed to an understanding of the relative explanatory power of formal and acoustic frameworks. Previous work on Licensing by Cue has shown that this framework can explain phenomena like retroflex licensing, where segmental acoustics and phonotactics (as well as patterns of assimilation in clusters) conspire to indicate
that segments are e.g. left-anchored. In such phenomena, phonotactic patterns seem to be the natural result of segmental acoustics, and acoustics are the basis of the constraints that govern phonotactics in this situation.

A strong version of Licensing by Cue could claim that all such patterns of edge-sensitive phonotactics are the result of acoustic asymmetries, and that any acoustically-asymmetric segments would show corresponding phonotactic asymmetries. The acoustic properties of laterals, however, demonstrate that this strong claim cannot be true. Lateral phonotactics are describable in terms of their left-edge segmental context; lateral acoustics, however, are if anything right-anchored. This mismatch, where lateral phonotactics do not follow from their acoustics and instead must be the result of formal, sonority-based principles, demonstrates that Licensing by Cue cannot be strictly deterministic but must instead be one of many mechanisms operating in a phonological grammar to determine phonotactic patterns. While grammars may allow segmental acoustics to determine phonotactics, they may also allow other (formal) properties of segments, like sonority, to determine phonotactics as well.
### Appendix. Tokens

Tokens used in the acoustic experiment. Underlined *aLa* sequences are those which were measured; a number following a token indicates multiple instances of that word.

<table>
<thead>
<tr>
<th>Jingulu</th>
<th>Warlpiri</th>
<th>Ngandi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Palatal (5)</strong></td>
<td><strong>Palatal (15)</strong></td>
<td></td>
</tr>
<tr>
<td>caa'anana</td>
<td>cama'ala</td>
<td></td>
</tr>
<tr>
<td>caa'ankunu</td>
<td>camala (2)</td>
<td></td>
</tr>
<tr>
<td>ka'ara-atji</td>
<td>wa'anka (10)</td>
<td></td>
</tr>
<tr>
<td>ka'aru-wuru</td>
<td>wa'a (2)</td>
<td></td>
</tr>
<tr>
<td>na'arijinjincu</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Alveolar (9)</strong></td>
<td><strong>Alveolar (13)</strong></td>
<td><strong>Alveolar (10)</strong></td>
</tr>
<tr>
<td>tat'uwala</td>
<td>calanju (6)</td>
<td>abunkalalakgalala</td>
</tr>
<tr>
<td>kala</td>
<td>ca'ala (4)</td>
<td>abunkalalakgalala</td>
</tr>
<tr>
<td>walanca (3)</td>
<td>na'ala (3)</td>
<td>abunkalalakgalala</td>
</tr>
<tr>
<td>wantala-alu</td>
<td></td>
<td>a'dapbalan</td>
</tr>
<tr>
<td>wupala</td>
<td></td>
<td>amalapinybiŋ</td>
</tr>
<tr>
<td>ja'pala-nu</td>
<td></td>
<td>kugalar</td>
</tr>
<tr>
<td>jarintu-wala</td>
<td></td>
<td>mabalara?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ma'dalawanbut</td>
</tr>
<tr>
<td></td>
<td></td>
<td>magalanan? (2)</td>
</tr>
<tr>
<td><strong>Retroflex (8)</strong></td>
<td><strong>Retroflex (12)</strong></td>
<td><strong>Retroflex (14)</strong></td>
</tr>
<tr>
<td>malaluuka</td>
<td>nalamarim (10)</td>
<td>agalgalgalal (3)</td>
</tr>
<tr>
<td>walaku-ŋ (4)</td>
<td>narpalala (2)</td>
<td>agalgalgalal</td>
</tr>
<tr>
<td>walu (3)</td>
<td></td>
<td>amala</td>
</tr>
<tr>
<td></td>
<td></td>
<td>alapunjiŋ (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kuca</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kuwalan?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>magalaralal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>magalaralal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>na'alan (3)</td>
</tr>
</tbody>
</table>
References


Lateral acoustics and phonotactics in Australian languages

Department of Linguistics
South College
University of Massachusetts
Amherst, MA 01003

flack@linguist.umass.edu