Identifying consonantal tasks via measures of tongue shaping: a real-time MRI investigation of the production of vocalized syllabic /l/ in American English

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Abstract

Liquids are unique in their ability to occupy syllable onset, nucleus, and coda positions in American English, as well as the fact that they are composed of two lingual gestures. Upon inspection of /l/ in syllable nucleus and coda positions using real-time MRI, it appears that the tongue tip constriction we might expect for /l/ is often not present, a phenomenon called /l/-vocalization. However, it is not merely the case that the consonantal gesture of /l/ is completely lost in these syllable positions, leaving behind a simple vocalic configuration. Though there is often no raising of the tongue tip in an attempt to make contact with the alveolar ridge, the /l/ exhibits complex tongue shaping involving curling in the region of the tongue blade. The result is a lowered tongue blade relative to the tongue tip and dorsum. This shaping is captured through measures of Gaussian curvature at evenly spaced points along the tongue. The results indicate that /l/-vocalization in the syllable rhyme does not involve a complete loss of the consonantal nature of the lateral, but rather a modification of its realization.

Index Terms: liquids, syllabic consonants, vocalization

1. Introduction

Examination of the varying realization of consonants, particularly liquids, across syllable positions can provide us with interesting insights into the distinctions we draw between consonants and vowels. Traditionally, the syllable nucleus is seen as the domain of the vowel, and the margins, particularly the onset, as the domain of the consonant. We may expect, then, that if a consonant were to occur in syllable nucleus position it might be altered in a way that would make it more vocalic. The /l/ of American English provides us with an interesting case study for these predictions due to the fact that it can occur not only in syllable onset and coda positions, but can serve as a syllable nucleus (at least in unstressed positions) as well [1].

The production of laterals involves the formation of a central constriction with airflow through side channels. This complex tongue shaping is achieved through the coordination of multiple lingual gestures. Descriptions of the two gestures of /l/ have often distinguished between the ‘consonantal’ tongue tip gesture and the ‘vocalic’ tongue body gesture [2], [3]. The phenomenon of /l/-vocalization, in which the tongue tip constriction is significantly reduced or even lost altogether, is attested in post-vocalic (coda) position in American English [4], [5]. Here we will examine this process of vocalization when /l/ is in syllable nucleus position.

The precise nature of the product of /l/-vocalization is not clear. If the process involves simply the deletion or complete suppression of the lateral’s consonantal gesture, we would expect the vocalized /l/ to resemble a back vowel with a similar tongue body constriction [6]. On the other hand, if /l/-vocalization does not eliminate the lateral’s consonantal element, but rather alters its realization, we would expect to see some form of the complex tongue shaping that is synonymous with liquid consonants. In the absence of an observable tongue tip closure, this study examines tongue shaping during the production of /l/ in syllable positions conducive to vocalization.

2. Methods

2.1. Target items

The images used in this study were taken from the MRI-TIMIT database compiled by the University of Southern California’s SPAN (Speech Production and Articulation kNowledge) group. The database includes several speakers of various dialects of American English reciting a phonetically balanced corpus of four hundred sixty sentences. This study examines the speech of two female subjects who were singled out as the most consistent producers of vocalized /l/ forms.

The dataset contained instances of /l/ in several syllable positions: onset (simple and clusters), coda (simple and clusters), nucleus, and intervocalic/ambisyllabic. Table 1 lists the number of tokens of /l/ in each syllable position.

Table 1. *Number of tokens of /l/ across syllable positions.*

Syllable position	Number of tokens
Onset	50
Coda	29
Ambisyllabic/intervocalic	22
Nucleus	39

In addition to variable syllable position, there was a wide variety of surrounding vowel and consonant contexts. Of particular interest are coronal versus non-coronal consonants immediately preceding or following the /l/.

2.2. Acquisition of real-time MRI images

Midsagittal images of the subject’s vocal tract (glottis, pharynx, and oral and nasal cavities) were acquired at Los Angeles County Hospital using a real-time MRI protocol developed specifically to examine speech production [7]. Each subject lay on her back with head stabilized throughout the scan. Images were reconstructed at a rate of 23.18 frames per second. The field of view for each image is 200mm x 200mm with a resolution of 68 x 68 pixels.

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2.3. Image analysis

Tongue and palate edge tracking was performed using a custom-designed graphical user interface in MATLAB [8], [9]. A polar-rectangular grid of approximately thirty lines orthogonal to the vocal tract was laid over the video images. For each frame of video, edges of the upper and lower surfaces of the vocal tract were automatically detected at each gridline and corrected manually if necessary. Figure 1 shows a single frame of video with overlaid grid and outlined vocal tract edges.

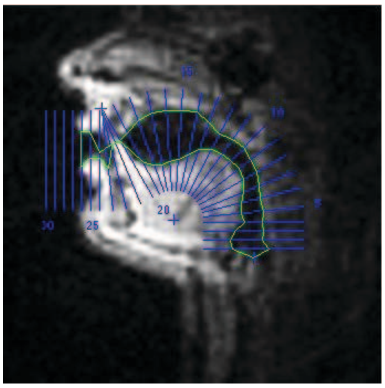

Figure 1: *Frame of tongue edge-tracked MRI video with overlaid analysis grid*

Tongue shaping during the production of /l/ was measured by calculation of Gaussian curvature. First, the curvature of the lower surface of the vocal tract was down-sampled to fifteen evenly spaced points. For each set of three adjacent points, the inverse of the diameter of the circle passing through these three points was calculated and multiplied by 100. This curvature score was measured as negative whenever the center of that circle lay outside of the plane of the tongue curvature, corresponding to tongue curling.

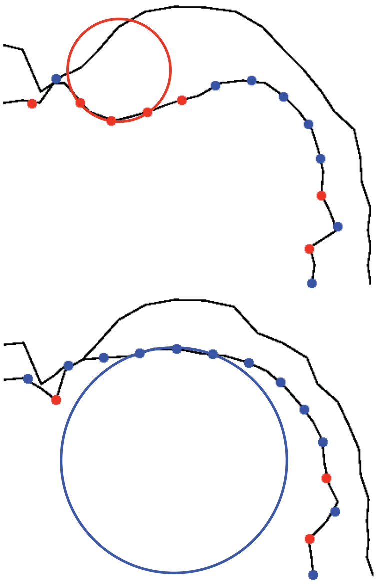

Figure 2: *Evenly spaced points along tongue contour during production of /l/ (above) and /d/ (below). Blue indicates positive curvature; red indicates negative.*

3. Results

3.1. Rate of Vocalization

The rate of vocalization of non-coronal-adjacent /l/ across syllable positions is reported in Table 1. Here we consider only those tokens of /l/ that were not produced adjacent to another coronal consonant, as if was often not clear whether any achievement of tongue tip contact was due to that coronal alone, or to both the coronal and the /l/. A token of /l/ was recorded as vocalized if the tongue tip made no contact in the dental/alveolar region at any point during its production. Though vocalization is attested in all positions, it is especially frequent in nucleus and coda positions, where a vast majority of tokens were vocalized.

Table 2. *Rate of vocalization for non-coronal adjacent /l/ across syllable positions.*

	Rate of Vocalization		
Syllable Position	**Speaker 1**	**Speaker 2**	**Mean**
Onset	51.85%	3.70%	27.77%
Ambisyllabic/ Intervocalic	40.91%	31.82%	36.36%
Coda	90.47%	76.19%	83.33%
Nucleus	88.24%	70.58%	79.41%

3.2. Tongue Shaping of Non-Vocalized /l/

The majority of tokens of /l/ in onset position (simple and as part of a cluster) and intervocalic/ambisyllabic position were produced with both backing of the tongue dorsum and tongue tip closure at the upper teeth or the alveolar ridge. These positions appear not to prompt /l/ vocalization to the degree that syllable nucleus and coda positions do.

All tokens of onset or intervocalic /l/ also exhibited some measure of curling along the tongue blade. To illustrate, Table 1 reports the curvature scores of one point along the tongue blade region during production of the word 'lack,' and Table 2 reports the curvature scores at the tongue blade during the production of the word 'silly.' The specific point along the blade was selected for each token because it showed the greatest degree of negative curvature during the production of /l/. Accompanying figures provide a time course of the curling of the tongue for /l/. Note that negative curvature is present during the production of /l/, but is absent or of a reduced magnitude during the adjacent vowel or vowels. Recall that a negative curvature score corresponds to tongue curling, and greater absolute value for this score corresponds to greater magnitude of this curling.

Table 3. *Curvature score at point on the tongue blade for each frame of the word 'lack.' Frame 1 corresponds to the production of [l], and frame 6 to the production of [æ].*

Frame	**Curvature Score at Tongue Blade Point**
1	-1.76
2	-4.56
3	-4.06
4	-1.83
5	0.07
6	-0.60

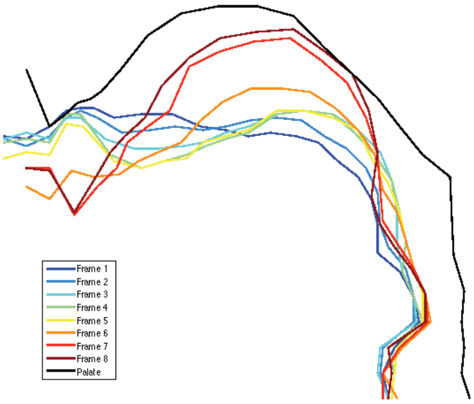

Figure 3: *Time course of the production of 'lack' [læk].*

Table 4. *Curvature score at point on the tongue blade for each frame of the word 'silly.' Frame 1 corresponds to the production of [ɪ] preceding [l], and frame 8 to the production of [i] following [l].*

Frame	Curvature Score at Tongue Blade Point
1	0.89
2	-1.48
3	-2.28
4	-2.39
5	-3.76
6	-4.06
7	-0.73
8	0.13

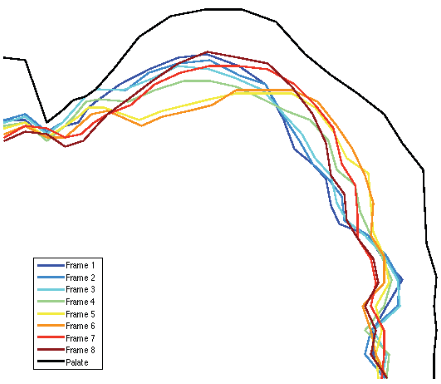

Figure 4: *Time course of the production of 'silly' from [ɪ] to [i].*

3.3. Tongue Shaping of Vocalized /l/

Examination of the instances of /l/ in syllable nucleus and coda position (simple and as part of a cluster) showed that most were produced without any discernable tongue tip closure, or even raising of the tongue tip to produce such a closure. However, despite the lack of tongue tip closure or raising during the production of /l/ in these syllable positions, there is observable curling along the tongue blade for all tokens. To illustrate, Table 5 reports the curvature scores along the tongue blade region during production of the utterance-final token 'unbeatable,' in which the last syllable contains vocalized /l/ in syllable nucleus position. Table 4 reports the curvature scores along the tongue blade region during production of utterance-final 'wall.' Note that negative curvature is present during the production of /l/, but is absent after the offset of gestural control at the end of the utterance.

Table 5. *Curvature scores at the tongue blade for each frame of the final syllable of 'unbeatable.' Frame 1 corresponds to the beginning of production of [l] simultaneous with the closure of [b], and frame 11 to the utterance-final jaw closure following the syllabic [l̩].*

Frame	Curvature Score at Tongue Blade Point
1	1.68
2	1.87
3	0.34
4	-0.47
5	-1.52
6	-1.66
7	-1.43
8	-1.66
9	-0.47
10	-0.48
11	0.49

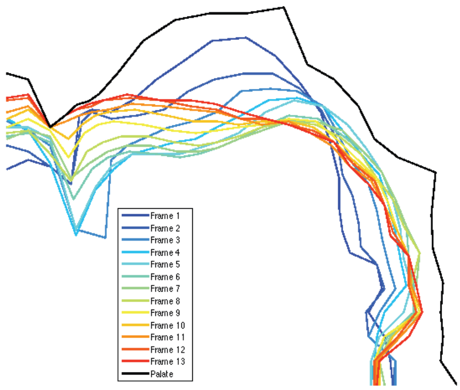

Figure 5: *Time course of the production of the final syllable of 'unbeatable.' Note the lack of complete closure between the tongue tip and alveolar ridge during the production of /l/ in the first few frames.*

Table 6. *Curvature scores at point on the tongue blade for each frame of the word 'wall.' Frame 1 corresponds to the beginning of the transition from the [ð] of 'the' to [w], and frame 8 to the last frame of production of [l] before the beginning of utterance-final jaw closure.*

Frame	*Curvature Scores at Tongue Blade Point*
1	1.85
2	-0.95
3	-0.95
4	-1.43
5	-1.74
6	-0.09
7	0.48
8	1.03

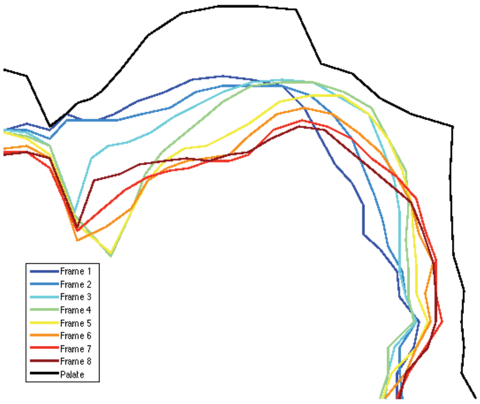

Figure 6: *Time course of the production of 'wall.' Note that the tongue tip is not near the alveolar ridge during the production of /l/.*

4. Discussion

The realization of the consonantal nature of /l/ varies across syllable positions. While the so-called vocalic gesture of /l/, involving backing of the tongue dorsum, is always present, the consonantal tongue tip gesture may not always be apparent when looking only at the achievement of some kind of constriction. Both syllable nucleus and coda position are sites of pervasive /l/-vocalization, resulting not merely in undershoot of the tongue tip gesture, but often in no discernable raising of the tongue tip at all.

This /l/-vocalization is not strictly a process that eliminates consonantal gestures, however. During vocalized /l/ in syllable nucleus and coda position, tongue curling was produced, not by raising of the tongue tip, but by lowering of the tongue blade. This curling was captured through the presence of significant negative Gaussian curvature that was measured during the production of /l/, but not during the production of surrounding material, whether vowel or consonant.

It appears that there are two modes of production of the consonantal element of /l/. One is the prototypical tongue tip closure at the alveolar ridge. The other is tongue curling through blade lowering, which is present whether or not tongue tip closure takes place. This calls into question what the goal of production for American English /l/ really is. If there is no constriction at the alveolar ridge, blade lowering cannot be said to achieve the opening of side channels for airflow, from which laterals get their name. During vocalized /l/, the vocal tract remains open. It may be instead that this tongue curling and blade lowering achieves some other production goal, the nature of which should be investigated further. If that is the case, this production goal would also need to account for the fact that in some syllable positions, tongue tip constriction does occur more often than not. This formation of constriction may facilitate the true production goal of /l/, rather than being the main consonantal production goal of /l/ itself.

5. Conclusion

The variable nature of /l/ across syllables positions continues to inform us about the nature of consonantal and vocalic gestures and their domains within the syllable. What remains unexplained for now is why /l/-vocalization is favored in some syllable positions and not others, and more generally the reason why consonantal elements are favored in one syllable position, and vocalic elements in another. Perhaps pursuing the idea of a non-constriction-based consonantal task for /l/ can shed light on what tongue tip closure is really achieving during the production of /l/, and therefore why it is necessary in one position but not another. As a class of multigestural segments on the boundary between consonant and vowel, liquids and their variable production can provide a rich source of information on this subject.

6. Acknowledgments

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7. References

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