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/l/ VARIATION IN AMERICAN ENGLISH: A CORPUS APPROACH

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We investigated the variation of /l/ in a large speech corpus through forced alignment. The results demonstrated that there is a categorical distinction between dark and light /l/ in American English. /l/ in syllable onset is light, and /l/ in syllable coda is dark. Intervocalic /l/ can be either light or dark, depending on the stress of the vowels. There is a correlation between duration (the rime duration and the duration of /l/) and /l/-darkness for dark /l/, but not for light /l/. Intervocalic dark /l/ is less dark than canonical syllable-coda /l/, but it is always dark, even in very short rimes. Intervocalic light /l/ is less light than canonical syllable-onset /l/, but it is always light. We argue that there are two levels of contrast in /l/ variation. The first level is determined by its affiliation to a single position in the syllable structure, and the second level is determined by its phonetic context.

Keywords: Corpus Phonetics; Forced Alignment; Syllable; Variation; Liquid

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1 Introduction

It has long been observed that the lateral liquid /l/ in English has two main varieties: a light /l/ and a dark /l/. Jones (1966) described the distinction between the two varieties by making a comparison to vowel quality: "An /l/ [light /l/] formed with simultaneous raising of the front of the tongue has a certain degree of acoustic resemblance to /i/, and one [dark /l/] articulated with a depression of the front of the tongue (behind the articulating tip) and raising at the back has an u-like quality or 'u-resonance' as it is often called." (1) Instrumental investigations of /l/ production in English have revealed two articulatory gestures: raising of the tongue tip and backing of the tongue dorsum. (2-7) Both the extent and the timing of the two gestures were found to be related to the "darkness" of /l/. Acoustically, the light /l/ has a relatively high F2 and a relatively low F1, whereas the dark /l/ has a relatively low F2 and a relatively high F1. (8-10)

The two variants of /l/ have traditionally been classified as categorically distinct allophones. (e.g. 11, 12) Generally speaking, the dark /l/ appears in syllable rimes and the light /l/ in syllable onsets. However, Sproat and Fujimura (1993) argued that the light and dark allophones are not categorically distinct. (3) They proposed that the single phonological entity /l/ involves two gestures - a vocalic dorsal gesture and a consonantal apical gesture. The two gestures are inherently asynchronous: the vocalic gesture is attracted to the nucleus of the syllable whereas the consonantal gesture is attracted to the margin ("gestural affinity"). When producing a syllable-final /l/, the tongue dorsum gesture shifts left to the syllable nucleus, such that the vocalic gesture precedes the consonantal tongue apex gesture. When producing a syllable-initial /l/, the reverse situation holds. As an important piece of evidence for their proposal, Sproat and Fujimura (1993) found that the backness of pre-boundary intervocalic /l/ is correlated with the duration of the pre-boundary rime. The /l/ in longer rimes is darker. Their explanation was that when the rime is short, the tongue dorsum gesture may not have enough time to reach its full target, and therefore the /l/ is lighter. They also found that the lightest pre-boundary /l/ can be as light as the prevocalic light /l/, and they explained this result by "gestural separation", i.e., conflicting tongue dorsum gestures will avoid temporal overlap. In very short rimes, the tongue dorsum gesture of the syllable-final /l/ may follow the apex gesture, as in light /l/, avoiding a clash with the preceding (tautosyllabic) vowel's dorsum gesture. Therefore, the quality of /l/ is not categorically determined by its affiliation to syllable positions.

The claim made by Sproat and Fujimura (1993) that there is no categorical distinction between light and dark /l/ in English has been supported by several other studies. Huffman (1997) extended the investigation to the acoustic properties of word-medial, intervocalic onset /l/ following schwa, e.g., in *below*. (13) Her study suggested that the dorsum gesture for the onset /l/ may also be shifted leftward, making a dark /l/. Gick and colleagues investigated the articulatory gestures of /l/ in three positions: prevocalic (e.g., *Fay lame*), intervocalic (e.g., *fail aim*) and postvocalic (e.g., *fail maim*). (6, 14) They found that both a tongue tip raising gesture and a tongue dorsum backing gesture were present in all positions. Compared to the tongue tip gesture, the tongue dorsum gesture had a positive lag in the prevocalic position, a negative lag in the postvocalic position, and no significant lag in the intervocalic position. Scobbie and Pouplier (2010) conducted an EPG study of vocalization and tongue dorsum retraction in word final /l/ in different contexts. (7) Their study showed that the tongue tip gesture of the word-final /l/ was more onset-like in prevocalic and more coda-like in pre-consonantal contexts. The tongue dorsum gesture, however, remained retracted and did not adopt an onset-like form or timing even when /l/ is prevocalic. In addition, the segmental identity of the following consonant (/l#b/ vs. /l#h/) affects the rate of /l/ vocalization (i.e., absence of alveolar contact). These studies challenged the traditional view that obligatory light and dark /l/ exist, coded at the level of phonology and determined by syllable positions.

However, although the gradient nature of /l/ darkness requires reconsideration of the categorical treatment of /l/ in traditional phonology, it may not be necessary or even appropriate to abandon the existence of a categorical distinction. Bermúdez-Otero and Trousdale (forthcoming) argued that the darkening and vocalization of word-final prevocalic /l/ can be better understood from the perspective of the life cycle of phonological processes. (15) They proposed that two cognate processes of /l/-darkening exist. The first process applies in the phonology, is historically older and applies at the word level (i.e., morphosyntactic domains). This process introduces a categorical distinction between light and dark /l/. The second process applies in the phonetics, where the relative timing of the tongue-tip and tongue-dorsum gestures is adjusted in realizations of dark /l/, but not light /l/. Hayes (2000) collected native speakers' judgments on how it is appropriate for a canonical light or dark /l/ to appear in structurally different positions. (16) His data showed that although the native speakers' intuitions on the well-formedness of dark and light /l/ in different contexts are gradient, the differences in judgment show an authentic effect of the underlying structural differences. To explain the gradient well-formedness intuitions, Hayes (2000) proposed a modification in the framework of Optimality Theory (17) by assigning different levels of constraint strictness to certain constraints while preserving the categorical distinction of light and dark /l/ in the constraints.

The studies reviewed above were based on small amounts of articulatory, acoustic, or judgment data collected through controlled stimuli in laboratory settings. Because the variation of /l/ is determined by many factors other than its affiliation to syllable positions or its immediately adjacent phones, (e.g. 13, 18-22) many results in previous studies failed to reach statistical significance (see discussions in Scobbie and Pouplier (2010) on Gick et al. (2006), and in Bermúdez-Otero and Trousdale (forthcoming) and Hayes (2000) on Sproat and Fujimura (1993)). Hence, the robustness of the results needs to be tested with large corpora of naturally occurring speech. In a corpus study of the variation of /l/ in American English, we used a forced alignment technique to measure the degree of darkness of /l/ in a large speech corpus. (23) We investigated /l/ in three positions: word-medial /l/ following a stressed vowel and preceding an unstressed vowel (denoted as V1LV0, hereafter), word-medial /l/ following an unstressed vowel and preceding a stressed vowel (V0LV1, hereafter), and word-final /l/ following a stressed vowel (V1L#, hereafter). We found that, consistent with Sproat and Fujimura (1993), /l/ darkness was correlated with the rime duration for /l/ in V1LV0 and V1L#. However, no such correlation was found for /l/ in V0LV1. Furthermore, /l/ in V1LV0 was always dark, even for very short rime durations. This result contradicts the proposal of Sproat and Fujimura (1993) that there is no categorical distinction between dark and light /l/.

This study is an extension of our previous study reported in Yuan and Liberman (2009). (23) In the previous study, we treated all word-final instances of /l/, whether preceding a consonant or a vowel, as one class. This may present a problem, especially for the forced alignment technique we applied (described in Section 2), if word-final intervocalic /l/ behaves very differently from word-final /l/ preceding a consonant in terms of /l/ darkness. Therefore, we separate tokens of word-final /l/ preceding a vowel and those preceding a consonant in this study. In addition, word-initial /l/ is also investigated in this study. We aim to compare intervocalic /l/ (both within a word and across word boundaries) with canonical syllable-onset /l/ and canonical syllable-final /l/. In phonology, it is generally agreed that an intervocalic consonant preceding a stressed vowel is syllable onset. The syllable affiliation of an intervocalic consonant following a stressed vowel, however, has been extensively debated. Based on the Maximal Onset Principle (24, 25) such a consonant should be onset of the following syllable, whereas, based on the Stress Principle (26, 27) it should be coda of the preceding syllable.

There is phonological evidence, such as the operation of aspiration and flapping of /t/ in English, that suggests that an intervocalic consonant following a stressed vowel is more coda-like. Experimental studies have shown mixed results. (e.g. 6, 7, 28-31) For example, Turk's (1994) experiment on vertical movements of the upper lip during the production of bilabial stops showed that stops following stressed vowels and preceding unstressed vowels patterned with syllable final stops and did not share the combined characteristics of syllable-initial and syllable-final stops. (31) On the other hand, as reviewed above, the studies of Gick et al. (2006) and Scobbie and Pouplier (2010) found that intervocalic /l/ appeared to be intermediate between onset-like and coda-like forms in terms of articulatory gestures and their relative timing. Several proposals have been made in phonology regarding the syllable affiliation of intervocalic consonants following stressed vowels, including ambisyllabification (belonging to both the preceding and the following syllable), (25, 32, 33) resyllabification (being the coda of the preceding syllable) (34, 35) and prosodic approaches against ambisyllabification or resyllabification (36, 37).

This study contributes to the literature by providing an understanding of variation of /l/ in large speech corpora from the perspective of syllabification and syllable structure. In the following sections we first introduce our method for measuring /l/-darkness through forced alignment. The data and analysis are presented in Sections 3 and 4, respectively, and discussed in Section 5.

2 Investigating the variation of /l/ through forced alignment

Forced alignment has been widely used for automatic phonetic segmentation in speech recognition. This task requires two inputs: recorded audio and (usually) word transcriptions. The transcribed words are mapped into a phone sequence in advance by using a pronouncing dictionary or grapheme to phoneme rules. The most frequently used approach for forced alignment is to build a phonetic recognizer based on a Hidden Markov Model (HMM). Typically every phone in the target language is represented as an HMM that consists of three states: the beginning part of the phone (s_1), the middle part of the phone (s_2), and the end part of the phone (s_3), plus a special start state (s_0) and end state (s_4) for entering and exiting the phone. From the training data, an acoustic model (e.g., a Gaussian Mixture Model (GMM)) is built for each state (except s_0 and s_4), as well as the transition probabilities between pairs of states (Figure 1). The speech signal is analyzed as a successive set of frames (e.g., every 3-10 ms). The alignment of frames with phones is determined via the Viterbi algorithm, (38) which finds the most likely sequence of hidden states given the observed data and the acoustic model represented by the HMMs. The acoustic features used for training HMMs are normally cepstral coefficients such as Mel-frequency cepstral coefficients (MFCCs) (39) and Perceptual Linear Prediction (PLP) (40). The reported performances of state-of-the-art forced alignment systems range from 80%-93% agreement (of all boundaries) within 20 ms compared to manual segmentation. (41) Human labelers have an average agreement of 93% within 20 ms, with a maximum of 96% within 20 ms for highly trained specialists. (42)

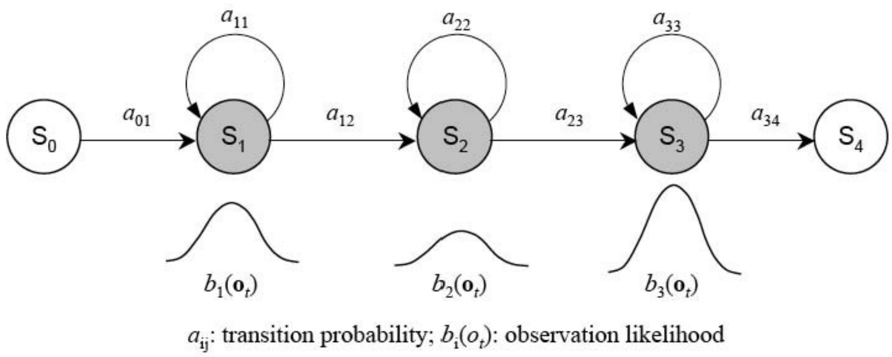

Figure 1: Hidden Markov Model.

In addition to providing automatic phone segmentations, forced alignment can also be used to investigate phonetic variation. If a word has multiple pronunciations in the pronouncing dictionary, forced alignment will choose the most probable pronunciation for the acoustic observation. Fox (2006) demonstrated that a forced alignment technique worked well in studying the distribution of s-deletion in Spanish. (43) Yuan and Liberman (forthcoming) used forced alignment for the automatic detection of “g-dropping” (e.g., *walkin’*) in American English. (44) The study reported that the agreement rates between the forced alignment method and native English speakers were comparable to the agreement rates among the native speakers. Furthermore, probability scores associated with the forced alignment procedure, i.e., the log probability (log probability density) of the aligned segment to be a particular phone, provide a new perspective for investigating phonetic variation in speech.

In Yuan and Liberman (2009), we developed an innovative technique to measure the “darkness” of /l/ based on probability scores from forced alignment. In this method, we trained two models of /l/: one for light /l/ and another for dark /l/. The two models were able to identify word-initial vs. word-final /l/s with an accuracy of greater than 90%. To compute a score that can measure the degree of /l/-darkness, we ran forced alignment twice. All tokens of [l] were aligned first using the light /l/ model and then using the dark /l/ model. The difference between the log probability scores from the dark /l/ alignment and the light /l/ alignment - the *D* score, as defined in (1) - measures the darkness of /l/; the larger the *D* score is, the darker the /l/ will be.

(1) $D = \log p(l \mid L2) - \log p(l \mid L1)$;
(L1 and L2 are the models for light and dark /l/, respectively).

3 Data and procedure

We used the same corpus as in Yuan and Liberman (2009), the SCOTUS corpus, which in full includes more than 50 years of oral arguments from the Supreme Court of the United States. The Justices’ utterances (i.e., speaker turns) were extracted from the recordings and utilized in this study. The data set contained 25.5 hours of speech, in which there were a total of 21,706 /l/ tokens. The phone boundaries were automatically determined using the Penn Phonetics Lab Forced Aligner (http://www.ling.upenn.edu/phonetics/p2fa/). The aligner was trained on the same data set using the HTK toolkit (http://htk.eng.cam.ac.uk/) and the CMU American English Pronouncing Dictionary (http://www.speech.cs.cmu.edu/cgi-bin/cmudict/). The acoustic models are GMM-based, monophone HMMs. Each HMM state has 32 Gaussian Mixture components on 39 PLP coefficients.

Two models of /l/ were trained using the corpus: one for /l/ in the canonical onset position (L1) and another for /l/ in the canonical coda position (L2). Initially, word-initial /l/ (e.g., *like*) and /l/ in word-initial consonant clusters (e.g., *please*) were categorized as L1 (light); word-final /l/ preceding a consonant (e.g., *full capacity*) and non-word-final /l/ in word-final consonant clusters (e.g., *felt*) were L2 (dark). All other instances of /l/, including word-medial /l/ (e.g., *melody*) and word-final /l/ preceding a vowel (e.g., *full of*), were ambiguous (they could be either L1 or L2). During each iteration of training, the 'real' pronunciations of the ambiguous /l/ were automatically determined, and the acoustic models of L1 and L2 were updated. After the training, the *D* score of every /l/ token in the data set was computed by subtracting the log probability score of aligning the token using the L1 model from the score of aligning the token using the L2 model (as defined in Section 2).

The *D* scores of the /l/ tokens in five different positions are analyzed in this study: 1. word-initial, followed by a stressed vowel (#LV1); 2. word-final, between a stressed vowel and a consonant, without a pause at the word boundary (V1L#C); 3. word-final, between a stressed and an unstressed vowel, without a pause at the word boundary (V1L#V0); 4. word-medial, between a stressed and an unstressed vowel (V1LV0), and 5. word-medial, between an unstressed and a stressed vowel (V0LV1). The number of tokens and the syllable affiliation of each position are listed in Table 1.

Table 1: Summary of the /l/ tokens analyzed in the study.

Position	Syllable affiliation	Number of tokens
#LV1	Onset	3,019
V1L#C	Coda	1,812
V1L#V0	coda or ambisyllabic	688
V1LV0	onset, coda, or ambisyllabic	1,708
V0LV1	Onset	1,117

4 Analysis

4.1 The effect of syllable position on /l/ quality

Figure 2 plots the mean *D* scores of /l/ at various positions. The *D* scores are negative for /l/ in #LV1 and V0LV1, and positive for /l/ in V1L#C, V1L#V0 and V1LV0. The *D* score is the difference between the probability of being a dark /l/ and that of being a light /l/; negative scores indicate a light /l/, and positive scores indicate a dark /l/. The result that /l/ in V1LV0 has a negative score suggests that it is coda-like but not syllable onset in terms of its acoustic characteristic. Besides a categorical distinction between the dark and light /l/, Figure 2 also shows a gradient quality variation within each category. V1LV0 and V1L#V0 have lower positive *D* scores (less dark) than V1L#C, and V0LV1 has higher negative D scores (less clear) than #LV1. A small difference also exists between V1L#V0 and V1LV0, but it is not statistically significant ($t\ (1052.8) = 1.84$, $p = 0.066$). These results are largely consistent with the native speakers' judgment data in Hayes (2000), but with two major differences: 1. in Hayes (2000), V1LV0 is more similar to light /l/ whereas our result is that it is more similar to dark /l/; 2. there is little difference between V1L#V0 and V1LV0 in our results, but they are significantly different in Hayes (2000).

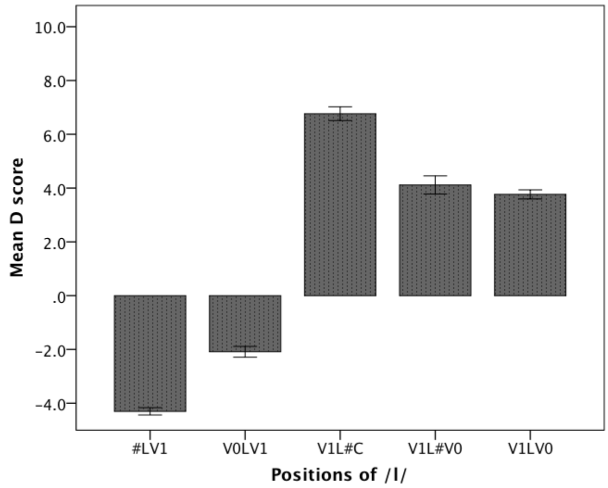

Figure 2: Mean *D* scores of /l/ at different positions.

/l/ is less dark in V1L#V0 and V1LV0 than in the canonical coda position, V1L#C. This result is consistent with the claim that intervocalic /l/ following a stressed vowel is ambisyllabic. Interestingly, /l/ in V0LV1 is less light than in the canonical onset position, #LV1. This suggests that instances of word-medial intervocalic /l/ preceding a stressed vowel are also phonetically "ambisyllabic" (i.e., they have a quality that is intermediate between the onset and the coda), although it is generally agreed in phonology that such /l/ is syllable onset.

Although pre-tonic (preceding a stressed vowel) and post-tonic (following an stressed vowel) intervocalic /l/ are both phonetically "ambisyllabic", they are still categorically distinct. Pre-tonic intervocalic /l/ is light and has a negative *D* score, and post-tonic intervocalic /l/ is dark and has a positive *D* score. Moreover, as shown in Figure 3, the duration of /l/ in V0LV1 does not affect its *D* score whereas in V1LV0 there is a positive correlation between the duration of /l/ and its *D* score. This result is different from that of Huffman (1997), who found a correlation between /l/ duration and darkness in V0LV1.

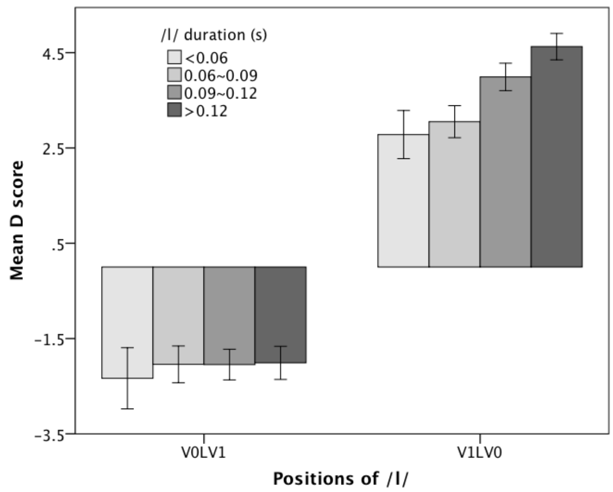

Figure 3: The effect of the duration of /l/ on its quality in V0LV1 vs. V1LV0.

4.2 The effect of rime duration on /l/ darkness

Figure 4 illustrates the effect of rime duration, including both /l/ and the preceding vowel, on the degree of darkness of /l/ in V1L#C, V1L#V0, and V1LV0. In V1L#V0 and V1LV0, /l/ in longer rimes has larger D scores, and hence is darker. This result is consistent with that of Sproat and Fujimura (1993), who focused only on /l/ in V1L#V0. The relationship between rime duration and darkness for /l/ in V1L#C is non-linear; for shorter rimes the correlation is positive, whereas for longer rimes, the correlation is negative, and /l/ reaches its peak of darkness when the rime (more precisely, the stressed vowel and /l/) duration is approximately 200 ms. The same pattern has been found for word-medial pre-consonantal /l/ (V1LC) in our previous study (Author, 2009). Although further research is needed to understand the non-linear relationship between rime duration and /l/ darkness in pre-consonantal /l/, the result suggests that rime duration is not the only factor that determines /l/ darkness. This conclusion is also supported by the difference between /l/ in V1L#V0 and V1LV0 and /l/ in V1L#C. As seen in Figure 4, at every rime duration, whether short or long, ambisyllabic /l/ (V1L#V0 and V1LV0) is always less dark than canonical /l/ (V1L#C). Clearly, this difference cannot be explained by rime duration.

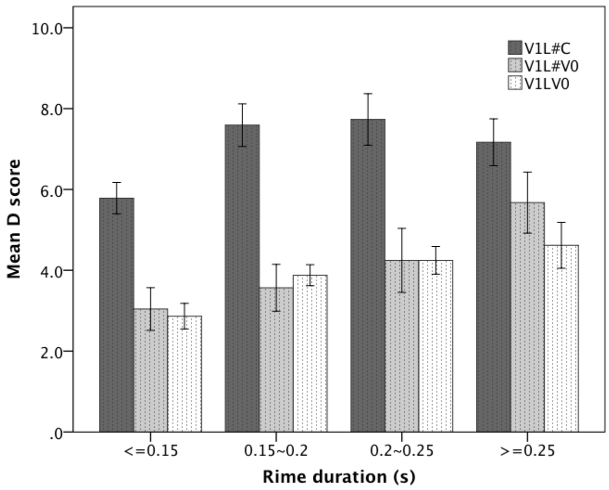

Figure 4: The effect of rime duration (the duration of /l/ and the preceding vowel) on /l/ darkness.

Figure 4 also shows that /l/ following a stressed vowel and preceding an unstressed vowel is always dark ($D > 0$), even in very short rimes. This result contradicts the finding of Sproat and Fujimura (1993) that such /l/ in very short rimes can be as light as canonical light /l/.

5 Discussion

The analysis above demonstrates that there is a categorical distinction between dark and light /l/ in American English. /l/ in syllable onset is light and /l/ in syllable coda is dark. Intervocalic /l/ can be either dark or light, depending on the stress of the vowels preceding and following it. /l/ that occurs after a stressed vowel is dark, and /l/ that occurs before a stressed vowel is light. That is, the stressed vowel attracts intervocalic /l/ into its syllable. This result favors the resyllabification proposal (34, 35) in which intervocalic post-tonic /l/ is re-syllabified to syllable coda from syllable onset. On the other hand, our analysis also showed that there are within-category differences regarding /l/ quality. Intervocalic dark /l/ is less dark than canonical syllable-coda /l/, and intervocalic light /l/ is less light than canonical syllable-onset /l/. This result favors the ambisyllabification proposal (25, 32, 33) in which intervocalic post-tonic /l/ belongs to both syllable onset and syllable coda. The results suggest that the variation of /l/ in American English involves two levels of contrast. The first level is categorical and the second level is within-categorical. Resyllabification may explain the first level of contrast, and ambisyllabification may explain the second level of contrast, but neither is sufficient alone. One solution is to combine the two proposals. For example, the operation of syllable affiliation may be stratal or hierarchical. In the first tier, a segment is affiliated/linked to only one position in the syllable structure. In the second tier, another affiliation/linkage may be added.

However, we favor a proposal similar to that of Bermúdez-Otero and Trousdale (forthcoming), who draw a distinction between phonological and phonetic processes. (15) We propose that the first level of contrast in the variation of /l/ is determined by its affiliation to a single position in the syllable structure, i.e., syllable onset vs. syllable coda (31). The second level of contrast is determined by the phonetic context, for example, intervocalic (6), the rime duration (3), the effect of vowel quality (13) and the effect of the following consonant (7). Scobbie and Pouplier (2010) argued that "[we] do not think that the many cases of 'ambisyllabicity' in the literature need to involve a change in syllable structure. …the bulk of instrumental phonetic evidence supports our view precisely because word-final consonants vary, and often appear to be intermediate between onset-like and coda-like forms." (7) We agree with this argument and our study provides evidence for it: structurally motivated ambisyllabification alone (linking to both onset and coda) cannot explain why both intervocalic pre-tonic and post-tonic /l/ have intermediate quality but are categorically different. On the other hand, the phonetic process involved in the variation of /l/ cannot override the phonological process. The duration effect on /l/ darkness, for example, does not suggest that no categorical distinction exists between dark and light /l/ (as proposed in Sproat and Fujimura, 1993); rather, it shows the characteristic of one category, the dark /l/. This can be seen from our result that duration affects the darkness of dark /l/ but not light /l/.

Our proposal differs from that of Bermúdez-Otero and Trousdale (forthcoming) in two ways. First, Bermúdez-Otero and Trousdale (forthcoming) proposed that the phonological process involved in /l/-darkening applies to the morphosyntactic domains. In our proposal, the phonological process applies to the domain of syllables. We found that pre-tonic word-medial and word-final intervocalic /l/ share the same pattern, although word-medial /l/ in our data may or may not be a morpheme boundary. Second, the effect of rime duration on /l/ variation is seen as a purely phonetic process applied to only dark /l/ in Bermúdez-Otero and Trousdale (forthcoming)'s proposal. In our proposal, the effect of rime duration represents a characteristic of dark /l/. The phonetic process is sensitive only to phonetic context and applies to both light and dark /l/. In the intervocalic context, the phonetic process is probably determined by mechanisms involving attraction, separation, or the coordination of different articulatory gestures. (3, 4, 30, 45, 46) We found that rime duration is not the only factor that determines the darkness of dark /l/. Given the same rime duration (short or long), intervocalic dark /l/ is always less dark than canonical syllable-coda /l/. Also, dark /l/ preceding a consonant exhibits a non-linear relationship between darkness and rime duration.

Finally, pre-tonic intervocalic /l/ is less dark in word-medial positions than in word-final positions when the rime is long (>= 250ms, as shown in Figure 4). Further research is needed to explain this result. Rubach (1996) reported that native speakers have strong intuitions that an intervocalic consonant is ambisyllabic only if the preceding stressed vowel is short (lax), presumably because in English lax vowels cannot appear in open syllables. (33) Therefore, it might be that when the preceding vowel is long, word-medial intervocalic /l/ becomes less affiliated to the coda position of the preceding syllable.

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