

Allophonic variation in English /l/ and its implications for phonetic implementation

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English /l/ has traditionally been classified into at least two allophones, namely light, which typically occurs syllable initially, and dark, which occurs syllable finally. While it has been recognized that intervocalic /l/s that precede phonological boundaries may be phonetically between the two extremes, most researchers have tended to assume that the allophones of a phoneme are categorically different elements. This paper presents acoustic and X-ray microbeam data for English /l/, both initial and preceding various phonological boundaries, in the context /i – ɪ/. The primary articulatory measures of the light–dark contrast are shown to be: (1) a greater retraction and lowering of the tongue dorsum for darker variants of /l/; (2) in darker variants of /l/, an earlier occurrence of the dorsal retraction and lowering extremum relative to the apical advancement extremum, in contrast to the timing in the lighter variants of /l/ where the dorsal extremum is temporally later than the apical extremum. It is also shown that the /l/'s darkness evaluated by the articulatory measures above—as well as by formant frequency measures—correlates strongly with the acoustically measured duration of the rime containing a pre-boundary /l/.

We interpret our results as evidence that there is no reason to treat the light and dark allophones as categorically distinct phonological (or phonetic) entities in English. Rather, the single phonological entity /l/ is phonetically implemented as a lighter or darker variant depending upon such factors as the /l/'s position within the syllable, and the phonetic duration of the prosodic context containing the /l/. We propose that /l/s involve a *vocalic* dorsal gesture as well as a *consonantal* apical gesture. We suggest that vocalic gestures have a strong affinity for the nucleus of the syllable, whereas consonantal gestures have a strong affinity for the margin. The two gestures of /l/ are thus inherently asynchronous, with the vocalic gesture in syllable-final /l/s preceding (i.e., being closer to the nucleus than) the consonantal gesture, and with the reverse situation holding in syllable-initial /l/s. For this explanation to work, phonetic implementation must have access to information on the intrasyllabic position of phonological elements. We argue further that coarticulatory undershoot accounts for a large part of the correlation of darkness with duration.

1. Introduction

In many forms of English, prevocalic /l/ is distinguishable phonetically from post-vocalic or syllabic /l/; contrast the /l/ in *lip* ['lɪp], with the /l/ in *pill* ['pɪl], *milk* [m'ɪlk], or *whittle* ['wɪtl]. The prevocalic allophone of /l/ is often called "light" (or "clear"; Hattori, 1984, p. 91; Bladon & Al-Bamerni, 1976), whereas the other allophone, including both the post-vocalic and the syllabic cases, is termed "dark". While there are dialects of English where the light-dark dichotomy is claimed not to exist (see Wells, 1982), the distinction is widely reported for both American and British English. It is well known that the basic acoustic correlate of the distinction is that the light instantiation of /l/ has a relatively high F_2 and a low F_1 , whereas the dark instantiation has a lower F_2 and a higher F_1 ; for American English, see Potter, Kopp & Green (1947); Lehiste (1964), *inter alia*; and for British English, see Bladon & Al-Bamerni (1976); Maddieson (1985), *inter alia*. The basic articulatory distinction is that in dark /l/s the body of the tongue is more retracted than in light /l/s; for American English, see Giles & Moll (1975); and for British English, see Gartenberg (1984). To complete the picture somewhat, we note that there are dialects of English where post-vocalic [ɫ] has become vocalized to something like [ɤ]; Hardcastle & Barry (1985) and Wells (1982) discuss this phenomenon in dialects of British English. Hardcastle & Barry's evidence points to the variation between [ɫ] and [ɤ] being non-categorical and sensitive to articulatory and perceptual factors.

Now, it is commonly assumed that allophones of a phoneme, such as [l] and [ɫ], should be regarded as distinct entities. This assumption is often merely implicit in discussions of allophonic variation; however, Giles & Moll (1975, p. 223) explicitly argue that "pre- and post-vocalic /l/ ... should not be considered as the same element physiologically, but as separate elements with perhaps different learned motor patterns". The assumption is also typically adopted by phonologists. For example, Halle & Mohanan (1985) derive dark /l/s from light /l/s via a phonological rewrite rule that adds the feature specification [+back] to /l/s in post-vocalic position. Clearly such an approach is founded on the assumption that in order to describe how one goes from an abstract phonemic representation to actual pronunciation, one needs an intermediate level of representation where allophones are represented as categorical entities.

A complication for this picture arises when one considers the properties of *intervocalic* /l/s that occur before some sort of linguistic boundary; for example the /l/ in *feel-ing*, which occurs before the morphological boundary preceding the affix -ing, or the /l/ in *feel it*, which occurs before the boundary separating the clitic *it* from the verb *feel*. Such /l/s would not normally be considered to be *prevocalic* because of the boundary which intervenes between them and the following vowel, yet they do not behave like canonical post-vocalic /l/s either. As is shown by both Lehiste (1964) for American English, and Bladon & Al-Bamerni (1976) for British English, such /l/s are intermediate in quality between the light and dark variants. In the Bladon & Al-Bamerni study, for example, the /l/s in *feel it* or *feel ill*, though not fully light, were more similar to the light /l/ in *Ely* than to a dark /l/, such as that in prepausal *feel*. While various explanations for this behavior may come to mind, the possibility suggests itself that there may be an effect of duration on the quality of /l/. This is because, as is well known (cf. Crystal & House, 1988), a sequence such as /il/ will generally have a longer duration in prepausal position than it will in

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phrase-medial position. As we noted above, a primary difference between light and dark /l/s is that dark /l/s have a more retracted tongue body than light /l/s. Perhaps non-prepausal intervocalic /l/s are lighter than prepausal /l/s because in non-prepausal position the duration of the syllable is such that the tongue retraction does not reach its full target. Of course, this analysis crucially assumes that the phonetic duration of, say, a syllable can be (partly) determined *a priori* by linguistic factors such as the position of the syllable relative to a boundary, or the stress status of that syllable: furthermore, the time allotted to a gesture associated with that syllable would be greater or lesser depending upon the duration of the syllable as determined in part by these extrinsic factors. We can develop this line of inquiry further by considering the observation of Lehiste (1980) that the strength of linguistic boundaries appears to correlate positively with the duration of phonetic elements preceding those boundaries. Suppose one had a syllable ending in a phoneme sequence such as /il/: if one were to continuously vary the duration of that sequence by varying the strengths of the following linguistic boundary, might it be the case that one would find a continuum of qualities of /l/ from dark in the case of the longest syllables to light in the case of the shortest syllables? Might it also be the case that the lightest pre-boundary /l/s would turn out to be as light as canonical prevocalic /l/s? Might one further argue that there is no need to make a *categorical* distinction between light and dark /l/ allophones, but instead that one should derive the phonetic properties of /l/ in part from durational considerations and in part from expected differences between prevocalic and post-vocalic consonants?

In this paper we shall present articulatory and acoustic data on /l/ production in four American speakers and one (quasi-) British speaker, which suggest answers to these questions. We shall show that the quality of pre-boundary intervocalic /l/s is correlated with the duration of the pre-boundary rime. The duration of the pre-boundary rime is in turn related to the strength of the boundary in question: thus, we shall sample the space of pre-boundary /l/s by examining contexts with boundaries of various phonological strengths. A crucial result about pre-boundary /l/s is that, before the weakest boundaries, the /l/s can be as light as or even lighter than initial /l/s, as measured by various acoustic and articulatory factors. We shall suggest articulatory undershoot as the explanation for these observations: for instance, we shall propose that the lighter quality of pre-boundary /l/s in short durational contexts is due, in part, to the failure of the tongue dorsum to be retracted as fully as it would be for a canonical dark /l/.

As we shall see, though, there are differences between prevocalic and post-vocalic /l/s that cannot be explained in terms of duration. For example, there is the observation of Giles & Moll (1975) that whereas for light /l/s the tongue makes an apical contact, for dark /l/s apical contact is often not observed. These facts apparently cannot be accounted for purely in terms of coarticulatory undershoot, since it is far from obvious why, in the longer post-vocalic contexts in which one usually finds dark /l/s, the tongue could not make an apical contact. Instead, we will attribute such observations to more widely observed differences between *syllable-initial* consonants (i.e., consonants in the onset of the syllable) and *syllable-final* consonants (those in the coda); in anticipation of this proposal, the pre-theoretical terms "prevocalic" and "post-vocalic"—which we have been using for reasons of exposition and fidelity to (some of) the phonetic tradition—will henceforth be replaced with "syllable-initial" and "syllable-final", respectively.

By arguing that much of the substantial variation in quality in English /l/ allophones can be explained by a combination of factors including duration and intrasyllabic position, we hope to have shown that the mapping from an abstract phonological representation to actual pronunciation does not require the positing of a level of representation where [l] and [ɫ] are distinct phonological or physiological entities.

2. Experimental design, subjects and data analysis

2.1. Subjects and data collection methods

Simultaneous articulatory and acoustic data were collected at the University of Wisconsin X-Ray Microbeam Facility (Nadler, Abbs & Fujimura, 1987). The Microbeam System provides automatic tracking of pellets (2.5–3.0 mm diameter gold spheres) placed on the articulators (Fujimura, Kiritani & Ishida, 1973; Kiritani, Itoh & Fujimura, 1975).

The subjects discussed in this paper consisted of four speakers of Midwestern American English—CS (female), CC (female), AD (male) and DB (male)—all in their early twenties; and one speaker of British English with a fair amount of American English influence—speaker RS (male) (late twenties). With the exception of speaker RS (one of the authors of this paper), none of the speakers were aware of the nature of the experiment, nor did they have any phonetic training. All speakers were informally assessed as having normal speaking and hearing according to routine subject recruitment procedures used by the Microbeam Facility. None of the subjects had ‘vocalized’ syllable-final /l/ common in some dialects and discussed in Hardcastle & Barry (1985).

Pellets were placed at three locations on the tongue: near the tip of the tongue; in the mid-region of the blade of the tongue; and on the dorsum of the tongue. These pellets are henceforth referred to as TT, TM and TD, respectively. Note that it is not possible to place a pellet exactly on the tip of the tongue since this interferes with articulation. Table I gives the position of the three tongue pellets for the five speakers as measured from the tip of the fully extended tongue. In addition to the tongue pellets, reference pellets were placed on the upper incisor and the bridge of the nose, and pellets were also placed on the lower incisor and lower lip (at the vermilion margin). All measurements of pellet position given in this paper assume a co-ordinate system with the origin at the upper incisor pellet; the *x*-axis is defined to agree with the occlusal plane of the subject. A backward movement of a pellet corresponds to an increase in magnitude for the negative *x* value for the pellet position.

EMG data were collected for speakers CC, DB and RS using hooked wire electrodes (Hirano & Ohala, 1969; Honda, Miyata & Kiritani, 1983). Electrode insertions were performed by experienced laryngologists. We will not report on the EMG data here; we merely mention the fact that three subjects did have EMG electrodes inserted into various tongue muscles, since it is always possible that such invasive procedures will affect articulation. (While we do not report on the EMG

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TABLE I. Tongue pellet placement

Speaker	Tongue tip to pellet distances (mm)		
	TT	TM	TD
CS (F, Am.)	10	40	70
CC (F, Am.)	8	41	83
AD (M, Am.)	9.5	30	60
DB (M, Am.)	9	38	75
RS (M, Br.)	10	30	61

part of the experimental study in this paper, the hypotheses we present here were considerably influenced by our informal observation of the EMG data.)

2.2. Stimuli for the /i - ɪ/ trochaic context

Our primary set of stimuli consisted of sentences containing pre-boundary (final) and post-boundary (initial) /l/s in a trochaic (i.e., strong-weak) stress context, with the segmental context being held constant as /i - ɪ/, the one exception being the /h/ context which was /i - hɪ/. Because we were interested in testing a wide range of variation in duration for the pre-boundary cases, we devised a set of boundaries with a variety of different strengths; cf. the discussion of the relation between boundary strength and pre-boundary duration in Section 1. An attempt was made to keep the syllables of interest in roughly the same position in the different carrier sentences, as far as possible. In addition, we also kept the onset of the syllable preceding the /l/ and the final consonant of the syllable after the /l/ constant at /b/ and /k/, respectively; however, this resulted in nonsense words, so for two of the speakers (CS, AD) we added examples with real words beginning with consonants other than /b/. We did not observe any systematic differences between nonsense data and real-word data in these paradigms so we did not collect the real-word data with the other three speakers.

The primary stimuli are listed in Table II. The last column of the table gives the symbols that we will use to plot the data for each of the classes. These symbols will also be used as shorthand names for the utterance types. Below we give a fuller description to clarify some of the cases:

- (i) Before a major intonation boundary: here we use sentence-initial vocatives, which are typically implemented with an intermediate or intonational phrase break (Beckman & Pierrehumbert, 1986, p. 297).
- (ii) VP-internal phrase break: the break chosen was between two NPs in a double-object construction.
- (iii) Before “#” or “+” boundaries: in the sense of Chomsky & Halle (1968)—“+” is the boundary between (most) latinate affixes and their bases, whereas “#” is the affix before the more productive non-latinate derivational and inflectional affixes.
- (iv) Intervocalic with no boundary: depending upon one's theory, one would expect these /l/s to be syllable-initial (assuming the Maximal Onset Principle), syllable-final (Borowsky, 1987), or ambisyllabic (Kahn, 1976):
- (v) Word initial: these /l/s are necessarily syllable-initial in any phonological description.

TABLE II. Primary stimuli for the /i-1/ context. The /l/ of interest is shown in boldface. Sentences 2, 4, 6, 8, 10, 12, 14, 15 and 16 were uttered by speakers CS and AD only

Environment	No.	Sentence	Plotting character
Before /h/	1	Mr Beel Hikkóvsky's from Madison.	"h"
Before /h/	2	Mr Neal Hikkóvsky's from Madison.	"h"
Major intonation boundary	3	Beel, equate the actors.	" "
Major intonation boundary	4	Neal, equate the actors.	" "
VP phrase boundary	5	Beel equates the actors.	"V"
VP phrase boundary	6	Neal equates the actors.	"V"
VP-internal boundary	7	I gave Beel equated actors.	"P"
VP-internal boundary	8	I gave Neal equated actors.	"P"
Compound-internal boundary	9	The beel-equator's amazing.	"C"
Compound-internal boundary	10	The seal-equipment's amazing.	"C"
"#" boundary	11	The beel-ing men are actors.	"#"
"#" boundary	12	The kneel-ing men are actors.	"#"
"+" boundary	13	The beel-ic men are actors.	"+"
"+" boundary	14	The tel-ic men are actors.	"+"
No boundary	15	Mr Beelik wants actors.	"%"
No boundary	16	Mr Beelik's from Madison.	"%"
Word initial	17	Mr B. Likkóvsky's from Madison.	"l"

(vi) Before /h/: these /l/s are necessarily syllable-final since /l/ cannot occur before another consonant as part of an initial consonant cluster in English and there is therefore no chance of resyllabification. [We chose /h/ rather than some other syllable onset since /h/ can be considered a voiceless vowel (Catford, 1977), with no articulatory specifications other than glottal abduction, and thus is less likely than some other consonants to interfere directly with lingual articulation. It is nonetheless possible that the laryngeal gesture for [h] causes some displacement of the tongue body; see Honda (1988) for some relevant discussion.]

We had some *a priori* notion of the relative linguistic strengths of the boundaries in question, which we give in (1), using the plotting characters listed in Table II:

$$+" < \# < "C" < "h" < "P" < "V" < "l" \quad (1)$$

The "+"-boundary affixes are generally associated with more significant phonological effects on their bases (e.g. stress shift or velar softening) than are "#" boundary affixes. For similar reasons, "#" can be considered to be weaker than the compound boundary, and all of the boundaries "+", "#", and "C" are weaker than the phrasal boundaries "P", "V" and "l". The VP-internal boundary ("P") is weaker than the (across) VP boundary ("V") on syntactic grounds, and since neither of those boundaries is (necessarily) implemented as a major intonational boundary, both of them are (generally) weaker than "l". We positioned the /h/-type after the compound type since the /h/ examples were (nonsense) personal names—*Beel Hikkóvsky*—and it seems reasonable to assume that such proper names are prosodically intermediate between compounds and full phrases. The compounds used in this experiment were uttered with compound (left-hand) stress whereas the nonsense names took phrasal (right-hand) stress, suggesting that the compounds may be analyzed phonologically as words whereas the names should be analyzed as a (small) phrase.

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Roughly four utterances of each stimulus were collected from each speaker. Pellet mistracking occurred with a small portion of the utterances. When this was noticed during data acquisition, the subject was generally asked to utter the same material again. However, there were occasionally cases where mistrackings and other processing errors were not noticed, resulting in fewer than four utterances for some of the stimuli. Speakers were asked to produce all utterances at a conversational rate.

2.3. Measurements

Data were processed at the Microbeam Facility to correct for subjects' head movements. The corrected pellet track signals were smoothed by low-pass filtering with a cut-off frequency of 10 Hz using a third-order Butterworth filter. Low-pass filtering is necessary for analyzing pellet track data to remove measurement noise and to allow for the accurate evaluation of extrema.

Special display and analysis software written at the University of Wisconsin for microbeam data processing was used to make measurements of the data, with the aid of the Waves signal display program (Talkin, 1989). A number of events were measured:

- (i) Time of acoustic onset of vowel (/b/ explosion, /n/ explosion, or the onset of voicing after voiceless initials) preceding /l/ (V1).
- (ii) Time of acoustic onset of /l/ (spectral discontinuity in formant structure determined by visual inspection). Note that this measurement is more or less difficult to make, depending upon whether the /l/ is lighter (in which case the spectral discontinuity at the left edge is quite evident) or darker (in which case there may be little or no discontinuity). For dark /l/s, onset was in all cases marked immediately *after* the rapid F_2 motion characteristic of the transition between /i/ and /l/.
- (iii) Time of acoustic offset of /l/ (spectral discontinuity at the /l/ release or the beginning of silence—possibly, though not necessarily, due to a glottal stop—determined by visual inspection).
- (iv) Time of acoustic onset of vowel after /l/ (V2) (voice onset of vowel if there is an [h] or glottalization, otherwise identical with time of acoustic offset of /l/).
- (v) Time of acoustic offset of V2 (typically, the beginning of /k/ closure).
- (vi) Visually determined time and x , y values of *extremum* of upward and forward movement of the TT pellet for /l/ (henceforth [Tip Extremum]).
- (vii) Visually determined time and x , y values of *extremum* of lowering of the TM pellet for /l/ (henceforth [Mid Lowering Extremum]).
- (viii) Visually determined time and x , y values of *extremum* of retraction of the TD pellet for /l/ (henceforth [Dorsum Retraction Extremum]).

Formant values for F_1 and F_2 were automatically extracted for the temporal midpoints of V1, /l/ and V2. Because of the way that the onset and offset for /l/ were defined, the F_2 and F_1 values at the mid-point of /l/ were not sampled during the rapid F_2 transition between /i/ and /l/, but were representative of periods of relative stability in F_2 and F_1 .

A measure which we shall be making much use of in the ensuing discussion is the time duration. This is simply defined as the length of the interval between the

acoustic onset of V1 and the acoustic offset of /l/ (though see Section 3.2 for the application of this definition to the syllable-initial cases).

3. Results

3.1. Differences between light and dark /l/s

In order to establish our claim that pre-boundary /l/s vary continuously from the darkest variants, to variants that are as light as syllable-initial cases, we need to provide some reliable articulatory and acoustic measures of "darkness" in the context of our experiment. We therefore start by considering the differences between *canonical light* /l/s and *canonical dark* /l/s; we pick for the canonical light versions, the word-initial /l/s in sentence 17 from Table II and for the canonical dark versions, /l/s before major intonational boundaries (sentences 3 and 4); note that the latter contexts are the closest to being pre-pausal of all the contexts in our stimulus set.

In Table III we present data showing the basic acoustic and articulatory differences between the canonical light and dark /l/s. Starting with the acoustic measure, in columns 3-5 we give the mean values for F_2-F_1 in Hz for light and dark /l/s from the stated contexts for each of the five subjects, along with the scores from a (two-tailed) *t*-test, which show that there is a significant difference between the values for F_2-F_1 for the light and dark versions. All *t*-values are significant at at least the 0.05 level. These results confirm observations of Lehiste (1964), *inter alia*.

Turning to articulatory measures, we note first of all that both light and dark /l/s show a retraction of the dorsum and a lowering of the middle of the tongue relative to the positions of those parts of the tongue for the mid-point of the preceding /i/. However, the degree of retraction and lowering is greater for our canonical dark /l/s than for the canonical light /l/s: this confirms some observations of Giles & Moll (1975). In columns 6-8 and 9-11 of Table III we give means for [Dorsum Retraction Extremum](x) and [Mid Lowering Extremum](y) position, in millimeters, for canonical light and dark /l/s for all five subjects, along with the associated *t*-scores. All *t*-scores are significant at at least the 0.05 level except for the differences for [Mid Lowering Extremum](y) for speakers CS and CC.

As Giles & Moll (1975) report, all /l/s involve a forward movement of the tongue tip, and as we noted previously all /l/s involve some amount of retraction and lowering of the body of the tongue relative to the preceding /i/. A heretofore unreported difference between light and dark /l/s, which we have observed, involves the value of the lag between the time at which the tongue tip reaches its extremum of forward movement and the time at which the tongue dorsum reaches its extremum of retraction and lowering movement. We shall call this value [Tip Delay] and define it as in (2):

$$[\text{Tip Delay}] = \text{time}([\text{Tip Extremum}]) - \text{time}([\text{Mid Lowering Extremum}]) \quad (2)$$

(We could also have defined this using [Dorsum Retraction Extremum] in place of [Mid Lowering Extremum]: however, because the mid lowering movement involves a very clear and sharp extremum, we found that the time of the [Mid Lowering Extremum] was the easier of the two values to measure and seemed to yield more reliable results.) In columns 12-14 of Table III we give values for [Tip Delay], in

seconds, for canonical light and dark /l/s. The value of [Tip Delay] is greater for dark /l/s than for light /l/s, all *t*-scores being significant at at least the 0.05 level. Note that for light /l/s the value of [Tip Delay] is negative, meaning that [Tip Extremum] is reached before [Mid Lowering Extremum]. In contrast, for dark /l/s [Mid Lowering Extremum] is reached before [Tip Extremum].

3.2. The effects of boundary strength on pre-boundary /l/s

In the previous section we gave some properties that distinguish canonical light initial /l/s from canonical dark pre-boundary /l/s. In this section we show that the quality of pre-boundary /l/s varies continuously with the duration of the (pre-boundary) rime in which the post-vocalic /l/ finds itself. As we have already described, we elicited pre-boundary /l/s before a wide array of boundary types, including lexical boundaries (sentences 9–14) and various phrasal boundaries (sentences 1–8). As outlined in (1), we had an *a priori* notion of the relative linguistic strengths of the various boundaries. As we discussed in Section 1, we expected that the *a priori* ordering given in (1) would correlate reasonably well with the durations of the rimes in the syllables immediately preceding the boundary. It will be observed in the figures to be discussed in this section that this expectation was by and large met. However, more important for our purpose than the existence of this correlation is the fact that the selected range of boundary types allowed us to fairly effectively sample the space of pre-boundary rime durations ranging from the shortest (e.g., the “+” context) through the longest (e.g., the “|” context).

We have hypothesized a correlation between rime duration and the quality of the pre-boundary /l/. In Table IV we present data showing that F_2-F_1 , [Dorsum Retraction Extremum](x) or [Mid Lowering Extremum](y), and [Tip Delay] do indeed correlate with the duration of the rime containing the syllable-final pre-boundary /l/. In the table, R^2 values are given for the regression of each measure of /l/ quality against the pre-boundary rime duration: i.e., with the measure of /l/ quality being the dependent variable; F-scores for the correlations are all significant at at least the 0.05 level. Columns 3–4 of Table IV show that rime duration accounts for at least half of the variation in F_2-F_1 for all speakers except CC (and even here the correlation is significant at the 0.01 level). In columns 5–8,

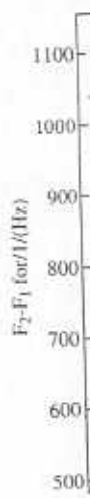
TABLE IV. Correlation of rime duration with F_2-F_1 , [Dorsum Retraction Extremum](x), [Mid Lowering Extremum](y), and [Tip Delay]. R^2 and associated F values are given for each correlation. The second column gives the degrees of freedom for the F computations. Abbreviations are as follows: DRE(x), [Dorsum Retraction Extremum](x); MLE(y), [Mid Lowering Extremum](y); TDel, [Tip Delay]

Speaker	Deg. of freedom	F_2-F_1		DRE(x)		MLE(y)		TDel	
		R^2	F	R^2	F	R^2	F	R^2	F
CS	1, 53	0.50	53.9	0.43	39.78	0.10	6.03	0.65	96.37
CC	1, 26	0.37	15.5	0.63	43.45	0.18	5.87	0.25	8.49
AD	1, 54	0.61	83.4	0.51	55.72	0.55	65.19	0.65	101.76
DB	1, 19	0.73	52.2	0.48	17.63	0.68	39.73	0.21	5.14
RS	1, 24	0.73	65.6	0.33	11.95	0.57	31.40	0.53	26.91

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we see that for all speakers, except CS, rime duration accounts for at least half of the variation in at least one of [Mid Lowering Extremum](y) or [Dorsum Retraction Extremum](x). Finally, columns 9-10 show that rime duration accounts for at least half of the variation in [Tip Delay] for pre-boundary /l/ for three out of the five speakers (CS, AD, RS), with a lower prediction for the other two (CC, DB).

In addition to hypothesizing a *correlation* between pre-boundary /l/ quality and pre-boundary rime duration, we also hypothesized that one would find a *continuum* of /l/ types ranging from dark to light if one samples a sufficient number of boundary conditions. In Figs 1-3 we plot data from representative speakers illustrating the correlation between the properties of /l/ and rime duration just discussed and demonstrating a continuum of /l/ qualities as assessed by the various phonetic measures that we have considered. While the correlation scores reported above pertain to the pre-boundary cases only, in the plots we also show the data for initial /l/s: we wish to include these cases in order to make the point that the lightest of the pre-boundary /l/s are usually as light or even lighter than initial /l/s by whatever criterion for lightness one chooses to pick. (In order to be able to plot these points on the same scale as the pre-boundary case, we will use the same definition of "rime duration" as before; however, it must be borne in mind that this definition does not really make sense for the initial cases since what is really being measured in those cases is the duration of the pre-boundary rime, which is just the vowel preceding the /l/, *plus* the duration of the heterosyllabic /l/.)

On the face of it, the observed continuum is not what would be expected on the assumption that /l/ has two distinct light and dark allophones: in particular, the data do not appear to show a bimodal distribution (each mode corresponding to one of the putative allophones), and thus it does not appear that the residue of the regressions previously discussed can be usefully explained by positing an additional

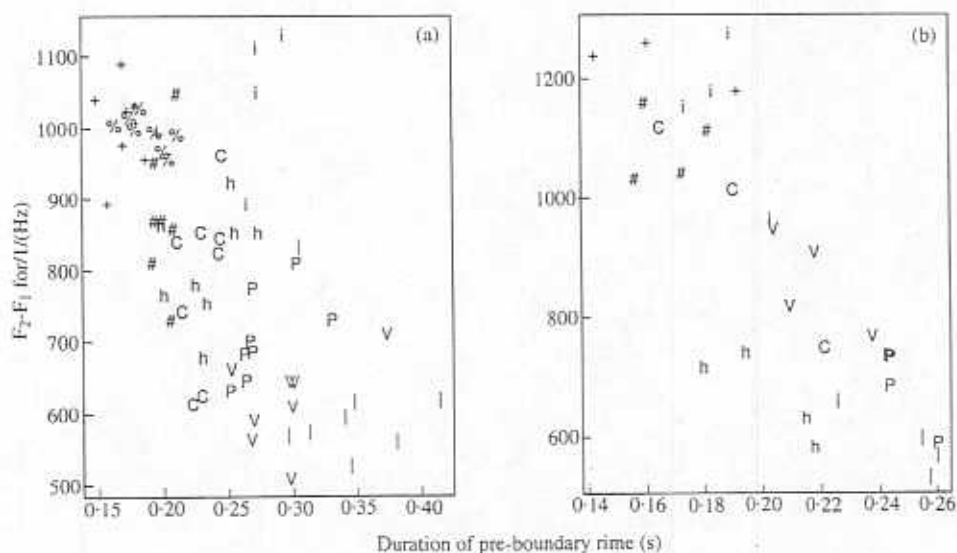


Figure 1. Plots showing the relation between F_2-F_1 (in Hz) and pre-boundary rime duration (in s) for (a) speaker CS and (b) speaker RS. See Table II for plotting characters.

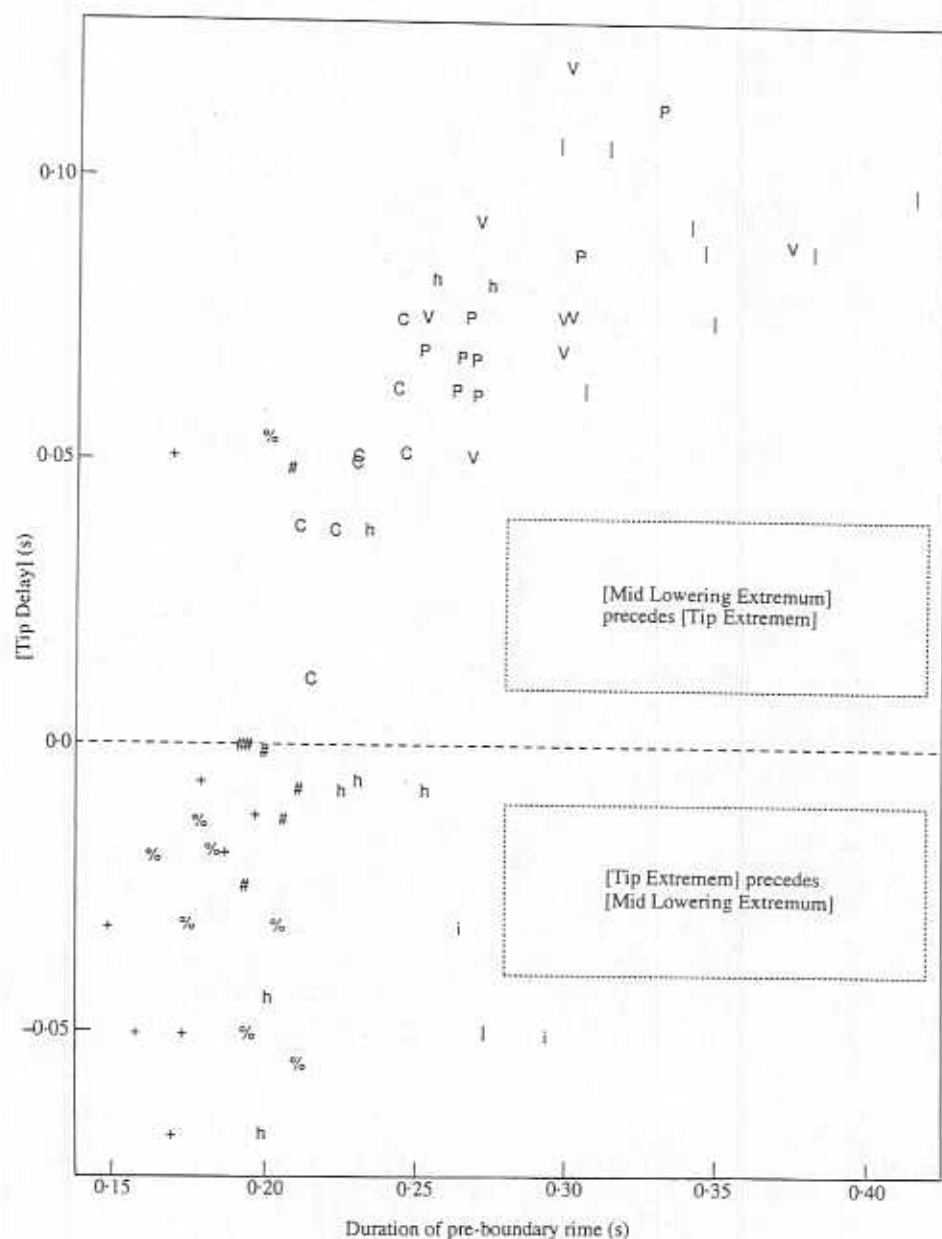


Figure 3. Plot showing the relation between [Tip Delay] (in s) and pre-boundary rime duration (in s) for speaker CS. As previously discussed, in the lightest /l/s [Tip Extremum] is reached before [Mid Lowering Extremum]; these /l/s appear towards the bottom of the plot. In contrast, darker /l/s have the opposite order of [Tip Extremum] and [Mid Lowering Extremum]; dark /l/s appear towards the top of the plot.

dorsum for dark /l/s. In light of our observations, we would like to propose that all /l/s involve both an apical extension and a dorsal retraction/lowering component: this is in line with proposals of Fujimura, Miller & Escobar (1977) and Fujimura & Lovins (1978), who discuss tongue body activity for /l/ in general. [Recently, Browman & Goldstein (1989) have also suggested that /l/ involves a tongue blade gesture, one which has "a [narrowed] value for C[onstriction] S[hape]" (p. 229).] More specifically, we would like to propose that all /l/s involve two *gestures*, one gesture corresponding to the apical extension, henceforth termed the *apical gesture*, and the other corresponding to the dorsal retraction and lowering, the *dorsal gesture*. We use the term *gesture* here roughly as it is used by Browman & Goldstein (1986; 1989; 1992), to mean a clearly identifiable motion towards an apparent target. We are not making any technical claims concerning the precise nature of speech gestures, and neither are we making any assumptions concerning techniques for decomposing articulator movements into gestures (see Boyce, Krakow, Bell-Berti & Gelfer, 1990; Fujimura, 1992).

We will make the standard assumption (see, for example, Chomsky & Halle, 1968) that English /l/ is phonologically represented as a [+coronal] consonant and that it is also specified as [+lateral]. The [+coronal] specification corresponds, of course, to the apical gesture. We will assume that the dorsal gesture is a consequence of the specification [+lateral]; see Browman & Goldstein (1989, pp. 228–229). Lateral sounds are produced by narrowing the tongue blade, causing channels to be opened along the sides of the blade around the point of main constriction. Of course, one cannot directly measure tongue narrowing using the X-ray microbeam, but since the tongue's volume is incompressible (see Fujimura & Kakita, 1979, and also Stone, 1990, for some discussion), the volume which is displaced by narrowing will show up in the form of lengthening of the tongue blade. This in turn means that there will be outward displacement of the anterior and posterior ends of the blade. The proposed dorsal gesture for /l/ is thus consistent with the implementation of [+lateral] as a narrowing of the tongue blade.

We turn now to the broad differences between light and dark /l/s as outlined in (3). In order to explain those properties we would like to make the assumption that gestures can be characterized as either intrinsically *consonantal* or intrinsically *vocalic*, where these terms are defined as in (4). [Coleman (1992b) makes the compatible proposal that phonological feature representations have vocalic and consonantal subcategories, and that /l/ is distinctively marked for both the consonantal and vocalic subcategories; see also Clements (in press), Gussenhoven & van de Weijer (1990) and Odden (1991) for further discussion and related proposals.]

- (4)a. Consonantal gestures are those that produce an extreme obstruction in the mid-sagittal plane.
- b. Vocalic gestures are those gestures that *do not* produce an extreme obstruction; furthermore vocalic gestures may actually involve the *opening* of a channel as in the case with velum lowering.

The apical gesture of /l/ is a consonantal gesture. On the other hand, the dorsal retraction gesture is a vocalic gesture since it does not produce a radical constriction in the vocal tract. This latter point is related to the common assertion that dark /l/s may be viewed as basically vocalic. Giles & Moll (1975, p. 223) assert that the

"post-vocalic" more significant /l/s, it may be in mind that it is a graded articulation gesture.

(5)a.

b.

These are the consonantal and vocalic gestures (5a), it is a weakly English gesture than it is in context, it weakens the well-exposed [and so] consonantal lowering of the vocalic proper difference in production than it illustrates nasals syllables.

Given the outline of the vocalic observation, previous studies for syllables we discuss because of the differences in the syllables of other

"post-vocalic /l/ may be considered to be vocalic in nature"; since dark /l/s have a more significant dorsal retraction gesture and a less extreme apical gesture than light /l/s, it makes sense that they should be considered more vocalic. It should be borne in mind that observed gestures (as opposed to phonological features) are inherently graded and non-categorical in nature and that therefore it is sensible to talk about a gesture being more or less vocalic. We will further assume the following:

- (5)a. Consonantal gestures tend to be stronger—i.e., have greater displacements—in syllable-initial position and weaker in syllable-final position.
- b. Vocalic gestures tend to be weaker—i.e., have lesser displacements—in syllable-initial position and stronger in syllable-final position.

These ideas are related to the fact that the universally basic syllable type is CV: consonantal gestures are more typically manifested at the beginnings of syllables and vocalic gestures at the end. The claims can be readily documented. With respect to (5a), it is commonly observed that syllable-final instances of a consonant are more weakly articulated than syllable-initial instances. For example, in many dialects of English, the apical articulation of /t/ is better instantiated in syllable-initial position than it is in syllable-final position; in the latter case /t/ even reduces to [ʔ] in some contexts in some dialects, which can be thought of as the most extreme articulatory weakening of the apical consonantal gesture for /t/. Furthermore, both claims are well-exemplified by the behavior of nasals; here we are indebted to Krakow (1989) [and see also Fujimura (1977; 1990) and Browman & Goldstein (1992)]. Nasal consonants involve a consonantal closure gesture and another gesture—velum lowering—which, since it does not involve a radical constriction of the vocal tract, is vocalic on the above definition. These consonants show a number of interesting properties in many languages. First of all, and consistent with (5b), in many different languages including English, French and Japanese, final nasals are produced with significantly lower (i.e., more extreme) target position of the velum than initial nasals are. Secondly, and consistent with (5a) as Krakow (1989) has illustrated with the study of /m/ articulation in English, the consonantal gesture for nasals (in this case the lip closure gesture) has a significantly greater displacement in syllable-initial position than in syllable-final position.

Given that the assumptions in (5) are justified, the explanation of the observation outlined in (3a) is straightforward. *Ceteris paribus*, syllable-final /l/s should have a (vocalic) dorsal gesture with a greater displacement than do syllable-initial /l/s, as observed. Furthermore syllable-initial /l/s should have a (consonantal) apical gesture with a larger displacement than syllable final /l/s. As we have noted previously, it has been observed (e.g., by Giles & Moll, 1975) that the apical gesture for syllable-final /l/s does have a smaller displacement for many speakers, though we did not directly measure this effect in our speakers. These points are important because they imply that a major portion of the difference between syllable-initial and syllable-final /l/s can be derived from much more generally observable differences between syllable-initial and syllable-final consonantal and vocalic gestures. Put in a slightly different way, positing two distinct allophones for English /l/ has the effect of obscuring the broader generalizations that are true not just of syllable-initial and syllable-final /l/, but syllable-initial and syllable-final consonants of other types too; see also Browman & Goldstein (1992).

We now need to explain the differences between light and dark /l/s with respect to [Tip Delay], outlined in (3b). In order to account for this trend, we will propose the following principle of "gestural affinity":

- (6)a. Consonantal gestures are attracted to syllable margins.
- b. Vocalic gestures are attracted to syllable nuclei.

This proposal receives some independent support from the behavior of nasals. Velum lowering for syllable-final nasals extends earlier into the preceding context than is the case for syllable-initial nasals. [As Krakow notes (1989, p. 179), the velum lowering timing facts account for the historical tendency for syllable-final nasals—but not syllable-initial nasals—to induce nasal assimilation on preceding vowels.] This is consistent with the claims in (6) in that the vocalic gesture of syllable-final nasals is clearly attracted (leftwards) to the nucleus of the syllable. (The vocalic gesture of initial nasals is, however, not attracted towards the nucleus, but is roughly coincidental with the consonantal gesture.)

The assumptions in (6) directly predict (3b). In syllable-final /l/s, the (vocalic) dorsal gesture is attracted to the nucleus of the syllable, whereas the (consonantal) apical gesture is attracted to the (right) margin of the syllable; [Tip Delay] will thus be expected to have a positive value. In syllable-initial cases, the reverse prediction is made, with the result that [Tip Delay] will have a negative value. We note that while the broad differences in timing between light and dark /l/s receive a rather natural phonetic account given the assumptions in (6), they constitute counter-evidence to any proposal that light and dark /l/ be represented as phonologically distinct allophones: recall that in Halle & Mohanan's (1985) treatment, for instance, light and dark /l/ were represented as phonologically distinct. It is generally assumed that the relative timing of multiple gestures (or targets) is specified by (possibly language specific) phonetic implementation rules, and is not specified at any level of *phonological* representation; see Sagey (1986; 1988), Browman & Goldstein (1986), Bird & Klein (1990), Silverman & Pierrehumbert (1990), *inter alia*. Hence the existence of a robust gestural timing difference between light and dark /l/ suggests that the variation in /l/ should be regarded as phonetic, not phonological.

We have thus, with the proposal of some assumptions that can largely be independently justified, provided an account of why syllable-initial and syllable-final /l/s have the properties that we and others have observed. Finally, we need to explain the correlation, summarized in (3c), between the quality of pre-boundary /l/ and the duration of the pre-boundary rime. As we saw in the previous section, both the value of [Tip Delay], and the extent of the dorsal retraction and lowering gesture, correlate with the duration of the pre-boundary rime. Let us first consider [Tip Delay]; the reader may find Fig. 4 useful in the ensuing discussion. In the longest pre-boundary rimes there is a large time interval between the nucleus, to which the vocalic dorsal retraction/lowering gesture is attracted, and the final margin, to which the consonantal apical gesture is attracted. In shorter rimes the vocalic gesture conflicts with the dorsal gesture of the vowel of the nucleus: that is, in the front vowel context at least, the dorsum of the tongue must move back from its position for the /i/ to reach the position for the /l/, and this motion is accompanied by a considerable delay due in part to the relatively large mass of the tongue body. As the rime duration decreases, the dorsal retraction gesture for the

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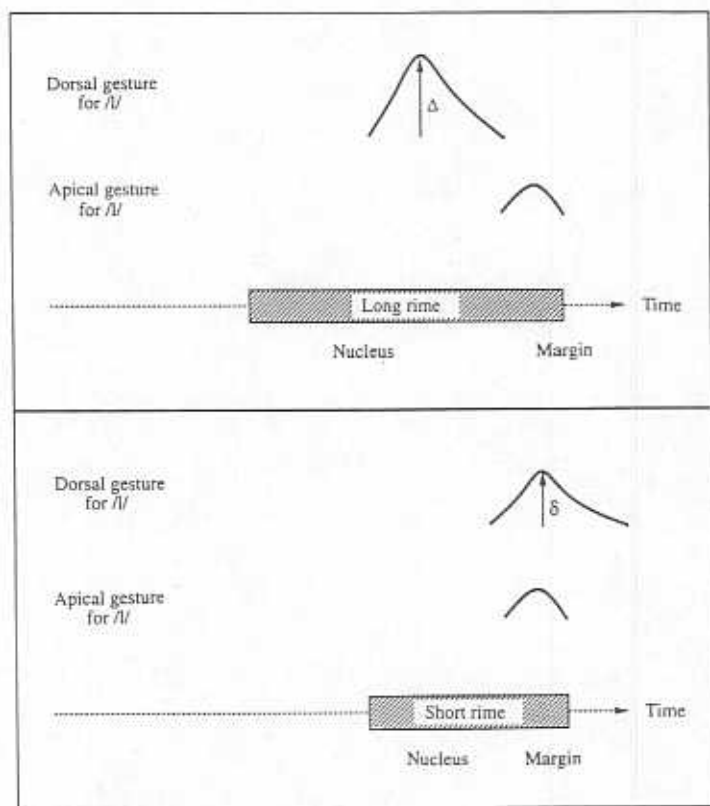


Figure 4. A schematic illustration of the effects of rime duration on pre-boundary post-nuclear /l/. In the top panel is shown the situation with a long rime. The dorsal gesture (top) is attracted to the nucleus and therefore reaches its extremum earlier than the apical gesture (bottom), which is attracted to the margin of the syllable. The dorsal gesture has a relatively large displacement, Δ . In the bottom panel is shown what happens in a short rime. The dorsal gesture is still attracted to the nucleus, but because of the relatively short duration of the rime and because the tongue body is relatively massive, it occurs much closer to the (right) margin of the syllable and may even reach its extremum later than the apical gesture. The displacement $\delta < \Delta$ is also smaller since there is not enough time for the dorsal gesture to reach the full target.

/l/ will be temporally closer to the apical gesture. With the shortest pre-boundary rimes, the dorsal retraction gesture will end up roughly coincidental with or will even occur after the apical gesture, thus mimicking the behavior found in syllable-initial /l/s. We thus expect to find the observed correlation between the duration of the rime and [Tip Delay].

At the same time, the extent of the dorsal retraction and lowering gesture exhibits coarticulatory undershoot. In the longest rimes, namely those preceding the strongest boundaries, the tongue dorsum is able to reach the full extent of the retraction gesture, starting from the position for a front vowel. As the boundary becomes weaker and the pre-boundary rime concomitantly shorter, the time allotted for the gestures associated with the /l/ will become shorter, and the dorsal retraction gesture will be less able to attain the full target. We therefore expect the observed

weaker retraction in /l/s preceding weaker boundaries. Thus, we claim that the assumptions in (6), coupled with a fairly simple model of coarticulatory undershoot, explain a major component of the observed facts in (3c). Although undershoot does not account for all of the variation, it is nonetheless interesting that a fairly simple principle can explain a fair amount of the data.

For those readers interested in the phonological implications of these results, we note that they suggest rather strongly that the phonetic quality of /l/ preceding lexical boundaries does not necessarily constitute evidence for resyllabification across such boundaries: for example, Halle & Mohanan (1985) assumed, because intervocalic /l/ appears light before "+", "#", or "C" boundaries, that therefore there must be a resyllabification rule that reassociates an /l/ preceding one of these boundaries to the following syllable. Our results suggest that such a rule is unnecessary. Indeed, the resyllabification rule that Halle & Mohanan proposed had an embarrassing property: while /l/s do indeed become lighter when preceding lexical boundaries, stops such as /k/ are not aspirated in such contexts (/kicking/ is not pronounced *[k^hik^hɪŋ]), which is what one would expect if /k/ resyllabified. This meant that the rule had to be stated so as to specifically apply to /l/. Note that we derive all desired results if we assume that *no* consonants resyllabify before lexical boundaries—at least not in trochaic constructions: /l/s will be light (for durational reasons, as we have seen) and stops will be weak in articulation—and as a corollary unaspirated—as predicted by (5a).

We believe that we have produced sufficient evidence to call into question the traditional assumption that light and dark /l/s in English are two different elements, whether one considers them different from a phonological point of view (as do, e.g., Halle & Mohanan, 1985) or from a physiological point of view (as do Giles & Moll, 1975). Rather the differences between light and dark /l/s reported here and elsewhere—the degree of retraction and lowering of the tongue dorsum, the relative timing of the dorsal and apical gestures, and the extent of constriction achieved by the apical gesture—can all be understood as deriving from more general independently justifiable properties of syllable-initial *vs.* syllable-final elements. Properties of the syllable-initial and syllable-final versions of /l/ are phonetically predictable and there should therefore be no need to list distinct allophones to encode these properties. This is really a special case of the proposal by Coleman (1992a, p. 47), where it is suggested that "allophony can be regarded as the different interpretation of the same [phonological] element in different structural contexts, rather than as involving several slightly different phonological objects instantiating each phoneme".

Further evidence for this conclusion comes from the fact that in pre-boundary /l/s, we find a range of /l/ qualities depending mainly upon the duration of the pre-boundary rime containing the /l/. Indeed, we believe that one of the reasons that the division of /l/ into at least two distinct allophones has appeared so convincing in the past is that there have been no studies which have taken the effect of duration into consideration. Giles & Moll consider three speech rates, but give no exact measures of duration. [They do note a coarticulation effect of rate, reporting that "as the rate of utterance was increased, the position of the tongue dorsum for pre-vocalic /l/ was shifted toward the position appropriate for the vowel following /l/" (pp. 211–212).]

Given these considerations, we suggest that the burden of proof is on those who would claim that English /l/ allophones are distinct to justify the necessity of that

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assumption. We do of course realize that we are making our claims on the basis of data from only four American and one British speaker, for /l/s in the /i-ɪ/, trochaic context. This might be seen as a limitation on the generality of those claims. We would counter that the light-dark distinction evident in pairs of examples like *Mr B. Likkovsky's from Madison* and *Beel, equate the actors* is as clear an example of the supposed distinction as one can find and that any theory would at least have to account for our observations in the contexts that we have considered.

It is clear from our small study that the range of issues that need to be addressed in any evaluation of allophonic variation is highly complex. We expect that other examples of such variation will show similar complexity, and it is certain that complete studies of such variation must take many factors into account, not only to the extent that we have tried to do here for the subset of /l/ variation which we have considered, but also considering such features as stress and style, which we did not directly study. But, we feel, it should no longer be taken for granted that two allophones, even ones as apparently different as the [ʔ] and [tʰ] of /t/, represent two distinct categories: we expect that variation in such cases will also prove to be graded, once enough contexts are considered and sufficient articulatory data are examined.

5. Remarks on some related issues

We end here by discussing a few other issues which this research raises. First of all, our findings concerning the articulatory properties of dark /l/ call into question the aptness of the term "velarization" in describing the darkening of /l/; see, e.g., Ladefoged (1982, p. 211). A velarized sound ought to show significant *raising* of the tongue dorsum towards the velum. In contrast, while dark /l/s clearly show more retraction of the dorsum compared with light /l/s, we find no evidence of raising towards the velum. The tongue surface represented by the mid-tongue pellet exhibits the opposite tendency, namely tongue surface lowering, in the front vowel context. (The characterization that dorsum retraction but not dorsum raising is involved in /l/ is also valid for the back vowel context /o-ə/, for which we collected some articulatory data for some speakers. We hope to report more fully on these other contexts elsewhere.)

Secondly, a very important question remains: why does English have the observed variation in /l/? It is usually assumed the light/dark variation is not universal; German, for example, is said to lack it, as are some dialects of English, as we noted in the Introduction (cf. Wells, 1982). However, where it does occur, as in Dutch or Portuguese, the variation seems always to be in the same direction, syllable-initial /l/s being light and syllable-final /l/s being dark. This latter observation is a happy one, insofar as the phonetic account of English /l/ variation ought in principle to predict similar variation in other languages; while phonetic principles may not have the status of universals, they ought at least to reflect robust tendencies, or else to represent one of a number of choices in a palette of alternative strategies. The question, then, is where a language like German fits in. There would seem to be two possibilities, neither of which can be confirmed without further investigation. The first is that German /l/s involve a dorsal retraction gesture as in English, but that for some reason the articulatory differences between light and dark /l/s, which one might thus expect in German, are simply not as extreme as in English. The second is that German /l/s, although they are [+lateral], do not involve retraction of the

tongue dorsum. Leidner (1973) showed that there is a peak activity for the styloglossus muscle for /l/ in English; this was also confirmed by our own EMG studies, which we hope to report on elsewhere. Perhaps the dorsal retraction in German laterals is not enhanced by extrinsic lingual muscles as it seems to be in English. Then, if we make the further assumption that it is the involvement of the extrinsic muscles, in particular, which makes the dorsal retraction in English /l/ vocalic, we could explain the difference between the two languages: since German /l/s would lack a vocalic dorsal component there would be no reason to expect the same variation as one finds in English. In any event, while we are as yet unsure how our findings for English will pan out in other languages, we feel that we have provided a reasonable account of English /l/ allophony that does not make use of the assumption that allophones must be treated as phonologically distinct entities.

We wish to thank Bob Nadler for help in conducting data acquisition at the University of Wisconsin, Madison, and both Nadler and Chuck O'Hare for help in setting up the Microbeam analysis software at Bell Labs and OSU. We also thank Yasu Momiyama for performing the EMG insertions on speaker RS, and Kiyoshi Honda for performing the insertions on speakers CC and DB. Kiyoshi Honda also gave us useful discussion on EMG issues. Additional assistance was obtained from John Westbury in establishing the pellet position co-ordinate system both in data acquisition and analysis. For useful discussion of various previous versions of this paper we wish to thank Mary Beckman, Juliette Blevins, John Coleman, Peter Ladefoged, Janet Pierrehumbert, Chilin Shih, audiences at Cornell University, the University of Texas at Austin and the LSA December 1989 Annual Meeting, participants in a Fujimura's seminar at OSU, in particular Ilse Lehiste, and several anonymous commentators.

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