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North American /l/ both darkens and lightens depending on morphological constituency and segmental context

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It is uncontroversial that, in many varieties of English, the realization of /l/ varies depending on whether /l/ occurs word-initially or word-finally. The nature of this effect, however, remains controversial. Previous analyses alternately analyzed the variation as darkening or lightening, and alternately found evidence that the variation involves a categorical distinction between allophones or a gradient scale conditioned by phonetic factors. We argue that these diverging conclusions are a result of the numerous factors influencing /l/ darkness and differences between studies in terms of which factors are considered. By controlling for a range of factors, our study demonstrates a pattern of variability that has not been shown in previous work. We find evidence of morpheme-final darkening and morpheme-initial lightening when compared to a baseline of morpheme-internal /l/. We also find segmental effects such that, in segmental contexts which independently darken /l/, one can observe /l/ lightening, and contexts which independently lighten /l/ can make lightening effects undetectable. Morphological and prosodic effects are hence sometimes trumped by segmental context. Once contextual effects are controlled for, there is evidence both for morphologically-conditioned /l/-darkening and for morphologically-conditioned /l/-lightening, both of which can be understood as a result of prosodic differences reflecting morphological junctures.

Keywords: /l/-darkening; allophonic variation; morphological constituency; prosodic boundaries; vowel reduction

1. Introduction

The realization of /l/ in North American English is subject to substantial variation. This is often characterized as allophonic variation between velarized, or dark, [ɫ] and light [l]. Distribution of these allophones is generally described as dependent on syllable structure with light [l] occurring in onsets and dark [ɫ] occurring in rhymes. While it is uncontroversial that the pronunciation of /l/ in English alternates between dark and light realizations, there is substantial disagreement on how to analyze this alternation. Some authors assume syllable-final darkening (Halle & Mohanan, 1985), while others assume initial lightening (Recasens, 2012); some authors assume that there is a categorical distinction between contextually determined allophones (Halle & Mohanan, 1985; Hayes, 2000), while others argue that there is a gradient phonetic scale between dark and light /l/ (e.g., Sproat & Fujimura, 1993; Lee-Kim, Davidson, & Hwang, 2013).

In general, works on English /l/ compare /l/s across different contexts and identify differences in darkness based on acoustic, articulatory, or impressionistic criteria. In some cases, the contexts that are compared include initial and final position relative to some domain such as the word, morpheme, or syllable. In theory, when initial and final contexts are compared, any difference between them may be attributed to either darkening or lightening, depending on which context is interpreted as the baseline. If initial /l/ is lighter than final /l/, interpreting initial /l/ as the baseline leads to an analysis in which final /l/ is subject to a darkening process, perhaps attributed to patterns of gestural alignment (e.g., Sproat & Fujimura, 1993). If final /l/ is interpreted as the baseline, this provides a possible analysis in which initial /l/ is subject to a lightening process, perhaps arising from initial strengthening. In practice, the latter possibility is rarely considered. Most literature on variation in English /l/ either explicitly argues for /l/-darkening or focuses on other aspects of the variation.

One goal of the present study is to determine whether evidence similar to that used in accounts of /l/-darkening can be adduced in support of an /l/-lightening effect in initial position of a word or morpheme relative to /l/s that occur internal to morphological constituents. In spite of the wealth of literature on factors influencing /l/-darkness, this specific question has rarely been addressed.[1] Studies which focus on other issues, unsurprisingly, do not provide data which can clarify this question. Consider, for example, the stimuli from a recent production study (Lee-Kim et al., 2013), aimed at testing for effects of morphological structure:

(1) a. …the cool headphones…
b. …the coolest headphones…
c. …the coupless revolution…

By holding the segmental context constant and varying the location of the morpheme boundary relative to /l/, Lee-Kim et al. are able to find compelling evidence for the presence of morphological effects. They find a three-way distinction with word final /l/, as in (1a), being darker than word-internal, morpheme-final /l/, as in (1b), which is in turn darker than word-internal, morpheme-initial /l/, (1c).

With respect to the question of /l/-lightening, note that this set of comparisons does not include realization of /l/ in segmentally similar morpheme-internal environments where the /l/ is not adjacent to a morpheme boundary on *either* side (e.g., *tulip*). Although Lee-Kim et al. (2013) are able to identify different degrees of darkness in different positions, the lack of a morpheme-internal condition means that we cannot determine whether the effect we see in these examples is due to morpheme-final darkening (potentially applying in *coolest*) or to morpheme-initial lightening (potentially applying in *coupless*), or a combination of the two.

Questions of whether variation in the realization of /l/ may be due to lightening or darkening are also difficult to address with data in Lee-Kim et al. (2013) because realization of /l/ was only investigated in words in which a reduced vowel follows. Prior research has shown that the quality of the surrounding vowels, especially the following vowel, affects the degree of darkness of /l/ (Jones, 1956, p. 90; Lehiste, 1964, p. 10). One of our findings is that vowel reduction has a strong effect, and renders /l/ much darker,

[1] Recasens (2012) is an exception. Recasens (2012) argues that American English has a process of initial lightening based on crosslinguistic comparison of /l/ darkness measures in word-initial, word-final, and intervocalic position. Analysis of North American English, however, is not the focus of Recasens' study which is concerned with crosslinguistic variation in /l/-darkness in different vocalic contexts. The American English data included is taken from earlier work by Lehiste (1964). Further discussion of Recasens (2012) is provided in Section 8.

to the point of obscuring the full pattern of alternation since this makes morphological and prosodic darkening effects hard to detect. Other studies tried to avoid the issue of the effects of surrounding vowels by only using front vowels (e.g., Sproat & Fujimura, 1993), but we find that this leads to the converse problem that the effect of lightening becomes difficult to detect.

Limitations of previous studies with respect to the question of /l/-lightening and darkening follow from two sources. First, a number of factors which affect the realization of /l/ are not independent. In addition to syllable structure, previous literature has identified morphological constituency (e.g., Lee-Kim et al., 2013; Strycharczuk & Scobbie, 2017), duration (e.g., Sproat & Fujimura, 1993), stress (e.g., Jensen, 2000), and segmental context (e.g., Giles & Moll, 1975) as playing a role in /l/ darkness. But these factors are confounded in various ways. For example, not all vowels occur in unstressed syllables and most English affixes are unstressed. This means stress, vowel context, and morphological affiliation are not independent and teasing apart potential confounds with a full range of factors is not possible. Second, many previous studies have assumed that /l/-darkening is the appropriate phonological analysis of variation in English /l/ and have been designed in order to provide environments in which /l/-darkening can be detected. Thus, Sproat and Fujimura (1993) consider intervocalic /l/s only in the context of adjacent front vowels because this is the environment in which /l/-darkening is most apparent. That the direction of the effect (darkening or lightening) was not considered an open question may also have been the reason why morphological effects were often studied without a monomorphemic control condition.

The present study reports on a series of production experiments which elicit /l/ in a variety of morpho-syntactic, prosodic, and segmental environments. We include cases of /l/ in initial and final position of words and morphemes as well as /l/s in morpheme-internal contexts. Morpheme-internal /l/ is interpreted as a baseline. Differences between initial and internal /l/ are interpreted as lightening whereas differences between internal and final /l/ are interpreted as darkening. Our results show that in order to see the full pattern of variation of /l/-realization, we have to take into account multiple sources of both lightening and darkening, which may make the effect of other factors affecting /l/ realization indiscernible. The experiments reported on here show that once contextual factors are taken into account, there is evidence for both /l/-darkening *and* /l/-lightening. Some results reported below replicate previous findings. The finding that word-final /l/ is darker than word-initial /l/ is well-established in the literature as is the darkening effect of a following morpheme boundary (e.g., Sproat & Fujimura, 1993; Hayes, 2000). The full pattern of variability described below, however, has not been reported elsewhere. Specifically, we show that a preceding morpheme boundary has a lightening effect on /l/ in some segmental contexts whereas in other contexts morpheme-final darkening is the primary effect of morphological constituency.

2. Previous research

There is a rich descriptive literature on /l/-allophony, both in English (Wells, 1982; Olive, Greenwood, & Coleman, 1993; Hughes, Trudgill, & Watt, 2005) and crosslinguistically (see summary in Mielke, Baker, & Archangeli, 2016). Work on /l/ also includes a significant number of acoustic and imaging studies on the realization of /l/ in English (e.g., Lehiste, 1964; Sproat & Fujimura, 1993; Gick, 2003; Scobbie & Pouplier, 2010; Proctor & Walker, 2012) and various languages (e.g., Recasens & Espinosa, 2005; Recasens, 2012). In English, the distribution and realization of allophones of /l/ varies significantly across dialects and this dialectal variation has also been subject to extensive instrumental investigations (e.g., Scobbie & Wrench, 2003; Carter & Local, 2007; Turton,

2014, 2017; De Decker & Mackenzie, 2017). Allophones identified as dark and light differ in acoustic and articulatory properties. Dark [ɫ] is characterized acoustically by a lower F2 and higher F1 relative to light [l]. In terms of articulation, /l/ is gesturally complex, involving both a tongue tip gesture and a tongue dorsum gesture. Dark [ɫ] has greater tongue root retraction and tongue body lowering than light [l]. The allophones also differ in gestural timing. In light [l], the tongue tip gesture is simultaneous with, or earlier than, the tongue dorsum gesture whereas the tongue dorsum gesture precedes the tongue tip gesture in production of dark [ɫ] (e.g., Sproat & Fujimura, 1993; Browman & Goldstein, 1995). Major factors argued to influence /l/-darkness are summarized below.

2.1 The role of the syllable

In language varieties with variable realization of /l/, syllabic position is often reported to play a crucial role, with light /l/s occurring in onsets and dark /l/s occurring in rhymes (e.g., Halle & Mohanan, 1985; Olive et al., 1993). It is by no means established that syllabification is indeed the crucial factor conditioning /l/ darkness, since in many of the examples used to establish this correlation, syllabification correlates with word or morpheme boundaries. Furthermore, some studies have presented evidence against any categorical alternation at all, once gestural timing is taken into account (e.g., Sproat & Fujimura, 1993; Lee-Kim et al., 2013), and have argued instead in favor of a gradient analysis of /l/ realization, according to which darkness correlates with other factors such as duration and morpheme structure. We will consider these alternative factors influencing /l/-darkness in turn.

2.2 The role of word and morpheme boundaries

One such factor, and a focus of the present study, is the location of /l/ relative to morpho-syntactic boundaries. Early work by Lehiste (1964) compared formant values of word-final and word-initial /l/, as well as word-internal /l/ preceding a morpheme boundary (e.g., *meal-y*) and following a morpheme boundary (e.g., *free-ly*). Lehiste identified the /l/ in *free-ly* as an 'initial-like allophone' and the /l/ in *meal-y* as a 'final-like' allophone (1964, p. 47). The role of morpho-syntactic boundaries on /l/-darkness was examined in subsequent work in an influential study by Sproat and Fujimura (1993). This work examines both acoustic and articulatory data from /l/ productions occurring word-finally, word-initially, and word-internally preceding a variety of linguistic boundaries. They argue that light and dark /l/ are not categorically distinct entities, but rather, that /l/ darkness is realized on a continuum. In addition to the expected finding that word-initial /l/s are light and word-final /l/s are dark, Sproat and Fujimura (1993) report intermediate degrees of darkness when intervocalic /l/ precedes a linguistic boundary, such as a compound or affix boundary. They argue against a phonological rule of /l/-darkening in English (e.g., Halle & Mohanan, 1985) and instead claim that differences in darkness between /l/s in various positions follow from differences in gestural timing between onsets and codas that apply to all segments. Additional variation in darkness is attributed to variation in rhyme duration with /l/-darkness correlating with rhyme length.

Although Sproat and Fujimura (1993) consider the effect of a number of different boundaries following /l/, their study did not include certain environments, such as the word-internal morpheme-initial context (e.g., *free-ly*) included in Lehiste (1964). The morpheme-initial environment is included in Hayes' (2000) study of acceptability judgments of dark and light /l/ in a variety of contexts. On the basis of acceptability judgments, Hayes proposes the following hierarchy from lightest to darkest.

The acceptability judgments in Hayes (2000) show a gradient cline depending on the nature of a following boundary, and are thus consistent with Sproat and Fujimura's (1993) claim that there is a phonetic continuum of /l/-darkness. Hayes, however, argues for an

Table 1: Hierarchy of /l/ darkness based on acceptability judgments in Hayes (2000).

Lightest ←					→ **Darkest**
word-initial (*light*)	intervocalic and morpheme-initial (*free-ly*)	intervocalic in monomorphemic forms (*Dayley*)	intervocalic and morpheme final (*mail-er*)	word-final before a clitic (*mail it*)	word-final (*mail*)

alternative analysis in which categorically distinct dark and light /l/ are produced at different rates in different positions, with these variable rates affecting listeners' judgments of the acceptability of dark versus light /l/ in any given position.

Like Hayes (2000), Lee-Kim et al. (2013) include a post-morpheme boundary context in their study of morphological effects on /l/-darkness. Their study presents acoustic and ultrasound data on /l/ productions in three environments; word-finally in isolation (e.g., *cool*), word-internally preceding a morpheme boundary (e.g., *cool-est*), and word-internally following a morpheme boundary (e.g., *coup-less*). On the basis of these data, Lee-Kim et al., like Sproat and Fujimura, argue for a continuum of /l/ darkness. Specifically, they found the articulatory and acoustic properties of /l/ in the pre-boundary condition to be intermediate between the word-final and post-boundary conditions.

More evidence for gradient morphological effects comes from work on a different dialect. Recent work on Southern British English by Strycharczuk and Scobbie (2016, 2017) finds articulatory differences in the realization of /l/ in monomorphemes (e.g., *hula*) and preceding affix boundaries (e.g., *fool-ing*). In addition to /l/-darkening, Southern British English has a process of u-fronting which is blocked when a following /l/ is syllabified in the coda (e.g., *fool*). Strycharczuk and Scobbie (2016, 2017) compare morpheme-internal (*hula*) and morpheme-final (*fool-ing*) conditions for both the vowel and the /l/. The vowel is relatively front and the /l/ relatively light in monomorphemes like *hula* compared to forms like *fooling* in which the /ul/ sequence precedes a morpheme boundary. There was substantial variation in the magnitude of the distinction between speakers, leading them to conclude that the morphological boundary conditions gradient phonetic differences rather than alternations of categorically distinct allophones, at least for some speakers (Strycharczuk & Scobbie, 2016, p. 90).

Turton's (2014, 2017) crossdialectal study looks at articulatory and acoustic data from /l/s in a number of morphosyntactic environments. Data from ultrasound imaging in Experiment 1 of Turton (2014) provides evidence for an effect of morphological boundaries on /l/-darkness for speakers of Essex and American English. These speakers show a distinction between /l/s in *helix* and *heal-ing* which Turton interprets as evidence of /l/-darkening at the stem-level. This is in contrast to the RP, Manchester, and Middlesbrough speakers included in the study who show no evidence of morphological effects but display varying degrees of coda and phrase-final darkening. Although this experiment did not include the word-internal, morpheme-initial environment (e.g., *free-ly*) this context was included in Experiment 2 of Turton (2014), also reported in Turton (2017). This experiment was designed primarily to determine whether variation in /l/-darkness shows evidence of a gradient or categorical distribution across a range of contexts and does not focus on minimal comparison of environments which differ in the position of /l/ relative to morphological boundaries.[2]

[2] Because establishing morphosyntactic effects was not the focus of Turton's (2014) Experiment 2, the morpheme-initial contexts included all differ from morpheme-internal ones along some other dimension, precluding the possibility of attributing differences in darkness to a preceding morpheme boundary. The morpheme-initial stimuli (e.g., *free-ly*) differ from morpheme-internal stimuli either in the quality of the following vowel (e.g., *helix*) or in location of stress (e.g., *believe*).

2.3 The role of duration

As discussed above, Sproat and Fujimura (1993) argue that duration is an additional factor which accounts for a substantial amount of variation in /l/ darkness with darker /l/s occurring in longer rhymes. In their analysis, shorter /l/s result in articulatory undershoot of the backing and lowering gestures present in the realization of dark /l/. In their data, intervocalic, pre-boundary /l/s in rhymes of short duration can be as light as word-initial /l/s (1993, p. 301). Other studies provide more ambiguous results. Focusing on tongue backing and F2 as correlates of /l/-darkness, Huffman's data shows that "while longer /l/'s are not always backer, backer /l/'s are usually longer" (1997, p. 135). Yuan and Liberman's (2011a) study of /l/-darkness in the Supreme Court corpus used forced alignment to assign a darkness score to /l/s in a variety of positions. Their data show a correlation between length and darkness for those /l/s classified as dark but not for those classified as light. These findings are not consistent with Sproat and Fujimura's claim that pre-boundary /l/s in very short rhymes can be as light as canonical light /l/s. Turton (2014) finds a weak correlation between darkness and duration overall but with significant variation between speakers of different dialects. For some speakers, Turton (2014) found a correlation only for /l/s categorized as dark, consistent with Yuan and Liberman's findings. For others, Turton (2014) found a correlation across all /l/s with no difference between a light and dark category. Still others showed no significant correlation between darkness and duration.

2.4 The role of context

In addition to effects of duration and linguistic boundaries, coarticulatory effects of adjacent vowels also influence degree of /l/-darkness. Front vowels have a lightening effect on /l/ whereas back vowels have a darkening effect (e.g., Jones, 1956; Lehiste, 1964; Giles & Moll, 1975). Following vowels have been identified as having a greater effect on darkness than preceding ones (e.g., Jones 1956, p. 90; Lehiste, 1964, p. 10). This claim, however, may be subject to reevaluation in light of subsequent work arguing that dark /l/ is less subject to coarticulatory effects than light /l/ (e.g., Bladon & Al – Bamerni, 1976; Recasens, Fontdevila, & Pallarès, 1996). The greater coarticulatory effect of following vowels may be due to the lightness of prevocalic /l/ in the language varieties being described as opposed to the relative darkness, and greater articulatory resistance, of post-vocalic /l/. This interpretation is consistent with findings from Proctor and Walker's (2012) real-time MRI study of English liquids. They found lower, more retracted tongue dorsum postures for coda /l/s than for onset /l/s when vowel context is held constant. When comparing articulations across different contexts, Proctor and Walker (2012) found more variability in tongue dorsum retraction due to coarticulatory effects of adjacent vowels in onset /l/s than in coda /l/s.

2.5 The role of stress

Another important contextual factor is word stress. The studies cited above primarily look at word-initial /l/, word-final /l/, or intervocalic /l/ in trochaic forms. Huffman (1997) provides acoustic analysis of word-medial /l/s in iambic forms. Intervocalic onset /l/s in iambs (e.g., *below*) are compared with /l/s in word-initial onset clusters (e.g., *blow*). The intervocalic /l/s following schwa have lower F2, indicative of greater tongue-root retraction and darker /l/, than the /l/s in comparable onset clusters. This suggests that /l/s are darker in the intervocalic, iambic context relative to post-consonantal /l/s in onset clusters. Huffman interprets this as evidence of gestural separation between the /l/ and a following stressed vowel in forms like '*below*' and hence, a shift of the tongue dorsum

gesture leftwards, towards the preceding schwa. Oxley, Roussel, and Buckingham (2007) compare formant values of /l/s in trochaic and iambic contexts and found acoustically darker /l/s in trochaic coda contexts (e.g., *peel a peach)* than in iambic onset contexts (e.g., *a leaf*).

Iambic and trochaic forms are included in Yuan and Liberman's (2011a) corpus study of /l/-darkness. They found that word-medial, intervocalic /l/s in trochaic forms are darker than those in iambic forms, although both have darkness scores intermediate between canonical light /l/s, identified as those occurring in word-initial position, and canonical dark /l/s, those occurring word-finally before a consonant.

2.6 Summary

The literature on dark and light /l/ provides evidence that gradient phonetic factors such as duration and adjacent vowel quality play a role in conditioning /l/-darkness, in addition to categorical factors such as position relative to syllable and morpheme boundaries. Following Sproat and Fujimura (1993), a number of works argue that light and dark /l/ are points on a phonetic continuum of /l/-darkness, rather than categorically distinct allophones (e.g., Huffman, 1997; Lee-Kim et al., 2013). Others, however, argue that a categorical distinction between dark and light /l/ coexists with gradient effects on /l/-darkness (e.g., Scobbie & Pouplier, 2010; Yuan & Liberman, 2011a; Bermúdez-Otero & Trousdale, 2012; Turton, 2014, 2017).

Phonological analyses of dark and light /l/ are also diverse. Some analyses propose a rule of /l/-darkening in coda position, either based on surface syllabification (e.g., Yuan & Liberman, 2011a) or mediated by morpho-syntactic boundaries in cyclic analyses (e.g., Halle & Mohanan, 1985; Bermúdez-Otero & Trousdale, 2012). In an account of North American English, Jensen (1993, p. 128, 2000) proposes an analysis of foot-internal darkening whereas Recasens (2012) suggests that North American English has a process of /l/-lightening in initial position. The experiments reported on below control for a number of factors reported to influence /l/-darkness and attempt to disambiguate between possible accounts of variation in /l/-darkness in North American English.

3. Methodology

Our study aims to provide a better understanding of the effects of word and morpheme boundaries on /l/-darkness and, more specifically, to determine whether the observed pattern of variability can be more appropriately characterized as /l/-lightening or /l/-darkening. By considering a greater range of contexts than earlier studies, we are able to differentiate between a variety of hypotheses about the conditioning environments for dark and light /l/. In addition to the effect of morphosyntactic boundaries, we are also interested in the effect of vocalic context, specifically the environment of a reduced vowel. The reduced vowel context is of particular interest because of the relationship between vowel reduction and other factors correlated with /l/-darkening. Reduced vowels occur only in unstressed position and most English affixes contain reduced vowels. As a result, many previous studies investigating the influence of stress (e.g., Oxley et al., 2007) or morpheme structure (e.g., Lee-Kim et al., 2013) on /l/-darkness have included only items with reduced vowels either preceding or following /l/. Aspects of our study are designed to investigate whether patterns of variability in /l/-darkness are alike in the context of reduced and unreduced vowels when other factors are held constant. The following reports on a series of four production studies which used the same methodology and differed only in the morpho-syntactic, prosodic, and segmental contexts present in the stimuli. Details of each study are described in the following sections.

3.1 Experimental design and stimuli

Participants were presented with orthographic representations of English words and phrases and asked to read them aloud. Participants were asked to say the sentences casually, "as if you were talking to a friend," to avoid an overly formal register. For each experiment, stimuli varied in the location of /l/ relative to a morphological boundary. Each experiment had multiple items consisting of words or phrases matched for segmental context and varying in the location of /l/. We use the term 'item' to refer to stimulus sets from the different conditions that are closely matched for segmental content (e.g., {jail owner, jay loaner}).

In addition, participants were presented with an equal number of fillers to act as distractors. The fillers matched the general prosodic category of the words or phrases in the stimuli. For example, fillers for Experiment 1, which compares word-initial and -final /l/s within compounds (e.g., *jail owner* vs. *jay loaner*) consist of other novel compound nouns. Stimuli and fillers were recorded within the carrier phrase "Please say [x] again" in order to eliminate utterance-final and utterance-initial prosodic effects.

All fillers and stimuli were ordered in a playlist that was pseudo-randomized for each participant. No participant saw the same phrases in the same order. Furthermore, each playlist was ordered such that no stimuli of the same item or condition appeared adjacent to one another. Participants were recorded in a sound-attenuated booth at the Linguistics Department at McGill University. Recordings were made by use of a Logitech H390 USB recording headset with a sampling rate of 44100 Hz.

3.2 Participants

All participants were native speakers of North American English, mostly undergraduate students from McGill. A total of 83 participants took part in the experiments: 23 in Experiment 1, 22 in Experiment 2, 17 in Experiment 3, and 21 in Experiment 4.

3.3 Data analysis

Collected data were automatically segmented using the Prosodylab-Aligner (Gorman, Howell, & Wagner, 2011) a forced-aligner which provides a word-by-word and segment-by-segment alignment between the speech signal and the transcription. Duration, F1, and F2 were automatically extracted for each intervocalic /l/ and preceding vowel using Praat (Boersma & Weenink, 2017). F1 values above 1000 Hz were excluded, as were F2 values above 2200 Hz, on the assumption that these values constitute Praat labeling errors such that a higher formant was accidentally measured. Across all experiments, a total of 1931 tokens were included in the analysis after 5.5% of the observations were excluded due to unrealistic formant measurements. Following previous research, F2-F1 was used as a measure of /l/-darkness (see e.g., Sproat & Fujimura, 1993). Dark /l/ has a higher F1—a correlate of tongue body lowering—and lower F2—a correlate of tongue root retraction—than light /l/. As both lowering and retraction contribute to /l/-darkness, F2-F1 provides an overall measure of /l/-darkness.

While a growing body of research uses forced-alignment as the first step in acoustic analysis (e.g., Clayards & Doty, 2011; DiCanio, Nam, Amith, García, & Whalen, 2015; Labov, Rosenfelder, and Fruehwald, 2013; Renwick, Baghai-Ravary, Temple, & Coleman, 2013; Yuan & Liberman, 2011b), we also compared the results of the automatic alignment with results from a subset of data in which the /l/ boundaries were hand-adjusted. The subset of data consisted of 276 tokens (approximately 50%) selected randomly from Experiment 2 (e.g., *freely, Healy, mealy* and *velum, realest, kneeless*). Experiment 2 was chosen as this experiment investigates effects of preceding and following morpheme boundaries in different segmental contexts and thus represents the most important test of

our hypotheses. It also includes both following unreduced (2A) and reduced (2B) vowels, which we analyze separately. For the hand annotations, the onset and offsets of /l/ were chosen at the midpoint of the F2 transitions from the surrounding vowels, where possible, and were also checked by ear.

F2-F1 at the midpoint of the /l/ as well as duration of the /l/ were calculated based on both hand and auto-alignments and compared. Correlations for F2-F1 were high and root means squared errors (RMSE) were small (2A r = 0.96, RMSE = 54 Hz; 2B r = 0.96, RMSE = 67 Hz) illustrated in **Figure 1A**. Correlations for /l/ durations were substantially lower (2A r = 0.49, RMSE = 33 ms; 2B r = 0.39, RMSE = 30 ms). It is perhaps surprising that segmentations of the /l/ could be quite different between the two alignment methods and yet the F2-F1 measures taken from the midpoints are quite similar. To understand this we examined the differences in the onset and offset boundaries for /l/ as well as the midpoints (**Figure 1B**). We found that the hand-aligned /l/s were on average longer than the auto-aligned /l/s (2A mean hand = 95 ms, mean auto = 72 ms; 2B mean hand = 93 ms, mean auto = 89 ms), but that in general the midpoints of the /l/s were very similar with a distribution of differences centered tightly around zero (2A mean = 1 ms, sd = 16 ms, 2B mean = –7 ms, sd = 15 ms). **Figure 2** illustrates the relationship

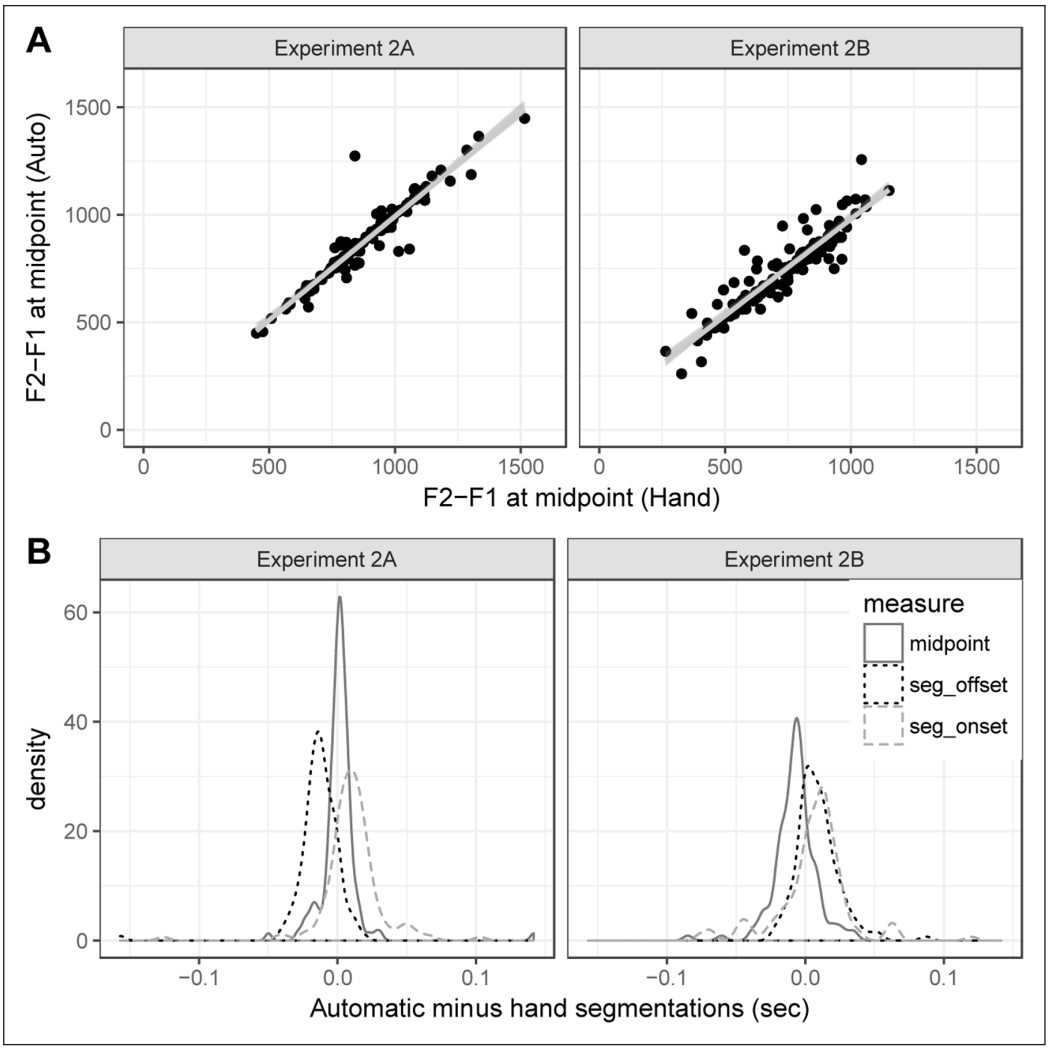

Figure 1: Comparison of automatic and hand adjusted alignments for a subset of Experiment 2 data. **A)** Correlation between F2-F1 measures at /l/ midpoint based on automatic and hand-alignment **B)** Distribution of differences between automatic and hand-alignment for /l/.

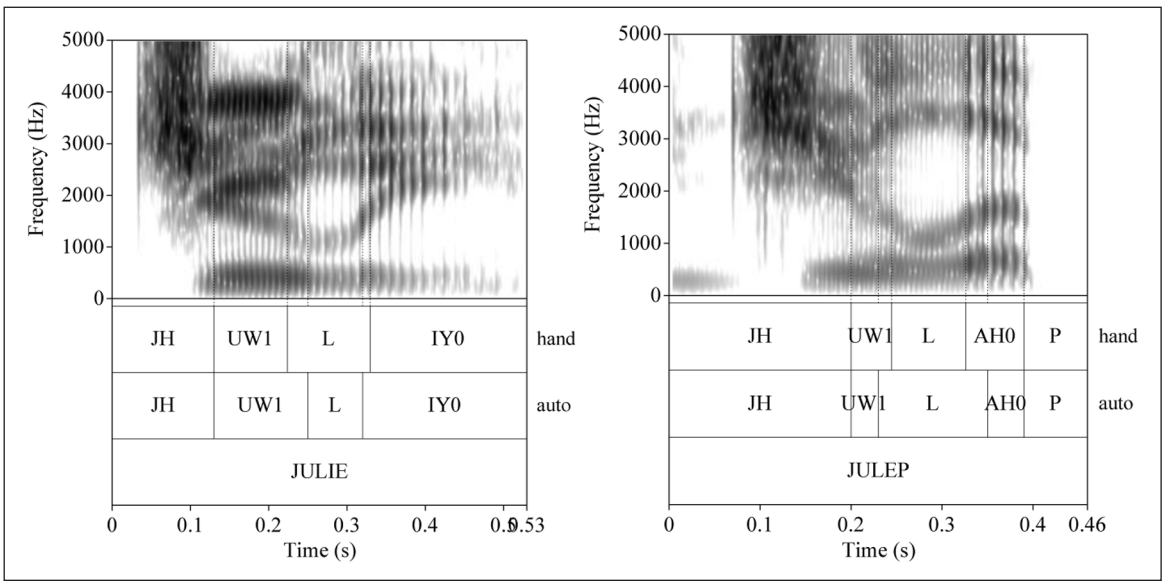

Figure 2: Spectrograms and auto-alignments for segments as well as hand-adjusted /l/ boundaries for two target words extracted from the productions of two different speakers in Experiment 2. Left is Experiment 2A, Right is Experiment 2B.

between auto- and hand-aligned segmentations of /l/ for two example productions from Experiment 2. Overall the alignments seem to be slightly worse for Experiment 2B which includes an adjacent reduced vowel, but we do not think this will negatively impact our results.

The low correlation of /l/ duration is perhaps not surprising, since it is difficult, and often in fact arbitrary, to measure the boundary between the vowel and /l/, particularly in cases where /l/ is dark (e.g., Sproat & Fujimura, 1993; Lee-Kim et al., 2013; Turton, 2014) and the human and automatic annotations may reflect different criteria for this boundary, as seen in **Figure 2**. This provides support for the methodological choice of previous studies which have used duration of a preceding vowel and /l/ rather than the /l/ alone, even in cases where the vowel and /l/ are not syllabified together (e.g., Sproat & Fujimura, 1993; Turton, 2014, 2017). We will therefore follow these precedents and use the rhyme for duration measures in our analysis.

We found very good agreement between the hand-aligned and auto-aligned midpoints for /l/ and so the following results report F1-F2 from the midpoint of the auto-alignments. In addition, F1 and F2 were measured at five points within each /l/, at the onset of the segment, at 25% duration, 50% duration, 75% duration, and at the offset. Although we use the midpoint as the measure of /l/-darkness in the following, analyses of F2-F1 values at all five time points are reported in Appendix B. Patterns of variation in /l/-darkness determined on the basis of midpoint measurements are qualitatively similar across multiple time points. With one exception, effects of condition reported as significant are significant at minimally two time points, the midpoint and one other, and most are significant at three or more time points. One effect of condition and one interaction are significant only at the midpoint. In these cases, we discuss the limitations of the significance findings in the text and interpret the results based on midpoint measurements cautiously. In addition, effects which were found not to be significant at the midpoint but which are significant at the 25% or 75% duration points are discussed.

In the next sections, we report results and statistical analyses from several experiments. In each, we used linear mixed effects regression using the lmer4 package (Bates, Mächler, Bolker, & Walker, 2015) in R (R Core Team, 2016) to model F2-F1 as a measure of /l/

darkness. Rhyme Duration was centered and standardized and added as a fixed effect to each model to control for the expected effect of duration on /l/ darkness (Sproat & Fujimura, 1993; Yuan & Liberman, 2009, 2011a) as well as claims that differences in /l/ darkness across morphosyntactic environments can be largely accounted for in terms of rhyme duration (Sproat & Fujimura, 1993). Although analyses below focus on effects of Position, by including duration in our models, we show that effects of condition are not reducible to durational effects. Random intercepts were fit for participants and items, and random slopes were included for all fixed effects, when appropriate. Models were fit without correlation parameters among random effects, so that a larger number of random slopes could be fit per factor.[3] Significance was assessed using t-tests with Satterthwaite degrees of freedom using the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017).

4. Experiment 1: Word boundaries or duration?

As discussed in previous sections, prior studies have shown that word-initial /l/s are realized as lighter than word-final /l/s. One interpretation of this pattern is that there is a phonological process of word-final or syllable-final /l/-darkening (e.g., Halle & Mohanan, 1985). Another interpretation is that greater relative darkness of word-final /l/s results from their greater duration in conjunction with differences in gestural timing between onset and coda consonants that apply to all segments, rather than specifically to /l/ (Sproat & Fujimura, 1993). Our first experiment examines differences in darkness between intervocalic word-initial and word-final /l/ in phrases (Experiment 1A) and compounds (Experiment 1B). Because word-initial and final /l/ differ in location both relative to word-boundaries and relative to syllable-boundaries, differences established here are consistent with a range of possible analyses. By analyzing data from /l/s elicited in these positions, we are able to establish that the variety of English used by our speakers does distinguish dark and light /l/. We also examine the role of duration in an attempt to evaluate the hypothesis that differences in darkness are largely reducible to gestural differences attributed to duration (Sproat & Fujimura, 1993).

Experiment 1 compares darkness of word-initial and word-final /l/s under phrasal stress and under compound stress, as illustrated below.

(2) Experiment 1A, phrases:
Please say ‘woo lasses’ again. vs. Please say ‘fool asses’ again.
Experiment 1B, compounds:
Please say ‘jay loaner’ again vs. Please say ‘jail owner’ again.

Experiment 1 had a total of 11 item sets consisting of a word-final and a word-initial /l/, five containing phrases and six containing compounds. Each item set consists of a near minimal pair as in (2). In each pair, we matched the quality of the vowels adjacent to the /l/ and manipulated the location of /l/ relative to the compound boundary or the word boundary under phrasal stress. A full list of items for all experiments can be found in Appendix A. Twenty-three speakers of North American English took part in Experiment 1.

[3] We originally did attempt to include correlation parameters among random effects but this resulted in a lack of convergence in many cases. We decided to leave them out for all models in order to use a consistent model structure across experiments. Following the suggestion of an anonymous reviewer, we later fitted models that included correlations where possible and compared the results with those presented here. In most cases, there was no difference in the significance of results across models. In the two instances where we did find differences, those are discussed in footnotes throughout the text.

4.1 Results

In **Figure 3**, and in subsequent figures, representative items are used as labels in order to make the figure more easily interpretable. The data given, however, include data from all items for each experiment. **Figure 3** illustrates that our speakers showed a clear difference in the darkness of intervocalic /l/ in word-initial position and word-final position under both phrasal and compound stress. This difference is in the expected direction, with pre-boundary, final /l/ having a lower F2-F1 value (and hence a darker realization) than post-boundary, initial /l/.

Data were analyzed using a linear mixed effects regression model with fixed effects for Position (Initial vs. Final, where Initial is taken to be the baseline), Comparison type (Phrasal vs. Compound, where Phrasal is baseline), and Rhyme Duration and interactions for Position * Rhyme Duration and Position * Comparison type. Participant and Item were included as random intercepts and Condition * Rhyme Duration was included as a random slope term for both. Position * Comparison type was included as a random slope term for Participant only as each item belonged to only one Comparison type. Additional models were run individually on the data sets from initial and final position to assess the effect of Rhyme Duration separately for each position.[4]

Table 2 confirms a significant effect of Position on /l/-darkness in the model including both positions. This model also found a significant effect of Rhyme duration on /l/-darkness with /l/s in longer rhymes having lower F2-F1 values. The interaction between Position and Rhyme-Duration was not significant. Rhyme-Duration was significant in both models for initial and final position.

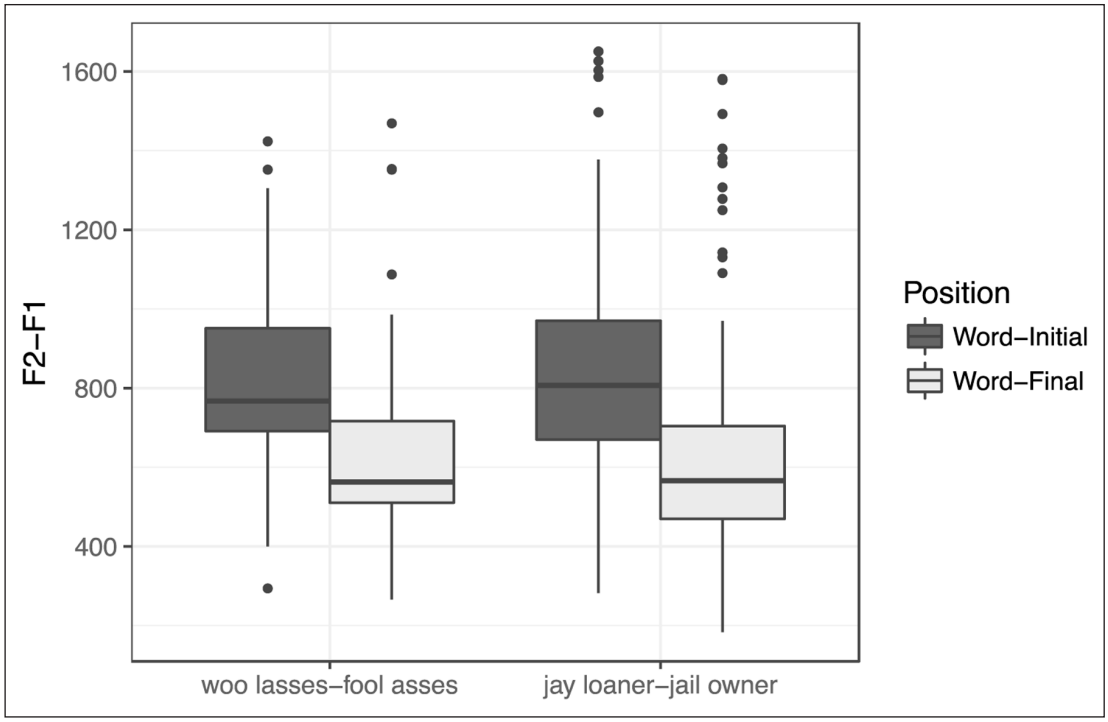

Figure 3: Experiments 1A and 1B: F2-F1 in phrases and compounds, in word-initial vs. word-final position.

[4] The model structure for the whole data set was: Initial vs. Final*Rhyme Duration + Initial vs. Final*Phrasal vs. Compound + (Initial vs. Final*Rhyme Duration || item) + (Initial vs. Final*Rhyme Duration + Initial vs. Final*Phrasal vs. Compound || participant).

The model structure for each of the initial and final subsets was: Rhyme Duration *Phrasal vs. Compound + (Rhyme Duration || item) + (Rhyme Duration*Phrasal vs. Compound || participant).

Table 2: Mixed Effects Regression Models for F2-F1 for word-initial vs. word-final /l/, in two-word phrases and in compounds, in a single model (leftmost column) and for initial and final positions separately (rightmost two columns).

	Both			**Initial**			**Final**		
	Est.	***t***	***p***	**Est.**	***t***	***p***	**Est.**	***t***	***p***
(Intercept)	711.58	21.57	**<0.0001**	831.64	20.25	**<0.0001**	596.62	21.10	**<0.0001**
Initial vs. Final	−288.66	−9.13	**<0.0001**						
Rhyme Duration	−220.56	−5.11	**<0.0001**	−191.92	−3.73	**0.01**	−246.28	−4.30	**<0.001**
Phrasal vs. Compound	40.59	0.70	0.50	51.87	0.78	0.46	30.98	0.59	0.57
Initial vs. Final: Duration	−59.45	−0.86	0.40						
Initial vs. Final: Phrasal vs. Compound	−0.25	−0.01	0.99						
Duration: Phrasal vs. Compound				−156.71	−1.88	0.08	−29.62	−0.32	0.76

4.2 Discussion

Our results replicate earlier findings that word-initial instances of /l/ are lighter in North American English than word-final instances. There is a significant effect of duration on /l/-darkness with longer rhymes having darker /l/s, consistent with Sproat and Fujimura's (1993) observation that darkness of pre-boundary /l/s is correlated with duration. The inclusion of rhyme duration in our model shows, however, that effects of position relative to a word-boundary do not reduce to durational differences in our data. Sproat and Fujimura also acknowledge that not all differences in darkness can be attributed to duration and argue that, in comparisons of canonical light (word-initial) and dark (word-final) /l/, differences in darkness also follow from differences in the relative timing of the apical and dorsal gestures with gestural timing being sensitive to syllabification (1993, p. 308). The relation between rhyme duration and darkness was significant for both word-initial and word-final /l/s, and we did not find a significant interaction between duration and position. These results thus differ from Yuan and Liberman (2009, 2011a) who found a significant effect of duration only for those /l/s in word-final or post-tonic position. Discussion of following experiments will focus on the effect of position, rather than duration, although duration is included as a control in the statistical models throughout.

Differences between word-initial and word–final intervocalic /l/s are consistent with a number of possible analyses, as discussed in the introduction. In order to disambiguate between these possible analyses, it is necessary to consider additional environments, specifically word-internal /l/ adjacent to an affix boundary and morpheme-internal /l/. These environments are included in Experiment 2.

5. Experiment 2: Lightening or darkening?

In order to establish whether positional differences reflect lightening or darkening of /l/, we need to look at a broader range of cases than those investigated in Experiment 1. In Experiment 2, we compared morpheme-medial /l/ with /l/ at the beginnings and ends of morphemes. The effect of morpheme boundaries on /l/-darkness has been considered in previous studies (e.g., Sproat & Fujimura, 1993; Hayes, 2000; Lee-Kim et al., 2013). As discussed above, however, many studies do not include examples in which /l/ occurs in the full range of positions relative to the relevant boundaries and are thus unable to determine whether morphological boundaries trigger a process of lightening, darkening, or both.

Our experiment consists of two subexperiments, Experiment 2A and Experiment 2B.

Experiment 2A involves words in which /l/ is followed by an unreduced vowel and Experiment 2B involves words in which /l/ is followed by a reduced vowel. Since various studies have found that vowel quality affects the realization of /l/ (e.g., Bladon & Al – Bamerni, 1976; Espy-Wilson, 1992; Recasens & Espinosa, 2005), we were interested in whether observed differences in /l/ darkness are influenced by vocalic context. Stimuli for Experiment 2A consisted of four item sets.[5] An example is shown below:

(3) a. Morpheme-Initial: Please say 'freely' again.
b. Morpheme-Internal: Please say 'Healey' again.
c. Morpheme-Final: Please say 'mealy' again.

Experiment 2B follows Lee-Kim et al. (2013) in that it examines suffixes with reduced vowels, but we add the control condition of word-internal /l/ without an adjacent morpheme boundary. The preceding vowel quality varied between items and the vowel following the /l/ was a reduced vowel in all cases. For all items, *–less* was the affix used in the morpheme-initial condition and *–est* was used for the morpheme-final condition, as in Lee-Kim et al. (2013).[6] There were six item sets in Experiment 2B, one of which is shown below:

(4) a. Morpheme-Initial: Please say 'kneeless' again.
b. Morpheme-Internal: Please say 'velum' again.
c. Morpheme-Final: Please say 'realest' again.

Together, Experiments 2A and 2B include morpheme-initial, -final, and -internal /l/ in the context of following full and reduced vowels. Preceding vowel quality varies between items but is held constant across conditions for each item. All items in Experiment 2 have trochaic stress. Although identical stress and segmental contexts lead us to expect syllabification of /l/ to be alike across conditions, the actual position of the /l/ within the syllable in these examples is not obvious. While intervocalic consonants are generally considered onsets by the principle of onset maximization, English consonants in trochaic contexts, like the /l/s in these items, have also been argued to be codas (e.g., Wells, 1990) or to be ambisyllabic (e.g., Kahn, 1976). Furthermore, processes sensitive to syllabification may be influenced by morphological structure in cyclic models of phonological operations (e.g., Chomsky & Halle, 1968; Kiparsky, 2000; Bermúdez-Otero, 2011) or in Optimality Theory models which incorporate paradigm uniformity constraints (e.g., Burzio, 1994; Benua, 1995; Hayes, 2000). Thus, while the stimulus sets are designed to test for effects of morphological constituency and control for all other factors, we cannot eliminate the possibility that syllabification is also affected by morpheme boundaries.

Experiments 2A and 2B were run in a single session, with the trials of the two stimulus sets interspersed in a pseudorandom order. Twenty-two speakers of North American English participated in the study.

[5] We included an additional control condition with a following reduced vowel, to allow for a direct comparison within this sub-experiment. For the item set we use for illustrating, the control condition involved the word 'ceiling': "Please say 'ceiling' again." See the appendix for the full list.

[6] Some of our stimuli were taken from their stimulus set, but we also added new stimuli.

5.1 Results

In discussing the results, we will first consider the morpheme-initial, -internal, and –final conditions as in (3) and (4), leaving discussion of the additional control condition of monomorphemes with following reduced vowels (e.g., *ceiling*) until later in this section. This allows us to directly compare the effect of morphological constituency when a full vowel follows /l/ and when a reduced vowel follows /l/ as well as to determine any overall effect of vowel reduction on /l/-darkness. The results are illustrated in **Figure 4**. Overall, /l/ appears to be realized as darker when a reduced vowel follows.

Looking just at the results with following unreduced vowels, it appears that morpheme-internal /l/ (as in *Healey*) is more similar to morpheme-initial /l/ (as in *free-ly*), and morpheme-final /l/ is substantially darker (as in *meal-y*). This is what is expected if the /l/ variation is due to final darkening.

However, when looking just at the pattern with following reduced vowels, it looks like /l/ in morpheme-medial position (as in *velum*) is more similar to morpheme-final /l/ (as in *real-est*) and much darker than morpheme-initial /l/ (as in *knee-less*). This is what is expected if the effect on /l/ is due to morpheme-initial lightening.

We fitted a mixed effects regression model in order to assess the significance of these patterns. Our three main questions were: Is initial /l/ lighter than medial /l/ (which would indicate an initial lightening effect)? Is final /l/ darker than medial /l/ (which would indicate a final darkening effect)? And is there an overall effect of vowel reduction on /l/ realization? In order to answer these questions, the factor Position was treatment coded so that both Initial and Final position were compared to the reference level of Medial position. We also centered the factor Vowel Reduction (Unreduced vs. Reduced) to avoid correlations with interactions and to ensure model convergence. Finally, we added Rhyme Duration as a factor to the model, as a control. We fit individual models for Experiments 2A and B, as well as a model combining the data from both subexperiments

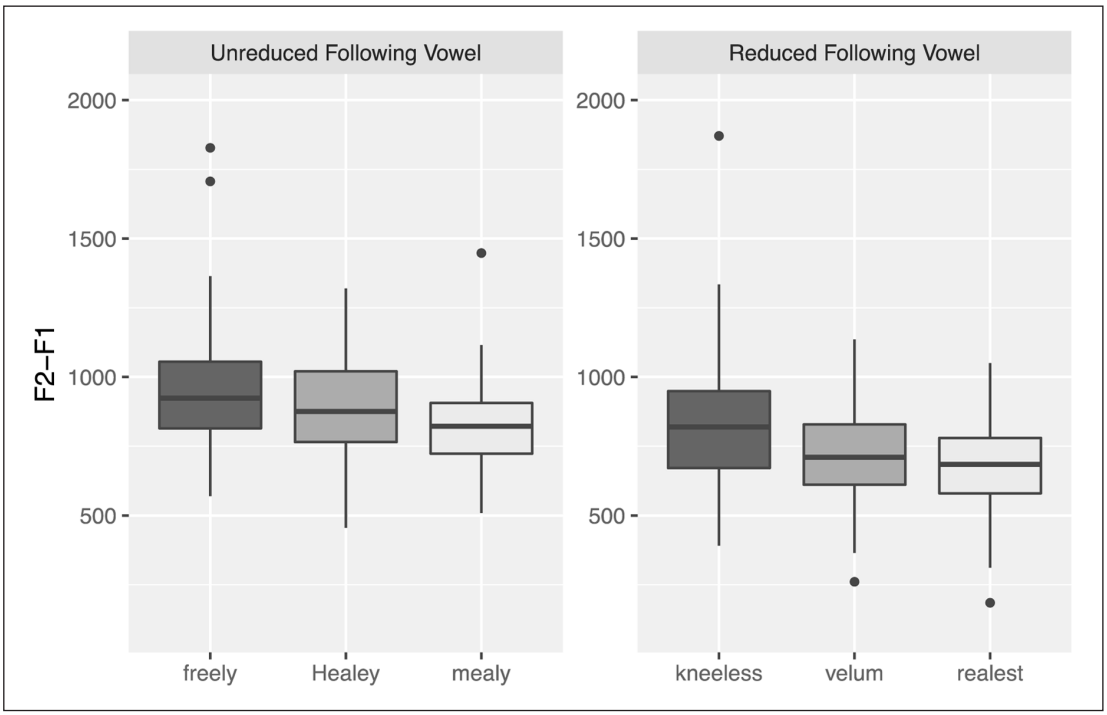

Figure 4: F2-F1 Experiments 2A and B, effect of morpheme boundary position for words with a following unreduced and reduced vowel.

which included an additional interaction between Vowel Reduction and Position. All three models included random intercepts for Participant and Item with slopes for Position and Rhyme Duration. The model combining the two data sets also included an additional random slope term for Vowel Reduction and its interaction with Condition.[7] Results of the models are shown in **Table 3**.

The overall model including both subexperiments finds a significant effect of vowel reduction, showing that a following reduced vowel results in darker /l/. It also finds differences between medial /l/ and both initial and final /l/. This suggests that there is both an initial lightening effect of a preceding morpheme boundary and a final darkening effect of a following morpheme boundary, relative to the morpheme-internal case. Only one of these effects is found to be significant in each of the subset models: If an unreduced vowel follows, the pattern looks more like final darkening; and when a reduced vowel follows, the pattern looks more like initial lightening. Note, however, that the lack of an interaction in the overall model shows that this apparent difference between the subexperiments is not statistically significant. In addition, the difference between morpheme-final and morpheme-internal /l/, which is not significant at the midpoint when a reduced vowel follows, is significant at one time point, 25% into the duration of the /l/ (see Appendix B, Tables 5 and 6). This suggests that a morpheme-final darkening effect plays a role in the context of a following reduced vowel, as suggested by the model which includes the whole dataset, but that in the following reduced vowel context this effect is differently timed and perhaps less robust than the initial lightening effect. The initial lightening effect seen in the model including only reduced vowels, on the other hand, is not significant at any time point when a full vowel follows the /l/.

We now cast an additional look at the data from Experiment 2A, taking into account the additional control condition. **Figure 5** illustrates how the control condition patterns relative to the other conditions already examined. The plots show that the magnitude of darkening due to a following reduced vowel (*ceiling* vs. *Healey*) is comparable to the effect of darkening due to morpheme-final position (*meal-y* vs. *Healey*).[8]

Table 3: Results of mixed model regression for Experiment 2.

	Both			**Unreduced (2A)**			**Reduced (2B)**		
	Est.	***t***	***p***	**Est.**	***t***	***p***	**Est.**	***t***	***p***
(Intercept)	786.82	23.01	**<0.0001**	882.58	23.08	**<0.0001**	721.49	16.27	**<0.0001**
Medial vs. Initial	86.47	2.90	**0.01**	38.49	1.33	0.20	112.54	3.61	**<0.01**
Medial vs. Final	−60.35	−2.99	**0.02**	−75.92	−3.39	**<0.001**	−46.04	−1.42	0.22
Rhyme Duration	−85.22	−2.09	0.06	−52.38	−1.36	0.24	−27.08	−1.24	0.25
Unreduced vs. Reduced	−157.89	−2.84	**0.02**						
Medial vs. Initial: Unreduced vs. Reduced	75.29	1.95	0.09						
Medial vs. Final: Unreduced vs. Reduced	30.69	0.75	0.48						

[7] The model structure for the overall model was the following: (Medial vs. Initial + Medial vs. Final) * Unreduced vs. Reduced + Rhyme Duration + ((Medial vs. Initial + Medial vs. Final) * Unreduced vs. Reduced + Rhyme Duration || participant) + (Medial vs. Initial + Medial vs. Final + Rhyme Duration || item).

The model structure for the subsets with only reduced or unreduced following vowels was: (Medial vs. Initial + Medial vs. Final) + Rhyme Duration + ((Medial vs. Initial + Medial vs. Final) + Rhyme Duration || participant) + (Medial vs. Initial + Medial vs. Final + Rhyme Duration || item).

[8] According to the estimates in Table 3 in the model when both sets are considered, it appears that the effect of a following reduced vowel is in fact higher than the effect of morpheme position.

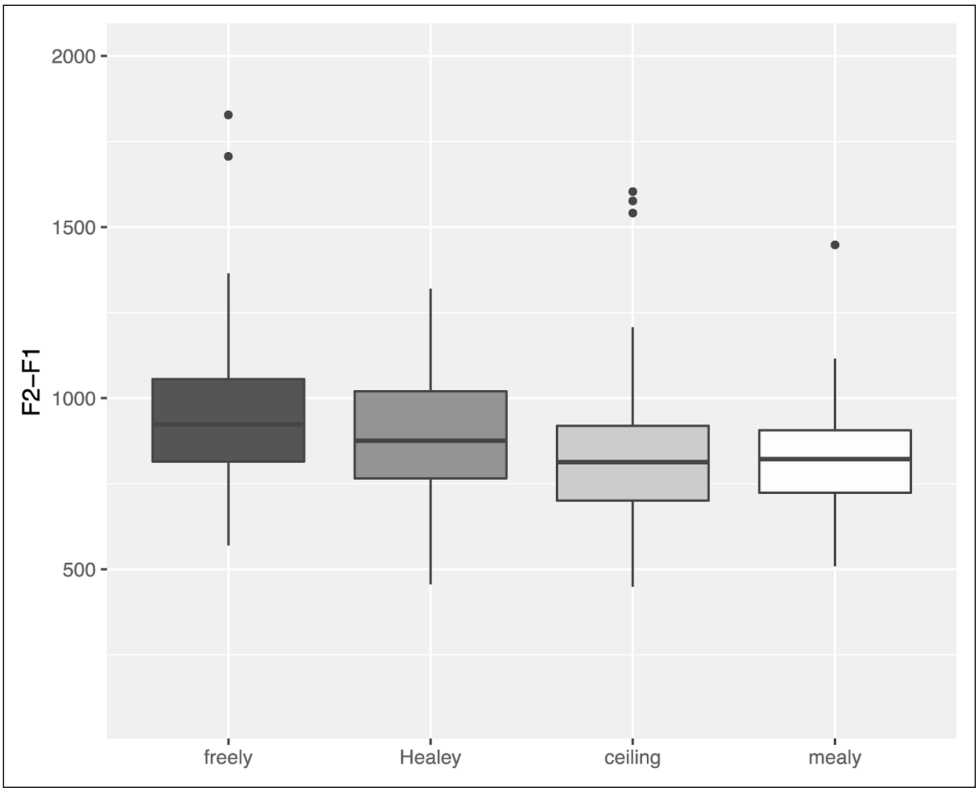

Figure 5: F2-F1 For Experiment 2A with suffixes that involved unreduced vowels. The additional control with a following reduced vowel has a darkness measure comparable to the morpheme-final case.

5.2 Discussion

Overall, our data support previous findings (e.g., Lee-Kim et al., 2013) that morphological constituency affects /l/-darkness and that such effects cannot be attributed solely to stress, duration, or surrounding vowel quality. Our data also shows that a following reduced vowel overall renders /l/ darker, an effect similar in size to the effect of position within the morpheme. Furthermore, our data establishes new insights into whether these effects are better thought of as initial lightening or final darkening. If we had run only one of the subexperiments (either the one with following unreduced vowels or with reduced vowels), we might then wrongly conclude that there is only evidence for either final darkening or initial lightening. Instead, the data shows clear evidence for both effects. In order to appreciate the full pattern, it is crucial to look at different types of contexts, ones that make /l/ independently appear darker or lighter. Only then can we see evidence for both types of effect.

The null effects we observed in the two subexperiments (no lightening with following unreduced vowels, no darkening with following reduced vowels) should be interpreted with caution in light of the non-significant interaction and they may in fact reflect small effects that we failed to detect due to a lack of power. It seems plausible that a final morphological darkening effect may be harder to detect when there is already darkening due to a reduced vowel, and similarly, morphologically induced lightening might be harder to detect when an unreduced high vowel follows. Indeed, small trends for these non-significant effects are visible in **Figure 4** and in the case of the context of a following reduced vowel, a significant effect of morpheme-final darkening is detectable at the 25% duration of the /l/. The non-significance of the interaction shows that there is no statistical evidence that lightening or darkening was not at play in both subexperiments.

Our results suggest that in order to study the variation of /l/ realization, it is crucial to control for other sources of darkening and lightening. One important factor is whether the

following vowel is reduced, which affects /l/ darkening at least as much as whether /l/ is in morpheme-final position. In the next experiment, we explore whether it also matters whether the preceding vowel is reduced.

6. Experiment 3: The effect of a reduced preceding vowel

Does a preceding reduced vowel affect /l/ in similar ways as a following reduced vowel? We address this question by looking at /l/ in word-internal, word-initial, and word-final position in the context of a preceding reduced vowel and in the context of a preceding full vowel. An experiment comparable to Experiment 2, which involves morpheme boundaries rather than word boundaries, is unfortunately not possible, due to the absence of English suffixes which begin with /l/ and receive stress.

A second question of interest concerns the exact nature of the morpheme-internal realization that we observed. So far, we have looked at morpheme-internal /l/ occurring between a stressed and an unstressed vowel. As discussed in discussion of Experiment 2, the syllabification of consonants in trochaic forms in English is subject to debate. Such consonants have been argued to be codas (e.g., Wells, 1990) or to be ambisyllabic (e.g., Kahn, 1976). Regardless of these claims, consonants preceding an unstressed syllable are uncontroversially foot-internal and Jensen (2000) argues that foot-internal position is the relevant context of /l/-darkening in some varieties of American English. These points raise the question of whether morpheme-internal /l/s in the onset of stressed syllables may pattern with morpheme-initial /l/s rather than with morpheme-internal /l/s in onsets of unstressed syllables. In light of these issues, we designed Experiments 3A and B to compare the darkness of word-final /l/ to word-initial and word-internal /l/s in foot-initial position.

The stimuli consist of item sets that involve four forms matched for quality of the surrounding vowels and differing in the position of /l/ relative to a word boundary. Conditions include word-internal, word-initial preceded by a function word, word-initial preceded by a lexical word, and word-final. All stimuli have main word stress following the /l/. In Experiment 3A, an unreduced vowel precedes the /l/, as illustrated by the example item set in (5). Experiment 3A consisted of three comparable item sets.

(5) a. Word-initial, preceding content word: Please say ‘buy lean’ again.
b. Word-initial, preceding function word: Please say ‘I lean’ again.
c. Word-internal: Please say ‘Eileen’ again.
d. Word-final: Please say ‘Kyle Een’ again.

An example item set for Experiment 3B, in which a reduced vowel precedes the /l/, is illustrated in (6). There were three item sets in Experiment 3B.

(6) a. Word-initial, preceding content word: Please say ‘soda leak’ again.
b. Word-initial, preceding function word: Please say ‘the leaf’ again.
c. Word-internal: Please say ‘belief’ again.
d. Word-final: Please say ‘beautiful eave’ again.[9]

[9] Glottal stop insertion occurs variably in English before vowel-initial words. Although we did not analyze our data to identify instances of glottal stop insertion, we expect that some instances of forms like ‘Kyle Een’ and ‘beautiful eave’ were realized with a glottal stop before the word-initial vowel. Previous literature shows a rate of glottal stop insertion of approximately 20% in similar contexts (e.g., Dilley et al., 1996). Stress and boundary type have been identified as factors which affect the rate of glottal stop insertion (e.g., Pierrehumbert, 1995; Garellek, 2012; Davidson & Erker, 2014), suggesting that presence of glottal stop before vowel-initial words relates to the strength of prosodic boundaries. Subsequent sections of this paper argue that prosodic boundaries play a role in conditioning darkening of a preceding /l/ and lightening of a following /l/. Given that presence of glottal stop has been argued to reflect the strength of prosodic boundaries, it is an interesting question whether the presence of glottal stop correlates with greater darkness of a preceding /l/. We leave this question for future research.

The two subexperiments, 3A and 3B, were presented interspersed with each other in pseudorandom order. Seventeen speakers of North American English participated in the study.

6.1 Results

Results for both experiments are shown in **Figure 6**, below. The figure shows that /l/ in words with a preceding reduced vowel tends to be darker compared to words with a preceding unreduced vowel. In both subexperiments, initial /l/ appears to be lighter than final /l/. The status of /l/ in medial position appears to differ depending on vowel reduction: When an unreduced vowel precedes, it seems to be similar to an /l/ in initial position, leading to an overall pattern that suggests an effect of /l/-darkening in word-final position; when a reduced vowel precedes, it appears to group more with word-final /l/, compatible with an overall pattern in which initial /l/s lighten.

In order to assess the statistical significance of these patterns, we again fitted three mixed effects regression models, one for Experiment 3A, one for Experiment 3B, and one which included the data from both subexperiments.[10] Model results are reported in **Table 4**. We coded Position using three orthogonal contrasts (Helmert coding): The first contrast compares the final position to all other positions (Final vs. Other: e.g., *Kyle Een* vs. others); the second compared word-initial and word-medial /l/ (Initial vs. Medial*:* e.g., *Eileen* vs. *I lean* and *buy lean*); and the third compared whether the word preceding word-initial-/l/ was a lexical or function word (Lexical vs. Functional: e.g., *I lean* vs. *buy lean*). As in the previous models, the control factor Rhyme Duration was included as a fixed effect and as a random slope term, and random intercepts were included for Item and Participant. Random slopes were also fit for Final vs. Other. Finally, in the combined

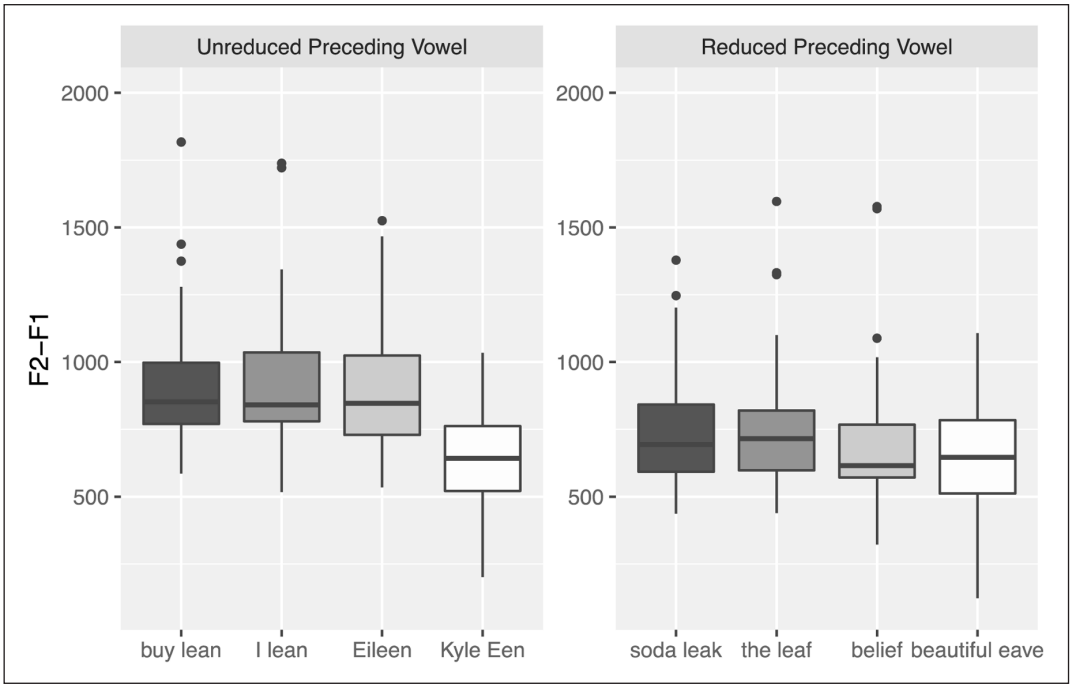

Figure 6: F2-F1, Experiments 3A and 3B.

[10] The model structure over the overall model was: (Final vs. Other + Initial vs. Medial + Lexical vs Functional) + Unreduced vs. Reduced + Final vs. Other: Unreduced vs. Reduced + Rhyme Duration + (Final vs. Other * Unreduced vs. Reduced + Rhyme Duration || participant) + (Final vs. Other + LogDuration || item).

The model structure for the subsets with reduced and unreduced vowels was: Final vs. Other + Initial vs. Medial + Lexical vs. Functional + Rhyme Duration + (Final vs. Other + Rhyme Duration || participant) + (Final vs. Other + Rhyme Duration || item).

Table 4: Results of mixed model regression for Experiment 3.

	Both			Unreduced (3A)			Reduced (3B)		
	Est.	***t***	***p***	**Est.**	***t***	***p***	**Est.**	***t***	***p***
(Intercept)	788.31	21.47	**<0.0001**	842.77	21.97	**<0.0001**	726.61	12.77	**<0.001**
Final vs. Other	−189.80	−4.62	**<0.01**	−262.69	−5.33	**0.03**	−90.63	−1.35	0.30
Initial vs. Medial	−6.39	−0.29	0.77	−7.84	−0.25	0.80	−8.404	−0.28	0.78
Lexical vs. Functional	7.90	0.39	0.70	−5.605	−0.20	0.84	18.97	0.65	0.52
Unreduced vs. Reduced	−102.61	−1.83	0.10						
Rhyme Duration	36.65	1.01	0.31	1.16	0.03	0.98	70.34	1.65	0.12
Final vs. Other: Unreduced vs. Reduced	179.53	2.36	0.08						

model, a factor Preceding Vowel was included, as well as its interaction with Final vs. Other. These factors were also included as random slopes for the factor Participant.

Position (Final vs. Other) was significant, such that word-final /l/ was darker than /l/ in other positions (i.e., final darkening), both in the combined model and in the model that considered only the data in which an unreduced vowel precedes. Position (Initial vs. Medial) and (Lexical vs. Functional) were not statistically significant in any model. There were no significant interactions between Position and Preceding Vowel. Looking at the subset models, we see a pattern similar to that in Experiment 2 where, when fitting models only on the respective data subsets, there is no significant effect of final darkening in the context of a preceding reduced vowel indicating that these effects might be harder to detect in some contexts (and possibly also with small samples). The non-significance of the interaction, however, shows that there is no statistical evidence that word-final darkening was not at play in both subexperiments.[11]

The darkening effect of preceding reduced vowels suggested by **Figure 6** is not statistically significant based on the midpoint measure used in our models. However, models based on time points taken across the duration of the /l/ show a significant darkening effect of preceding vowel reduction at the segment onset and at 25% of the /l/ duration (Appendix B, Table 7). The effect of a following reduced vowel found in Experiment 2 was significant at 25%, 50%, 75%, and at the offset of the /l/ (Appendix B, Table 4). Considering data from the two experiments shows that, unsurprisingly, the darkening effect of a preceding reduced vowel is realized earlier within the production of /l/ and the darkening effect of a following reduced vowel is realized later. The effect of a following reduced vowel also persists through a greater duration of the /l/.

6.2 Discussion

Data from Experiment 3 shows evidence of word-final darkening, such that word final /l/ is realized as darker compared to other positions. There was no evidence, however, for initial-lightening. Word-initial and medial /l/ patterned alike, even in the subset of data with a reduced preceding vowel, where there appears to be a clear pattern toward a lightening effect in the figure. Relative to the other experiments reported here, Experiment 3 had few items; three items for each of experiment 3A and 3B. Given that

[11] In this case, the interaction of Position (Final vs. Other) and Unreduced vs. Reduced ($p = 0.08$ in table 4), does reach significance with an alternate model structure which includes correlation parameters among random effects. The difference in the significance of this interaction across slightly different models suggests that the lack of significance in the reported model may follow from a power issue due to the relatively small number of items in this experiment and that this effect should be interpreted with caution.

there are four conditions per item and that we used a model with complex random effects, we may have overfitted our data.

7. Experiment 4: Effects of different morpheme boundaries

Hayes (2000) suggested that there is a scale of /l/ realization, in which the frequency of dark /l/ depends on the strength of the junctures between /l/ and a following morpheme/word. In Experiment 2 above, we only included the derivational affixes—*est/-less and –y/-ly*. In order to assess whether there are further distinctions between different types of boundaries, we compare here morpheme-internal /l/ and morpheme-final /l/ when the following morpheme is an inflectional suffix (*-ing*), a derivational suffix (*–er*), or a clitic (*it*). The acceptability judgment study reported in Hayes (2000) suggests that light /l/ is less acceptable in pre-clitic position (e.g., *mail it*) than in pre-affix position (e.g., *mail-er*), with light /l/ being less acceptable in both of these positions than in morpheme-internal position (e.g., *Dayley*). Other studies either do not consider different types of word-internal boundaries (e.g., Lee-Kim et al., 2013) or do not find significant differences between boundary types (e.g., Sproat & Fujimura, 1993). Our third experiment investigates the influence of a range of boundary types on /l/ darkness.

Experiment 4 contains three sub-experiments, Experiment 4A, 4B, and 4C. For each sub-experiment, items consist of pairs matched for adjacent vowel quality and differing in whether the /l/ is morpheme internal or precedes a morpheme boundary, as shown below.

(7) Experiment 4A: *Inflectional Suffix:*
Morpheme-Internal: Please say 'ceiling' again.
Morpheme-Final: Please say 'kneeling' again.

Experiment 4B: *Derivational Suffix:*
Morpheme-Internal: Please say 'cellar' again.
Morpheme-Final: Please say 'seller' again.

Experiment 4C: *Clitic:*
Morpheme-Internal: Please say 'skillet' again.
Morpheme-Final: Please say 'kill it' again.

Experiment 4A had three items, and Experiments 4B and C had six items each. Twenty-one participants took part in all three experiments, which were run together as a block, using the same methodology as previous experiments.

7.1 Results

Results of all subexperiments are shown in **Figure 7**, below. F2-F1 values are lower for morpheme-final /l/ than for morpheme-internal /l/ in the context of a following *–ing*. With a following *–er*, values appear very similar in the morpheme-internal and morpheme-final contexts and when *it* follows /l/ the difference appears to be in the opposite direction from what is expected, with F2-F1 values being higher in morpheme-final position.

We fitted mixed effects regression models for each subexperiment and a combined model including all data from Experiment 4. For each subexperiment, we treatment-coded a factor Position comparing Internal vs. Final, with Internal as the baseline. This was included as both a fixed factor and as a random slope for each participant and item. We again included Rhyme Duration as a control factor and as a random slope term, and Participant and Item as random intercepts. In the combined model, we included a Helmert-coded factor Experiment that differentiated the subexperiments. The first contrast compared Clitic vs. Suffix, and the second was restricted to the suffix subexperiments and compared *–ing* vs. *–er*. Each contrast

was included as a fixed effect, as well as its interaction with Position. This factor and its interactions were also included as random slopes for Participant in the combined model.

Results of the mixed model regression with data from all subexperiments is shown in **Table 5**. This model shows no significant effect of morpheme-final versus morpheme-internal position. The model does show a significant effect of *-ing* versus *–er*. Higher F2-F1 values for /l/s preceding *–ing* are also clearly visible in **Figure 7**. We also find a significant interaction between morpheme position and whether the boundary type is a suffix boundary or a clitic boundary. This interaction is significant only at the midpoint measure and not at any other time points throughout the duration of the /l/ (Appendix B, Table 10) and should therefore be interpreted cautiously.

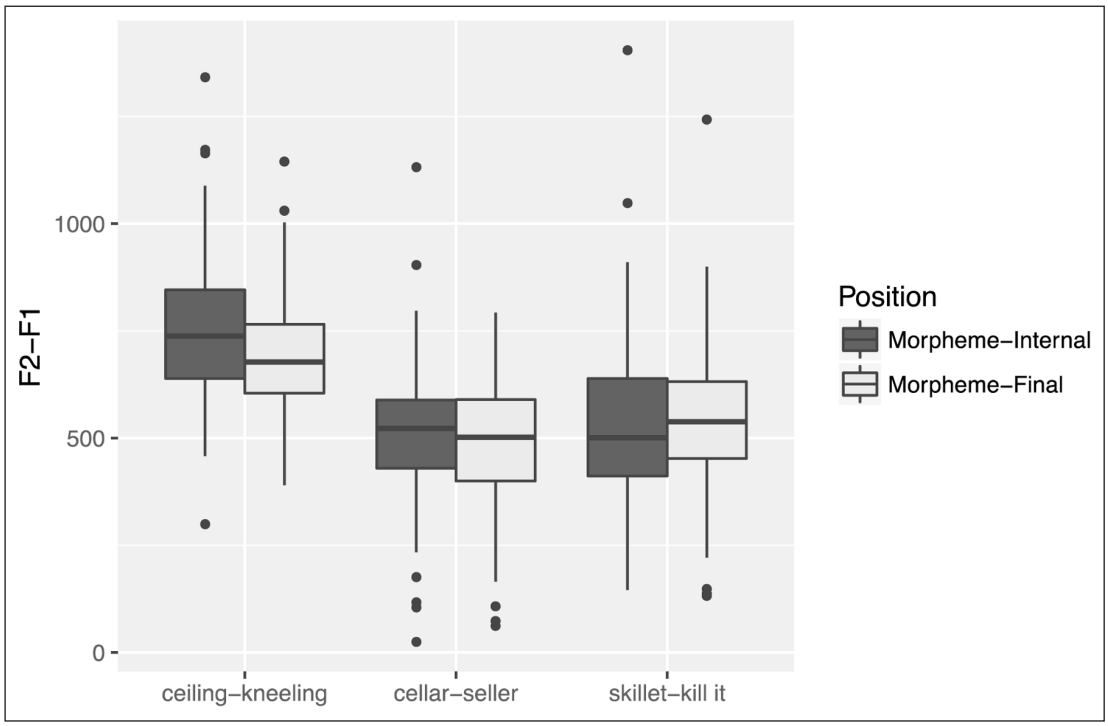

Figure 7: F2-F1 Experiment 4A, Inflection (*ceiling-kneel-ing*), 4B, Derivation (*cellar-sell-er*), and 4C, Clitic (*skillet-kill it*).

Table 5: Results of mixed model regression Experiment 4, all data.[12]

	All		
	Est.	***t***	***p***
(Intercept)	554.33	20.02	**<0.0001**
Internal vs. Final	–20.56	–1.79	0.10
Clitic vs. Suffix	–73.83	–1.62	0.13
–ing vs. *–er*	171.03	3.75	**<0.01**
Rhyme Duration	–13.35	–0.66	0.51
Internal vs. Final: Clitic vs. Suffix	51.98	2.26	**0.04**
Internal vs. Final: *–ing* vs. *–er*	–36.33	–1.60	0.13

[12] The model structure for the whole dataset was the following: Internal vs. Final * (Clitic vs. Suffix + Ing vs. Er) + Rhyme Duration + (Internal vs. Final + Rhyme Duration || item) + (Internal vs. Final * (Clitic vs. Suffix + Ing vs. Er) + Rhyme Duration || participant).

Table 6: Results of mixed model regression Experiment 4, by morphological boundary type.

	Inflection (4A)			Derivation (4B)			Clitic (4C)		
	Est.	***t***	***p***	**Est.**	***t***	***p***	**Est.**	***t***	***p***
(Int.)	723.87	17.64	**<0.0001**	493.49	14.48	**<0.0001**	535.09	11.70	**<0.0001**
Internal vs. Final	−62.13	−2.68	**<0.01**	−23.03	−1.41	0.17	8.27	0.36	0.73
Rhyme Duration	−33.68	−1.23	0.24	−17.76	−0.53	0.60	−0.66	−0.02	0.98

Results of three models fitted to Experiment 4A (*-ing*), Experiment 4B (*-er*), and Experiment 4C (*it*) are shown in **Table 6**.[13]

We failed to find any significant differences between medial position and final position for /l/s followed by the derivational suffix *–er* or the clitic *it*. A significant effect of position was found for the inflectional suffix *–ing* with /l/s preceding the suffix being significantly darker than morpheme-internal /l/s in the same segmental context. We interpret this result cautiously, however, as the effect was significant at the midpoint only and not at any other measurement point during the /l/ (Appendix B, Table 11).[14] The lack of a significant effect of position relative to a morpheme boundary in the context of following *–er* must also be interpreted cautiously as there is a significant effect of position for this data set at the measurement point taken at 25% of the /l/ duration (Appendix B, Table 12).

7.2 Discussion

When data from Experiments 4A, B, and C are considered together, our results fail to detect a main effect of morpheme position, internal vs. final, on darkness. However, this main effect was qualified by a significant interaction with juncture type. In light of the significant difference in darkness found between morpheme-final and morpheme-internal /l/ in the context of a following high front vowel (Experiment 2A, *meal-y* vs. *Healey*) and the failure of such an effect in the case of a following reduced vowel (Experiment 2B, *real-est* vs. *velum*),[15] these results lend further credence to the idea that the darkening effect due to a following reduced vowel may make darkening harder to detect. When we consider the models fitted to each of the subexperiments, we find a significant difference between morpheme-internal and morpheme-final /l/ at the midpoint measure in the case of the inflectional affix *–ing*. This difference, in contrast to the complete absence of such a difference, when a clitic follows, is not consistent with Hayes (2000) who predicts a higher likelihood of dark /l/ before clitic boundaries than before affix boundaries. We interpret our result, not as following from differences in the effect of different boundary types, but as following from differences in the quality of the vowel following the /l/. Although we class all following vowels as reduced in this experiment, the vowel which follows /l/ in inflectional forms like *ceiling* and *kneel-ing* is nonetheless higher and fronter than the schwa present in cases where a clitic follows the /l/ (e.g., *kill it*). Presence of morpheme-final darkening may be more discernible in cases where the relatively high vowel in *–ing* follows /l/ than cases where a schwa follows /l/. In the case of the following derivational suffix *–er*, we did not find a significant effect of morpheme-final position at the midpoint measure but did find such an effect at the measurement point taken at 25% of the /l/

[13] The model structure used for the data subsets of Experiment 4A, 4B, and 4C was: Internal vs. Final + Rhyme Duration + (Internal vs. Final + Rhyme Duration || item) + (Internal vs. Final + Rhyme Duration || participant).

[14] In addition, this effect, already interpreted cautiously here because it is significant only at the midpoint measure, is not significant in the alternate model structure which includes correlation parameters among random effects.

[15] Based on F2-F1 midpoint measures from the data subsets for each subexperiment.

duration. This raises the possibility that a morpheme-final darkening effect is present in this context but that it is realized earlier in the articulation of the /l/ and is masked at later time points by anticipatory coarticulation with the following reduced vowel. The particular quality of the reduced vowel in these cases is also affected by the following /r/ and this rhoticization may further contribute to contextual darkening effects.

8. Summary and discussion

Considered as a whole, these experiments provide evidence that both morphological constituency and vowel reduction have a sizeable impact on /l/ realization. Most importantly, we find that morphological boundaries have both a darkening effect on preceding /l/s and a lightening effect on following /l/s when compared to a baseline of morpheme-internal /l/. Previous results about the effect of position in the literature are often ambiguous between an interpretation in which /l/ is subject to initial lightening or to final darkening. By including a morpheme-internal control condition in our experiments, we provide evidence that this difference is in fact the result of both morpheme-initial lightening and morpheme-final darkening. The full pattern of variation can only be appreciated when the effects of the surrounding vowels are controlled for.

The density estimations in **Figure 8** illustrate the pattern we find with data pooled from all experiments. Data points are coded according to initial, final, and medial conditions where initial includes both word-initial and morpheme-initial conditions and final includes both word-final and morpheme-final conditions. All /l/s coded as medial are both word-medial and morpheme-medial. Data are separated into cases where /l/ is followed by a reduced vowel, cases where /l/ is preceded by a reduced vowel, and cases where full vowels occur both preceding and following /l/.

Looking at **Figure 8**, we see that, when a reduced vowel follows /l/, /l/s in word- or morpheme-initial position are lighter (have larger F2-F1) than /l/s in final and internal position, with no difference between the latter two conditions. If these forms were considered in isolation, an analysis in terms of initial lightening appears to be the most parsimonious. When /l/ is both preceded and followed by an unreduced vowel, /l/s in morpheme- or word-final condition are darker than internal and initial /l/s, which pattern together. The pattern when a reduced vowel precedes is slightly less clear, in that it is not obvious whether internal /l/ patterns more with initial /l/ or with final /l/. Overall, our results provide evidence for *both* initial lightening and final darkening, and the apparent lack of one or the other effect when reduced/unreduced vowels follow may simply be a power issue arising when independent factors make darkening or lightening harder to detect. The proposal that both /l/-lightening and /l/-darkening are present and conditioned by morphological boundaries differs from previous reports in the literature,

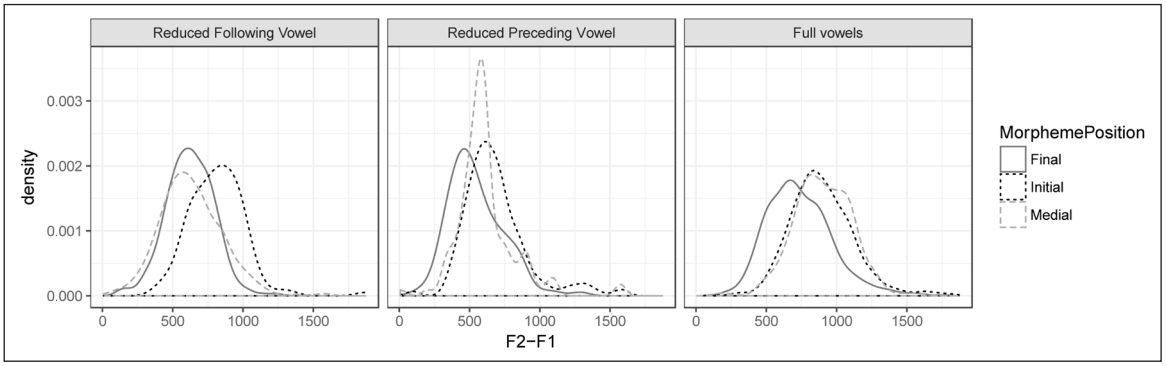

Figure 8: Distribution of F2-F1 across all experiments according to morpheme position and vowel context.

most of which argues for /l/-darkening triggered by some combination of syllabification (e.g., Yuan & Liberman, 2011a), morphological constituency (e.g., Strycharczuk & Scobbie, 2017), and rhyme duration (e.g., Sproat & Fujimura, 1993; although, see Recasens, 2012, who proposes a process of /l/-lightening in American English).

8.1 Evidence of morphological darkening and lightening effects

While patterns of variation in /l/-darkness differ considerably between dialects of English and even between individual speakers (e.g., Scobbie & Pouplier, 2010), we do not believe that dialect differences between our speakers and speakers included in previous studies can explain our pattern of results. We would not expect the same factors to condition variation in /l/-darkness across studies carried out among distinct populations. However, the methodologies of previous studies would fail to find the coexistence of lightening and darkening processes, even if both processes were present among the speakers included in the studies.

One reason that previous studies could not provide evidence for both lightening and darkening follows from the large number of factors that affect /l/-darkness and the potential interactions between them. For example, we found consistent effects of adjacent vowel quality which modulated our results. Coarticulatory effects of adjacent vowels on the realization of /l/ are well established (e.g., Lehiste, 1964; Bladon & Al-Bamerni, 1976) and the expectation that adjacent back vowels have a darkening effect on /l/ whereas front vowels have a lightening effect on /l/ is acknowledged in much of the literature on dark and light /l/. However, attempts to control for these effects in experimental stimuli have been shaped by a priori assumptions that /l/-darkening is the appropriate phonological analysis. Many studies have intentionally used items in which /l/s are adjacent to front vowels because of the expectation that /l/-darkening will be most apparent in this environment (e.g., Sproat & Fujimura, 1993; Scobbie & Pouplier, 2010; Turton, 2014, 2017). While we also found effects of /l/-darkening in the context of a following high vowel (e.g., *free-ly, meal-y, Healey*) we found effects of morpheme-initial /l/-lightening in the context of a following reduced vowel (e.g., *real-est, knee-less, velum*). These contexts are deliberately excluded in work which assumes that the appropriate analysis is /l/-darkening and, hence, evidence of lightening is not found in these studies.

The significant number of factors influencing /l/ darkness can also lead to confounds such that a difference in darkness attributed to one factor may, in fact, be attributed to some other aspect of the data. For example, Oxley et al. (2007) investigate effects of stress, syllabification, and adjacent vowel context on /l/-darkness. However, all /l/s in iambic contexts in their study (e.g., *a leaf*) are also word-initial and all /l/s in trochaic contexts (e.g., *peel a peach*) are word-final leading to ambiguity in whether differences in darkness across conditions should be attributed to word-boundaries or foot-structure. Yuan and Liberman's (2011a) study of /l/-darkness uses forced alignment of corpus data and is therefore able to include a large amount of data (8,344 /l/ tokens, **Table 1**) relative to other studies. They find intervocalic, word-internal /l/s to be significantly darker when preceded by a stressed vowel than when followed by a stressed vowel. Yuan and Liberman (2011a) attribute this difference to syllabification, arguing that /l/s followed by stressed vowels are unambiguous onsets and /l/s preceded by stressed vowels are resyllabified as codas of the preceding, stressed syllable (2011a, p. 42). A number of potentially relevant factors, such as morphological constituency and adjacent vowel quality, are not considered in Yuan and Liberman's study. Given the robustness of their findings and the large amount of data analyzed, the presence of additional factors does not necessarily affect the interpretation of the results. However, factors such as stress, morphological constituency, and adjacent vowel quality are not independent in English. Presumably, a

non-trivial number of word-medial /l/s preceded by stressed vowels are morpheme-final (e.g., *sell-er, sell-ing, meal-y*) whereas few or none of the word-medial /l/s followed by a stressed vowel are morpheme-final. Many word-medial /l/s preceded by stressed vowels will also be followed by a schwa whereas none of the /l/s followed by stressed vowels will be followed by schwa. Differences in darkness attributed to stress and syllabification may therefore result from differences in morphological constituency or vocalic context.

Support for an analysis which includes both lightening and darkening can be found by examining the crosslinguistic typology of /l/-systems. Recasens (2012) investigates the acoustic properties of /l/ in 23 languages and dialects which have been described as light /l/ or dark /l/ languages in previous studies. In addition, the difference between initial and final /l/s and the effect of an adjacent front versus back vowel is examined for each language in the study. American English is classified as a dark /l/ language, based on descriptions in previous literature and F2 values of /l/ in intervocalic position. American English is alone among the dark /l/ languages, however, in having a substantial difference in F2 between initial and final /l/ in the context of a high, front vowel (*li* vs. *il*). Recasens (2012) observes that lighter /l/s are expected to vary more according to position than darker /l/s (2012, p. 377) but American English does not conform to this generalization and shows a greater difference between initial and final /l/ than all the dark /l/ languages and all but two of the light /l/ languages in the study (Recasens' **Figure 5**, p. 377). Of the six languages classified as dark /l/ languages by Recasens, American English has the highest F2 initially when followed by /i/ and the lowest F2 finally when preceded by /i/ (**Figure 3**, p. 375). Based on a comparison of F2 values in initial, final, and intervocalic position, Recasens concludes that the substantial difference between initial and final /l/ in American English is largely due to a rise in F2 in initial position (2012, p. 378). The data presented are, however, consistent with an analysis relying on both initial lightening and final darkening.

8.2 Effect of vowel context

The effect of vocalic context, and particularly vowel backness, on /l/-darkness has been well documented (e.g., Jones, 1956; Lehiste, 1964; Giles & Moll, 1975). As described above, we were particularly interested in investigating the effect of reduced vowels on /l/-darkness because of the relationship between vowel reduction and other factors associated with /l/-darkening such as stress and morphological constituency. Effects of vowel reduction cannot be isolated from other vowel qualities such as place, height, and duration. However, while schwa is often described as a mid, central vowel, Flemming (2009) identifies schwa as a "very short vowel with at best a weakly specified vowel quality target." Therefore it should perhaps be considered differently from other mid or central vowels. Our results from Experiment 2 show that a following reduced vowel darkens /l/ in a similar way to a morpheme boundary (*velum* vs. *Healey*). Our results may in part be due to the reduced vowel being backer than the high front vowels it was contrasted with. While some other studies which include /l/s in the context of a following reduced vowel argue that darkening effects are due to the influence of stress and syllabification (e.g., Oxley et al., 2007; Yuan & Liberman, 2011a) the results of our comparison of /l/s preceding reduced and unreduced vowels cannot be attributed to stress or syllabification, as these were held constant. Thus we conclude that some aspect of the vowel quality (be it backness, height, or reduction itself) is responsible for this effect.

When /l/ follows a reduced vowel, it is expected on the one hand to be light relative to other contexts (e.g., Yuan & Liberman, 2011a) because it is in the onset of a stressed syllable and, hence, in foot-initial position. Previous literature has, however, identified a darkening effect of preceding schwa. Huffman (1997) examines /l/s after schwa and finds

them to be darker than /l/s in initial consonant clusters. She suggests that /l/-darkening following schwa results from gestural separation between the /l/ and the stressed vowel making the /l/ gesture align more with the preceding vowel when there is a schwa. Strycharczuk and Scobbie (2017) found that /l/ after /ʊ/ was likely darker and showed less morphological conditioning than /l/ following /u/. This is also consistent with darkening for a more centralized vowel. Our results for the effect of preceding schwa were less consistent. Although an apparent darkening effect of a preceding reduced vowel is visible in the midpoint data in Fig. 6, this effect was significant at the onset of the /l/ and at 25% of its duration but not at the midpoint. This is perhaps consistent with Huffman's gestural alignment hypothesis with the alignment of the gestures shifting over the course of the /l/.

8.3 Lightening and darkening as initial strengthening and final lengthening

Our results demonstrate differences in /l/ darkness conditioned by morphological boundaries and are thus generally consistent with the body of literature demonstrating that morphological constituency correlates with subphonemic properties in the realization of segment strings (e.g., Lehiste, 1960).

One interpretation of these results is that morphological constituency affects prosodic boundaries, and that different realizations of /l/ reflect the effect of prosodic boundaries on the timing of gestures. In this view, /l/-lightening can be related to processes of domain-initial strengthening (e.g., Fougeron & Keating, 1996) and patterns of darkening can be related to pre-boundary and final lengthening (e.g., Byrd & Saltzman, 2003; Turk & Shattuck-Hufnagel, 2007), both of which affect the phonetic realization of individual speech sounds.

One type of prosodic boundary which is expected to affect the phonetic realization of /l/ is the syllable boundary. In classical generative accounts of /l/-darkening, a phonological rule changes the feature specifications of /l/ depending on its position within a syllable. For example, Halle and Mohanan (1985) propose a rule which changes the [–back] specification of /l/ to [+back] when the /l/ occurs in a syllable rhyme. However, Browman and Goldstein (1995) and Sproat and Fujimura (1993) argue that such rules miss a significant generalization concerning the coordination of gestures in distinct syllabic positions. /l/ is gesturally complex, involving both a tongue-tip gesture and a tongue dorsum gesture. In syllable onsets, these gestures are temporally aligned whereas in codas, the tongue dorsum gesture precedes the tongue-tip gesture. Sproat and Fujimura (1993) identify this difference in gestural timing as a key component of the distinction between dark and light /l/. Differences in gestural timing conditioned by syllabic position are not, however, specific to /l/, but are characteristic of consonantal articulations in general (Sproat & Fujimura, 1993). Browman and Goldstein (1995) discuss similarities in the timing relation between the apical and dorsal gestures of /l/ and the labial constriction and velum-lowering gestures of /m/. In onsets, the labial and velic gestures are aligned but in codas, the onset of velum-lowering precedes the labial closure, resulting in nasalization of the preceding vowel. Browman and Goldstein (1995) and Sproat and Fujimura (1993) thus argue that a specific rule of /l/-darkening misses the generalization that there is an intrinsic relation between gestural timing and syllabic position which is common to several, and possibly all, consonantal articulations. A similar account in terms of coordination and coupling strength is given in Scobbie and Pouplier (2010).

However, differences in acoustic measures of darkness in our results cannot all be attributed to coda/onset distinctions. In particular, the difference in darkness found between forms such as *knee-less* and *velum* is not straightforwardly attributable to syllabification

as the /l/ is expected to be syllabified as an onset in both forms. Syllabification may play a role in this difference if we appeal to the proposal that intervocalic consonants are ambisyllabic in trochaic forms (e.g., Kahn, 1976). Because stress and vocalic context are the same in *knee-less* and *velum*, ambisyllabicity is explanatory here only in combination with the proposal that the morphological boundary triggers a prosodic boundary which blocks syllabification of the /l/ as ambisyllabic in forms such as *knee-less*. In such an account, differences in gestural timing attributed to syllabic position may play a role in the darker realization of /l/ found in the morpheme-internal context. Smith, Baker, and Hawkins (2012) also say that syllabification can account for differences in timing between matched segments in mono-morphemic forms such as *mistakes* and poly-morphemic forms such as *mistimes*, if a prosodic boundary is posited to co-occur with the morphemic boundary.

Evidence for the effect of morphological constituency on gestural timing, regardless of theories of syllabification, is provided in Cho (2001). Cho (2001) uses EMA and EPG data to demonstrate that gestural coordination of phoneme sequences such as /ti/ and /ni/ is more consistent within monomorphemes than across morpheme boundaries. Although Cho's study considers gestural coordination across segments, our results are consistent with similar properties holding across distinct gestures within a single, complex segment. That is, the simultaneity of the tongue-tip and tongue-dorsum gesture associated with light /l/ may be more coordinated (more precisely simultaneous) when a word-internal /l/ occurs at a morpheme-boundary (e.g., *knee-less*) than when the /l/ is not adjacent to a boundary (e.g., *velum*). The lighter acoustic measures of morpheme-initial /l/ may follow from tighter gestural coordination. Lee-Kim et al. (2013) also extend the coupling analysis of Scobbie and Pouplier (2010) to morphological boundaries such that the tongue-tip and tongue-dorsum gestures couple with adjacent vowels more strongly within a morpheme.

In addition to coordinated phasing of complex gestures, morpheme- and syllable-initial position is subject to other processes identified as domain-initial strengthening. Consonants in initial position of prosodic domains have been shown to undergo articulatory strengthening both in English (Fougeron & Keating, 1996) and cross-linguistically (Keating, Cho, Fougeron, & Hsu, 1999). Articulatory strengthening in these studies is measured as greater linguopalatal contact and greater duration. The results of Smith et al. (2012) could also be interpreted as differences in articulatory strength conditioned by morpheme-boundaries, as they find greater aspiration of plosives in morpheme-initial position following a prefix boundary (e.g., *mistimes*) than following a segmentally identical pseudoprefix (e.g., *mistakes*). /l/-lightening shares articulatory properties with other forms of initial strengthening. Light /l/ has a greater degree of contact between the tongue tip and the palate than does dark /l/, making an analysis in terms of initial /l/-lightening consistent with Fougeron and Keating's (1996) general claim that initial strengthening is realized as greater linguopalatal contact.

The data in our study cannot, however, be accounted for with a process of initial lightening alone as many of our experiments show evidence of morpheme-final darkening. A final darkening pattern is particularly clear in the context of a following high, front vowel (e.g., *Healy* vs. *free-ly* vs. *meal-y*) where we found morpheme-initial and morpheme-internal /l/ patterning together in contrast to a darker realization of /l/ in morpheme-final contexts like *meal-y*. An analysis in terms of final darkening can also be analyzed as being triggered by morphological constituency and prosodic boundaries. Final darkening can be related to final lengthening. Lehiste (1980) demonstrates a correlation between the strength of a linguistic boundary and the length of the segments preceding the boundary. Turk and Shattuck-Hufnagel (2007) show that phrase-final syllables are lengthened, and Byrd and Saltzman (2003) provide evidence of general gestural slowing preceding prosodic

boundaries. The correlation of /l/-darkness and duration (e.g., Sproat & Fujimura, 1993; Yuan & Liberman, 2009, 2011a) supports an analysis in which some differences in /l/-darkness can be attributed to lengthening of /l/ in final position of a prosodic domain. Lengthening alone is not sufficient to account for the differences in darkness found across conditions in our data, however, as demonstrated by the inclusion of duration in our statistical models. In fact, we found a significant effect of duration only in the experiment comparing word-initial and –final /l/ in trochaic contexts (Experiment 1). An interaction of duration and differences in gestural timing conditioned by affiliation to constituents within the syllable, as suggested by Sproat and Fujimura (1993), may account for a substantial amount of the variation in darkness in our data.

Since our evaluation of /l/-darkness is based on acoustic, rather than articulatory, measures, accounting for differences in darkness in terms of gestural coordination or articulatory strengthening remains speculative. We nonetheless feel that the gestural account presented above is well-motivated in accounting for allophonic processes triggered by both preceding and following morpheme boundaries. Evidence for initial strengthening, final lengthening, and differences in gestural coordination of other segments is established for both syllabic boundaries and for morphological ones. Reference to these processes in the analysis of /l/-darkness allows the morphological effects demonstrated here and elsewhere to be mediated by the same mechanisms involved in observed effects of syllabic position since both are triggered by the presence of prosodic boundaries. This is an advantage of this account which is not apparent in studies that do not consider the impact of both following and preceding boundaries. Nonetheless, we acknowledge that our results are compatible with a wide range of analyses. This includes approaches in which there is a direct interaction between morphology and phonetics (e.g., Bybee, 2001), rather than one mediated by phonological categories and prosodic boundaries. Some support for this position is found in Strycharczuk and Scobbie's (2016) study of u-fronting and /l/-darkening in Southern British English where some speakers show a small but consistent distinction between /ul/ sequences in monomorphemes (e.g., *hula*) and preceding a morpheme boundary (e.g., *fool-ing*). They suggest that this pattern provides evidence of morphological conditioning of gradient phonetic processes.

Our experiments do not directly address the question of whether variation in /l/-darkness results from the distribution of categorically distinct allophones or gradient phonetic properties. Strengthening, lengthening, and changes in gestural timing are potentially gradient processes and the interpretation of our results given here is consistent with the view that /l/-darkness is a phonetic continuum. Our results are also consistent, however, with proposals arguing for a categorical alternation between allophonic categories coexisting with gradient phonetic effects (e.g., Yuan & Liberman, 2009, 2011a; Bermúdez-Otero & Trousdale, 2012; Turton, 2014, 2017). Turton (2014, 2017) uses articulatory discontinuity and bimodal distribution of quantitative articulatory measures as diagnostics for categoricity. She provides evidence for the coexistence of categorical and gradient patterning in the distribution of /l/-darkness for some speakers. The categorical component of an analysis using both categorical and gradient processes could consist of a change in feature values (e.g., Halle and Mohanan, 1985) or the replacement of the coronal node with a dorsal node as the primary articulator (Bermúdez-Otero & Trousdale, 2012) in a feature-geometric account. With respect to our data, a categorical rule of this type may apply in one position, such as morpheme-finally, and be overlaid with gradient phonetic effects of initial strengthening and final lengthening. Alternatively, a categorical distinction could also result from a change in gestural alignment which applies to consonantal gestures more generally (e.g., Browman & Goldstein, 1995), again, coexisting with gradient phonetic effects.

Although our findings are compatible with a number of proposed analyses of /l/-darkness, they do require that processes which condition variation in /l/-darkness must make reference to both preceding and following boundaries. Differences between morpheme-initial and morpheme-internal /l/ found in the context of following reduced vowels (e.g., *velum* vs. *knee-less*) cannot be accounted for with reference to syllable-final or morpheme-final position. Differences found between morpheme-final and morpheme-internal /l/ in the context of a following high-front vowel (e.g., *Healey* vs. *meal-y*) cannot be accounted for with reference to syllable-initial or morpheme-initial position. Our data as a whole thus require interacting processes which refer to the effect of both preceding and following boundaries.

9. Conclusion

This study provides evidence that North American English speakers have both morpheme-initial /l/-lightening and morpheme-final /l/-darkening. This dual pattern is only detectable once the effects of surrounding vowels are taken into account. In particular, we show that reduced vowels have a darkening effect on /l/, which can obscure morphological effects on /l/-realization. When studying the variation in the realization of /l/, we have to correct for contextual darkening and lightening effects in order to detect darkening and lightening conditioned by morphological factors. Earlier studies mostly considered environments in which /l/ is relatively light, and found evidence for /l/-darkening. The experiments reported on here show that when a wider range of segmental and prosodic contexts are considered, we find evidence of both /l/-darkening and /l/-lightening.

Additional Files

The additional files for this article can be found as follows:

- **Appendix A.** List of Stimuli. DOI: https://doi.org/10.5334/labphon.104.s1
- **Appendix B.** Mixed Effects Regression Models for Five Time Points Throughout /l/. DOI: https://doi.org/10.5334/labphon.104.s2

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Competing Interests

The authors have no competing interests to declare.

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