

Research Article

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Edge strengthening and phonetic variability in Spanish /l/: an ultrasound study

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Abstract: Previous research has shown that /l/ in Spanish displays patterns of articulatory variability that are determined by a complex interaction of phonetic, phonological and dialectal factors. In this study, we report the results of an experiment using Ultrasound Tongue Imaging (UTI) that tests /l/-articulations in a dialectal cross-section of Spanish speakers. We show that lengthening of /l/ in phrase-edge contexts is accompanied by articulatory distinctions (e.g. root/dorsum retraction) for some speakers, whereas others produce lengthened realisations of /l/ in these contexts without observable differences in tongue position. We also find acoustic evidence for reduction in utterance-medial intervocalic and preconsonantal environments (duration, intensity, F1 frequency measures are discussed). However, articulatory correlates of reduction are not consistently observed across speakers in these contexts. As well as relating the results to prosodically-driven strengthening and reduction patterns, our findings are of relevance to debates about resyllabification in Spanish. Specifically, we argue that our results cannot be straightforwardly accommodated under phonological analysis assuming that word-final consonants regularly resyllabify across word boundaries prevocally.

Keywords: articulation; reduction; Spanish laterals; strengthening; ultrasound

1 Introduction

In this paper, we discuss patterns of articulatory variability in Spanish /l/ on the basis of data from Ultrasound Tongue Imaging (UTI). In connection with previous research using other instrumental techniques such as electropalatography (EPG), this study

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makes two main contributions. Firstly, we examine to what extent variation in /l/ is attributable to the segmental context in which it occurs. Secondly, we consider what effect prosodic boundaries have on the realisation of /l/. Overall, the data bear upon the question of whether patterns of phonetic strengthening and weakening can be predicted on the basis of phonological structural factors. In addition to investigating the role that prosodic structure at different levels plays in this, we also query what the implications of phrasal resyllabification may be for determining patterns of articulatory variability.

1.1 Sonorant reduction in Spanish

We begin by surveying the literature on consonant reduction in Spanish. Given its importance as a phonetic feature of the language, consonantal reduction is discussed in all major descriptive works on Spanish, both early and more recent. The phenomenon of *Iberian Spirantisation* is well known and has been extensively studied both in Spanish (Gili-Gaya 1966; Hualde et al. 2011; Josselyn 1907; Martínez-Celdrán 1991; Mascaró 1991; Navarro-Tomás 1972) and other languages spoken in the Iberian Peninsula (e.g. Cruz-Ferreira 1995: 92; Hualde 1991: §4.2; Hualde et al. 2010a; Martínez-Celdrán and Regueira 2008; Mascaró 1991; Mateus and d'Andrade 2000: 10; Wheeler 2005: §2.1). Similarly, /s/-lenition in Spanish, commonly referred to as *aspiration*, has been the subject of extensive phonological, phonetic and socio-phonetic work (e.g. Broś 2020; Holmquist 2015; Kaisse 1996, 1999; Parrell 2012; Torreira 2006, inter alia). Yet despite being mentioned in phonetic descriptions of the language, sonorant reduction in Spanish has received less attention.

Reduction has been shown to occur both in /n/ and /l/-articulations in a number of Spanish varieties, and dialect-specific reductions of /r/ have also been documented (e.g. Ecuadorian rhotic assibilation, see e.g. Bradley 1999). Regarding nasals, the diachronic process of *nasal absorption* is of relevance, whereby coda nasals progressively weaken until the nasal consonant is lost and nasality is transferred onto the preceding vowel: e.g. $Vn > V^n > \tilde{V}$. In Spanish, word-final nasal velarisation (Harris 1984) has also been interpreted as reductive in some more recent accounts (e.g. de Lacy 2006; Piñeros 2006), and others have argued that velarisation could be an intermediate step in a diachronic trajectory towards nasal absorption (Trigo 1988). There is also evidence that the intervocalic /n/ in Spanish can be produced with reduced articulatory magnitude. Honorof (1999) compared realisations of intervocalic /n/ produced by three speakers of Peninsular Spanish using Electromagnetic Midsagittal Articulometry (EMA): /n/ was tested both word-medially and in the context of a preceding and following word boundary, i.e. in /VnV/, /V#nV/ and /Vn#V/ contexts. /n/ was found to be reduced in all of these contexts, particularly at faster

speaking rates, for two of the three participants. Honorof refers to this phenomenon as intervocalic nasal *deocclusivisation*. Similarly, Ramsammy (2012) observes on the basis of EPG data that dialect-specific realisations of word-final [n] and [ŋ] in Peninsular Spanish display evidence of reduction in word-final intervocalic position. That is, that linguo-palatal contact is significantly lower in phrase-medial /VN#V/ contexts compared to phrase-final prepausal /VN#/.

Existing research reveals that /l/ in Spanish may also be sensitive to reduction in intervocalic and preconsonantal environments. Similar to the vocalisation of nasal consonants, Alba (1979) discusses the occurrence of /l/-vocalisation in a rural Dominican dialect (i.e. Cibaño). Here it is noted that /l/ is realised as a high vocoid, both in word-medial and word-final preconsonantal contexts: e.g. [fajta] *falta* ‘lack’, [ajyo] *algo* ‘something’, [baujɛno] *baúl lleno* ‘full chest’. Consonantal /l/ is preserved word-medially in intervocalic (e.g. [dola] ‘dollar’) and postconsonantal contexts (e.g. [aβla] ‘speak.3sc’). Word-finally, intervocalic /l/ displays variation: e.g. pronominal *él* vocalises in [ejaβla] *él habla* ‘he speaks’, whereas the consonantal /l/ in the article *el* is preserved prevocally in [elombre] *el hombre* ‘the man’.

Hualde and Colina (2014: 189) note that neutralisation of coda /l/ and /r/ occurs in a number of Spanish dialects. In Puerto Rican Spanish, for example, the outcome of neutralisation varies between a consonantal /l/ and a rhoticised /l/ that is intermediate between a lateral and a tap: e.g. [po^hlfaβol] *por favor* ‘please’. Neutralisation of /l/ and /r/ has also been documented in Andalusian varieties. Hualde and Colina (2014) mention examples like [elohpitá] *el hospital* ‘the hospital’ and [muhé] *mujer* ‘woman’ in which final /l/ and final /r/, respectively, are categorically deleted. Coda /l/ can also be realised as [r] word-medially in examples like *alto* [arto] ‘high’, and in word-final preconsonantal contexts like [erniño] *el niño* ‘the boy’.

In studies with a more phonetic focus, EPG has been employed to examine variability in Spanish /l/. Kochetov and Colantoni (2011) tested the coronal consonants of Spanish focussing on Argentinian and Cuban dialects. All consonants were tested word-initially. In word-initial /l/, it was noted that EPG contact patterns show complete closure across the palate for speakers of both dialects. However, Argentinian speakers produced the /l/-closure at a more anterior location than the Cuban speakers. This difference in anteriority similarly affected realisations of /r/ in the two dialect groups.

Ramsammy (2021) used EPG to test the realisation of word-final /l/ in Peninsular Spanish. The results show patterns of gradient reduction of /l/ that depend both on the segmental context and the phonological position in which /l/ occurs. Of particular interest is the fact that /l/ displays a strong tendency for articulatory reduction in word-final prevocalic environments. Here, /l/ typically shows incomplete closure across the front area of the palate. This contrasts, for example, to word-final prepausal /l/ which consistently shows complete closure at a significantly more anterior

location on the palate. Realisations of phrase-final /el#/ therefore show some articulatory resemblance to the word-initial /l/-tokens produced by the Argentinian participants in Kochetov and Colantoni (2011). In turn, this suggests that /l/ may be subject to articulatory strengthening in certain contexts, such as prepausally.

One further study, whilst not dealing specifically with articulatory reduction, is relevant for the general discussion of /l/-variation in Spanish. Proctor (2011) studied liquid realisations in Spanish and Russian using ultrasound. For Spanish, data from 5 Latin American speakers were recorded. Productions of intervocalic /l, r, r/ were examined in three vowel contexts (namely /a_a/, /e_e/ and /u_u/) and compared to productions of /d/. Regarding /l/, three main points emerge from the analysis. Firstly, it was found that the speakers exerted more control on the position of the dorsum in /l/-realisations than in /d/-realisations: in fact, there was more variation in dorsum position in /d/ than in any of the liquids tested. Secondly, all liquids produced greater carry-over coarticulatory effects on following vowels than /d/. Thirdly, tongue position for /l/ was found to resemble the configuration for the vowel /e/, whereas /r/ has a more /o/-like configuration, and /r/ is more schwa-like.

1.2 Edge strengthening

The findings of the research discussed above indicate that /l/, like /n/, is subject to phonetic reduction in intervocalic contexts; but there is also evidence that /l/ may display phonetic strengthening elsewhere. A wealth of previous phonetic research has shown that segments adjacent to major prosodic boundaries (e.g. utterance, phonological phrase, intonational phrase, P-word), are produced with greater articulatory magnitude than in domain-medial contexts. Thus, whereas segments in domain-medial positions may be more likely to show signs of articulatory weakening, reduction or undershoot, the opposite is observed when segments occur at the edges of major prosodic domains. In this paper, we refer to this phenomenon as *edge strengthening*.

With reference to consonants, strengthening and weakening present a challenge to define concretely. This is because, depending on the class of sounds being referred to, the same phonetic features may be considered correlates of either enhancement or reduction. There may also be important differences between languages (cf. Torreira and Ernestus 2011). However, a number of existing studies have identified patterns of variation in duration, gestural magnitude/articulator displacement and linguo-palatal contact as potential correlates of strengthening and weakening in consonants. These features are commonly noted in studies that have aimed to study consonantal variation in different prosodic environments.

Edge-strengthening effects have been most extensively studied in English. In an EPG study on American English, Fougeron and Keating (1997) studied repetitions of the syllable /no/ in different prosodic positions. All speakers showed a tendency to produce /n/ with higher levels of linguo-alveolar contact in domain-initial positions than in domain-medial positions: this effect was observed within the utterance domain, the IP and the Phonological Phrase (Fougeron and Keating 1997: 3731).¹ Two of the speakers also showed increased contact in /n/ in domain-final syllables compared to domain-medial syllables. In a related study, Keating et al. (2003) compared the effects of domain-initial strengthening in the English data from Fougeron and Keating (1997) to new data from French, Korean and Taiwanese. A clear finding was replicated over the consonants tested for each language, i.e. /t/ and /n/, namely that domain-initial segments displayed robust effects of strengthening in high prosodic domains (i.e. the utterance and IP). Significantly less evidence of edge strengthening was found when these consonants occurred initially in lower domains (i.e. Accentual Phrase, word and syllable domains).

Keating et al. (1999) also used EPG to examine the realisation of English consonants across different syllabic and phrasal contexts. Within the syllable domain, /t, d, k/ showed a tendency to be produced with greater amounts of tongue contact in onset position than in coda position. A second experiment looked at the effect of phrase boundaries on /t, d, n, l/. When these consonants occurred as word-initial onsets, tongue contact was greater in phrase-initial position than phrase-medial position. Contact was generally reduced in all word-final coda realisations, and this reduction was more extreme phrase-medially than phrase-finally (i.e. prepausally).

EMA has also been applied to studying edge strengthening. Byrd et al. (2005) examined realisations of /p, f, t/ in onset versus coda position both at phrase edges (i.e. phrase-initially and phrase-finally) and phrase-medially. Durational measurements confirm that these consonants are articulated with longer closure durations in phrase-edge contexts than phrase-medially. Furthermore, onset realisations are generally longer than coda realisations. The results from articulatory tracking are somewhat less consistent than the strong durational trends, and articulatory strengthening (i.e. *spatial strengthening* in the authors' terms) "is not exhibited consistently across subjects, consonants or syllable position" (Byrd et al. 2005: 3867). However, the general finding of greatest relevance for the current study is that the majority of participants articulated /f/ and /t/ with a greater displacement of articulators and degree of constriction at phrase edges than phrase-medially.

Tabain (2003) reports data from an EMA experiment designed to test the effects of prosodic boundaries on the magnitude of /aC/-sequences in French. Similar to the

¹ See Cho and Keating (2009) for related work that compares /n/-realisations in domain-initial versus domain-medial positions with EPG.

results of Byrd et al. (2005), durations of the vowel /a/ and the following consonant—which was varied between /b, d, g, f, s, ʃ/—are longer when a high prosodic boundary intervenes between them (e.g. utterance or IP) than when a lower prosodic boundary intervenes (e.g. AP or word). Moreover, all three speakers show the largest displacement of the tongue body in utterance-initial consonant realisations. The degree of displacement shows progressive decline over smaller prosodic domains. A similar result obtains for the vowel /a/ (measured, in this case, by jaw displacement) for two of the speakers. The jaw is in its lowest configuration when the /a/ is followed by an utterance boundary. Progressively smaller displacements of the jaw are observed across the other domains, i.e. IP > AP > word.

1.3 Phrasal resyllabification

For Spanish, edge strengthening has not been extensively studied. However, the question of how prosodic structure interacts with strengthening and reduction patterns is important in relation to the somewhat contentious issue of *phrasal resyllabification*. Phonological descriptions of Spanish have generally assumed that word-final coda consonants resyllabify before vowel-initial words through coda capture: e.g. /los#otros/ → [lo.so.tros] ‘the others’ (Colina 1995, 1997, 2006, 2009b; Harris 1983, 1989; Hualde 1992; Robinson 2012; Roca 1992; Torreira and Ernestus 2012). This operation has played an important role in theoretical accounts of opaque alternations in Spanish.

For example, there is considerable cross-dialectal variation in the patterning of [h]-allophones of /s/ in aspirating Spanish dialects.² Kaisse (1999) discusses Buenos Aires Spanish in which [h]-realisations of /s/ are restricted to canonical codas: i.e. [dih.ko] ‘disco’, [deh.kar.ɣar] ‘discharge’, [doh.pa.lah] *dos palas* ‘two shovels’. In prevocalic contexts, resyllabification of /s/ through coda capture is argued to bleed aspiration, both word-medially and across word boundaries: e.g. /des-igual/ → [de.si.ɣual] ‘unequal’; /dos#alas/ → [do.sa.lah]. This scenario contrasts with other varieties—including Rio Negro Argentinian Spanish and a set of Caribbean dialects (‘Caribbean IP’ in Kaisse 1999)—where aspiration does occur prevocalically, but only in phrasal contexts. Hence, these varieties have [de.si.ɣual], as in Buenos Aires Spanish, but /dos#alas/ → [do.ha.lah]. A third pattern (Kaisse’s ‘Caribbean I’) shows aspiration both in phrasal environments like [do.ha.lah] and

² As noted in §1, aspiration (and also /s/-voicing) are sometimes described in terms of lenition, i.e. as a reduction or weakening of coda /s/. As categorical patterns, these are distinct from the non-discrete weakening of consonants that may occur in domain-medial positions, as described in §1.2. Other categorical allophony patterns that target sonorants, like nasal velarisation and rhotic assibilation, are similarly distinct from domain-medial weakening, as we refer to it here.

word-medially (i.e. [de.hi.yʎal]).³ In these cases, Kaisse argues that word-level resyllabification fails to displace prefix and word-final /s/ into the empty onset of the following syllable. Accordingly, /s/ in these environments remains in the coda and is a target for aspiration to [h]: i.e. in *desigual*, /des-igual/ → [deh.i.y-ʎal] → [de.hi.yʎal]; and in *dos alas*, /dos#alas/ → [doh.a.lah] → [do.ha.lah].

Bermúdez-Otero (2011) presents a similar solution to the problem of /s/-voicing in Highland Ecuadorian Spanish (cf. Bradley 2005; Colina 2009a; Lipski 1989; Robinson 1979; Strycharczuk et al. 2014). In this case, word-final /s/ voices to [z] before vowel-initial words despite the fact that word-medial intervocalic /s/ does not: i.e. [ga.za.kre] *gas acre* ‘acid gas’ versus [ga.sa] *gasa* ‘gauze’. Like Kaisse’s analysis of aspiration, Bermúdez-Otero proposes that examples like [ga.za.kre] are the result of two-stage computation. At the word level, the final /s/ in /gas/ is subject to a neutralisation process that removes laryngeal features from coda sibilants. This generates a laryngeally underspecified /S/ which is then categorically voiced by default when it resyllabifies into onset position in the phrasal domain: i.e. /gas/ → [gaS]_{WL} → [ga.za.kre]_{PL}. Since the /s/ in items like [ga.sa] never occurs in coda position at any point in its derivation, it is not a target for word-level delaryngealisation. It therefore also escapes default voicing to [z] at the phrase level.

A further example is Ramsammy’s (2013) treatment of opaque nasal velarisation. Here, it is argued that Peninsular velarising Spanish velarises word-final /n/ to [ŋ] and that this operation is strictly limited to final nasal codas at the word level. The occurrence of syllable-initial [ŋ] is therefore ascribed to phrasal resyllabification. Any word-final coda [ŋ] that is generated at the word-level resyllabifies into onset position at the phrase level in the context of a following vowel-initial word: e.g. /pan/ → [paŋ]_{WL} ‘bread’; /paŋ#a.θi.mo/ → [pa.ŋa.θi.mo]_{PL} ‘unleavened bread’.

These analyses collectively assume that resyllabification operates in a regular and exceptionless manner in Spanish: i.e. that any empty onset slot word-initially is obligatorily filled by capture of a preceding coda consonant, if one is present. However, more recent work has challenged this assumption. In particular, in an acoustic study on word-final /s/ in Peninsular Spanish, Strycharczuk and Kohlberger (2016) show that word-final prevocalic /s/ is characterised by a longer acoustic duration than /s/ in preconsonantal coda position and a shorter duration than /s/ in canonical onset positions (i.e. both word-medially and word-initially). The fact that /s/-duration in the /Vs#V/ context is intermediate between /Vs(#)C/ and /V(#)sV/ contexts is argued to be evidence for incomplete phrasal resyllabification (see also Hualde and Prieto 2014). Relatedly, Ramsammy (2021) argues that the high degree of reduction observed in realisation of word-final prevocalic /l/ is unexpected under the

3 See also Broś (2020) on Chilean Spanish, which resembles the Caribbean I pattern.

view that word-final consonants resyllabify across a word boundary in prevocalic contexts. More specifically, if this process does indeed apply in Spanish, it does not predict a pattern whereby /l/ in derived onset position displays consistently less palato-alveolar contact than /l/ in any of the coda environments that were tested.

1.4 The current study

The findings of the previous research summarised above motivate the research questions that we seek to address in the present study. These are as follows:

- RQ1: To what extent does /l/ vary acoustically and articulatorily depending upon the location of prosodic boundaries?
- RQ2: Is there evidence of strengthening of /l/ when it occurs at major prosodic boundaries and evidence of relative reduction of /l/ in other contexts?
- RQ3: Does /l/ have the same realisation in all intervocalic environments, or do prosodic boundaries play a role?
- RQ4: To what extent do the results in respect of RQ2 and RQ3 provide evidence for the operation of resyllabification across word boundaries in Spanish?

RQ1 asks whether phrase-initial and phrase-final realisations of /l/ will display effects of domain-edge strengthening resembling those reported in the studies discussed in Section 1.2. We also seek to investigate to what extent domain-edge strengthening effects may be dialect-specific or more general. RQ2 asks to what extent intervocalic reduction in /l/ affects the tongue position in the two dimensions that are captured by UTI (i.e. tongue height and tongue advancement/retraction). Relatedly, RQ3 poses the question of whether the occurrence of different prosodic boundaries may condition articulatory reduction in /l/. As discussed in Section 2 below, we test /l/ in three different intervocalic environments, namely /VlV/, /V#lV/ and /Vl#V/. We focus specifically on /l/ given that it occurs freely in these environments in Spanish.⁴ As well as investigating whether a P-word boundary intervening between a preceding or following vowel and /l/ will attenuate or even enhance the effects of intervocalic reduction, RQ4 queries whether /l/ in the putative resyllabification context—i.e. /Vl#V/—will display phonetic behaviour that differentiates it from other intervocalic contexts where /l/ is not a target for resyllabification.

⁴ Unlike other sonorants that show a similar distribution, previous research on /l/ has confirmed that it is relatively stable in articulatory terms (Proctor 2011). /l/ seldom participates in dialect-specific allophony (in contrast to nasals, rhotics and /s/, which, cross-dialectally, more frequently exhibit velarisation, assibilation and voicing, respectively).

The rest of the paper is organised as follows. Section 2 describes the methods employed in the study. The results are then presented in Section 3. Section 4 is a discussion of the salient patterns in the data centring around the research questions listed above, and Section 5 concludes the paper.

2 Methods

2.1 Participants

15 native speakers of Spanish were recruited for the study. All received a £10 payment for participation. The age range of the participants was 20–40, with a mean age of 29:7. 9 speakers self-identified as female, and 6, as male. Data from one female speaker from Mexico and one male speaker from the Canary Islands were excluded prior to annotation due to poor ultrasound image quality. We therefore included the 13 speakers listed in Table 1 below in the analysis.

As noted, we chose to recruit a diverse group of speakers specifically in order to explore whether any patterns of /l/-variation might be observable cross-dialectally. CaF1 and CaM1 are simultaneous Catalan-Spanish bilinguals, and are therefore considered separately from the Spanish participants who do not also speak Catalan (i.e. SpF5, SpF6, SpF7, SpF8 and SpM5). ChM2 is a Chilean Spanish-English early bilingual who has been simultaneously exposed to both languages since birth. The other participants are all second-language speakers of English having acquired

Table 1: Participants in the study.

Speaker code	Gender	From
CaF1	Female	Catalonia, Barcelona
CaM1	Male	Catalonia, Barcelona
ChM2	Male	Chile, Santiago
ChM3	Male	Chile, Viña del Mar
CoF2	Female	Colombia, Bogotá
CoF3	Female	Colombia, Bogotá
MeF4	Female	Mexico, Chihuahua
MeM4	Male	Mexico, Mexico City
SpF5	Female	Spain, Badajoz
SpM5	Male	Spain, Cádiz
SpF6	Female	Spain, Gran Canaria
SpF7	Female	Spain, Madrid
SpF8	Female	Spain, Oviedo

English late through educational instruction. We also note that speaker SpM5 speaks an Andalusian variety of Spanish that shows significant phonological differences from the varieties spoken by the other Spanish and Latin American participants. We report on these differences in Section 3.

2.2 Procedure

An EchoBlaster 128 ultrasound machine and 20 mm probe (depth = 90 mm, field of vision = 81.89°) were used for this experiment. Recording took place in a sound-attenuated room. Participants wore a head stabilisation unit (Articulate Instruments Ltd.) which holds the ultrasound probe in a fixed position under the chin during recording. The experiment was administered in the *Articulate Assistant Advanced* software platform (AAA, Wrench 2003–2021). Ultrasound and audio recordings were taken simultaneously using AAA's automatic synchronisation.⁵ Ultrasound images were captured with an average framerate of 68 frames per second. Audio data were recorded with a sampling rate of 22.1 kHz using a lavalier microphone (Sony ECM-55B) attached to the head stabilisation unit.

Participants were presented with stimuli on a computer screen and asked to read them aloud. The stimuli are listed in Table 2 below: the IPA transcriptions represent a relatively conservative Latin American variety (e.g. Standard Mexican Spanish). These are short, meaningful phrases designed to test the phonetic realisation of /l/ in a range of phonological environments. Target stimuli were presented in a fully randomised order along with distractors that were included with the goal of obscuring the purpose of the experiment. Speakers read either four or five repeats of the stimulus set depending upon the time that was available for recording.⁶ A small number of productions containing reading errors or disfluencies were discarded prior to analysis.

As indicated, these stimuli assume a version of the prosodic hierarchy in which the prosodic phrase, φ , dominates the prosodic word, ω , and the prosodic word in turn dominates the syllable, σ (Nespor and Vogel 1986). All of these phrases constitute a single IP and Utterance, such that /l/s at the edges of the φ -domain also

⁵ AAA generates a hardware pulse on completion of each ultrasound frame. This series of pulses is recorded on channel 2 of the computer's soundcard with the speech audio recorded on channel 1. An automatic process detects the rising edge of each pulse, notes the time in the recording and tags the corresponding ultrasound frame with this time (Alan Wrench, p.c., Jan 2023).

⁶ We were limited to c. 20–30 min per speaker. Beyond this timeframe, wearing the head stabilisation unit can cause discomfort to participants.

Table 2: Stimuli.

Target phrases			Morpho-syntactic context	Prosodic domain		
				ϕ	ω	σ
a.	<i>Leen los libros</i> [leen los liβros]	'They read the books'	[_{Phr} [_{Wd} le-...]	initial	initial	initial
b.	<i>Hay otro nivel</i> [aɪ otro niβel]	'There is another level'	...-el _{Wd}] _{Phr}]	final	final	final
c.	<i>Pelen las patatas</i> [pelen las patatas]	'Peel the potatoes'	[_{Wd} ...-ele-...]	medial	medial	initial
d.	<i>Los libros se leen</i> [los liβros se leen]	'Books are for reading'	...-e _{Wd}][_{Wd} le-...]	medial	initial	initial
e.	<i>Un nivel emancipado</i> [un niβel emansipaðo]	'An emancipated level'	...-el _{Wd}][_{Wd} e-...]	medial	final	final ^a
f.	<i>Afelpen los sillones</i> [afelpen los siʎones]	'Upholster the armchairs'	[_{Wd} ...-elpe-...]	medial	medial	final
g.	<i>Un nivel personal</i> [un niβel personal]	'A personal level'	...-el _{Wd}][_{Wd} pe-...]	medial	final	final
Distractor phrases						
h.	<i>Cuidan los libros</i> [kuiðan los liβros]	'They look after the books'				
i.	<i>Hay otro grupo</i> [aɪ otro grupo]	'There is another group'				
j.	<i>Corten las cebollas</i> [korten las seβoʎas]	'Cut up the onions'				
k.	<i>Los libros se cuidan</i> [los liβros se kuiðan]	'Books are looked after'				
l.	<i>Un grupo emancipado</i> [uŋ grupo emansipaðo]	'An emancipated group'				
m.	<i>Forren los sofás</i> [foren los sofas]	'Upholster the sofas'				
n.	<i>Un grupo personal</i> [uŋ grupo personal]	'A personal group'				

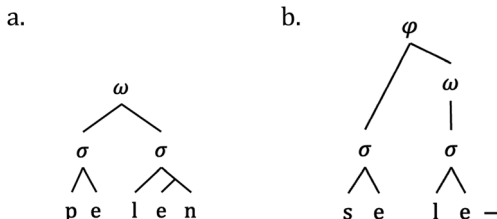
^aPotential target for phrasal resyllabification.

occur at the edges of the IP and the Utterance domains. Items (a) and (b) in Table 2 test the realisation of /l/ in ϕ-initial and ϕ-final contexts, respectively. In both cases, the /l/ is flanked by a stressed /e/. These are the domain-edge sites where we expect to observe effects of edge strengthening. Items (c–e) test /l/ in intervocalic environments where /e/ is also used as the flanking vowel (i.e. both preceding and following the /l/).⁷ In (c), /l/ occurs in a grammatical word-medial context. This

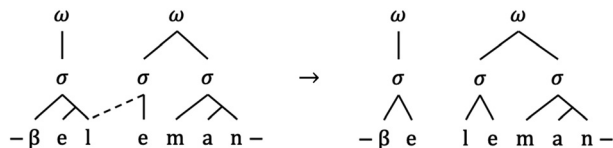
⁷ /e/ was chosen as the flanking vowel for number of reasons. These include image clarity: generally, the surface of the tongue is clearly visible along the root, body and blade in /e/-articulations. /e/ may

contrasts to (d), in which /l/ is grammatical word-initial after the clitic *se*. /l/ is grammatical word-final in (e). These items therefore test /l/ in the following prosodic structures:

- (1) Non-domain-final /l/: *pelen* and *se leen*



- (2) Resyllabification in *nivel emancipado*



In (1a), /l/ is σ -initial and ω -medial: it therefore coincides with the left edge of the lowest prosodic domain. In (1b), /l/ is in a more prominent position: it is syllable and prosodic word-initial, i.e. within the ω -domain that does not include proclitic *se*. (2) is the environment of particular interest for assessing the application of phrasal resyllabification. In its citation form, /l/ is syllable and word-final in the word *nivel*. However, if word-final resyllabification operates as shown, then this /l/ moves to a stronger prosodic position: i.e. it becomes syllable and prosodic-word initial. This entails the non-trivial assumption of *strict layering* (Nespor and Vogel 1986; Selkirk 1984, 1986): i.e. grammatical word-final /l/ in cannot be captured as the onset of a following syllable and simultaneously belong to the prosodic word [$_{\omega}$ ni β el].

Items (f) and (g) test the realisation of /l/ in preconsonantal position: i.e. preceding a word-medial /p/ in (f) and preceding word-initial /p/ in (g).⁸ As production of /p/ involves no lingual place-of-articulation gestures, these sequences

also be described as the phonologically “neutral” or unmarked vowel of Spanish. It has no distributional restrictions and it is the vowel used in epenthesis contexts, such as in adaptation of loanwords (e.g. [estandar] ‘standard’ or [esno β] ‘snob’ etc.). As already noted, Proctor (2011: 462) describes Spanish /l/ as having a similar dorsal target to /e/, such that flanking /e/ is probably the best choice in terms of attempting to minimise the coarticulatory influence of surrounding targets.

⁸ We acknowledge that *afelpar* is a marginal lexical item that speakers are unlikely to encounter in everyday spoken language. Words containing the /lp/ sequence are rare in Spanish, and we were limited to choosing the inflected form *afelpen* in order to maintain the /e_e/ vowel context.

were chosen with a view to avoiding the coarticulatory effect of other lingual obstruent targets.⁹ We include stimuli containing preconsonantal /l/ in order to provide a point of comparison between /l/ in this potential reduction site and /l/ in intervocalic position. Comparison of (f) and (g) further permit us to observe whether the occurrence of a ω -boundary in *nivel personal* has an effect on the reduction of /l/ in preconsonantal coda position.

2.3 Data reduction and analysis

2.3.1 Acoustic analysis

Audio recordings were exported into Praat (Boersma and Weenink 1992–2019) where /l/-realisations were hand-segmented through visual inspection of the waveform and spectrogram (see Figure 1). With the exception of phrase-initial /#le/, all /l/-realisations are postvocalic: discontinuities in the vocalic waveform coinciding with a loss of amplitude and change in formant structure (particularly F2) were used to identify the left segment boundary for [l]. The same features were used to identify the right segment boundary in prevocalic /l/-tokens. The acoustic onset of phrase-initial /l/ was identified at the onset of periodic voicing, and the acoustic offset of phrase-final /l/ coincided with a cessation of periodic voicing or an observable change in formant structure and established waveform pattern. The offset boundary for /l/ before /p/ was established at a point coinciding with reduction in amplitude and a loss of formant structure.

Following segmentation, acoustic measures were extracted by script. These included duration measurements, frequency of F1 and F2, and intensity minima and maxima in each /l/ and surrounding vowels. We measured the full acoustic duration of each /l/-realisation. /l/-duration values were log transformed to correct for a slight positive skew in the data. Formant frequency values were extracted at three time points, namely 10 %, 50 % and 90 % of full /l/-duration, using Praat's Burg algorithm with a window length of 25 ms. The maximum number of formants was set at 5 and frequency ceilings were set at 5 kHz for male speakers and 5.5 kHz for female speakers. Formant-frequency data were then normalised through z-transform for comparative analysis. As discussed below, we modelled F2–F1 Euclidian Distance (cf. Holmes-Elliott and Smith 2018) as well as fitting separate models for normalised F1 and F2.

⁹ For the same reason, we selected test words containing labial or labio-dental consonants in the vicinity of the target /l/ where possible: e.g. the verb *pelar* in (b) and the phrase *nivel emancipado* in (e).

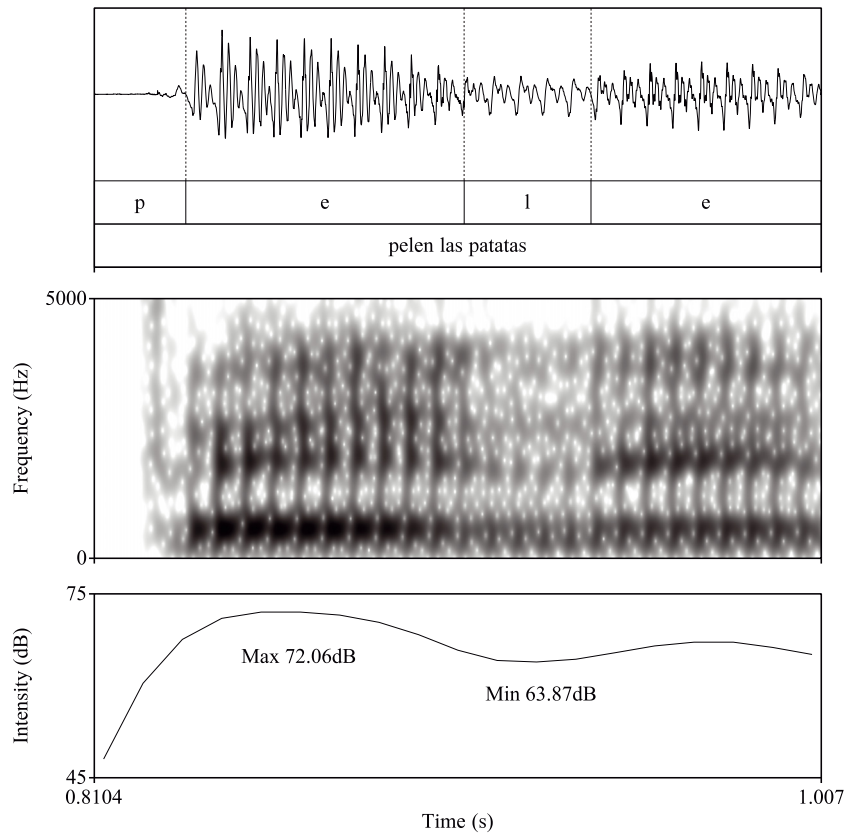


Figure 1: Segmentation of /l/ from the test word *pelen*, as produced by SpM5. Minimum and maximum intensity values used for the calculation of IntDiff are also shown on the intensity contour in the bottom panel.

Intensity minima and maxima were calculated using Praat’s cubic interpolation algorithm on unfiltered recordings. Whereas some studies employing intensity measures apply a filter above a certain frequency threshold to minimise effects of voicing, we determined this to be unnecessary for studying variation in /l/ (cf. Hualde and Zhang 2022: 8). Intensity values extracted from each token were then used to calculate *Intensity Difference* (henceforth, IntDiff), which quantifies the difference between the intensity minimum in each /l/ and the intensity maximum in the adjacent stressed vowel: thus, /lé/ for environments (a) and (d) in Table 2 and /él/ for (b), (c) and (e–g). This measure has previously been employed in the analysis of stop lenition in Spanish (Carrasco et al. 2012; Hualde et al. 2011), Catalan (Hualde

et al. 2010b; Hualde and Zhang 2022), Galician (Martínez-Celdrán and Regueira 2008) and Italian (Hualde and Nadeu 2011). In this study, we aim to assess whether IntDiff measurements correlate with patterns of /l/-variability across phonological contexts.

Statistical analysis of acoustic measurements was conducted using linear mixed-effects regression in R with the *lme4* (Bates et al. 2017) and *lmerTest* (Kuznetsova et al. 2020) packages. Post-hoc comparisons with Bonferroni adjustments were implemented using the *emmeans* package (Lenth et al. 2018) and plots are generated using *ggplot2* (Wickham et al. 2021). All models contained the factor *Context* as a fixed effect and a random intercept for *Speaker*. Models including *Dialect* and *Gender* as fixed effects were also fitted; however, inclusion of these predictors rarely improved fit. We attempted to fit models with an additional random intercept for *Average Syllable Duration*, which was calculated on a phrase-by-phrase basis. This typically created convergence issues that could not be resolved, such that *Average Syllable Duration* was dropped from the final models. Full model summaries are provided in the Appendix (Tables 5–9).

2.3.2 Articulatory analysis

As per usual practice, ultrasound data were recorded with the tongue tip to the right and the tongue root to the left (see Figure 2). The outline of the tongue in the first ultrasound frame in each /l/-realisation was hand traced along its visible surface in AAA (cf. Lawson et al. 2013). Spline tracing in following ultrasound frames was then automated using the *Track* function in AAA with subsequent hand correction where

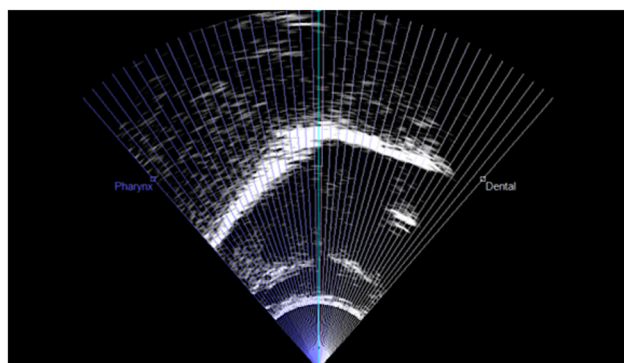


Figure 2: 42 fanpoints and tongue image in a single ultrasound frame extracted from the /l/-realisation in the word *pelen* produced by speaker SpM5.

necessary. Cartesian coordinate data from 42 fanpoints were extracted from all ultrasound frames corresponding to the full acoustic duration of each /l/.

Since the data come from both females and males, differences in oral tract size and shape—which can often be minimised in analysis of acoustic data by normalisation techniques—are particularly difficult to overcome when dealing with UTI data. This is further complicated by the fact that UTI records a different area of the tongue surface for each speaker. The probe is also situated at a different angle for every speaker, which is necessary both to ensure reasonable comfort for the speaker during the experiment and to achieve good image quality in recordings.

Our method for dealing with this issue was to rotate coordinate values on a speaker-by-speaker basis. This technique is typically used in research using other articulatory imaging methods, particularly EMA, and has been applied to UTI data in a number of studies (e.g. Heyne et al. 2019; Mielke et al. 2017; Strycharczuk and Scobbie 2017a; Strycharczuk and Sebrechts 2018). Rotation was carried out in MATLAB (The MathWorks 2021). As shown in Figure 3, the rotation point used was the highest y-value in averaged tongue contours representing the temporal midpoint of stressed /e/-realisations occurring in proximity to the target /l/s in each test item (cf. Heyne et al. 2019, who use maximal readings from the vowel /i:/ as a basis for rotation).¹⁰

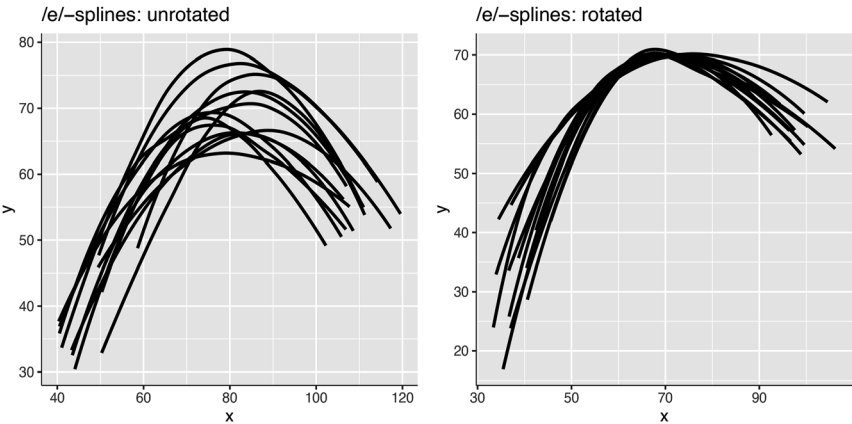


Figure 3: /e/-splines before (left) and after (right) centring and rotation. Splines represent the tongue position at the midpoint of stressed /e/ for each of the 13 individual speakers averaged over all realisations of the target stimuli listed in Table 2.

¹⁰ We are grateful to Donald Derrick for this suggestion.

Occlusal plane measurements that are sometimes used for calculating speaker-specific degrees of rotation were not available (cf. Strycharczuk and Scobbie 2017a, 2017b). We therefore estimated the optimal degree of rotation for each speaker based on the best visual alignment of splines that could be achieved.

Identifying patterns of variation also presents a challenge due to the high dimensionality of the data. We took two approaches to reducing this. Firstly, raw coordinate values extracted from /l/-realisations were rotated using the same speaker-specific degrees of rotation estimated on the basis of /e/-measurements. Data from all speakers were then pooled and submitted to a Principal Components Analysis. Values for the first six Principal Components (corresponding to c. 90 % of variation) were normalised by speaker using z-transform and further subjected to a Linear Discriminant Analysis (LDA). The LDA was trained on all test contexts listed in Table 2: this was performed using normalised Principal Components from ultrasound frames that occurred between the acoustic onset and offset of each /l/ (as determined by segmentation on the basis of acoustic landmarks, cf. Figure 1). We then used the timestamps on individual ultrasound frames and acoustic duration measures of each /l/ to calculate and plot time-normalised LD1 values for each test context in order to identify dynamic changes in the articulatory data over time (see §3.2; cf. Strycharczuk and Scobbie (2017b) and Strycharczuk and Sebrechts (2018) for a similar technique based on pixel-based analysis of UTI recordings).

Secondly, raw cartesian coordinate values were converted to polar values for the purpose of fitting splines for each test context on a speaker-by-speaker basis. This enables us to visualise fine-grained differences in tongue position across test contexts that are not identifiable in the time-aligned analysis. Spline fitting was carried out using GAMs (implemented using the *mgcv* package in R: Wood 2021). Polar coordinates were chosen in preference to cartesian coordinates as the former can produce a better fit, particularly at the periphery of the fan (cf. Mielke 2015; Recasens and Rodríguez 2016: 62). We included coordinate data extracted from all frames in each /l/-token, thereby taking into account changes in the configuration of the tongue over the full acoustic duration of each /l/. This yields a more conservative fit than one calculated on a single reference frame per token (e.g. acoustic midpoint or point of maximal tongue displacement). Fitted values for each test context were then converted back to cartesian coordinates and centred and rotated on a speaker-by-speaker basis in the same way as outlined above. The outcome of this process is illustrated in Figure 4: this shows fitted splines for all speakers in a subset of the /l/-data (namely the /ele/-test context) before and after rotation.

In the visualisations presented in §3.3, fitted /l/-splines are plotted with corresponding 95 % confidence intervals. As with the SS-ANOVA technique that has often been employed in the analysis of UTI data (e.g. Davidson 2006; Howson et al. 2014;

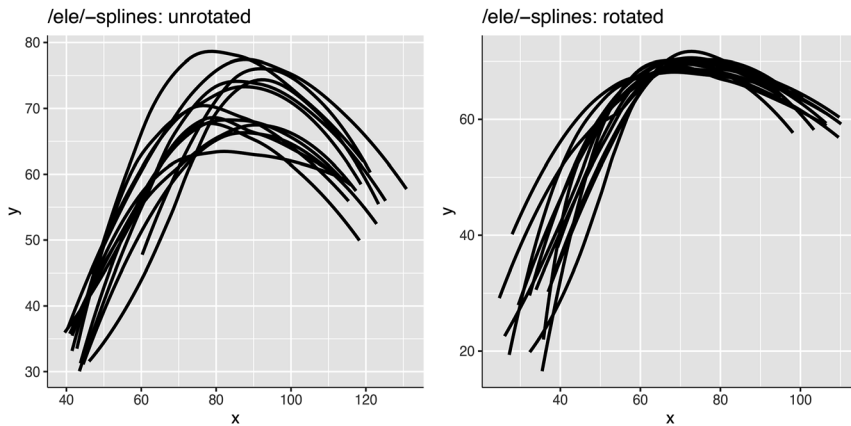


Figure 4: /l/-splines before (left) and after (right) centring and rotation. Splines represent the fitted tongue position for each of the 13 individual speakers calculated on coordinate data extracted from all repetitions of stimulus (c) in Table 2 (i.e. the /ele/ test context).

Kochetov et al. 2014; Lee-Kim et al. 2013; Mielke 2015; Strycharczuk and Sebrechts 2014) and the *loess* smoothing technique employed in Turton (2017), spline points where confidence intervals do not overlap indicate significant differences between tongue configurations.

3 Results

In §3.1 below, we first present the results from acoustic analysis and then discuss the UTI data in §3.2. It was necessary to exclude some data from SpM5 who, as noted, speaks an Andalusian variety of Spanish. SpM5 deleted all instances of utterance-final /l/, producing *nivel* as [ni'βe]. All recordings were carefully checked for acoustic or articulatory traces of an /l/-like articulation in this environment, but none were found. Furthermore, whereas SpM5 articulated an [l] consistently in both the word-initial intervocalic and word-medial preconsonantal environments (i.e. /e#le/ and /elpe/), this was not the case in the parallel word-final contexts. In /el#e/, the /l/ was realised as [l] in 2 out of 5 repetitions and was fully elided in the other 3. In /el#pe/, the /l/ was realised as [ɾ]. Whilst this is consistent with existing descriptions of Andalusian speech (e.g. Hualde and Colina 2014: 189, as mentioned), this speaker never produced /l/-rhotacisation word-medially (i.e. in the /elpe/ environment). In view of these facts, we removed all tokens of /el#/, /el#e/ and /el#pe/ produced by SpM5 from the analysis.

3.1 Acoustic analysis

3.1.1 /l/-duration

Pooled duration values for all test contexts are plotted in the left panel of Figure 5 below. Observe that /l/ has comparatively higher durations in both utterance-peripheral contexts than in utterance-medial contexts. Mean duration reaches 79.3 ms for /#le/ and 91.9 ms for /el#/. By contrast, /l/ is shortest in the word-medial intervocalic environment (i.e. /ele/, mean duration = 55.6 ms) with comparable values in the word-final intervocalic environment (i.e. /el#e/, mean duration = 57.5 ms) and both preconsonantal environments (i.e. mean values of 55.7 ms for /elpe/ and 58.1 ms for /el#pe/, respectively). Utterance-medial word-initial /l/ displays a longer duration than /l/ in all other utterance-medial contexts (i.e. a mean duration of 73.8 ms in /e#le/). Thus, /l/-duration appears to pattern on a scale of /el#/ > /#le/ > /e#le/ > /ele/, /el#e/, /elpe/, /el#pe/ from longest to shortest values.

These facts are confirmed by inferential testing. As noted, duration values were log transformed for the purpose of regression modelling. The best-fit model for duration includes Context as a fixed predictor and a random intercept for Speaker. Inclusion of Gender and Dialect as fixed effects did not improve model fit. A strong main effect of Context was observed: fitted values are plotted in the right panel of Figure 5. In comparison to the reference value (i.e. /ele/), /l/ is longer in the following environments: /#le/, $t = 9.864$, $p < 0.001$; /el#/, $t = 16.908$, $p < 0.001$; /e#le/, $t = 7.155$, $p > 0.001$. No significant differences between /ele/ and other utterance-medial contexts obtained: /el#e/, $t = 0.939$, $p > 0.05$; /elpe/ $t = 0.241$, $p > 0.1$; /el#pe/ $t = 1.027$, $p > 0.05$. Post-hoc comparisons further confirm that utterance-final /l/ is longer than /l/ in other contexts ($p < 0.001$ for all comparisons). Utterance-initial /l/ is longer than all

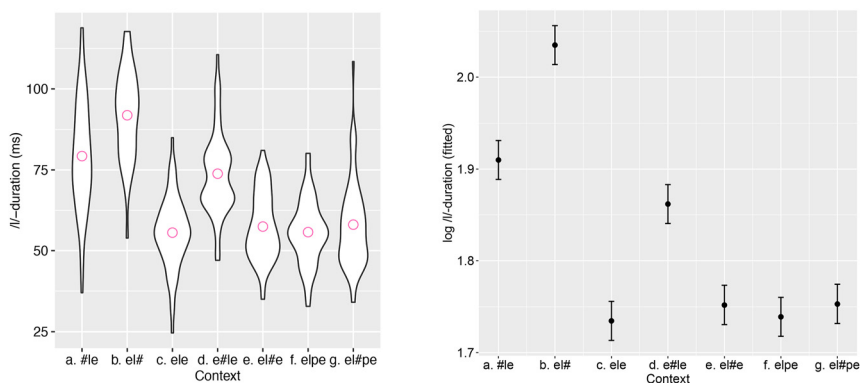


Figure 5: *Left panel:* /l/-duration in ms (circles represent mean values). *Right panel:* fitted values for log-transformed duration with 95 % confidence intervals.

instances of utterance-medial /l/ ($p < 0.001$ for all comparisons), and /l/ in the /e#le/ environment is also longer than in all other utterance-medial contexts ($p < 0.001$ for all comparisons).

3.1.2 Formant analyses

As detailed in §2.3.1, measurements of F1 and F2 were extracted at 0.1, 0.5 and 0.9 normalised timepoints in each /l/-realisation. Measures of F2–F1 Euclidian Distance at each timepoint per context were also calculated: these are plotted in Figure 14 in the Appendix. In all environments, we observe lower Euclidian Distance values at the durational midpoint than at the 10 % and 90 % durational landmarks. We infer from this that measurements extracted at the 50 % point provide a more accurate characterisation of the acoustic quality of /l/—i.e. at a point where coarticulatory influence from surrounding segments is minimal. We therefore opted to exclude values representing the 10 % and 90 % durational landmarks from the analysis.

Figure 6 shows normalised values for F1, F2 and F2–F1 Euclidian Distance at the durational midpoint of /l/ in each experimental context. We note that contextual differences in Euclidian Distance are quite small: values are highest in the /ele/ environment and lowest in the /el#pe/ environment. This effect is mirrored in the F2 data. F1 values, by contrast, show greater differences across test contexts. Mean values for normalised F1 pattern below 0 in the contexts where significant lengthening of /l/ was observed, namely, utterance-initially (–0.359), utterance-finally (–0.313) and in utterance-medial word-initial /l/ (–0.286). In the other environments where shorter /l/-durations were observed, mean values for normalised F1 are greater than 0: i.e. /ele/, 0.281; /el#e/, 0.359; /elpe/, 0.102; and /el#pe/, 0.0667.

Regression models with Context as a fixed effect and a random intercept for Speaker were fitted for Euclidian Distance and F2. For Euclidian Distance, a minor effect of Context obtained. As can be observed in Figure 6, this is due to the relatively high values in the /el#/ and /ele/ environments in comparison to the relatively low values in /el#pe/: /el#/~/el#pe/, $t = 4.043$, $p < 0.05$; /ele~/~/el#pe/, $t = 4.141$, $p < 0.01$. No other comparisons reached significance. Similarly, for F2, values in /el#pe/ are lower than in /el#/ ($t = 3.145$, $p < 0.05$) and /ele/ ($t = 4.435$, $p < 0.01$).

As expected, contextual effects on F1 are more robust. In addition to Context, the F1 model was fitted with Gender as an additional fixed effect, a Context $\times$ Gender interaction term and a random intercept for Speaker. Significant main effects of Context and Gender were observed, and a significant interaction. For Context, in comparison to the reference value, /ele/, F1 is significantly lower in /#le/ ($t = -5.819$, $p < 0.001$), /#el/ ($t = -6.462$, $p < 0.001$) and /e#le/ ($t = -4.885$, $p < 0.001$). Regarding Gender, F1 values are generally lower for male speakers than for female

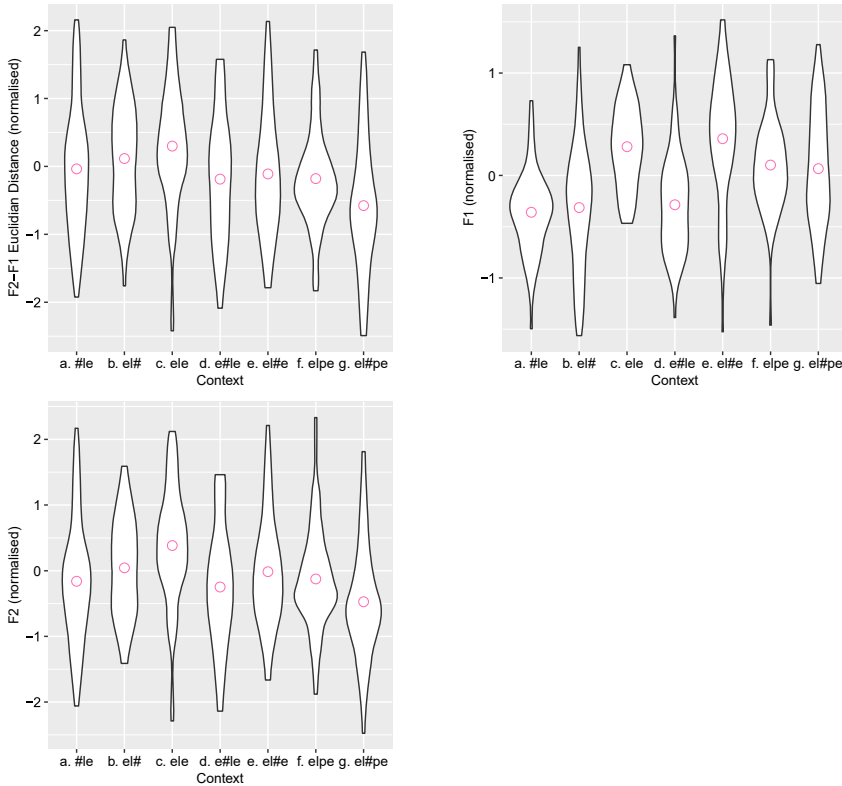


Figure 6: Formant frequency data extracted from the durational midpoint in /l/-realisations. Plots show z-scores for F2-F1 Euclidian Distance (upper left), F1 (upper right) and F2 (lower left). Circles indicate mean values.

speakers ($t = -3.318$, $p < 0.01$). Post-hoc comparisons reveal that this effect is only significant in the /el#e/ environment: female ~ male, $t = 3.549$, $p < 0.05$. In all other environments, the gender-based patterns are insufficiently robust to achieve significance ($p > 0.1$ in all cases): /#le/, $t = 0.343$; /el#, $t = -2.382$; /e#le/, $t = 0.26$; /elpe/, $t = 1.599$; /el#pe/, $t = 1.197$.

3.1.3 Intensity Difference

The regression model for IntDiff included Context as a fixed effect and a random intercept for Speaker. A strong main effect of Context was observed: fitted values for all test contexts are plotted in Figure 7. Values are significantly higher than the

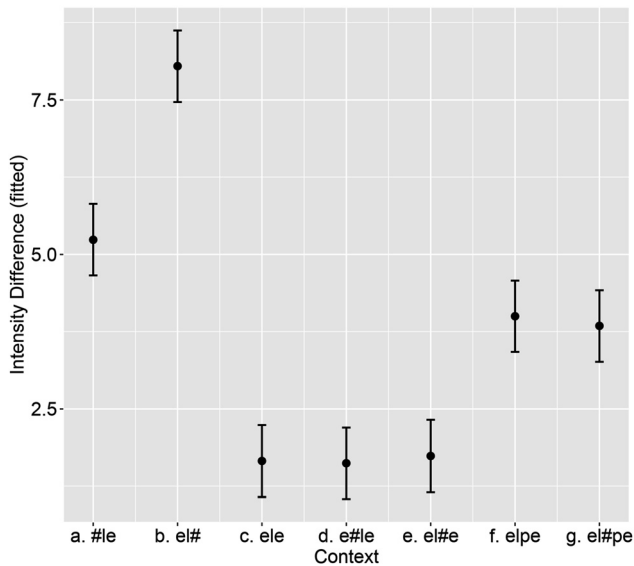


Figure 7: Predicted values for IntDiff per test context.

reference level, /ele/, for all levels of Context except /e#le/ and /el#e/: /#le/, $t = 8.811$, $p < 0.001$; /el#, $t = 15.712$, $p < 0.001$; /elpe/, $t = 5.759$, $p < 0.001$; /el#pe/, $t = 5.376$, $p < 0.001$. By contrast, marginally lower values are observed in /e#le/ ($t = -0.09$, $p > 0.1$) and marginally higher values in /el#e/ ($t = 0.197$, $p > 0.1$). This is interesting in regard to the fact that realisations of /l/ in the /e#le/ environment pattern with /el#/ and /#le/ for both duration and F1 in showing significant differences from all other test contexts. For IntDiff, by contrast, /e#le/ clearly patterns with the other utterance-medial intervocalic environments (i.e. /ele/ and /el#e/).

As indicated by the mean values listed in Table 3, this result obtains because minimum intensity readings in the intervocalic /l/ contexts are very close to the maximum intensity readings registered in surrounding stressed vowels. For /e#le/ specifically, mean values are 58.9 dB minimum intensity in /l/ versus 60.6 dB maximum intensity in the adjacent /é/. This equates to a mean IntDiff value of only 1.62 dB, which is comparable to values in the /ele/ and /el#e/: i.e. 1.658 and 1.768, respectively. This result therefore indicates that, with regard to intensity, /l/ is most similar to adjacent stressed vowels in utterance-medial intervocalic contexts. The location of intervening prosodic boundaries thus appears not to cause the observed low IntDiff values to vary significantly in these environments.

Table 3: Mean and standard deviation values per test context for minimum intensity in /l/, maximum intensity in the adjacent stressed vowel and Intensity Difference.

Context	/l/ min. intensity (dB)		/é/ max. intensity (dB)		IntDiff (dB)	
	Mean	St. dev.	Mean	St. dev.	Mean	St. dev.
a. /#le/	56.531	6.297	61.769	5.687	5.238	2.445
b. /el#/	47.736	5.947	55.78	5.718	8.043	3.605
c. /ele/	62.595	5.632	64.253	5.709	1.658	1.222
d. /e#le/	58.984	5.493	60.604	5.355	1.62	1.124
e. /el#e/	60.713	6.165	62.481	5.772	1.768	1.736
f. /elpe/	59.96	4.951	63.957	5.299	3.998	2.186
g. /el#pe/	58.022	5.992	61.864	5.474	3.842	2.174

3.2 Articulatory analysis

We now turn to the analysis of the UTI data. We begin by discussing general patterns in the data in §3.2.1. We report on patterns of speaker-specific variation in realisations of utterance-peripheral /l/ in §3.2.2. We then address utterance-medial intervocalic /l/ in §3.2.2 and preconsonantal /l/-realisations in §3.2.3.

3.2.1 Time-aligned dynamic analysis: initial observations on /l/-variation

As noted in Section 2.3.2, Principal Components Analysis and Linear Discriminant Analysis were applied to the pooled data for the purpose of identifying general patterns. Changes in LD1 across normalised time for each test context are shown in Figure 8 below. This measure provides an index of tongue-shape differentiation: i.e. overlap in confidence intervals indicates that the articulatory profile of /l/ in two given test contexts is highly similar, whereas non-overlap indicates that contextual /l/-realisations are distinct in some articulatory dimension. As discussed further in §3.2.2ff., LD1 roughly equates to tongue displacement, where higher values indicate a tendency for the tongue to reach a higher or more displaced maximum. These plots therefore allow for some important initial observations about contextual variability of /l/ to be made.

In the utterance-peripheral contexts, a strong category separation between /#le/ and /el/ is indicated. Values for word-medial /l/ (i.e. the /ele/ test environment) are also plotted for comparison. This reveals that, in general, all /l/-articulations are relatively stable: LD1 values for /#le/ strongly overlap with those for /ele/, and there is only minor fluctuation over time. In /el#/, the LD1 contour is also very stable in the

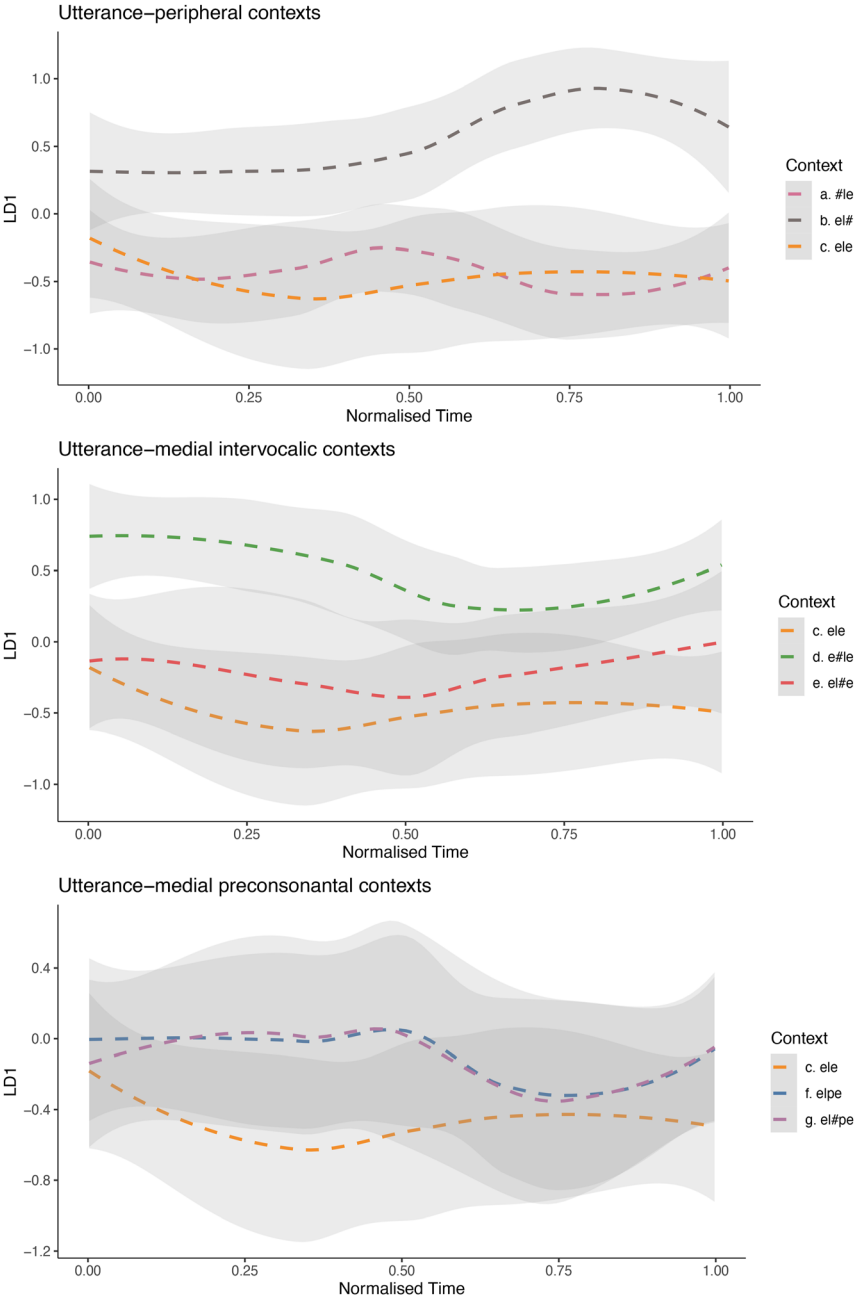


Figure 8: LD1 in normalised time. Upper panel: utterance-peripheral contexts (values for utterance-medial word-medial /l/ are shown for comparison). Middle panel: utterance-medial intervocalic contexts (values for utterance-medial preconsonantal contexts (values for utterance-medial word-medial /l/ are shown for comparison). Grey shading indicates 95 % confidence intervals.

initial 50 % durational phase, and a change is observable after the durational midpoint. This most plausibly equates to an articulatory change coinciding with the onset of articulatory release in the utterance-final context, i.e. the start of a chain of articulatory modulations leading to cessation of speech before silence. Most significantly, these findings provide an initial confirmation that production of /l/ in the utterance-final environment involves an articulatory differentiation from /ele/ and /#le/-realisations across all timepoints.

There are notable differences between the utterance-medial intervocalic /l/-realisations. For example, there is continuous overlap between /ele/ and /el#e/ which resembles the patterning of /ele/ and utterance-initial /#le/. This indicates that, overall, there is a degree of similarity between /l/-articulations in utterance-initial, utterance-medial word-medial and utterance-medial word-final intervocalic contexts.

By contrast, values for utterance-medial word-initial /l/ pattern separately, particularly in the 0–50 % durational window. Here, values are significantly higher than in /ele/ and /el#e/. Thus, /l/ in the /e#le/ environment shows a greater resemblance to utterance-final /l/ in the initial phases of its articulation, but a closer resemblance to /ele/ and /el#e/ in the latter articulatory phases.

/l/-realisations in both preconsonantal test contexts display an almost identical patterning in Figure 8. As shown, values for /elpe/ and /el#pe/ are somewhat higher—though not significantly so here—than for /ele/ in the first half of the articulation, whereas there is a close overlap between these three contexts after approximately 60 % duration. Interestingly, the fact that LD1 values in the preconsonantal contexts pattern around 0 indicates that these /l/-realisations bear the closest resemblance to word-final intervocalic /l/ (i.e. /el#e/), at least in the initial 50 % of the articulation.

Whereas we observed strong tendencies for /l/ in the /el#/, /#le/ and /e#le/-environments to be differentiated in durational and acoustic terms, the initial analysis of the articulatory data suggests that only /el#/ and /e#le/ pattern distinctly from other test contexts. In the following sections, we turn our attention to analysing speaker-specific patterns with a view to establishing more concretely how /l/-realisations in these contexts are spatially differentiated from others, and how consistently. In view of the finding that preconsonantal /l/ realisations display only minimal variation—both acoustically and articulatorily, as indicated in Figure 8—we focus the analysis exclusively on the utterance-peripheral (§3.2.1) and utterance-medial intervocalic contexts (§3.2.2).

3.2.2 Utterance-peripheral /l/

In general terms, there are high levels of speaker-specific variability in the articulatory data and contextual differences are often relatively small in magnitude.

Nevertheless, close examination of these patterns further elucidates the dynamic analysis presented above. Figure 9 shows fitted splines for utterance-initial and utterance-final /l/ for the Peninsular Spanish speakers. As in Figure 8, splines for utterance-medial /ele/ are also plotted for comparison. In general, contextual differences in tongue shape are minimal for speakers SpF5, SpF6 and SpF7: tongue shape is very stable both within and across contexts for these speakers. SpF5 produces utterance-final /l/ with the front body of the tongue in a marginally lower position than in utterance-initial and word-medial /l/. Despite this, there is a high degree of overlap in the dorsal and radical spline sections in the three test environments shown here.

Differences in tongue shape between contexts are observably greater for SpF8, SpM5 and the Catalan-Spanish bilinguals. As already noted, SpM5 deleted all instances of utterance-final /l/ such that only splines for /#le/ and /ele/ are shown in Figure 9. Here, the back body of the tongue body is in a lower configuration utterance-initially. For SpF8, utterance-initial /l/ has a different articulatory profile from utterance-final /l/. In /el#/, the dorsum reaches a higher maximum than in /#le/, whereas the spline for /#le/ shows almost complete overlap with /ele/. Similarly, the Catalan-Spanish bilinguals show evidence of tongue retraction in /el#/. For CaF1, the root is relatively retracted in utterance-final /l/ in comparison to utterance-initial /l/. Interestingly, /ele/ resembles /el#/ at the tongue root, but overlaps with /#le/ at the front body and blade. CaM1 also displays the greatest amount of root/dorsum retraction in /el#/. The root and dorsum are also retracted in /#le/ relative to the more fronted configuration for /ele/, although not to such an extent as in /el#/.

A similar pattern is observable in the data from some of the Latin American Spanish speakers. As shown in Figure 10, /l/-realisations produced by MeM4 bear a resemblance to those produced by CaM1. The tongue root is most retracted in /el#/, most advanced in /ele/, and has an intermediate position in /#le/. There is a greater degree of overlap in the anterior regions, by contrast. Root retraction in /el#/ is relatively minor for MeF4, but there is an observable difference between this context and /ele/. Interestingly, utterance-final /l/-realisations are strongly differentiated from other realisations in the front body for this speaker, where the tongue reaches a higher maximum in /el#/ than in both /#le/ and /ele/.

Similar to SpF5, SpF6 and SpF7, both Chilean speakers produce /l/s that show a considerable amount of overlap in these three test contexts. There is a small difference in /el#/ for ChM2 at the most radical fanpoints, which also causes the dorsum to have a marginally lower configuration. The contextual differences are somewhat greater for CoF2 and CoF3. These speakers' realisations bear some similarity to SpF8: i.e. utterance-initial /l/ is articulated with the tongue dorsum in a lowered position relative to a more raised position in /el#/. This effect is particularly strong for CoF3 who displays the most extreme degree of dorsum retraction in utterance-final /l/ of

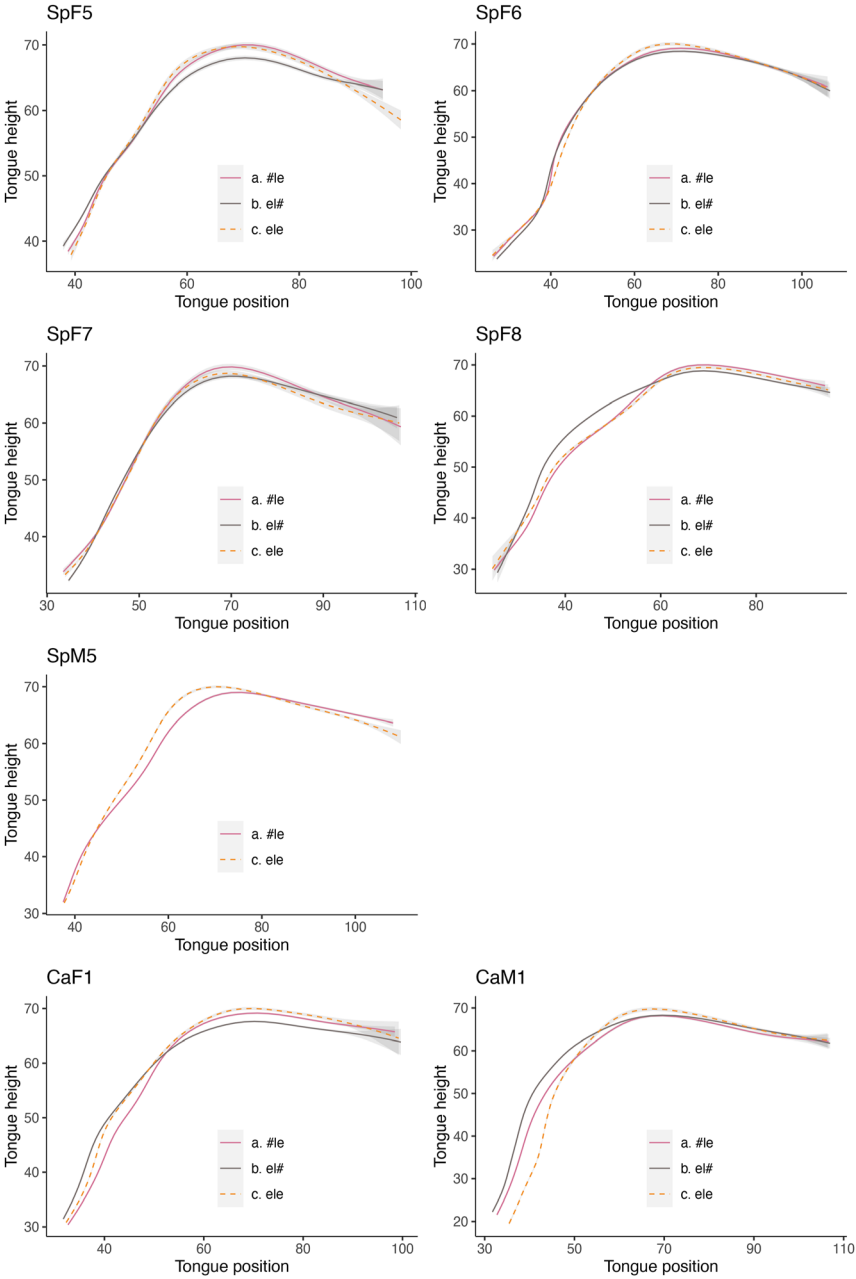


Figure 9: Fitted tongue splines for /#le/, /el#/ and /ele/: Peninsular Spanish speakers.

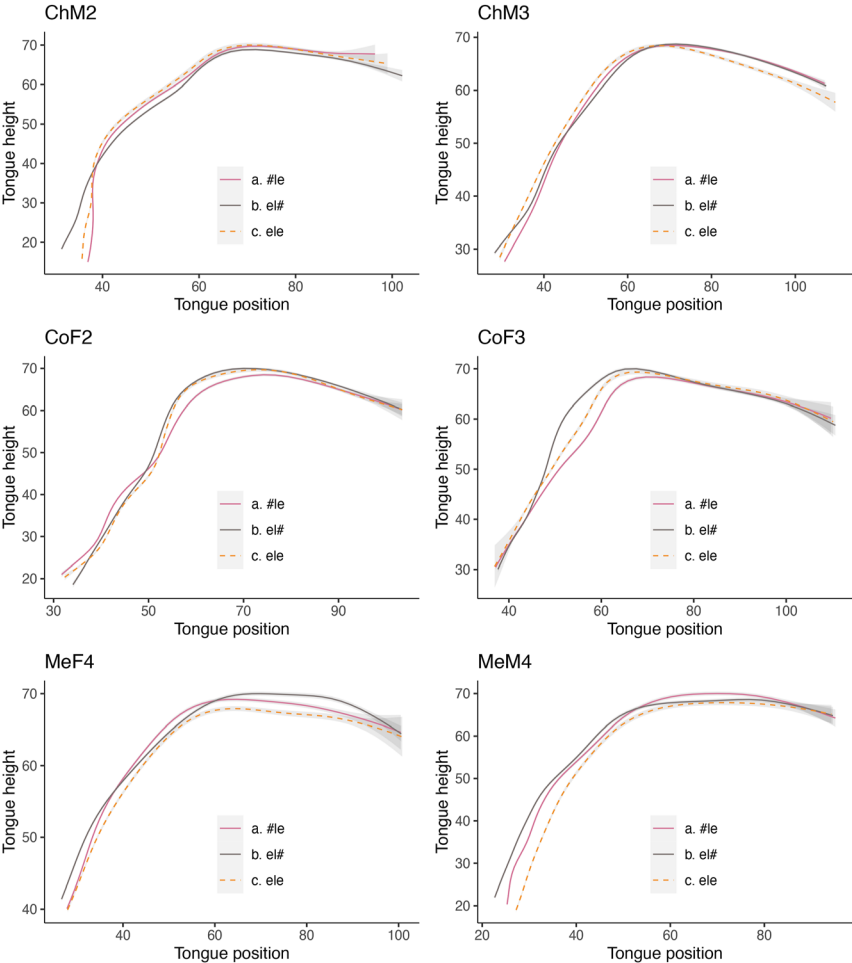


Figure 10: Tongue splines for /#le/, /el#/ and /ele/: Latin American Spanish speakers.

all the Latin American speakers. /ele/ shows a relatively high degree of overlap with /el#/ for CoF2, whereas CoF3 appears to produce an /l/-articulation in /ele/ that is intermediate between /el#/ and /#le/ in terms of dorsum position.

Tongue retraction in /el#/ is therefore well evidenced in both the Peninsular and Latin American groups. Whilst there are speakers in both groups who do not show this pattern, it is consistent enough in the data to produce the dynamic effect illustrated in Figure 8. However, evidence for articulatory enhancement in utterance-initial /l/ is weaker. Only CaM1, MeM4 and MeF4 show evidence of tongue retraction

in this environment, and this is consistently less robust than in /el#/ for each of these speakers. In general, these results therefore match what was observed in the dynamic analysis—unlike in /el#/, and in spite of the significant trends in the durational and acoustic measurements, there is no strong evidence for a pattern of articulatory differentiation in utterance-initial /l/ that could reasonably be attributed to contextual strengthening.

3.2.3 Utterance-medial intervocalic /l/

Similar to the utterance-peripheral /l/-realisations, the Peninsular Spanish speakers produce realisations of /l/ in utterance-medial environments that are characterised by extensive overlap in the spline plots. As illustrated in Figure 11, tongue position in /ele/, /e#le/ and /el#e/-realisations is only minimally different for SpF5, SpF6, SpF7 and SpF8. Splines for SpF5 and SpF6 display almost complete overlap in these three contexts. For SpF7 and SpF8, there is near-complete overlap in the splines in the dorsal region (and also the root for SpF8); however, the front body of the tongue reaches a slightly higher maximum in the word-final environment than in word-initial /l/ for both of these speakers. Word-initial /l/ therefore overlaps with word-medial /l/ for SpF7, whereas there is greater similarity between word-final /el#e/ and /ele/ for SpF8.

SpM5 exhibits a greater retraction of the tongue root in /e#le/ than in /ele/ despite overlap in the splines in the front-body region. A similar pattern occurs for CaM1: i.e. the greatest degree of retraction occurs in the /e#le/ environment. For CaF1, splines show a high level of overlap in the radical and dorsal regions. The tongue position in word-final /l/ is, nevertheless, somewhat lower in the front-body and blade/tip regions in comparison to /ele/ and /e#le/.

In spite of the dialectal difference, the articulatory patterns produced by ChM2 (Figure 12) bear a resemblance to those produced by CaM1 and SpM5. ChM2 produces /l/ in the /el#e/ context with an advanced root and lowered dorsum in comparison to the more retracted configuration in the /e#le/ environment. Furthermore, word-medial intervocalic /l/ is intermediate between these contexts: at the root, /l/ in /ele/ patterns closely with /el#e/, whereas there is extensive overlap between /ele/ and /e#le/ in the front body and tongue blade/tip. Similar contextual differences are also noted for MeF4 and MeM4: for both Mexican Spanish speakers, the dorsum is highest in /e#le/, and the root is more retracted both in /e#le/ and /el#e/ than in /ele/, if only to a minor degree for MeM4. By contrast, there is overlap in all three intervocalic /l/-splines in the front-body region for both MeF4 and MeM4.

Regarding the Chilean and Colombian speakers, the tongue configuration is almost identical in all three utterance-medial splines for ChM3 and CoF2, to the extent that /l/-realisations in these contexts appear to be spatially indistinguishable.

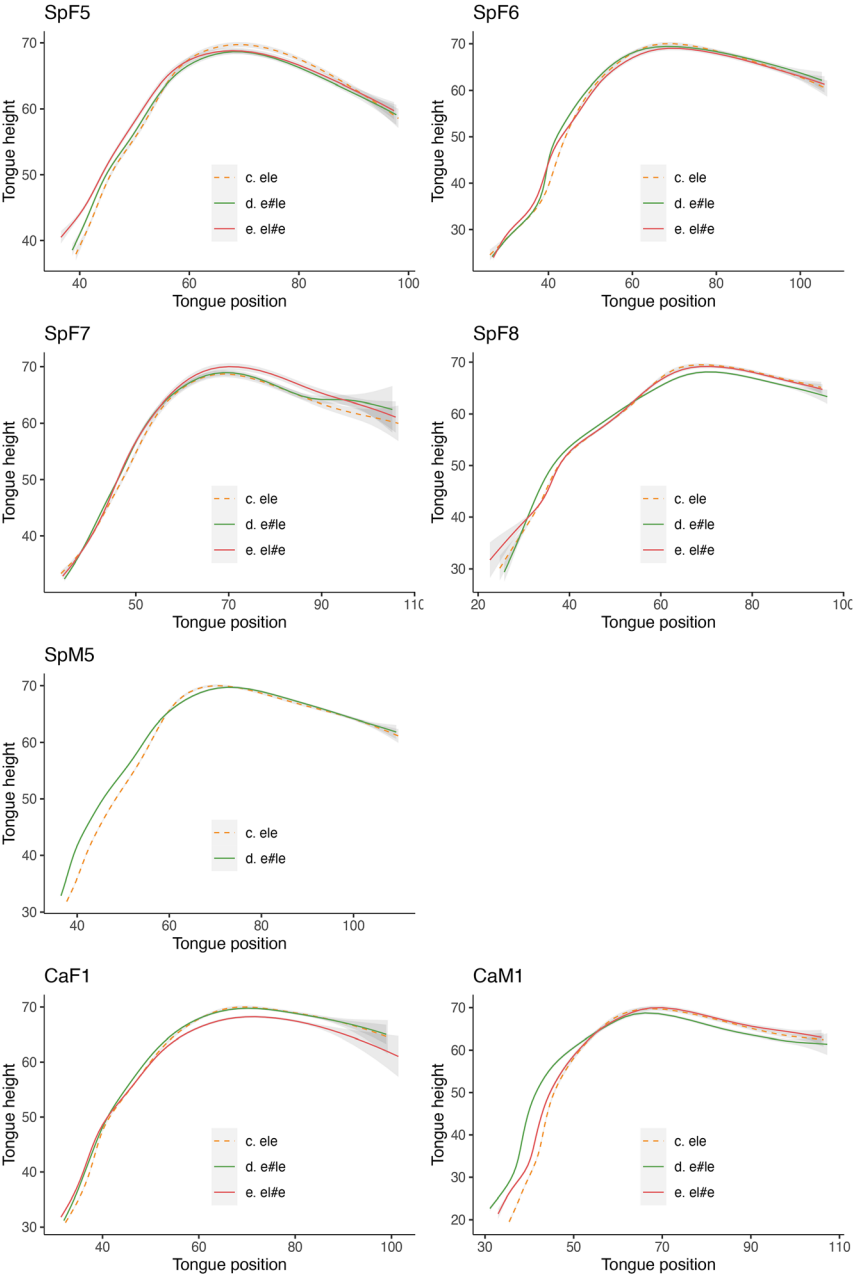


Figure 11: Tongue splines for utterance-medial /ele/, /e#le/ and /el#e/: Peninsular Spanish speakers.

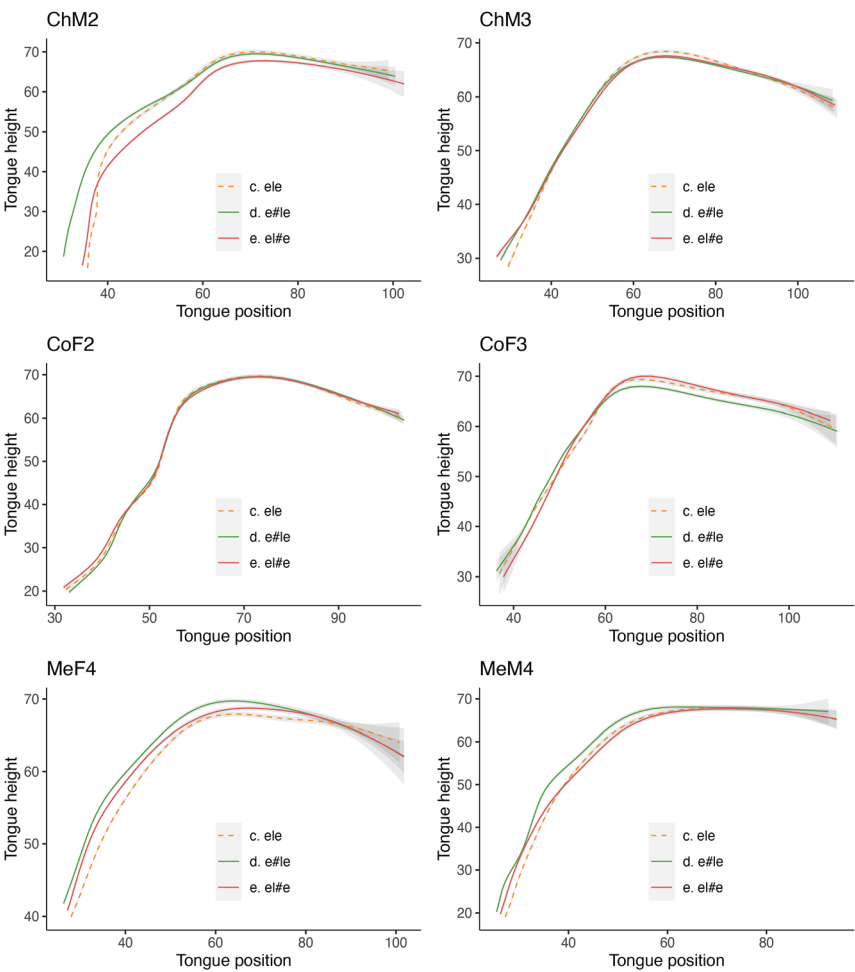


Figure 12: Tongue splines for utterance-medial /ele/, /e#le/ and /el#e/: Latin American Spanish speakers.

For ChM3, this is consistent with the utterance-peripheral /l/-realisations, which, as noted, are only minimally different. Whereas tongue splines for /#le/ and /el#/ shown in Figure 10 are much more observably distinct for CoF3, there is also a relatively high degree of overlap between the utterance-medial /l/-splines for this speaker. The front body does, however, have a slightly lowered position in word-initial intervocalic /l/.

In comparison to the utterance-peripheral contexts, spatial variation in /l/-articulation is therefore less extensive in the utterance-medial environments.

Evidence for greater tongue retraction in the word-initial environment is observed for speakers SpM5, CaM1, MeF4 and MeM4. This may contribute to higher LD1 values for /e#le/ observed in the dynamic analysis in the same way as in utterance-final /l/-realisations. However, since this is a less common pattern in the data, the overall effect is less dramatic in /e#le/.

3.3 Summary of findings

The analysis has confirmed that there is variation in the acoustic and articulatory qualities of /l/ depending upon the location of major prosodic boundaries. The findings of principal interest are summarised in Table 4. Acoustically, /l/ is characterised by significantly longer durations and a lower F1 frequency in two canonical onset environments: namely utterance-initially and in the word-initial utterance-medial context. Similarly, /l/ has a longer acoustic duration utterance-finally than in any other test context. This also correlates with significant F1 lowering. IntDiff values are highest in utterance-peripheral contexts and lowest in utterance-medial intervocalic contexts. Unlike /l/-duration and F1, the location of prosodic boundaries in the utterance-medial intervocalic test contexts does not cause observable effects on IntDiff.

Dynamic analysis of the articulatory data reveals that /l/-realisations in /el#/, and to a lesser extent in /e#le/, are phonetically distinct from other test contexts. Further “static” analysis of the articulatory data reveals high levels of speaker-specific behaviour, i.e. prosodic boundaries exert a greater influence on the contextual

Table 4: Summary of results. Yes/No values indicate whether the data provide evidence for edge-strengthening in /l/ at the site of the specific prosodic boundaries tested in the experiment along any of the acoustic or articulatory dimensions analysed. The boundaries in (e) indicate the possible application of phrasal resyllabification.

Test context	Boundary	Acoustic			Articulatory	
		Duration	F1	IntDiff	Time-aligned dynamic analysis	Speaker-specific analysis
a. /#le/	[_ɸ ...[_ω [_σ l... _σ]	Yes	Yes	Yes	No	Yes: CaM1, MeF4, MeM4
b. /el#/	...[_σ l] _ω [_ɸ]	Yes	Yes	Yes	Yes	Yes: SpF8, CaF1, CaM1, CoF3, MeF4, MeM4
c. /ele/	[_ɸ ...[_ω ...[_σ l... _σ] _ω ... _ɸ]	No	No	No	No	No
d. /e#le/	[_ɸ ...[_ω [_σ l... _σ] _ω ... _ɸ]	Yes	Yes	No	Yes	Yes: SpM5, CaM1, ChM2, MeF4, MeM4
e. /el#e/	[_ɸ ...[_ω [_σ l... _σ] _ω ... _ɸ] ?	No	No	No	No	No
f. /elpe/	[_ɸ ...[_ω ...[_σ l... _σ] _ω ... _ɸ]	No	No	No	No	No
g. /el#pe/	[_ɸ ...[_ω ...[_σ l... _σ] _ω ... _ɸ]	No	No	No	No	No

variability of /l/ for some speakers than others. In addition to the acoustic patterns, there is evidence that tongue retraction may function as a correlate of articulatory strengthening in /el#/ and /e#le/ contexts, at least for some speakers. For those speakers who do exhibit this pattern, the tongue root (and sometimes dorsum) reaches a more displaced maximum in these environments than in utterance-initial /l/ and word-medial /l/.

4 Discussion

4.1 Edge strengthening

Returning to our main research questions, RQ1 asks whether /l/ displays acoustic and articulatory variation across test contexts. Relatedly, RQ2 asks whether the observed patterns of variation are consistent with the theoretical claim that major prosodic boundaries are triggers for phonetic strengthening of adjacent phones, i.e. by edge strengthening.

The present results are consistent with the view that Spanish speakers manipulate duration as a mechanism of edge strengthening in the same way that has been shown previously for other languages (e.g. Byrd et al. 2005 for English). Thus, the observed durational cline, namely utterance-peripheral /l/ > word-initial /l/ > non-word-initial /l/, is indicative of a hierarchy of boundary signalling, whereby speakers control the duration of consonants in these environments in order to enhance the perceptual salience of high-level prosodic units. As well as the peripheral contexts, the observed elongation of /l/ in the utterance-medial word-initial environment is evidence that the demarcation of the left edge of P-words may also be functionally important. The use or non-use of durational extension of consonants may thus aid the listener in detecting the presence versus absence of P-word boundaries in segmentally identical sequences, such as /ele/ versus /e#le/. At least grammatical word-finally, this elongation is not observed. Whether this is interpreted as evidence that the right edges of P-words are less important to demarcate durationally than left edges depends on assumptions about their syllabification (cf. Wiltshire 2006 on the need to distinguish between left and right edges; we return to this issue in §4.2.).

Regarding intensity, we have observed that durational elongation of /l/ in utterance-peripheral contexts is accompanied by high IntDiff readings. Yet IntDiff is significantly lower in the utterance-medial word-initial environment—where /l/ displays lengthening and a low-frequency F1 that are also characteristic of peripheral realisations. Judging from our data, we suspect that IntDiff may be quite significantly affected by position of target vowels and consonants within the utterance. Within a general arc of intensity across an utterance, it is likely that consonants

in peripheral positions will display lower intensity minima than in utterance-medial positions. It is also possible that vowels are less prone to contextual variations in intensity than consonants, particularly where consonant weakening is dependent on the location of specific boundaries. If fluctuations in V-intensity maxima readings are globally smaller than variation in C-intensity minima in different utterance locations, then IntDiff may be a less reliable metric for identifying instances of contextual consonant reduction across prosodic contexts.

In the case of /l/, the situation is further complicated by the fact that intensity minima in sonorants are generally expected to be much higher than in realisations of stops or fricated and approximated realisations of stop phonemes. Our data do provide some evidence that coarticulatory influence of a following stop causes a lower intensity minimum in /l/: this corresponds to higher IntDiff values in /elpe/ and /el#pe/ test contexts. But it could also be the case that all instances of intervocalic /l/, regardless of the occurrence of adjacent prosodic boundaries, are partially deoccluded at the tongue tip (cf. Honorof 1999). Reduction of this sort would result in partial vocalisation of the /l/ (similar to what is sometimes observed in English: cf. Scobbie and Pouplier 2010). This may, in turn, contribute to the high intensity readings observed intervocalically for /l/ relative to the lower values observed in utterance-peripheral contexts.

The finding that F1 in /l/ is lower in the peripheral and utterance-medial word-initial environments also suggests that Spanish speakers may deploy phonetic resources other than duration for the marking of edges of major prosodic units. One plausible scenario that is also consistent with the high IntDiff readings in utterance-peripheral contexts is that /l/ is realised with greater linguo-alveolar occlusion in these environments. This would be consistent with the hypothesis that major prosodic boundaries condition articulatory realisations that require more effort from the speaker: e.g. involving a greater displacement of articulators.

As already discussed, the results from previous work using EPG have confirmed that Spanish speakers display variation in the location and degree of occlusion in /l/: e.g. Kochetov and Colantoni's (2011) work on Argentinian and Cuban Spanish and Ramsammy's (2021) study on Peninsular varieties. Although the acoustic properties of /l/ were not examined in those studies, we might expect that /l/-articulations involving a greater amount of lingual pressure on the palate at a more anterior location than in other environments may produce an observable effect on formant frequencies, particularly F1, and intensity. For /l/, such differences may also affect the degree of aperture in the lateral channels, which could also plausibly be a source of acoustic variability. This being the case, we might speculate that the observed cline in F1 (i.e. /el#/ > /#le/ > /e#le/ > elsewhere) would correlate with degree of linguo-palatal occlusion in these contexts. This cannot be corroborated directly on the basis of the current data because of the multi-

dimensionality of the variation involved: variation in place of articulation that may involve very precise articulatory configurations overlapping with contextual variation in degree of occlusion is not something that UTI is capable of recording. Further research using multiple imaging techniques—i.e. midsagittal tongue position and linguo-palatal contact—would be necessary to gain further insights into this.

In addition, syllable-final /l/s in the current data occupy the extremes of the durational range: i.e. maximal duration in /el#/ versus minimal duration in /elpe/ and /el#pe/. In general, the short duration of preconsonantal /l/ is to be expected under the view that articulating a sonorant in a cluster environment with a voiceless stop is phonetically costly. Durational clipping of /l/ in these contexts is consistent with the results of other studies, particularly on English (e.g. Lehiste 1980; Turton 2017). It could be the case that articulatory and aerodynamic pressures of producing /l/+stop sequences mask any effects of pre-boundary lengthening that may possibly manifest in /l#C/-sequences. This would explain the lack of robust observable differences between /elpe/ and /el#pe/ in the current data. It also presents a question for future investigation: i.e. whether other types of /l#C/-cluster (e.g. /l/+sonorant consonant) may be more generally amenable to enhancement than /l/+stop sequences.

Regarding the UTI data, root/dorsum retraction emerges as a recurring pattern in a subset of environments where acoustic correlates of edge strengthening are also observed. Regarding tongue retraction in /l/, Keyser and Stevens (2006: 51) note that dorsum position plays an important role in liquid articulations. More specifically, “tongue backing [in /l/] functions to maximise the acoustic difference between /l/ and /j/”. In our data, this pattern is restricted to the utterance-final and utterance-medial word-initial contexts, and as discussed, it is not consistent across speakers (cf. the articulatory results of Byrd et al. 2005). Thus, if dorsum retraction functions as an enhancement strategy to increase the perceptual distance between /l/ and /j/, it is not obvious why this should be observed most commonly in the /el#/ and /e#le/ test environments.

Relatedly, a shortcoming of the dynamic analysis presented in §3.2.1 is that it is based on pooled measurements, including those from speakers for whom tongue position in /l/ is very stable across test contexts. Consequently, it may well overestimate spatial variation in /l/ articulations for e.g. the Peninsular Spanish speakers who show only minor contextual differences across test contexts. Likewise, it may underestimate the contextual variation for those speakers for whom increased tongue displacement, particularly in the radical and dorsal regions, correlates with durational elongation of /l/ and F1 lowering. This pattern is significant, particularly in view of the questions we aim to address about syllabification, which are discussed further in §4.2 below.

Additionally, the Catalan-Spanish bilinguals display patterns that are not well evidenced in the monolingual Peninsular speakers, although clearer similarities between CaF1, CaM1 and some of the Latin American speakers were noted (particularly MeM4). In this study, we did not aim to test the articulatory differences between Spanish and Catalan /l/ in the speech of bilingual participants, but we acknowledge that phonetic transfer could be a possible source of some of the observed variation (cf. Simonet's 2010a, 2010b work on acoustic variation in /l/ in Catalan-Spanish bilingual speech).

Neither CaF1 nor CaM1 produced a dark [ɫ] when reading the Spanish-language materials for this study: there is no evidence of a back-vowel like articulatory configuration in any /l/ produced by these speakers that would be expected in a realisation of [ɫ] (cf. articulatory descriptions of English [ɫ]: Sproat and Fujimura 1993; Strycharczuk and Scobbie 2017a; Turton 2014, 2017).¹¹ Furthermore, the fact that Dialect never emerged as a significant predictor of variability in any of the models for the acoustic parameters we examined suggests that /l/-realisations produced the Catalan-Spanish bilinguals are not vastly different in quality from those produced by the monolingual speakers. There is, however, a limit to the conclusions we can draw on the basis of data from these speakers. Examining articulatory distinctions in /l/ in bilingual speech along the lines of Simonet's (2010a) acoustic study would be beneficial to shed further light on the question of mutual influence of language-specific light and dark /l/.

To summarise, our data confirm that /l/ displays variation in multiple phonetic dimensions that is dependent on the prosodic context that it occurs in. In broad terms, our findings are consistent with the results of previous articulatory work that has identified increased duration and larger displacement of articulators as correlates of strengthening at prosodic-domain edges. We have further identified patterns of acoustic variation (F1 and intensity lowering) that may be unique to /l/, and possibly even to Spanish /l/. We therefore view the results of this study as evidence that edge strengthening involves controlled and continuously variable manipulations of phonetic parameters, many of which are specific to the articulation of /l/.

4.2 Resyllabification?

We aimed to establish in line with RQs 3 and 4 whether a more extensive description of phonetic variation in /l/ could contribute to debates about phrasal resyllabification in Spanish. As shown in (2), the assumption of resyllabification across word boundaries renders word-final prevocalic /l/ (i.e. a *derived onset*) identical to the

¹¹ Similarly, no evidence of dark [ɫ]-like productions were observed in the articulatory productions from ChM2 either, who, as noted, is a Spanish-English early bilingual.

canonical word-initial prevocalic onset with regard to the location of the P-word boundary. This is the strongest interpretation of phrasal resyllabification. Of the three acoustic parameters analysed in this study, only IntDiff could be said to provide any evidence for acoustic similarity of /l/ in the three utterance-medial test contexts. Under the view that /l/ is in a canonical onset position in /ele/ and /e#le/-sequences (i.e. [-e.le-] in both cases) the fact that IntDiff values are equally low in realisations of /el#e/ might suggest an identical syllabification of this sequence. However, as we have shown, this is not consistent with analysis of other acoustic parameters.

The articulatory data are more complex. Some speakers, particularly the female Peninsular Speakers, showed no strong tendency to distinguish intervocalic realisations of /l/ articulatorily in the three test environments. However, for other speakers, the articulatory profile of word-final intervocalic /l/ is observably different from word-initial intervocalic /l/, even if in only a relatively minor way. In this connection, Proctor (2011) makes an important point: namely that Spanish /l/ is characterised generally by a high degree of articulatory stability, particularly in the dorsal region, and that “dorsal bracing” may be critical to achieving specific aerodynamic goals in /l/-production. Thus, whereas contextual variability in /l/ appears rather small for some speakers, this may be attributable in part to the fact that /l/s in Spanish are simply less articulatorily variable than other consonants (e.g. /d/) and also less variable than /l/s in other languages (particularly English).¹² We therefore take the view that the observed articulatory variability in /l/ across utterance-medial test contexts—particularly in /e#le/ versus /el#e/—does reflect selective deployment of controlled articulatory strategies that is at least partially dependent on prosodic factors.

In fact, the assumption of phrasal resyllabification is problematic in a number of non-trivial ways. Firstly, it is possible that resyllabification is dialectally variable and phonologically selective. For example, Robinson (2012) argues on the basis of judgements from native speakers of Ecuadorian Highland Spanish that word-final [z] and [ŋ] never resyllabify prevocalically. Similar statements have been made by Lipski (1989: 53), who asserts that “Spanish resyllabification is far from exceptionless”. Thus, contrary to the assumption that resyllabification is obligatory, non-resyllabification is equally well predicted by theoretical claims relating to onset well-formedness. Although the core vocabulary of Spanish tolerates the sonorants /l, n, r/ in onset and coda positions (including word-finally), sonorants are relatively poor onsets both with regard to their acoustic distinctiveness from surrounding vowels and universal phonological generalisations, such as the onset sonority hierarchy

¹² It must be also highlighted that detailed articulatory descriptions of /l/ in languages other than English do not exist. It cannot therefore be established whether what we have observed here for Spanish may be more or less representative of articulatory variation in /l/ where no phonologically-conditioned allophony pattern operates in the language.

(Gopal 2018; Gouskova 2004). There is therefore no principled reason to assume that word-final sonorant codas ought to behave in the same way as /s/ with regard to resyllabification;¹³ and similarly, no strong reason to expect that an identical coda-capture process operates in all /-C#V-/ sequences in Spanish.

Secondly, there are explanatory possibilities for the behaviour of word-final consonants in Spanish that do not rely on the assumption of categorical resyllabification. Strycharczuk and Kohlberger (2016) enumerate some of these under the label of *incomplete resyllabification*: for example, ambisyllabification, as illustrated in Figure 13(a). We do not view this as a plausible representational solution to the observed differences between /e#le/ and /el#e/. Assuming that word-final intervocalic /l/ remains linked to the coda node of one syllable and that resyllabification (i.e. by ambisyllabification) creates a new link to the onset node of a following syllable would reasonably entail the prediction that word-final /l/ should be longer than canonical onset /l/. Indeed, as Strycharczuk and Kohlberger (2016: 13–14) discuss in detail, ambisyllabic representations have commonly been invoked to account for increased duration in geminate consonants cross-linguistically. Our data from /l/ and Strycharczuk and Kohlberger's findings for /s/ both show precisely the opposite trend to that predicted by ambisyllabic elongation: canonical onsets are longer than word-final intervocalic /l/ and /s/. In addition, an ambisyllabification analysis might also predict articulatory enhancement in the word-final prevocalic context; but evidence for this has not been found for Spanish.

Incomplete resyllabification of word-final /l/ may take other forms too. In line with what Lipski (1989) and Robinson (2012) propose for Ecuadorian Spanish, word-final consonants may simply remain in the coda prevocally, as illustrated in Figure 13(b). Whereas that assumption presents a problem for analysis of certain phonological patterns, e.g. /s/-weakening in certain dialects (Colina 2006; Kaisse 1996), it captures the fact that word-final intervocalic /l/ generally patterns most closely with word-medial intervocalic /l/ in the current data. More specifically, it is the presence of a P-word boundary, not a syllable boundary, that has the greatest influence on the acoustic and articulatory quality of /l/ in these contexts: the shared characteristics of /ele/ and /el#e/ (i.e. [ω-e.le-] and [ω-el]) are therefore predictable on the basis that /l/ is not ω-initial in these contexts, unlike in /e#le/ (i.e. [ω.le-]). But even under the assumption that a phonological algorithm universally favours [-V.CV-] (e.g. Kager 1999: 95), there is no reason that such an algorithm cannot apply selectively,¹⁴ especially in consideration of the fact that /l/ may be a relatively poor choice of onset, as noted.

¹³ Recall that Strycharczuk and Kohlberger (2016) also show that the predictions of resyllabification for /s/ are not borne out, at least in data from Peninsular Spanish speakers.

¹⁴ An anonymous reviewer suggests a further possibility in this regard, namely that resyllabification could be triggered variably depending upon the type of boundary that intervenes between the

The third possibility illustrated in Figure 13(c) is that if word-final consonants do resyllabify across a word boundary, perhaps this happens independently of reassociations at higher levels of prosodic structure. As illustrated, this type of representation violates the strict layering principle. However, it may be in closest alignment to some native speaker intuitions, such as those that Robinson (2012) reports. It also captures the parallel patterning of /ele/ and /el#e/ that we have observed, namely because /l/ is non- ω -initial in these environments (unlike in /e#le/).

We do not aim to take a decisive position here on whether violations of the strict layering principle are better or worse than violations of the universal syllabification principle from a theoretical point of view, and space does not allow us to address this issue in full.¹⁵ One point that favours prosodifications like Figure 13(b), however, is that admitting structures like Figure 13(c) has the potential to vastly increase the range of licit prosodic structures in the language. Assuming that word-final coda consonants remain in the coda in prevocalic phrasal contexts is clearly less costly in this regard. Resolving this issue will nevertheless require additional work both of a theoretical and experimental nature (i.e. to test whether other permissible word-final consonants in Spanish display behaviour that resembles what has been observed here for /l/ and in Strycharczuk and Kohlberger's study on /s/). At present, therefore, the overall generalisation is that the assumption of categorical

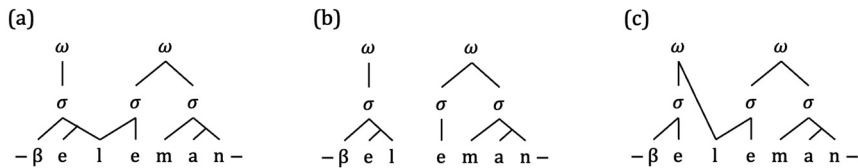


Figure 13: Incomplete resyllabification illustrated with the test phrase *nivel emancipado*.

Representations show (a) ambisyllabification, (b) non-resyllabification and (c) resyllabification without strict layering.

consonant and following vowel. Hypothetically speaking, resyllabification could be obligatory in, for example, clitic=host sequences (such as *los otros* ‘the others’, hence [lo.‘so.tros]), whilst failing to apply in a segmentally identical sequence spanning a P-word boundary (e.g. *varios otros* ‘some others’ [‘ba.ɾjos.o.tros]). We are not aware at the time of writing of theoretical treatments of Spanish syllabification that rely on discrete variable outcomes being generated at the site of specific prosodic boundaries. In the absence of evidence to the contrary, our working assumption is that whatever structural adjustments that take place at the syllabic level (even if that means no adjustment) also apply when syllable edges coincide with the edges of higher constituents.

¹⁵ Broś (2018) and Colina (2002) discuss issues around strict layering with reference to Spanish in more detail than we are able to provide here (relatedly, see Nespor 1999; Peperkamp 1994, 1996, 1997).

resyllabification in phrasal contexts is not strongly supported by experimental studies that have seriously engaged with the phonetic predictions of this process.

4.3 Limitations of the study

Constraints on recording procedure have imposed certain limits on this study that must be acknowledged. We have relied on a relatively small data sample that tests /l/-realisations in short phrases. Further insights into the operation of edge strengthening could be gained from studying longer units in which acoustic and articulatory differences in /l/ could be observed in prosodic domains not tested here: e.g. utterance edges versus intonational and accentual phrases and foot-initial versus non-foot initial positions utterance-medially. An anonymous reviewer also points out that further variability in enhancement patterns could be observed where prosodic boundaries coincide with morphological ones. For /l/, this is the case for denominal and deverbal adjectives like *formal* ‘formal’, *infantil* ‘infantile’ and *perjudicial* ‘damaging’ etc. in Spanish. We consciously focused on comparing realisations of morpheme-internal /l/ (i.e. as in *pel-e-n*, *afelp-a*, *nivel*, etc.): examining variation in affixal /l/ in items like *formal* was beyond the scope of this study. We therefore acknowledge that work specifically aiming to study articulatory variation at the site of overlapping prosodic and morphological boundaries would be of benefit for further elucidating the complexity of these patterns.

In our data, we have also observed quite extensive speaker-specific variability. It would be advantageous to study these patterns in a greater number of speakers of specific individual varieties. Our decision to recruit speakers of diverse Peninsular and Latin American dialects may have caused the influence of dialectal patterns of interest to be underestimated in the acoustic and articulatory analyses based on pooled data. We have highlighted that further work aiming to examine patterns of enhancement and reduction could be particularly fruitful in the case of Catalan-Spanish bilingual speech—i.e. with a view to understanding to what extent language transfer may contribute to key patterns we have identified, such as context-specific tongue retraction effects.

We have also focused exclusively on speech-production data in the current study. Additional work aiming to understand to how listeners perceive word-final consonants in Spanish—in terms of their grouping with prosodic units of differing sizes—would potentially shed further light on the question of whether resyllabification constitutes a perceptually real phenomenon in the language or not.

5 Conclusions

This study set out to address four research questions relating to the contextual variability of /l/ in Spanish. We have found evidence of both acoustic and articulatory

differentiation of /l/ in utterance-peripheral versus utterance-medial positions. We have ascribed the durational elongation, high IntDiff values and low F1 values observed in utterance-initial and utterance-final realisations of /l/ to edge strengthening: i.e. controlled phonetic enhancement in the context of high-level prosodic boundaries. In the ultrasound data, utterance-final /l/ was found to be articulated with a significant degree of tongue retraction for certain speakers, whereas evidence for articulatory differentiation of utterance-initial /l/ was less consistently observed.

In utterance-medial contexts, word-initial /l/ displays acoustic properties that distinguish it from word-medial and word-final realisations. Differences in tongue shape and position across utterance-medial test contexts are relatively minor. Pre-consonantly, /l/ is characterised by a short acoustic duration and relatively high F1 and intensity minima. Differences between utterance-medial word-initial versus word-final /l/ were also observed for a subset of speakers. We have further argued that these differences are not consistent with the assumption of a categorical resyllabification process that exceptionlessly targets word-final consonants preceding following vowel-initial words. We have therefore considered various alternatives to the traditional approach to phrasal resyllabification, including resyllabification without strict layering, ambisyllabification and non-resyllabification. We have suggested that the present results are more consistent with an analysis under which word-final consonants—or word-final /l/, at least—remains in coda position in /Vl#V/ contexts.

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Author contributions: This study represents collaborative work conducted by the two named authors. The second author was responsible for participant recruitment, data annotation and the production of ethics documents (Information Sheet and Consent Form). The second author was also present during data collection and oversaw all aspects of this. The first author was responsible for designing the experimental materials and administering the experiment with participants. The first author conducted the majority of the primary data analysis, the statistical analysis and was responsible for submitting the paper. Both authors contributed to writing the text of the paper and both have given their approval to the submitted version of the manuscript. Both authors agree to be accountable for all aspects of the work and to ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of interest statement: The authors have no conflicts of interest to declare.

Ethics statement: Ethical approval for this study was received from the Ethics Committee in the School of Philosophy, Psychology and Language Sciences at the University of Edinburgh prior to data collection (ref. 4171819-1). Informed consent from participants was obtained via an Information Sheet and Consent Form. As L1 speakers of Spanish were recruited for this study, both forms were written in Spanish. The Information Sheet made participants aware of risks and benefits to taking part in the study and it informed them specifically what would be done with the data associated with the study. They were informed how they could withdraw from the study without detriment, and the time limits on informing the researchers should they wish to do so. Contact information for the first author and the School Ethics Committee were provided. Prior to data collection, all participants were given the opportunity to view the experimental setup, including the equipment involved in the collection of Ultrasound data. They were given the opportunity to ask any questions about the procedure. All participants signed a printed Consent Form which was retained by the first author. No vulnerable persons were recruited for the study and there was no risk of coercion.

Appendices

Euclidian Distance at 3 timepoints

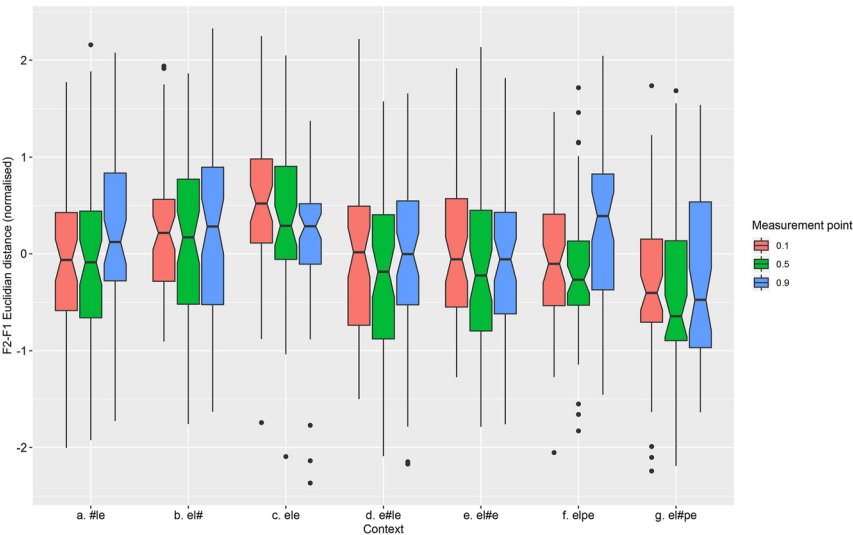


Figure 14: Normalised Euclidian Distance (F2–F1) at three timepoints.

Summaries of mixed-effects regression models

Table 5: Fixed effects in /l/-duration model (§3.1.1).

	Estimate	Std. Error	df	t	p
Intercept (c. /ele)	1.735e+00	1.452e−02	8.053e+01	119.437	<0.001
a. /#le/	1.751e−01	1.775e−02	3.990e+02	9.864	<0.001
b. /el#/	3.002e−01	1.775e−02	3.990e+02	16.908	<0.001
d. /e#le/	1.270e−01	1.775e−02	3.990e+02	7.155	<0.001
e. /el#e/	1.683e−02	1.791e−02	3.993e+02	0.939	0.348
f. /elpe/	4.278e−03	1.775e−02	3.990e+02	0.241	0.810
g. /el#pe/	1.824e−02	1.775e−02	3.990e+02	1.027	0.305

Table 6: Fixed effects in Euclidian Distance model (§3.1.2).

	Estimate	Std. Error	df	t	p
Intercept (c. /ele)	0.18698	0.135	202.187	1.390	>0.1
a. /#le/	−0.21696	0.184	398.751	−1.177	>0.1
b. /el#/	−0.02137	0.184	398.751	−0.116	>0.1
d. /e#le/	−0.37361	0.184	398.751	−2.028	0.043
e. /el#e/	−0.24482	0.186	399.344	−1.317	>0.1
f. /elpe/	−0.36488	0.184	398.751	−1.980	0.048
g. /el#pe/	−0.76311	0.184	398.751	−4.142	<0.001

Table 7: Fixed effects in F2 model (§3.1.2).

	Estimate	Std. Error	df	t	p
Intercept (c. /ele)	0.2764	0.129	218.03	2.139	0.033
a. /#le/	−0.4373	0.178	398.726	−2.451	0.015
b. /el#/	−0.2325	0.178	398.726	−1.303	>0.1
d. /e#le/	−0.5240	0.178	398.726	−2.937	0.004
e. /el#e/	−0.2445	0.18	399.367	−1.359	>0.1
f. /elpe/	−0.4441	0.178	398.726	−2.489	0.013
g. /el#pe/	−0.7912	0.178	398.726	−4.435	<0.001

Table 8: Fixed effects in F1 model (§3.1.2).

	Estimate	Std. Error	df	t	p
Intercept (c. /ele)	0.4818	0.112	188.271	4.317	<0.001
a. /#le/	−0.8941	0.154	392.697	−5.818	<0.001
b. /el#/	−0.9929	0.154	392.697	−6.461	<0.001
d. /e#le/	−0.7506	0.154	392.697	−4.884	<0.001
e. /el#e/	0.1004	0.156	393.499	0.645	>0.1
f. /elpe/	−0.2769	0.154	392.697	−1.802	0.072
g. /el#pe/	−0.2143	0.154	392.697	−1.395	>0.1
Gender: male	−0.5266	0.197	195.231	−2.680	0.008
/#le/: male	0.4602	0.269	392.927	1.714	0.087
/el#/: male	0.9871	0.269	392.927	3.676	<0.001
/e#le/: male	0.4763	0.269	392.927	1.774	0.076
/e#le/: male	−0.1652	0.27	393.193	−0.613	>0.1
/elpe/: male	0.2175	0.269	392.927	0.810	>0.1
/el#pe/: male	0.2952	0.269	392.927	1.100	>0.1

Table 9: Fixed effects in IntDiff model (§3.1.3).

	Estimate	Std. Error	df	t	p
Intercept (c. /ele)	1.65702	0.297	203.563	5.577	<0.001
a. /#le/	3.58116	0.407	399.223	8.811	<0.001
b. /el#/	6.38640	0.407	399.223	15.712	<0.001
d. /e#le/	−0.03674	0.407	399.223	−0.090	0.928
e. /el#e/	0.08059	0.41	399.784	0.197	0.844
f. /elpe/	2.34096	0.407	399.223	5.759	<0.001
g. /el#pe/	2.18511	0.407	399.223	5.376	<0.001

References

Alba, Orlando. 1979. Análisis fonológico de /r/ y /l/ implosivas en un dialecto rural dominicano. *Boletín de la Academia Puertorriqueña de la lengua española* 7. 1–18.

Bates, Douglas, Martin Maechler, Ben Bolker, Steven Walker, Rune Haubo Bojesen Christensen, Henrik Singmann, Bin Dai, Gabor Grothendieck & Peter Green. 2017. lme4 (R package, version 1.1–13).

Bermúdez-Otero, Ricardo. 2011. Cyclicity. In Marc van Oostendorp, Colin Ewen, Elizabeth Hume & Keren Rice (eds.), *The Blackwell companion to phonology*, 2019–2048. Malden, M.A.: Wiley-Blackwell.

Boersma, Paul & David Weenink. 1992–2019. Praat: Doing phonetics by computer.

Bradley, Travis G. 1999. Assibilation in Ecuadorian Spanish. In J. Marc Authier, Barbara E. Bullock & Lisa A. Reed (eds.), *Formal perspectives on Romance Linguistics: Selected papers from the 28th Linguistic Symposium on Romance Languages (LSRL XXVIII)*, 57–71. Amsterdam: John Benjamins.

- Bradley, Travis G. 2005. Sibilant voicing in Highland Ecuadorian Spanish. *Lingua(gem)* 2. 29–42.
- Broś, Karolina. 2018. Contiguity in prosodic words: Evidence from Spanish. *Posnań Studies in Contemporary Linguistics* 54(1). 37–82.
- Broś, Karolina. 2020. Domain modelling in Optimality Theory: Morphophonological cyclicity vs. stepwise prosodic parsing. *Journal of Linguistics* 56. 3–43.
- Byrd, Dani, Sungbok Lee, Daylen Riggs & Jason Adams. 2005. Interacting effects of syllable and phrase position on consonant articulation. *Journal of the Acoustical Society of America* 118(6). 3860–3873.
- Carrasco, Patricio, José Ignacio Hualde & Miquel Simonet. 2012. Dialectal differences in Spanish voiced obstruent allophony: Costa Rican versus Iberian Spanish. *Phonetica* 69. 149–179.
- Cho, Taehong & Patricia Keating. 2009. Effects of initial position versus prominence in English. *Journal of Phonetics* 37. 466–485.
- Colina, Sonia. 1995. *A constraint-based analysis of syllabification in Spanish, Catalan and Galician*. University of Illinois at Urbana-Champaign PhD Dissertation.
- Colina, Sonia. 1997. Identity constraints and Spanish resyllabification. *Lingua* 103. 1–23.
- Colina, Sonia. 2002. Interdialectal variation in Spanish /s/ aspiration. In James Lee, Kimberly Geeslin & Clancy Clements (eds.), *Structure, meaning and acquisition in Spanish*, 230–243. Somerville, MA: Cascadia Press.
- Colina, Sonia. 2006. Optimality-theoretic advances in our understanding of Spanish syllable structure. In Fernando Martínez-Gil & Sonia Colina (eds.), *Optimality-theoretic studies in Spanish phonology*, 172–204. Amsterdam: John Benjamins.
- Colina, Sonia. 2009a. Sibilant voicing in Ecuadorian Spanish. *Studies in Hispanic and Lusophone Linguistics* 2(1). 3–30.
- Colina, Sonia. 2009b. *Spanish phonology: A syllabic perspective*. Washington D.C.: Georgetown University Press.
- Cruz-Ferreira, Madalena. 1995. European Portuguese (Illustration of the IPA). *Journal of the International Phonetic Association* 25(2). 90–94.
- Davidson, Lisa. 2006. Comparing tongue shapes from ultrasound imaging using smoothing spline analysis of variance. *Journal of the Acoustical Society of America* 120(1). 407–415.
- de Lacy, Paul. 2006. *Markedness: Reduction and preservation in phonology*. Cambridge: Cambridge University Press.
- Fougeron, Cécile & Patricia A. Keating. 1997. Articulatory strengthening at the edges of prosodic domains. *Journal of the Acoustical Society of America* 101(6). 3728–3740.
- Gili-Gaya, Samuel. 1966. *Elementos de fonética general*. Madrid: Gredos.
- Gopal, Deepthi. 2018. *Similarity and representations in sonorant phonology*. University of Manchester PhD thesis.
- Gouskova, Maria. 2004. Relational hierarchies in Optimality Theory: The case of syllable contact. *Phonology* 21. 201–250.
- Harris, James W. 1983. *Syllable structure and stress in Spanish*. Cambridge, MA: MIT Press.
- Harris, James W. 1984. Autosegmental phonology, lexical phonology, and Spanish nasals. In Mark Aronoff & Richard Oehrle (eds.), *Language sound structure*, 67–82. Cambridge, Mass.: MIT Press.
- Harris, James W. 1989. Our present understanding of Spanish syllable structure. In Peter C. Bjorkman & Robert M. Hammond (eds.), *American Spanish pronunciation*. Washington, D.C.: Georgetown University Press.
- Heyne, Matthias, Donald Derrick & Jalal Al-Tamimi. 2019. Native language influence on brass instrument performance: An application of Generalized Additive Mixed Models (GAMMs) to midsagittal ultrasound images of the tongue. *Frontiers in Psychology* 10. 1–26.

- Holmes-Elliott, Sophie & Jennifer Smith. 2018. Dressing down up north: DRESS-lowering and /l/ allophony in a Scottish dialect. *Language Variation and Change* 30. 23–50.
- Holmquist, Jonathan. 2015. Gender and variation: Word-final /s/ in men's and women's speech in Puerto Rico's Western Highlands. In Manuel Díaz-Campos (ed.), *The handbook of Hispanic Sociolinguistics*, 230–243. Oxford: Wiley-Blackwell.
- Honorof, Douglas N. 1999. *Articulatory gestures and Spanish nasal assimilation*. PhD dissertation, Yale University.
- Howson, Phil, Ekaterina Komova & Bryan Gick. 2014. Czech trills revisited: An ultrasound, EGG and acoustic study. *Journal of the International Phonetic Association* 44(2). 115–132.
- Hualde, José Ignacio. 1992. On Spanish syllabification. In Héctor Campos & Fernando Martínez Gil (eds.), *Current studies in Spanish linguistics*, 475–493. Washington, D.C.: Georgetown University Press.
- Hualde, José Ignacio. 1991. *Basque phonology*. London; New York: Routledge.
- Hualde, José Ignacio & Sonia Colina. 2014. *Los sonidos del español*. Cambridge: Cambridge University Press.
- Hualde, José Ignacio, Oihana Lujanbio & Juan Joxe Zubiri. 2010a. Goizueta Basque (Illustration of the IPA). *Journal of the International Phonetic Association* 40(1). 113–127.
- Hualde, José Ignacio, Marianna Nadeu & Miquel Simonet. 2010b. Lenition and phonemic contrast in two Catalan dialects. In Sonia Colina, Antxon Olarrea & Ana Maria Carvalho (eds.), *Romance Linguistics 2009: Selected papers from the 39th Linguistic Symposium on Romance Languages (LSRL)*, 63–79. Amsterdam: John Benjamins.
- Hualde, José Ignacio & Marianna Nadeu. 2011. Lenition and phonemic overlap in Rome Italian. *Phonetica* 68. 215–242.
- Hualde, José Ignacio & Pilar Prieto. 2014. Lenition of sibilants in Catalan and Spanish. *Phonetica* 71. 109–127.
- Hualde, José Ignacio, Miquel Simonet & Marianna Nadeu. 2011. Consonant lenition and phonological recategorization. *Laboratory Phonology* 2. 301–329.
- Hualde, José Ignacio & Jennifer Zhang. 2022. Intervocalic lenition, contrastiveness and neutralization in Catalan. *Isogloss. Open Journal of Romance Linguistics* 8(4). 1–20.
- Josselyn, Freeman Marshall. 1907. *Études de phonétique espagnole*. Paris: H. Welter.
- Kager, René. 1999. *Optimality Theory*. Cambridge: Cambridge University Press.
- Kaisse, Ellen. 1996. The prosodic environment of s-weakening in Argentinian Spanish. In Karen Zagana (ed.), *Grammatical Theory and Romance Languages: Selected papers from the 25th Linguistic Symposium on Romance Languages (LSRL XXV)*, 123–134. Amsterdam: John Benjamins.
- Kaisse, Ellen. 1999. Resyllabification precedes all segmental rules: Evidence from Argentinian Spanish. In J. Marc Authier, Barbara E. Bullock & Lisa A. Reed (eds.), *Formal perspectives on Romance Linguistics: Selected papers from the 28th Linguistic Symposium on Romance Languages (LSRL XXVIII)*, 197–210. Amsterdam: John Benjamins.
- Keating, Patricia A., Taehong Cho, Cécile Fougeron & Chai-Shune Hsu. 2003. Domain-initial articulatory strengthening in four languages. In John Local, Richard Ogden & Ros Temple (eds.), *Papers in laboratory phonology*, 6, 143–161. Cambridge: Cambridge University Press.
- Keating, Patricia A., Richard Wright & Jie Zhang. 1999. Word-level asymmetries in consonant articulation. *UCLA Working Papers in Phonetics* 97. 157–173.
- Keyser, Samuel Jay & Kenneth N. Stevens. 2006. Enhancement and overlap in the speech chain. *Language* 82(1). 33–63.
- Kochetov, Alexei & Laura Colantoni. 2011. Coronal place contrasts in Argentine and Cuban Spanish: An electropalatographic study. *Journal of the International Phonetic Association* 41(3). 313–342.
- Kochetov, Alexei, N. Sreedevi, Midula Kasim & R. Manjula. 2014. Spatial and dynamic aspects of retroflex production: An ultrasound and EMA study of Kannada geminate stops. *Journal of Phonetics* 46. 168–184.

- Kuznetsova, Alexandra, Per Brunn Brockhoff, Rune Haubo Bojesen Christensen & Sofie Pødenphant Jensen. 2020. ImerTest (R package, version 3.1–3).
- Lawson, Eleanor, James M. Scobbie & Jane Stuart-Smith. 2013. Bunched /r/ promotes vowel merger to schwa: An ultrasound tongue imaging study of Scottish sociophonetic variation. *Journal of Phonetics* 41(3). 198–210.
- Lee-Kim, Sang-Im, Lisa Davidson & Sangjin Hwang. 2013. Morphological effects on the darkness of English intervocalic /l/. *Laboratory Phonology* 4(2). 475–511.
- Lehiste, Ilsa. 1980. Phonetic manifestation of syntactic structure in English. *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics* 14. 1–27.
- Lenth, Russell, Jonathon Love & Maxime Herve. 2018. Emmeans (R package, version 1.1.2).
- Lipski, John. 1989. /s/-voicing in Ecuadorian Spanish: Patterns and principles of consonantal modification. *Lingua* 79. 49–71.
- Martínez-Celdrán, Eugenio. 1991. Sobre la naturaleza fonética de los alófonos de /b, d, g/ en español y sus distintas denominaciones. *Verba, Anuario Galego de Filoloxia* 18. 235–253.
- Martínez-Celdrán, Eugenio & Xosé Luís Regueira. 2008. Spirant approximants in Galician. *Journal of the International Phonetic Association* 38(1). 51–68.
- Mascaró, Joan. 1991. Iberian spirantization and continuant spreading. *Catalan Working Papers in Linguistics* V(1). 167–179.
- Mateus, Maria Helena & Ernesto d'Andrade. 2000. *The phonology of Portuguese*. Oxford: Oxford University Press.
- Mielke, Jeff. 2015. An ultrasound study of Canadian French rhotic vowels with polar smoothing spline comparisons. *Journal of the Acoustical Society of America* 137. 2858–2869.
- Mielke, Jeff, Christopher Carignan & Erik R. Thomas. 2017. The articulatory dynamics of pre-velar and pre-nasal /æ/-raising in English: An ultrasound study. *Journal of the Acoustical Society of America* 142. 332–349.
- Navarro-Tomás, Tomás. 1972. *Manual de pronunciación española*, 17th edn. Madrid: Consejo superior de investigaciones científicas.
- Nespor, Marina. 1999. Stress domains. In Harry van der Hulst (ed.), *Prosodic systems in the languages of Europe*, 117–159. Berlin and New York: Mouton de Gruyter.
- Nespor, Marina & Irene Vogel. 1986. *Prosodic phonology*. Dordrecht: Foris.
- Parrell, Benjamin. 2012. The role of gestural phasing in Western Andalusian Spanish aspiration. *Journal of Phonetics* 40. 37–45.
- Peperkamp, Sharon. 1994. Prosodic constraints in the derivational morphology of Italian. In Geert Booij & Jaap van Marle (eds.), *Yearbook of morphology*. Dordrecht: Kluwer Academic Publishers.
- Peperkamp, Sharon. 1996. On the prosodic representation of clitics. In Ursula Kleinherz (ed.), *Interfaces in phonology*, 102–127. Berlin: Akademie Verlag.
- Peperkamp, Sharon. 1997. Output to output identity in word level phonology. In Jane A. Coerts & Helen de Hoop (eds.), *Linguistics in the Netherlands 1997*, 159–170. Amsterdam: John Benjamins.
- Piñeros, Carlos Eduardo. 2006. The phonology of nasal consonants in five Spanish dialects. In Fernando Martínez Gil & Sonia Colina (eds.), *Optimality-theoretic studies in Spanish phonology*, 146–171. Amsterdam: John Benjamins.
- Proctor, Michael. 2011. Towards a gestural characterization of liquids: Evidence from Spanish and Russian. *Journal of Laboratory Phonology* 2. 451–485.
- Ramsammy, Michael. 2012. *The realisation of coda nasals in Spanish*. University of Manchester PhD thesis.
- Ramsammy, Michael. 2013. Word-final nasal velarisation in Spanish. *Journal of Linguistics* 49. 215–255.
- Ramsammy, Michael. 2021. Contextual reduction of word-final /l/ in Spanish: An EPG study. *Journal of the International Phonetic Association*. <https://doi.org/10.1017/s0025100321000128>.

- Recasens, Daniel & Clara Rodríguez. 2016. A study on coarticulatory resistance and aggressiveness for front lingual consonants and vowels using ultrasound. *Journal of Phonetics* 59. 58–75.
- Robinson, Kimball. 1979. On the voicing of intervocalic s in the Ecuadorian Highlands. *Romance Philology* 33. 132–143.
- Robinson, Kimball. 2012. The dialectology of syllabification: A review of variation in the Ecuadorian highlands. *Romance Philology* 66. 115–145.
- Roca, Iggy. 1992. Stress and syllables in Spanish. In Héctor Campos & Fernando Martínez Gil (eds.), *Current issues in Spanish linguistics*. Washington, D.C.: Georgetown University Press.
- Scobbie, James M. & Marianne Pouplier. 2010. The role of syllable structure in external sandhi: An EPG study of vocalisation and retraction in word-final English /l/. *Journal of Phonetics* 38. 240–259.
- Selkirk, Elizabeth. 1984. *Phonology and syntax: The relation between sound and structure*. Cambridge, Mass.: MIT Press.
- Selkirk, Elizabeth. 1986. On derived domains in sentence phonology. *Phonology Yearbook* 3. 371–405.
- Simonet, Miquel. 2010a. Dark and clear laterals in Catalan and Spanish: interaction of phonetic categories in early bilinguals. *Journal of Phonetics* 38. 663–678.
- Simonet, Miquel. 2010b. Rating accented speech on continua: Nateness in speech production in highly proficient bilinguals. In Marta Ortega-Llebaria (ed.), *Selected Proceedings of the 4th Conference on Laboratory Approaches to Spanish phonology*, 37–46. Somerville, MA: Cascadia Proceedings Project.
- Sproat, Richard & Osamu Fujimura. 1993. Allophonic variation in English /l/ and its implications for phonetic implementation. *Journal of Phonetics* 21. 291–311.
- Strycharczuk, Patrycja & Martin Kohlberger. 2016. Resyllabification reconsidered: On the durational properties of word-final /s/ in Spanish. *Laboratory Phonology* 7(1(3)). 1–24.
- Strycharczuk, Patrycja & James M. Scobbie. 2017a. Fronting of Southern British English high-back vowels in articulation and acoustics. *Journal of the Acoustical Society of America* 142. 322–331.
- Strycharczuk, Patrycja & James M. Scobbie. 2017b. Whence the fuzziness? Morphological effects in interacting sound changes in Southern British English. *Laboratory Phonology* 8(1). 1–21.
- Strycharczuk, Patrycja & Koen Sebregts. 2014. Erring on the side of phonology. *Linguistics in the Netherlands* 31(1). 145–164.
- Strycharczuk, Patrycja & Koen Sebregts. 2018. Articulatory dynamics of (de)gemination in Dutch. *Journal of Phonetics* 68. 138–149.
- Strycharczuk, Patrycja, Marijn van't Veer, Martine Bruil & Kathrin Linke. 2014. Phonetic evidence on phonology-morphosyntax interactions: Sibilant voicing in Quito Spanish. *Journal of Linguistics* 50. 403–452.
- Tabain, Marija. 2003. Effects of prosodic boundary on /aC/ sequences: Articulatory results. *Journal of the Acoustical Society of America* 113. 2834–2849.
- The MathWorks, Inc. 2021. MATLAB. Update b edn.
- Torreira, Francisco. 2006. Coarticulation between aspirated-s and voiceless stops in Spanish: An interdialectal comparison. In Nuria Sagarra & Almeida Jacqueline Toribio (eds.), *9th Hispanic Linguistics Symposium*. Somerville, MA: Cascadia Proceedings Project.
- Torreira, Francisco & Mirjam Ernestus. 2011. Realization of voiceless stops and vowels in conversational French and Spanish. *Laboratory Phonology* 2. 231–353.
- Torreira, Francisco & Mirjam Ernestus. 2012. Weakening of intervocalic /s/ in the Nijmegen corpus of casual Spanish. *Phonetica* 69. 124–148.
- Trigo, Rosario L. 1988. *On the phonological derivation and behaviour of nasal glides*: MIT PhD Dissertation.
- Turton, Danielle. 2014. *Variation in English /l/: Synchronic reflections of the life cycle of phonological processes*. University of Manchester PhD thesis.

- Turton, Danielle. 2017. Categorical or gradient? An ultrasound investigation of /l/-darkening and vocalization in varieties of English. *Laboratory Phonology* 8(1). 1–31.
- Wheeler, Max W. 2005. *The phonology of Catalan*. Oxford: Oxford University Press.
- Wickham, Hadley, Winston Chang, Lionel Henry, Thomas Lin Pedersen, Kohske Takahashi, Claus Wilke, Kara Woo, Hiroaki Yutani & Dewey Dunnington. 2021. ggplot2 (R package, version 3.3.5).
- Wiltshire, Caroline. 2006. Prefix boundaries in Spanish varieties. In Fernando Martínez Gil & Sonia Colina (eds.), *Optimality-theoretic studies in Spanish phonology*, 358–377. Amsterdam: John Benjamins.
- Wood, Simon. 2021. Mgc v (R package, version 1.8–38).
- Wrench, Alan. 2003–2021. *Articulate Assistant Advanced (AAA)*. Articulate Instruments Ltd.