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# Laryngeal reduction and mora deletion in Mixtec: Phonetics in phonology

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This paper describes a process of laryngeal reduction in San Martín Peras Mixtec (SMPM; ISO: jmx), an Otomanguean language spoken in Oaxaca and by diasporic communities throughout Mexico and the US. In this process, roots containing a laryngealized vowel often appear in a highly reduced form in fast speech. Laryngeal reduction is gradient, dependent on speech rate, and lacks a phonologically-defined conditioning environment, giving it the characteristics of a phonetic process. However, it is at least sometimes correlated with a phonological process of mora deletion, as evidenced by the fact that some highly reduced laryngealized roots—but no unreduced laryngealized roots—undergo a phonological tone sandhi alternation that applies only to mono-moraic rising tones. The phonological process of mora deletion is argued to be conditioned by the same phonetic factors that drive laryngeal reduction, constituting an instance of a phonological process triggered by purportedly phonetic factors.

*Keywords: Mixtec; laryngealization; reduction; phonology–phonetics interface; tone*

## 1 Introduction

The relationship between abstract, discrete sound categories and their physical, gradient realization has been a central issue in phonology since before the emergence of generative phonology (see Zsiga 2020 for a detailed history). Throughout the years, researchers have posited different 'dividing lines' between abstract phonology and concrete phonetics. Table 1 shows a few of the proposed distinctions:

| Phonology | Phonetics | Exemplified in |
|---|---|---|
| Language-specific | Universal | Chomsky & Halle (1968) |
| Contrastive | Non-contrastive | Anderson (1975) |
| Abstract | Physical | Zsiga (2000) |
| Categorical | Gradient | Keating (1996) |

Table 1: Proposed dividing lines between phonology and phonetics.

Though there is certainly no consensus in the field, several of these dividing lines are no longer widely

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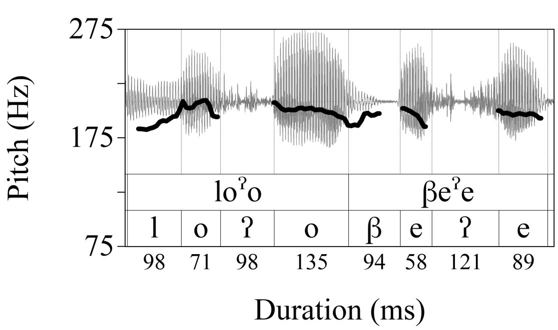
adopted. For example, an early idea was that phonology involved all language-specific knowledge while phonetics was a universal system that physically implemented that knowledge. However, the existence of language-specific phonetic patterns is now relatively uncontroversial (Keating 1985; Kingston & Diehl 1994; Ladd 2014; Kingston 2007; c.f. Volenec & Reiss 2017). Additionally, contrastive sound patterns were once commonly thought of as being the only instances of true phonology, with non-contrastive sound patterns being thought of as phonetic or 'automatic.' However, many processes that result in changes that are otherwise not contrastive in a given language, like some cases of allophony, are now analyzed as phonological (though see Dresher 2009 for an alternative account).

The two dividing lines between phonology and phonetics that are still accepted by many phonologists are the final two (see, e.g., Pierrehumbert 1990). Under the first, phonology involves abstract mental representations, and phonetics involves their physical implementation. Under the second, phonological processes result in categorical change while phonetic processes result in gradient change. Of course, these distinctions are not universally accepted: Articulatory Phonology posits that the physical gestures that produce speech sounds are the basic units of phonological contrast (Browman & Goldstein 1992). Though these are abstract gestures with respect to time and space (Gafos 2002), their dynamic nature allows for gradient, physically-defined effects on units of phonological representation, namely gestures. Additionally, many models of phonology build gradience directly into the phonological grammar (i.e., Flemming 2001; Hayes 2017). However, it is the case that much current work in phonology assumes either or both of the last two dividing lines above: phonology deals with abstract representations while phonetics deals with their physical implementation, and the units of phonology are categorical while the units of phonetics are inherently gradient.

In this paper, I show that even these proposed dividing lines between phonetics and phonology seem to break down in a process of laryngeal reduction in San Martín Peras Mixtec (SMPM). In SMPM, the acoustic correlates of laryngealization can vary greatly, as is the case in many languages (see, for example, Hillenbrand & Houde 1996; Gerfen & Baker 2005; DiCanio 2012; Whalen et al. 2016; Davidson 2021). In some cases, which I term *unreduced*, laryngealized vowels contain aperiodicity, glottal closure, and significant pitch and amplitude drops. In other cases, which I term *reduced*, many of these characteristics appear to be greatly weakened or altogether absent. Additionally, there are many 'in-between' forms, where some acoustic correlates of laryngealization appear to be weakened or missing, but others are not. An example of the two ends of this continuum is given below, where the laryngealized words [loˀo] ('small') and [βeˀe] ('house') surface in an unreduced form in (1) and in a reduced form in (2).[1]

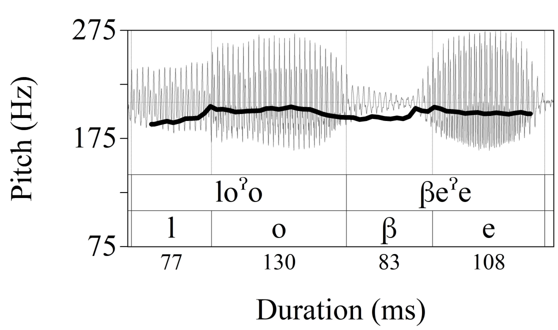
(1) **Unreduced**

ʃĩni ɾà loˀo βeˀe koni
see.COMPL 3M small house yesterday
'The boy saw a house yesterday.'




(2) **Reduced**

ʃĩni ɾà lo βe koni
see.COMPL 3M small house yesterday
'The boy saw a house yesterday.'




[1]Thanks to Ryan Bennett for the Praat script used to generate these images. The transcription of reduced forms of laryngealized words with a single vowel and no [ʔ] is not a claim about their phonological representation, but simply meant to convey the distinction between unreduced and highly reduced laryngealized roots in transcription.

I generally refer to the weakening or apparent loss of some of the acoustic correlates of laryngealization as *laryngeal reduction*. Laryngeal reduction in SMPM bears the hallmarks of a phonetic process under the views presented above. First, it is a process that is driven primarily by speech rate. In abstractionist theories of phonology, speech rate is a phonetic factor that is not relevant to a language's phonology (McCarthy 1986:249–50; Keating 1996:263; Myers 2000:265–266). That is, speech rate involves how quickly articulators move from one target to another, and it should not have an impact on the abstract mental representations that phonology works with. In other words, speech rate is a physical factor, while phonology is abstract. Second, laryngeal reduction is gradient, since there are many 'intermediate stages' of reduction. Given that gradience is often associated with phonetic sound patterns and categoricity with phonological patterns, this point provides another argument in favor of analyzing laryngeal reduction as a phonetic process. Finally, the process has no clear, phonologically-defined conditioning environment—it appears to be able to apply to any laryngealized root in any phonological environment. While unconditioned processes can be modeled phonologically (i.e., redundancy rules; Stanley 1967), the fact that laryngeal reduction involves an alternation means that a phonological account must be able to define exactly when it should occur. Without reference to some phonological configuration, this is much more difficult.

Despite the fact that laryngeal reduction has many of the characteristics of a phonetic process under the view that rate-conditioned, gradient processes are non-phonological, there is evidence that the endpoint of laryngeal reduction is correlated with a change in phonological representation. Specifically, highly reduced laryngealized roots often undergo a process of phonological tone sandhi that never applies to unreduced laryngealized roots. I will argue that this correlation is best understood as being the result of a phonological process of mora deletion that is driven by the purportedly extra-grammatical factor of speech rate. Though I leave the exact implementation of this interaction for future research, the immediate implication of this pattern is that speech rate can, in fact, influence phonological representations.

The paper is structured as follows: §2 gives necessary background, and §3 walks through the acoustic characteristics of laryngeal reduction. §4 outlines the process's phonetic nature, and §5 discusses the interaction of laryngeal reduction with tone sandhi. §6 concludes.

## 2 Background

### 2.1 Language info

SMPM is an Otomanguean language spoken by about 10,000 people in and around the municipality of San Martín Peras in western Oaxaca, Mexico (Instituto Nacional de Estadística y Geografía 2010). Additionally, there are an estimated 350,000 indigenous Oaxacans living in California (Rabadán & Salgado 2018), many of whom speak one of the multitude of indigenous Oaxacan languages. Speakers of the San Martín Peras variety of Mixtec are concentrated principally in the towns of Oxnard, Santa María, Salinas, and Watsonville (Mendoza 2020). The language has default VSO word order, though arguments regularly front to a pre-verbal position through various processes related to information structure (Ostrove 2018; Mendoza 2020; Hedding 2022), as is the case in other Mixtec languages (e.g., León Vásquez 2017 on Yucuquimi de Ocampo Mixtec; Macaulay 1996 on Chalcatongo Mixtec).

The aspects of SMPM's phonological system that are most immediately relevant for the present investigation are its use of a bi-moraic minimal word, its phonation system, and its robust tonal system. I will walk through each of these here.

### 2.2 Root shape and laryngealization

Syllable and root templates across Mixtec languages are relatively uniform: in general, coda consonants are disallowed, and lexical roots must meet a bi-moraic minimal word template (see Penner 2019 for a comprehensive overview), resulting in the root shapes CVCV, CVV, VCV, and VV. Another shared feature across Mixtec languages is that laryngealization, which is usually transcribed as a glottal stop [ʔ], patterns differently from other consonants. Laryngealization is restricted to root-medial positions in most Mixtec languages, and there may only be one instance of laryngealization per root.[2] Additionally, because laryngealization may be itself followed by a consonant, it occurs in what appears to be a coda position, though I argue later that these are not actually codas. The result of these characteristics is that laryngealized words in Mixtec languages tend to be of the shapes CVˀCV, CVˀV, VˀCV, or VˀV.

Another characteristic that differentiates [ʔ] from other consonants is that, in some Mixtec languages, laryngeal gestures are transparent for the purposes of tone sandhi. That is, words of the shape CVV and CVˀV behave in the same way with regard to tone sandhi, while other CVCV words do not (Macaulay & Salmons 1995:58). Finally, the vowels on each side of the [ʔ] in CVˀV words almost always match in vowel quality and nasality, while vowels in CVCV words do not always match. Because of these considerations, many researchers have advanced the hypothesis that laryngeal gestures in Mixtec languages are not consonants proper, instead positing that laryngealization is a higher-level feature of either vowels/moras (Gerfen 1999) or roots (Macaulay & Salmons 1995). For illustration, the representation of [βaˀa] ('good') in Chalcatongo Mixtec is reproduced below from Macaulay & Salmons (1995).

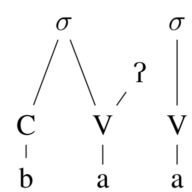



Figure 1: Macaulay & Salmons' (1995) representation of [βaˀa] ('good')

While these approaches vary on the specific level at which laryngealization is attached, they capture the same essential observation: laryngealization across Mixtec languages acts not as a consonant proper but as a suprasegmental feature expressed during the vocalic portion of a word.

The facts in SMPM basically mirror the Mixtec trend. First, there is a bimoraic minimal word requirement, as the only words that are monomoraic are functional items like weak pronouns and inflectional morphology on the verb, which are likely prosodically dependent. This fact, coupled with a strong ban on coda consonants, results in the following root shapes in SMPM (Table 2):[3]

| CVCV | CVV | VCV | VV |
|---|---|---|---|
| léló<br>'skunk' | lěè<br>'baby' | ámã́<br>'when?' | ĩĩ<br>'one' |

Table 2: Modal root shapes in SMPM.

Like in other Mixtec languages, contrastive laryngealization in SMPM surfaces only once per root, appearing root-medially in the middle of the two moras, either before a voiced consonant or a vowel. It never occurs root-finally, or root-initially.[4] When laryngealization occurs in between two vowels in a mono-morphemic

[2]Root-final glottalization and multiple instances of glottalization per root are found in Ayutla Mixtec (Pankratz & Pike 1967) and Zacatepec Mixtec (Towne 2011).

[3]Mono-morphemic words of the shape CVCVV and CVCVCV are less common, and most examples contain what is likely a fossilized prefix. For example, many animal names contain the fossilized prefix [tsi-/ʧi-], which is likely associated with the merger of the animal and historical round noun classes (Peters 2018).

[4]Like in other varieties of Mixtec (i.e., San Pedro Tulixtlahuaca; Becerra Roldán 2019:112), [ʔ] sometimes occurs epenthetically at the beginning of vowel-initial roots, but in SMPM this only happens to resolve vowel hiatus. As a result, I do not analyze these

word, the two vowels obligatorily match in quality and nasality. This results in the laryngealized root shapes in Table 3 below.[5]

| CV$^{ʔ}$CV | CV$^{ʔ}$V | V$^{ʔ}$CV | V$^{ʔ}$V |
|---|---|---|---|
| sì$^{ʔ}$βà<br>‘seed’ | k$^{w}$ì$^{ʔ}$i<br>‘fruit’ | i$^{ʔ}$nĩ́<br>‘hot’ | í$^{ʔ}$i<br>‘raw’ |

Table 3: Laryngealized root shapes in SMPM.

Because of the phonotactic restrictions on laryngealization in SMPM, I follow the Mixtec literature in analyzing [ʔ] as a suprasegmental feature associated to a vowel, not as a consonant proper. Throughout the paper, I will follow Penner (2019) in analyzing CVCV and CV$^{ʔ}$CV roots as bi-syllabic and CVV roots as monosyllabic. However, given the debate about the syllabification of CV$^{ʔ}$V roots (Penner 2019:87) and the lack of conclusive evidence for their syllabic status in SMPM, I do not rely on syllables in my analysis of CV$^{ʔ}$V roots.

An additional point of interest in SMPM's phonation system is that it has a laryngeal contrast between [ʔ] and [h]. This distinction is rare in Mixtec languages and is potentially an innovation (Peters 2018), as I know of no other Mixtec languages that make this contrast. Interestingly, Triqui languages also contrast final [ʔ] and [h] (DiCanio 2010; Hernández Mendoza 2017), meaning that it is possible that contrastive [h] in SMPM is a retention of Proto-Mixtecan [h] rather than an innovation. As seen in Table 4, contrastive [h] has the same phonotactic distribution as [ʔ], occurring only root-medially before voiced consonants or between two identical vowels. Because they share a phonotactic distribution, it is likely that [h], too, is the realization of a pattern of non-modal phonation. However, unlike [ʔ], [h] does not occur root-initially to resolve hiatus.

Finally, every root-medial, voiceless consonant is preceded by a [h]. It is unclear at present whether this is best analyzed as an instance of non-contrastive breathy phonation, or whether it is best analyzed as pre-aspiration of root-medial voiceless consonants, as it is analyzed in the neighboring variety of Alcozauca Mixtec (Mendoza Ruiz 2016) as well as Ayutla Mixtec (Pankratz & Pike 1967). Because non-contrastive [h] only occurs before root-medial consonants, the root shapes with non-contrastive [h] in Table 4 are a subset of those that contain contrastive [h]. Note also that vowel nasalization is contrastive in SMPM, as evidenced by the unpredictability of vowel nasalization in the words for ‘green’ and ‘skin’ in Table 4.

| CV$^{h}$CV | CV$^{h}$V | V$^{h}$CV | V$^{h}$V |
|---|---|---|---|
| $^{n}$tsì$^{h}$βǐ<br>‘egg’ | k$^{w}$î$^{h}$ǐ<br>‘green’ | ì$^{h}$mã̌<br>‘wax’ | ĩ̂$^{h}$ĩ̌<br>‘skin’ |

| CV$^{h}$CV | V$^{h}$CV |
|---|---|
| tá$^{h}$tà<br>‘father’ | i$^{h}$kǐ<br>‘bone’ |

Table 4: Roots with contrastive (left) and non-contrastive (right) [h] in SMPM.

Though roots with intervocalic [h] sometimes undergo reduction in a similar fashion to roots with intervocalic [ʔ], they do not reduce nearly as often, and many roots of this shape seem to never undergo analogous reduction. Because of these differences, I focus only on CV$^{ʔ}$V roots in this paper.

### 2.3 Tone

Another relevant aspect of SMPM's phonology is its robust system of tonal contrast. It has five phonemic tones: three level tones (v́ = High, v = Mid, v̀ = Low) and two contour tones (v̌ = Low-to-High rise, v̂ =

cases of laryngealization as underlying.

[5]As with CVCVCV words above, there are some CVCVʔV words, but these too contain the fossilized noun class prefix.

Falling tone). The tone-bearing-unit (TBU) is the mora, and a single mora may host any of the five phonemic tones (Peters 2017, 2018). Table 5 displays attested tonal melodies on CVCV (bi-syllabic, non-laryngealized roots with two short vowels), where every tone but the falling tone may occur on either the first or the second mono-moraic syllable (c.f. Peters 2018:23–26 on final falling tones).[6]

| | H | M | L | LH |
|---|---|---|---|---|
| H | léló ‘skunk’ | tʃúʰtu ‘cat’ | táʰtà ‘father’ | — |
| M | ijá ‘sour’ | leʰso ‘rabbit’ | jaʰkʷà ‘dirty’ | jiβǐ ‘person’ |
| L | tʃìʰtʃí ‘avocado’ | ⁿtàʰʃĩ ‘wet’ | jùʰkù ‘leaf’ | sàʰtǎ ‘back’ |
| LH | — | — | ʃǐlì ‘woodpecker’ | — |
| F | — | tʃêle ‘rooster’ | ʃânũ̀ ‘cigarette’ | îʰtũ̌ ‘tree’ |

Table 5: Tonal melodies on non-laryngealized CVCV roots.

Laryngealized roots show the same tonal melodies as CVCV roots, with a couple of potential exceptions. This fact suggests that SMPM is a laryngeally-complex language in the sense of Silverman (1997), as tone and phonation are fully cross-classified. That is, it is not the case that laryngealized vowels may host only a subset of the tones hosted on modal vowels, or vice versa. However, tonal melodies on CVV roots, which contain a bi-moraic long vowel with no laryngealization, are somewhat more restricted in that I only know of a handful of examples of CVV roots ending in a LH tone (Table 6). It is also worth noting that only CVV roots may host two phonemic tones on one long vowel, so only long vowels may host contours made up of three pitch targets (i.e., LH-L in Table 6), which are best thought of as tonal melodies.

| | H | M | L | LH |
|---|---|---|---|---|
| H | ĩ́ĩ́ ‘hail’ | ⁿtúu ‘black bug’ | kʷã́ã̀ ‘yellow’ | — |
| M | kʷií ‘hardworking’ | ĩĩ ‘one’ | ñũũ̀ ‘town’ | — |
| L | tsĩ̀ĩ́ ‘rat’ | — | ʃàà ‘chin’ | — |
| LH | — | — | lěè ‘baby’ | — |
| F | — | — | — | tʲôǒ ‘Mallow’ |

| | H | M | L | LH |
|---|---|---|---|---|
| H | tsʲéˀé ‘hard’ | jéˀe ‘door’ | jéˀè ‘bright’ | — |
| M | iˀní ‘hot’ | βeˀe ‘house’ | nãˀã̀ ‘early’ | jaˀǎ ‘chile’ |
| L | tsʲòˀó ‘flea’ | tsʲòˀo ‘root’ | sìˀβà ‘seed’ | ʃìˀǐ ‘mushroom’ |
| LH | — | — | mã̌ˀnã̀ ‘sleepless’ | — |
| F | — | — | kũ̂ˀũ̀ ‘sick’ | ñũ̂ˀũ̌ ‘dirt’ |

Table 6: Tonal melodies on modal CVV (left) and laryngealized (right) roots.

[6]Table 5 includes roots with non-contrastive [h] before a medial voiceless consonant, since this is one of the most common word shapes in the language and seems not to restrict the tones that may be hosted by the preceding vowel.

In addition to being integral to lexical contrasts, tone in SMPM is involved in expressing aspect and negation. For example, the following four examples differ only in the tone of the first mora of the verb, and the tone of the second mora does not change:

(3) $^{n}$tá$^{h}$ʧí saà
fly.CONT bird
'The bird flies.'

(4) $^{n}$ta$^{h}$ʧí saà
fly.POT bird
'The bird will fly.'

(5) $^{n}$tà$^{h}$ʧí saà
fly.COMPL bird
'The bird flew.'

(6) $^{n}$tǎ$^{h}$ʧí saà
NEG.fly.POT bird
'The bird won't fly.'

## 2.4 Phonological representation

At this point, it is possible to propose a phonological representation for laryngealized roots in SMPM. The first point is that laryngealized roots in SMPM meet the bi-moraic minimal word requirement. This is not to be taken for granted, since CV$^{ʔ}$V words have been analyzed as underlying mono-moraic CV$^{ʔ}$ in some Mixtec languages (i.e., Ixtayutla Mixtec; Penner 2019), with vowel epenthesis occurring to fulfill the minimal word template. This analysis, while likely correct for other Mixtec varieties, is unlikely for SMPM because each mora is associated with its own underlying tone, and the tone of one vowel is not predictable from the tone of the other (Table 6).[7] The other relevant point is that laryngealization is a supra-segmental feature that is realized on a vowel. Because in roots of the shape CV$^{ʔ}$CV, laryngealization precedes the medial consonant, I analyze laryngealization in SMPM as being linked to the first mora, not the second. These points—the bimoraic nature of laryngealized roots and the supra-segmental nature of laryngealization—motivate the following phonological representations for laryngealized roots in SMPM. The representation I assume is essentially the one outlined in Figure 1 above, but with a small change: each vowel is a separate mora, and I remain agnostic about their syllabic status. An illustrative example of the phonological representations I assume for the words [ts$^{j}$á$^{ʔ}$ǎ] ('Tecomaxtlahuaca') and [k$^{j}$a$^{ʔ}$mǐ] ('gourd/pumpkin') is given in Figure 2.


Figure 2: Phonological representations of [ts$^{j}$á$^{ʔ}$ǎ] ('Tecomaxtlahuaca,' left) and [k$^{j}$a$^{ʔ}$mǐ] ('gourd/pumpkin,' right).

This representation captures all of the main points discussed here: [ʔ] is a suprasegmental feature associated with the first mora of the root, each mora is associated with its own tone, and a single vowel feature is associated to both moras in CV$^{ʔ}$V roots. This representation serves as the basis for the analysis of laryngeal reduction and its interactions with tone sandhi discussed later.

## 2.5 Laryngeal reduction across Mixtec

SMPM is by no means the only Mixtec language in which laryngeal reduction occurs, but Mixtec languages do appear to vary in whether laryngealized roots undergo severe reduction. In discussions of the phonetic realization of contrastive laryngealization in Coscatlán Mixtec (Zendejas 2014:72–74) and San Pedro Tulixtlahuaca Mixtec (Becerra Roldán 2019:112–116), there is no note of highly reduced realizations of laryngealized words—they are either produced with glottal closure, creaky voice, or both. However,

[7] One might still posit an underlyingly mono-moraic CV$^{ʔ}$ form with one of the two tones as a floating tone, but there is no positive evidence in SMPM for such an analysis.

several works on other Mixtec languages discuss a process very similar to SMPM's laryngeal reduction. Laryngealized roots in these languages may lose their laryngealization (also called 'glottalization') in certain contexts. Moreover, the analogous processes are usually analyzed as involving the phonological deletion of the laryngeal feature and/or a vowel and have received a fair amount of attention in the Mixtec literature. For example, Pike & Small (1974:122–124) write that, in Coatzospan Mixtec, glottalized morphemes often "lose their glottal stop" in normal speech when they are not the rightmost member of a word phrase, but that "in slower, slightly emphasized speech, the same sequence of morphemes may [...] have two or more glottalized or lengthened syllables. Gerfen (1996, 1999) updates this claim, showing that underlying laryngealization only surfaces in positions of phrasal prominence. For example, (7) shows a sequence of two underlyingly laryngealized roots, but only the second surfaces with laryngealization when the two roots are combined to form a larger constituent. This is because only the rightmost root here receives phrasal stress.

(7) /tʲɨʔᶤβi/ + /βaʔa/ → [tʲɨβi βaʔa]
'to push' 'well'
'To push well' (Gerfen 1999:62)

Laryngeal reduction has also been noted by Macaulay (1996), who analyzes reduced laryngealized roots as having undergone two separate phonological processes—glottal deletion and vowel deletion—in connected speech.

(8) /bàʔà/ → [bàà] → [bà]
'Good' (Macaulay 1996:42)

Finally, Penner (2019) notes that when two laryngealized roots are combined to form a noun-noun compound in Ixtayutla Mixtec, the first often loses its laryngealization.

(9) /juˀù/ + /kúˀú$^{L}$/ = [jù-kùˀú]
'mouth' + 'bush'
'Bathroom' (Penner 2019:254)

The previous examples show that analogues of laryngeal reduction in other Mixtec languages have been analyzed as involving phonological change. However, phonologically-identical laryngealized roots also vary greatly in their realization. For example, in a production study conducted by Gerfen & Baker (2005) with speakers of Coatzospan Mixtec, participants were presented with a wordlist containing one word at a time, and asked to pronounce each of them. They saw the same list multiple times, and as a result pronounced the same word multiple times. In many cases, the same laryngealized word was produced in different ways by the same consultant in the same task. For example, some words with laryngealized vowels were produced one time with creaky voicing, dips and rises in amplitude, and long duration (Gerfen and Baker 2005:314), while the same word was pronounced by the same consultant another time as periodically voiced, with no creak or clear amplitude modulation (Gerfen & Baker 2005:315). Given that all productions of a given word were in isolation and separated from other repetitions by many filler items, each production of the same word presumably had the same phonological representation. Nonetheless, laryngealized roots in Coatzospan Mixtec were sometimes produced in a way that correlates with unreduced laryngealized roots in SMPM, and sometimes in a way that correlates with highly reduced laryngealized roots in SMPM.

It is clear, then, that a process analogous to laryngeal reduction occurs in other Mixtec varieties, and reduced laryngealized roots are often analyzed as having undergone a phonological process that deletes laryngealization or a vowel. However, productions of laryngealized roots that ostensibly have the same phonological representation can vary greatly, and this variation seems to track relatively well with laryngeal reduction in SMPM. This conglomeration of facts raises the question of whether laryngeal reduction in SMPM should be analyzed as phonological or phonetic in nature. That is, is the weakening and apparent loss of some of the acoustic correlates of laryngealization in SMPM the result of a phonological process that deletes a vowel and/or laryngealization, as proposed for Chalcatongo Mixtec in Macaulay (1996), or is it a phonetic process whereby a single phonological representation may be realized with a range of acoustic correlates? In order to answer this question, the following section investigates the acoustics of unreduced and reduced laryngealized roots and the conditioning environment(s) and driving factors behind laryngeal reduction, concluding that the process does not appear to have a clear phonological conditioning environment and is driven primarily by speech rate.

### 2.6 General research methods

All SMPM data in this paper come from the author's fieldwork with SMPM language consultants, either in Watsonville, California or in Ahuejutla, Mexico. Ahuejutla is a town of about 1,000-1,500 within the municipality of San Martín Peras. Most data points in the paper come from two consultants, both of whom lived in Watsonville, California during the period of data collection and use SMPM on a daily basis. Consultant 1 grew up in Ahuejutla, and Consultant 2 grew up in the town of San Martín Peras, which is the main town in the municipality. The contact language for elicitation sessions with both consultants was Spanish.

Methods for general data collection included translations of single words or full phrases from Spanish to SMPM, eliciting well-formedness judgments for target sentences in an appropriate discourse context and asking for repetitions, and an informal forced-choice task in which a consultant was presented with two grammatical sentences uttered by the linguist and asked which sentence sounded most natural. Methods for determining the phonemic category of tones in relevant words included eliciting target words in tone frame sentences (Pike 1948:50–52), viewing pitch tracks of target words in frame sentences in Praat (Boersma & Weenink 2020) and aggregate pitch plots in R (R Core Team 2013), and using tone sandhi processes that are sensitive to certain tonal specifications. Audio was recorded on zencastr.com (48 KHz, 16-bit) using a Cooler Master MH630 headset microphone.

It is worth noting that the majority of this work was carried out with two language consultants, which is a lower number than what is found in most phonetic studies. The principal reason for this is that the research was carried out online due to restrictions on in-person meetings during the COVID-19 pandemic. Additionally, travel restrictions largely prevented the collection of data in Oaxaca, where it would have been feasible to work with a larger number of language consultants. In order to compensate for the low number of consultants, a large number of observations were gathered across multiple tasks. For example, the amplitude section (§3.2) analyzes 498 productions from Consultant 1 (131 modal, long-vowel roots, 183 unreduced laryngealized roots, and 184 highly reduced laryngealized roots). The discussion of the gradience of laryngeal reduction (§3.5) analyzes 145 productions of laryngealized roots from Consultant 1, and 164 productions of laryngealized roots from Consultant 2. The discussion of the effect of speech rate (§4.3) relies on 120 sentence productions by Consultant 1, as well as a separate task carried out 1.5 years later which analyzes 145 productions from Consultant 1 and 160 productions from Consultant 2. Other sections, such as those on Duration (§3.4) and the maintenance of laryngealization (§3.3) rely on smaller numbers of productions per consultant, but are nonetheless robust enough to establish some conclusions. In this way, the small number of consultants for this paper is made up for by the collection and analysis of a high number of observations per consultant across a number of distinct tasks over a long time period.

## 3 The characteristics of laryngeal reduction

In answering the question of whether or not laryngeal reduction in SMPM should be understood as a phonological process that deletes a vowel and/or laryngealization, it is first useful to examine the acoustics of unreduced and highly reduced laryngealized roots. This point is relevant for two reasons: first, in a feed-forward model of the phonology–phonetics interface, one might assume that phonological alternations are somewhat straightforwardly reflected in the acoustic signal. Second, under many approaches to phonology, whether a process is categorical or gradient is indicative of its status as phonological or phonetic, respectively (e.g., Keating 1996). In this regard, examining the acoustics of laryngealized roots might yield some evidence as to its phonological or phonetic nature.

I begin this section by examining some of the acoustic correlates of laryngeal reduction to determine if there are systematic acoustic differences that are consistent with an analysis of reduction as involving a change in phonological representation. The measures investigated are pitch, intensity, H1-H2, and duration, and the results suggest that unreduced and highly reduced laryngealized vary systematically along some dimensions, namely their intensity and duration, but pattern together in their H1-H2 values and tonal make-up. I take these points to mean that, though some of the acoustic correlates of laryngealization are greatly weakened or absent in highly reduced laryngealized roots, at least some remain relatively robust, suggesting against a phonological analysis of laryngeal deletion. After discussing these characteristics, I demonstrate the gradience of the process, showing that laryngealized roots surface not only as unreduced or highly reduced, but in many intermediate forms. Under the assumption that phonological processes are categorical while phonetic processes are gradient, this provides another piece of support against a phonological analysis of reduction.

## 3.1 Pitch

Under an analysis such as Macaulay (1996), in which highly reduced laryngealized roots have undergone vowel deletion as in (8), it is possible (though not logically necessary) that deletion of a vowel also causes deletion of the tone associated with that vowel. In this light, it is worth examining the pitch profiles of unreduced and highly reduced laryngealized roots for any evidence of tonal deletion that might be indicative of a change in phonological representation. For that reason, this section outlines the pitch characteristics of unreduced and reduced laryngealized roots.

### *3.1.1 Methods*

The data collection methods described here apply to the data used for the analysis of pitch (this section), intensity (§3.2), and H1-H2 (§3.3), as the investigation of each of these measures was carried out on a subset of the same body of data. The data were gathered through an informal production task with Consultant 1 over the course of six elicitation sessions, with each session separated from the last by one or two weeks. This task was carried out at a time when Consultant 1 had developed a meta-linguistic awareness of laryngeal reduction and was able to differentially produce unreduced and highly reduced versions of laryngealized roots. Consultant 1 was asked to produce target words in the carrier sentence in (10). Because of the nature of the carrier sentence, all target words were nouns.

(10) ʃĩnĩ ɾà loˀo __ konĩ
COMPL.see 3M small __ yesterday
'The boy saw __ yesterday.'

Three phonological word types were produced in this task: laryngealized roots (CVˀV), modal, long-vowel roots (CVV), and bi-syllabic roots with a medial sonorant (CVCV). For laryngealized target words, the consultant produced the target word in its unreduced form five times, and then five more times in a reduced form. For non-laryngealized target words (CVV words and CVCV words with a medial sonorant), the consultant produced each word five times. The fifth and final of each set of productions was excluded from analysis to avoid any effect of intonation.

Consultant 1 was prompted to produce this five-sentence sequence for the unreduced and reduced forms of 46 laryngealized roots, resulting in 459 productions (one set only had four sentences instead of five). The final repetition of each set (92 tokens total) was excluded to eliminate any effects of list intonation, and the data used for analysis were 183 unreduced tokens and 184 reduced tokens. The five-sentence sequence was also produced by Consultant 1 for 33 CVV words, resulting in 164 productions (one set only had four sentences instead of five). After excluding the final repetition of each set (33 tokens), 131 productions remained for analysis. Finally, the consultant also produced this five-sentence sequence for 22 CVCV words, resulting in 110 productions. After excluding the final production of each set of sentences (22 tokens), 88 tokens remained for analysis.

The vowel of each token was measured from the beginning of its steady-state until the onset of the following consonant or the end of periodic voicing. Cuts were always made at zero crossings. For CVˀV words, vowel duration covered the entire vocalic portion of the word, including any creak or glottal closure. For CVCV words, the first vowel was measured from its steady-state until the onset of the following sonorant, and the second vowel was measured from its steady-state to the onset of the following consonant or the end of periodic voicing. The medial sonorant was then deleted, leaving a single long vowel for analysis. In the analyses that follow, the data were subsetted to control for relevant factors like tonal melody or vowel quality. In each case, the number of tokens is provided.

To investigate the pitch contours of unreduced and highly reduced laryngealized roots, laryngealized roots were subsetted by tonal melody from the data set described above. A Praat script extracted the average pitch across nine equally-spaced windows for each token, and data were illustrated as smoothed loess regression lines using the 'geom_smooth' function in the ggplot (Wickham 2016) package in R. The pitch plots were then visually analyzed for whether the relative relationship between their starting pitch and ending pitch was the same in the unreduced and reduced tokens (that is, whether the starting pitch was consistently higher or lower than the ending pitch). No statistical test was used to determine whether the pitch contours of the unreduced and reduced laryngealized roots were the same or different for three reasons: first, the two groups varied systematically in their duration, with the unreduced roots having an average duration of 374 ms (SE = 5 ms), and the reduced roots having an average duration of 143 ms (SE = 2ms). Duration differences have a large effect on pitch (see for example Gandour et al. 1999; Kuo et al. 2007; Cho & Flemming 2015), so the large differences in duration between unreduced and reduced laryngealized roots make pitch differences between unreduced and reduced laryngealized roots very likely. Second, unreduced roots almost always had strong laryngealization, marked by irregular vocal fold vibration or glottal closure. The reduced tokens usually had periodic vocal fold vibration throughout the vocalic portion of the laryngealized root. Since irregular vocal fold vibration and glottal closure also has a large effect on pitch (Kreiman et al. 2010; Keating et al. 2015) and resulted in null pitch readings for portions of many tokens, the differences in periodicity between the unreduced and reduced tokens were also likely to have an effect on their associated pitch. Finally, one tonal category (roots with a H-LH melody) had too few observations to conduct a reliable statistical analysis.

### *3.1.2 Results*

Loess regression lines for the pitch of unreduced and reduced laryngealized roots grouped by tonal melody are given in Figures 3 and 4. I only know of one laryngealized root with this melody, which is the place name [tsʲáˀǎ] ('Tecomaxtlahuaca'), so there are very few tokens represented in Figure 4. The gray shaded portion of the plots indicates the section of the unreduced forms in which laryngealization interrupts pitch, meaning that that portion of the pitch plot for the unreduced forms is often discontinuous and less reliable. The location of this gray portion was determined by examining the time points in unreduced laryngealized roots that had the largest number of N/A pitch readings across ∼180 tokens.

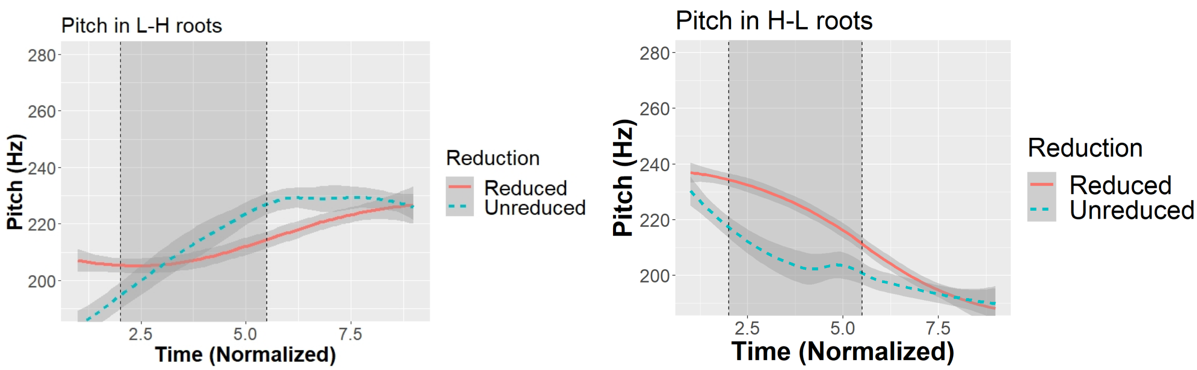



Figure 3: Aggregated pitch plots of unreduced and highly reduced productions of laryngealized roots with an L-H melody (left, 31 unreduced, 30 reduced) and a H-L melody (right, 24 unreduced, 17 reduced).

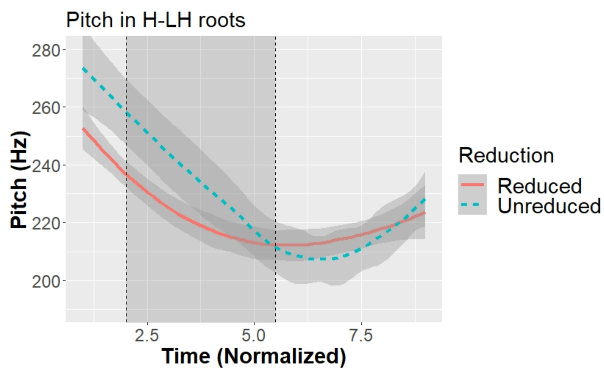



Figure 4: Aggregated pitch plot of unreduced and highly reduced productions of [tsʲáˀǎ] ('Tecomaxtlahuaca,' 8 unreduced, 8 reduced).

Visual analysis of the pitch plots above shows that the relative positions of the starting and ending pitch are the same in each case: pitch starts low and ends higher in the unreduced L-H roots, and it also starts low and ends higher in the reduced forms. Likewise, the pitch of H-L laryngealized roots begins high and ends low in both unreduced and reduced forms. In Figure 4, the same relationship between starting and ending pitch holds, and an additional similarity can be seen: for both unreduced and reduced forms, pitch reaches its lowest point in the middle of the vowel and then rises slightly toward the end of the vowel.

#### *3.1.3 Discussion*

Because the pitch plots show the same qualitative relationship between starting and ending pitch for unreduced and reduced laryngealized roots, I conclude that the tonal melody associated with a laryngealized root is maintained even in highly reduced forms. The similarity in pitch patterns can be taken to suggest that laryngeal reduction does not involve the deletion of phonological tones, though these results should be qualified by the fact that they are based on impressionistic analysis.

### 3.2 Intensity

One acoustic correlate of laryngealization is intensity, which tends to dip at the onset of laryngealization and to rise at its offset, creating a falling-then-rising intensity contour. This is shown in Figure 5 below, where the arrows indicate the direction of the intensity contour. In the unreduced form, intensity dips and then rises; in the reduced form, no such dip is seen. This section investigates the intensity contours of unreduced and reduced laryngealized roots.

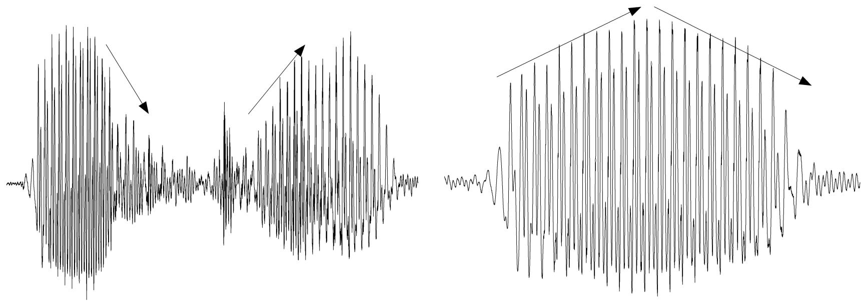


Figure 5: Unreduced (left, ∼280ms) and reduced (right, ∼140ms) forms of the laryngealized word [βeˀe] spoken in the same position by Consultant 1. Arrows indicate direction of intensity contour.

### *3.2.1 Methods*

In order to test whether there is a consistent effect of laryngeal reduction on a word's intensity contour, I analyzed intensity across all productions of unreduced, reduced, and CVV roots gathered using the informal production task described in §3.1. A Praat script extracted mean energy values from all of the tokens in 10-ms windows, and a separate R script[8] divided these windows up into five equally-spaced time windows for each token, averaging across energy values from the 10-ms bins. The data were analyzed with a linear mixed effects model using the lme4 package (Bates et al. 2015) in R, with intensity as the dependent variable. Word type (modal CVV, unreduced laryngealized, and reduced laryngealized), time step, and their interaction were the independent variables. Item was included as a random effect. Because the CVV roots have no laryngealization and thus no vowel-medial intensity dip, this class of words was used as the baseline for comparison.

### *3.2.2 Results*

The residuals of the model were normally distributed (R = 0.97). Model criticism was carried out using the `drop1()` function in the lmerTest package (Kuznetsova et al. 2017), and the full model was compared with a simpler model omitting the word type by time step interaction. This comparison was significant ($p < .001$) using Satterthwaites method, indicating that this interaction should not be excluded from the model. No further model simplification was possible. A visual representation of the intensity data is shown in Figure 6, and the model results are given in Table 7.

There was no main effect of reduced or unreduced word type, suggesting that the overall intensity of CVV, unreduced laryngealized roots, and reduced laryngealized roots was not reliably different. There were also no main effects of any time step, meaning that there was no consistent effect of time step across the entire data set. There were no significant interactions between reduced word type and time step, meaning that the intensity change from step to step in reduced laryngealized roots was not reliably different from that of CVV roots. However, at time steps 2 and 3, there were significant negative interactions between unreduced word type and time step, demonstrating that the intensity of unreduced laryngealized roots was lower at time steps 2 and 3 than in modal CVV roots. Finally, there was a significant but smaller positive interaction between unreduced word type and time step at time step 5, meaning the intensity of unreduced laryngealized roots was slightly higher at time step 5 than was the intensity of CVV roots at time step 5.

[8]Thanks to Yuan Chai for writing these scripts.

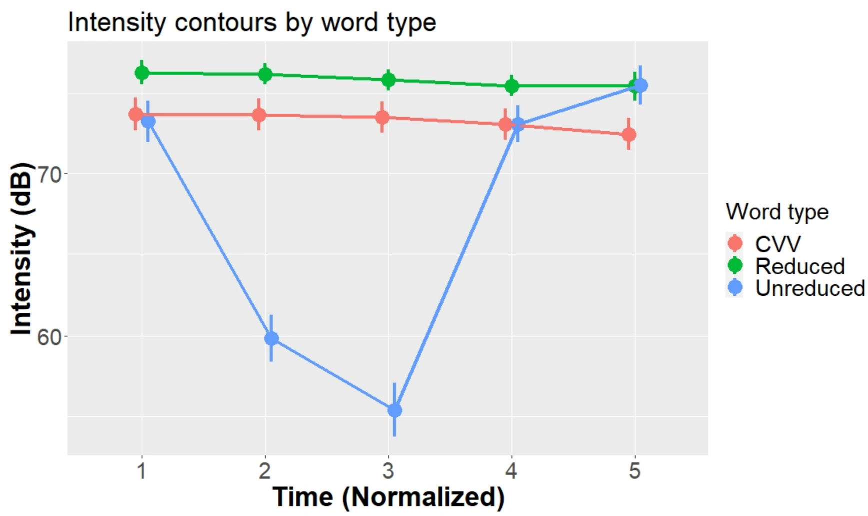



Figure 6: Time-normalized intensity (dB) values with 95% CI for unreduced and reduced laryngealized roots as well as modal, CVV roots (131 CVV, 183 Unreduced, 184 Reduced).

| **Predictor** | $\beta$ **(SE)** | **—t—** | **p-value** |
|---|---|---|---|
| Intercept | 73.22 (1.45) | 50.46 | $< .001$ |
| Reduced | 2.54 (1.74) | 1.46 | .15 |
| Unreduced | -.42 (1.73) | -.24 | .81 |
| Time step 2 | -.03 (.73) | -.03 | .97 |
| Time step 3 | -.18 (.73) | -.24 | .81 |
| Time step 4 | -.6 (.73) | -.83 | .41 |
| Time step 5 | -1.23 (.73) | -1.68 | .09 |
| Reduced x TS 2 | -.32 (.99) | -.32 | .75 |
| Reduced x TS 3 | -.54 (.99) | -.55 | .59 |
| Reduced x TS 4 | -.47 (.99) | -.47 | .64 |
| Reduced x TS 5 | .47 (1.08) | .43 | .66 |
| Unreduced x TS 2 | -13.37 (.96) | -13.9 | $< .001$ |
| Unreduced x TS 3 | -17.64 (.96) | -18.34 | $< .001$ |
| Unreduced x TS 4 | .45 (.96) | .47 | .64 |
| Unreduced x TS 5 | 3.47 (.96) | 3.61 | $< .001$ |

Table 7: Model results for intensity data.

### *3.2.3 Discussion*

Overall, the plot in Figure 6 and the results of the model in Table 7 show that the intensity of unreduced laryngealized roots dips in the middle of the vowel, followed by a rise. By contrast, both modal, CVV roots and highly reduced laryngealized roots have a relatively flat intensity contour. The clear difference in the intensity contours of unreduced and reduced laryngealized roots is consistent with a view of laryngeal reduction as involving the deletion of a laryngeal feature, an approach taken for other Mixtec languages (Macaulay 1996). However, phonologically-identical laryngealized roots may nonetheless appear in unreduced and reduced forms in Coatzospan Mixtec (Gerfen & Baker 2005), and Avelino (2010) documents wide variation in the realization of laryngealization in Yalálag Zapotec. In fact, Gerfen & Baker (2005) showed in a lexical decision task that Coatzospan Mixtec listeners can distinguish laryngealized words from their non-laryngealized counterparts based solely on a very small dip in f0 or amplitude alone, even with periodic vocal fold vibration throughout the vowel. It is clear, then, that the absence of some acoustic correlates of laryngealization from the signal does not automatically mean that laryngealization is absent or unrecoverable from the acoustic signal. The next section examines the H1-H2 of laryngealized and modal roots to determine whether this measure survives reduction.

## 3.3 H1-H2

H1-H2—the difference in amplitude between the first and the second harmonic—is generally lower in creaky voice than in modal voice (Kreiman et al. 2010; Keating et al. 2015; Garellek 2019), and it is a reliable corrolary of phonation contrasts in many languages (Keating et al. 2023). This section analyzes and compares the H1-H2 of laryngealized and modal roots.

### *3.3.1 Methods*

To investigate whether H1-H2 is an acoustic correlate of laryngealization in SMPM, and whether its value is maintained even in reduced laryngealized roots, I examined the H1-H2 of unreduced and highly reduced tokens of laryngealized words, as well as modal vowels in bi-syllabic CVCV words. Only words with mid vowels were examined to account for effects of the first formant on harmonic amplitude. Corrected H1-H2 was not used because of prevalent formant tracking errors, presumably caused by the consultant's high F0 (Garellek 2019:18). Nasal vowels and low vowels (both nasal and oral) were excluded from analysis because of the potential effect of nasal poles on harmonic amplitude (Simpson 2012), and high vowels were not analyzed because of the potential effect of the first formant on the amplitude of the harmonics. CVV roots were excluded because impressionistic analysis of their H1-H2 contours found variable patterns by tonal melody that were not entirely predictable. This variability was not found for CVCV roots.

Voicesauce (Shue 2010) was used to extract the uncorrected H1-H2 values from the vocalic portions of the selected tokens. Each H1-H2 reading was calculated within a 25 ms window that shifted by 1 ms for each reading. An R script, modified from Politzer-Ahles (2023), then defined five equally-spaced time windows for each token and calculated the average H1-H2 for each, averaging across every value in that time window. The data were analyzed using a linear mixed effects model in the lme4 package in R. H1-H2 was the dependent variable, and word type (modal CVCV, unreduced laryngealized, and reduced laryngealized), time step, and their interaction were the independent variables. Item was included as a random effect. Because the questions at hand are (1) whether laryngealized vowels and modal vowels have different H1-H2 values and (2) whether unreduced and reduced laryngealized roots have different H1-H2 values, unreduced laryngealized roots were used as the baseline for comparison.

Model criticism was carried out using the `drop1()` function in the lmerTest package, with the full model being compared to a model that omitted the word type and time step interaction. This comparison was not significant (p = .1) using Satterthwaite's method, suggesting that the additional predictive value of an interaction between time step and word type did not justify the additional model complexity. As a result, a new model was run with H1-H2 as the dependent variable, word type and time step as independent variables, and no interaction between the independent variables. Unreduced laryngealized roots were still used as the baseline for comparison.

### *3.3.2 Results*

The model's residuals were normally distributed (R = .98). Model criticism was carried out using the same method above, comparing the full model with a model omitting either of the independent variables. The comparison was significant for both word type ($p < .001$) and time step ($p < .001$), suggesting that neither variable should be omitted from the model. No further model simplification was possible. A visualization of the data is shown in Figure 7, and the results of the model are given in Table 8.

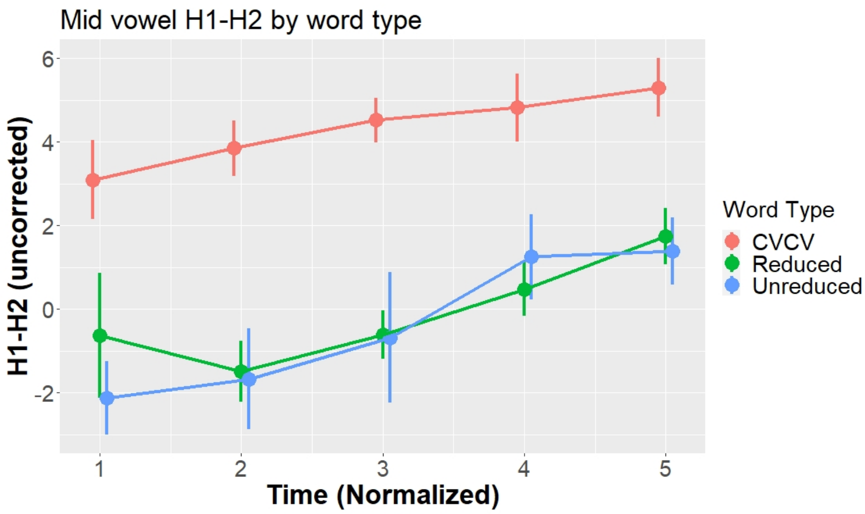



Figure 7: Time-normalized H1-H2 (dB, uncorrected) averages with 95% CI for the vocalic portions of mid-vowel roots (35 Unreduced, 32 Reduced, 32 CVCV).

| **Predictor** | $\beta$ **(SE)** | **\|t\|** | **p-value** |
|---|---|---|---|
| Intercept | -1.52 (.45) | -3.34 | $< .01$ |
| Reduced | .19 (.28) | .68 | .5 |
| CVCV | 4.5 (.64) | 7.03 | $< .001$ |
| Time step 2 | .25 (.37) | .68 | .5 |
| Time step 3 | 1.1 (.37) | 2.97 | $< .01$ |
| Time step 4 | 2.24 (.37) | 6.01 | $< .001$ |
| Time step 5 | 2.85 (.37) | 7.65 | $< .001$ |

Table 8: Results of the mixed effects model.

There was no main effect of reduced word type on H1-H2, meaning that the H1-H2 of unreduced and reduced laryngealized roots were not reliably different. There was a main positive effect of CVCV word type, which shows that the H1-H2 of modal vowels in CVCV words was significantly higher than that of vowels in unreduced laryngealized words. There were also main positive effects of time step at time steps 3, 4, and 5. This can be interpreted as meaning that H1-H2 rose throughout the vowel across all word types.

#### *3.3.3 Discussion*

Because the H1-H2 of modal vowels in CVCV roots was significantly higher than the H1-H2 of laryngealized vowels in unreduced laryngealized roots, I conclude that H1-H2 is lower on laryngealized vowels than modal vowels in SMPM. Additionally, because the H1-H2 of reduced laryngealized roots was not significantly different from that of unreduced laryngealized roots, the null hypothesis that these two word types have the same H1-H2 vowels cannot be rejected, lending support to the conclusion that the H1-H2 values that are characteristic of laryngealization in SMPM are maintained even in highly reduced laryngealized roots.

Importantly, the magnitude of the H1-H2 differences between laryngealized vowels and modal vowels is likely large enough to reliably cue a distinction between the two phonation types in SMPM. The mean H1-H2 for both unreduced and reduced laryngealized vowels is ∼4-5dB lower than the corresponding portions of modal vowels. Though this difference may seem relatively small, it is well above the reported H1-H2 just-noticeable difference (JND) of 2.6 dB for Gujarati listeners (Kreiman et al. 2010) and the JND of 2.72 dB for Mandarin listeners (Kreiman & Gerratt 2010). This fact, combined with the findings of Gerfen & Baker (2005) that Coatzospan Mixtec listeners are robustly sensitive to even small amplitude or pitch changes as signals of the presence of contrastive laryngealization, suggests that vowels in reduced laryngealized words are robustly different from modal vowels in a way that is likely perceptible to listeners. However, I have not established that SMPM listeners use H1-H2 in the perception of laryngealization, and the perception of phonation type by Gujarati and Mandarin listeners cannot be used to conclusively reason about the perception of phonation type by SMPM listeners. Still, given the currently-available evidence, it seems more likely than not that the differences in H1-H2 are large enough that even highly reduced laryngealized words can still be identified as laryngealized. That is, the acoustic evidence does not suggest that laryngeal reduction involves the deletion of a laryngeal feature from the phonological representation, but rather perhaps a weakening of some of the acoustic correlates of laryngealization under the pressures of fast speech.

Finally, the fact that H1-H2 rose for all word types may have a prosodic explanation. In SMPM, utterance-final vowels are often breathy, and breathiness is associated with higher H1-H2 (Garellek 2019). It is possible that, given that the target words were embedded in an unvarying frame sentence (10), they were at least sometimes produced with utterance-final prosody, resulting in some amount of final breathy voicing and a subsequent rise in H1-H2. Whatever the correct interpretation of the rising H1-H2 may be, though, it is clear that the unreduced and reduced laryngealized roots pattern together, to the exclusion of the modal vowels. This pattern suggests that one of the acoustic correlates of laryngealization is not reduced or erased even in highly reduced roots.

## 3.4 Duration

Another typical characteristic of highly reduced roots is that they are relatively short, as noted in §3.1 and §3.2. This is to be expected because, as shown in §4.3, laryngeal reduction happens most often in fast speech, and vowels in fast speech tend to be shorter. However, one relevant question is whether the durational reduction of laryngealized roots in fast speech is equivalent to or more drastic than the durational reduction of non-laryngealized roots in fast speech.

### *3.4.1 Methods*

To investigate this, another informal production task was carried out to measure the duration of laryngealized and non-laryngealized roots in both slow and fast speech. For this task, both Consultants 1 and 2 produced target words in a carrier sentence, and they were prompted to utter each sentence first slowly and then quickly. In this task, laryngealized roots (CVˀV), mono-syllabic long-vowel roots (CVV), and bi-syllabic roots with two mono-moraic short vowels (CVCV) were used as target words, and the duration of each vowel was measured from the beginning of its steady-state. For CVˀV words, vowel duration covered the entire vocalic portion of the word, including any creak or glottal closure.[9] For CVCV words, the duration of vowels in the first syllable ($\sigma_1$) were measured separately from the duration of vowels in the second syllable ($\sigma_2$). Considering the small number of items per condition, I report only basic descriptive statistics here

[9]Because I analyze laryngealization in SMPM as non-modal phonation, I include portions of creak and glottal closure in vowel duration because they are acoustic correlates of laryngealization, which is itself a part of the vowel.

### *3.4.2 Results*

The mean and median duration, standard deviation, and total number of tokens for each vowel type and prompted speech rate are given below.

| Vowel type | Slow | | | | Fast | | | | Mean difference across rates |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | SD | N | Mean | Median | SD | N | |
| CVˀV | 260 | 258 | 52 | 15 | 84 | 83 | 17 | 15 | 176 (68%) |
| CVV | 221 | 215 | 48 | 14 | 116 | 126 | 27 | 15 | 105 (48%) |
| CVCV, $\sigma$1 | 110 | 110 | 33 | 15 | 72 | 76 | 22 | 15 | 38 (35%) |
| CVCV, $\sigma$2 | 83 | 81 | 31 | 15 | 66 | 58 | 17 | 15 | 17 (20%) |

| Vowel type | Slow | | | | Fast | | | | Mean difference across rates |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Median | SD | N | Mean | Median | SD | N | |
| CVˀV | 230 | 223 | 51 | 12 | 103 | 99 | 21 | 12 | 127 (55%) |
| CVV | 210 | 200 | 59 | 11 | 102 | 98 | 15 | 12 | 108 (51%) |
| CVCV, $\sigma$1 | 110 | 111 | 29 | 12 | 63 | 65 | 19 | 12 | 47 (43%) |
| CVCV, $\sigma$2 | 79 | 80 | 14 | 12 | 60 | 63 | 11 | 12 | 19 (25%) |

Table 9: Duration (ms) by vowel type in prompted slow and fast speech for Consultant 1 (top) and 2 (bottom).

There are some clear trends in the data. First, there is an obvious difference in duration by prompted speech rate for all vowel types, with the fast productions having lower durations than the slow productions. Second, durational differences between fast and slow speech are largest for both consultants for CVˀV words, following by CVV words, and then $\sigma$1 and $\sigma$2 of CVCV words, respectively. However, the magnitude of durational changes differed by consultant.

### *3.4.3 Discussion*

For Consultant 1, the difference in duration for CVˀV vowels is striking, since they are much longer in slow speech than CVV vowels but much shorter in fast speech. For Consultant 2, however, the duration differences for CVˀV and CVV vowels are about the same. In other words, for one of the consultants surveyed here, the durational reduction of CVˀV words in fast speech appears to be more drastic than the durational reduction of CVV words. This tendency is consistent with the phonological analysis argued for later in §5.5, which claims that highly reduced CVˀV roots have phonologically short vowels at least some of the time, while CVV roots retain their long vowels in fast speech. One unresolved point, though, is that the drastic durational reduction is seen for average durations for Consultant 1, but not Consultant 2, even though the phonological analysis presented later applies to both Consultant 1 and Consultant 2's speech. This difference might be tied to Consultant 1's having developed metalinguistic awareness of laryngeal reduction by the point at which the task took place (see §3.1), while Consultant 2 had not.

## 3.5 Gradience

Finally, it is worth exploring the phonetic gradience of laryngeal reduction. So far in the discussion of the acoustic effects of the process, the tasks have focused on words that met the criteria of 'clearly unreduced' or 'clearly reduced.' However, it is the case that there are many tokens of laryngealized words that do not fit so neatly into these two categories. That is, while there are highly reduced forms and highly unreduced forms, there are many that fall somewhere in between. This fact is especially apparent in the acoustic consequences of laryngealization, which manifest in SMPM as a cline from glottal closure to apparent modal voice.[10] For example, the following waveforms all represent the vocalic portion of the word [loˀo] ('small'), uttered by the same consultant in the same syntactic position.

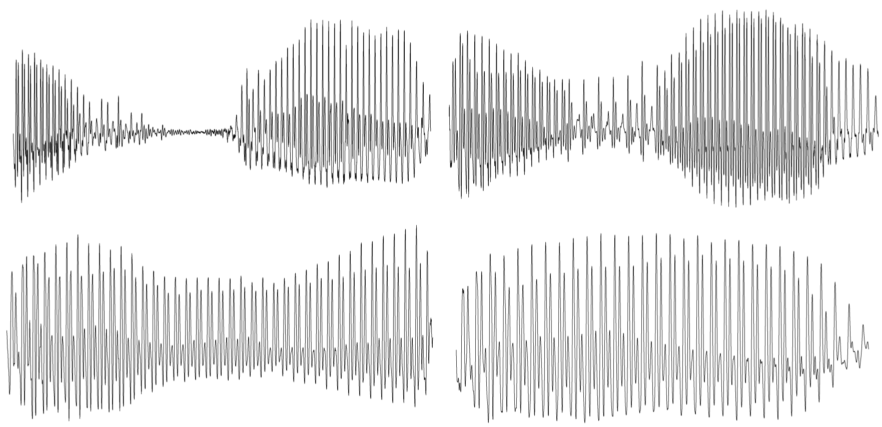


Figure 8: Four productions of the vocalic portion of the word [loˀo] ('small') by Consultant 1 in the same syntactic position. Top left = 298 ms, top right = 284 ms, bottom left = 180 ms, bottom right = 139 ms.

The form on the top left lasts ∼300ms and shows complete glottal closure corresponding to laryngealization, and the form on the top right lasts ∼285ms and shows creaky voice, evidenced by the widely spaced glottal pulses. The form on the bottom left lasts ∼180ms and shows regular vocal fold vibration throughout, but with a dip in intensity in the middle of the vowel. Finally, the form on the bottom right lasts ∼140ms and shows regular vocal fold vibration and no apparent dip in intensity due to laryngealization. This gradient realization of laryngealization is common throughout SMPM and highlights the phonetic characteristics of laryngeal reduction.

One might wonder whether acoustic measures that correlate with laryngeal reduction motivate the existence of two discrete categories (unreduced vs. reduced), or if they motivate a view of laryngeal reduction as ranging along a single continuum of the degree of reduction. In other words, one might wonder whether unreduced and reduced words represent two ends of a continuum with many intermediate forms (i.e., all realizations in Figure 8 are more or less equally likely), or whether words tend surface as unreduced or reduced only, with very few intermediate forms (i.e., only the top-left and bottom-right forms in Figure 8 are common, while the top-right and bottom-left forms are uncommon). In order to test this question, I conducted a production task aimed at measuring acoustic correlates of laryngealization across a large number of tokens produced at various rates of speech.

The relevant acoustic measures analyzed were the degree of amplitude dip and the duration of the vocalic portion of the word. The reasons to use these measures are as follows: first, as mentioned before, unreduced laryngealized roots have a large amplitude dip and rise, while highly reduced roots do not (Figure 5) Additionally, the previous section showed that reduced forms have a shorter duration than unreduced forms. If laryngealized words tend to be produced as either highly unreduced or highly reduced, then the distributions of these measures should be bi-modal. That is, using the example of amplitude dips, there should be two 'kinds' of productions: those with a large amplitude drop, and those with little to no amplitude drop.

[10]Interestingly, this squares with Gordon & Ladefoged's (2001) characterization of phonation types as existing along a continuum from open to closed vocal folds.

However, if laryngealized words range along a single continuum of reduction, then there should not be two main 'kinds' of productions; instead, words should vary along a continuum in terms of the degree of their amplitude dip. That is, the distributions for these measures should be uni-modal. Below, I present the details and results of this investigation.

### *3.5.1 Methods*

To examine the gradience of laryngeal reduction, Consultant 1 and Consultant 2 were asked in separate sessions to produce target words in the carrier sentence in (11).

(11) kã̀ˀ=ĩ̀ __ βiʰtsĩ
POT.say=1SG __ now
'I will say __ now.'

For each item, they produced the sentence five times, with the first repetition being produced very slowly and each subsequent repetition being produced more quickly than the last, with the result that the fifth and final was produced very quickly. If laryngealized words tend to surface as unreduced or reduced, with few 'in-between' forms, then the consultants should tend to switch at some point in the productions between the unreduced forms and the reduced forms. However, if laryngealized words are realized along a cline of the strength of laryngealization, then there should be many intermediate forms between highly unreduced and highly reduced forms in this task.

Both Consultant 1 and Consultant 2 took part in this task. Consultant 1 produced 140 tokens and Consultant 2 produced 164 tokens. There were 18 different target words of the shape CVˀV, which varied in consonant onset and vowel quality, and several target words were used multiple times. For each token, intensity dip was measured by finding the difference between the maximum and minimum intensity for the vocalic portion of a laryngealized word, with a larger difference correlating to a larger dip. Visual inspection of the raw intensity contours for all tokens confirmed that all large dips occurred in the first half of the vowel, as expected.[11] Duration was measured beginning at the steady state of the vowel. The resulting data sets contained the intensity dip and duration for each token by each consultant.

Two objective measures to test for bi-/multi-modality are outlined in Freeman & Dale (2013), namely Hartigans' dip statistic (Hartigan & Hartigan 1985) and the bimodality coefficient (SAS Institute 1990). Hartigans' dip test provides a 'dip' value, which is the greatest distance at any point between an empirical distribution (in this case, the set of recorded values for an acoustic measure across all tokens for one consultant) and a projected uniform distribution designed to minimize this distance. The greater the dip value, the less unimodal the distribution. The dip test also uses random sampling from the projected uniform distribution, and comparison of those samples to the empirical distribution, to determine the likelihood that the empirical distribution is unimodal or non-unimodal. So, the two values that result from the dip test are the dip value, which ranges between 0–0.25, and a p-value, which is the likelihood that the empirical distribution results from a unimodal distribution. A p-value lower than 0.05, then, means that the likelihood that the empirical distribution results from a unimodal distribution is less than 5%. A separate test is the bimodality coefficient (BC), which uses the skew and kurtosis of a distribution to make inferences about its modality, with the understanding that a bimodal distribution will have a low kurtosis, a high skew, or both. A distribution is considered to be bimodal if it has a value of 0.555 or higher.

As outlined in Freeman & Dale (2013), the dip test is conservative, almost never labeling truly unimodal distributions as multimodal, but sometimes judging bimodal distributions to be unimodal. The BC is less conservative, but sometimes identifies unimodal distributions as bimodal. It is also highly biased by skew, given that skew is taken into account in computing the measure. Because of these complementary characteristics, Pfister et al. (2013) recommend using both methods and considering their results together when

[11] All tokens have *some* difference between maximum and minimum intensity, but the differences for fully reduced words are much smaller than for unreduced words.

investigating the modality of a distribution, with converging results being definitive but differing results subject to interpretation. Following this recommendation, I computed both the Hartigans' dip test statistic and the BC in R using the 'diptest' package (Maechler 2021) and 'mousetrap' package (Kieslich & Henninger 2017), respectively. In addition to these measures, the data were represented visually for impressionistic analysis.

### *3.5.2 Results*

Density plots of the data are shown in Figure 9, and a scatter plot is shown in Figure 10. The scatter plot illustrates the relationship between duration and intensity dip for each token for each consultant. Visual inspection of the density plots suggests a prominent mode at lower values for all plots, though the leftmost apparent duration mode for Consultant 1 is not as prominent as the leftmost mode in the other plots. To the right of these, there are a fair number of tokens that occur in a relatively flat distribution, sometimes peaking in what appears to be a separate mode in the Durations for Consultant 1 and the Intensity dip for Consultant 2. Visual inspection of the scatter plot in Figure 10 suggests that the two measures are generally highly correlated with each other, grading in likelihood at higher values for each measure, and clumping together at low values for each measure. The link between the measures is confirmed by Pearson's correlation coefficient, which shows a significant positive correlation between duration and intensity difference for C1 ($r = 0.86$, $t = 19.3$, $p < 0.001$) and C2 ($r = 0.95$, $t = 36.4$, $p < 0.001$).

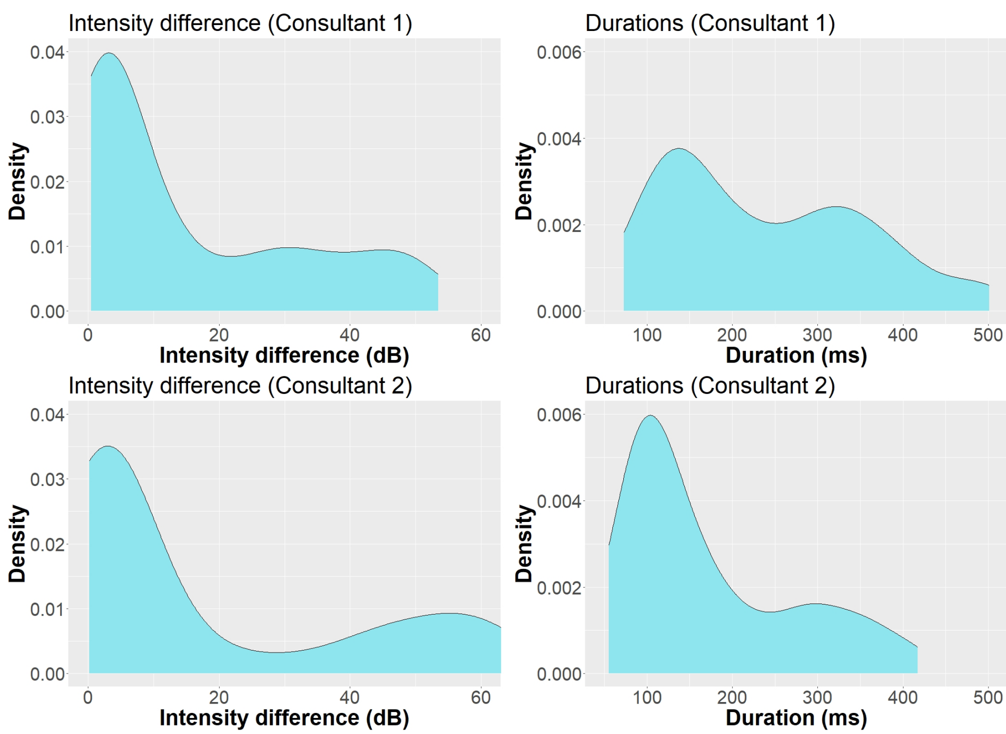



Figure 9: Raw distributions of amplitude dip and duration across all productions for both consultants.

The Hartigans' dip test statistic and the bimodality coefficient are given for each measure for each consultant in Table 10. As can be seen, Hartigans' dip test recognizes only the intensity differences for Consultant 2 as non-unimodal, while the BC judges every distribution as bi-modal. Interestingly, the durations for Consultant 1, which appear to have to clear modes in Figure 9, have the lowest value on the BC, barely surpassing the threshhold of 0.555 for bimodality. Given that both tests converge on the degree of intensity dip for Consultant 2 being bimodal it seems reasonable to conclude that this distribution is truly bimodal, albeit with a much smaller proportion of tokens having a very large intensity dip, and a much larger propor-

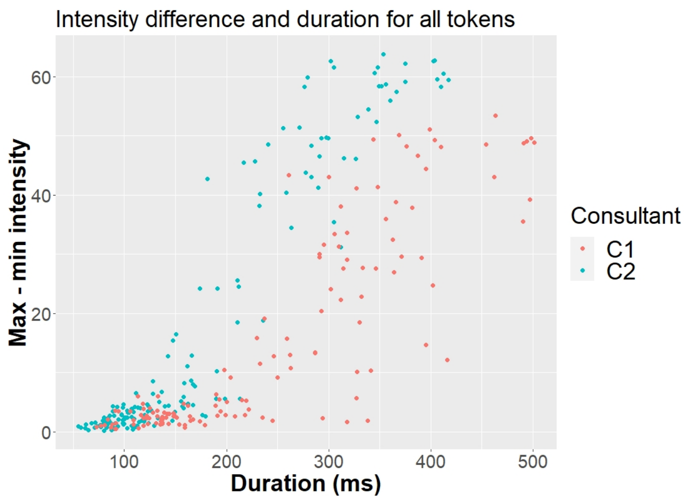



Figure 10: Scatter plot of duration (ms) and intensity dip for all tokens.

| | | Dip statistic | | BC |
|---|---|---|---|---|
| | | **D** | **p-value** | |
| **C1** | **Intensity diff.** | .027 | .727 | .774 |
| | **Duration** | .035 | .283 | .56 |
| **C2** | **Intensity diff.** | .05 | $< .01$ | .864 |
| | **Duration** | .019 | .974 | .707 |

Table 10: Results of Hartigans' dip test and bimodality coefficient (BC) across each acoustic measure for each consultant.

tion of tokens having a small intensity dip. On the other hand, the results for the other distributions are less clear. The results might be influenced by the density values themselves—the density values for duration are much smaller than for intensity differences. So, differences in the frequencies of particular duration values are smaller than differences in the frequencies of particular intensity dip values, and this could influence the results of the tests. In conclusion, though, one or more of the distributions may indeed be bimodal, but it appears not to be the case that all of the distributions are bimodal.

### *3.5.3 Discussion*

Tokens of laryngealized roots in this task can at least sometimes be sorted into different acoustic groups (e.g., intensity dip for C2, potentially duration for C1), with very high values representing a minority of tokens, and the rest of the tokens spanning a smaller range of values. In this sense, the postulation of two categories, namely 'reduced' and 'unreduced' is motivated by some aspects of the acoustic data. However, the leftmost modes of each distribution encompass relatively wide ranges of durations and intensity dips. In addition, qualitative evaluation of individual tokens in these modes shows a non-trivial range of variability along dimensions other than intensity dip and duration. For example, consider Figure 11, which shows two productions of the word [ʃĩˀĩ] ('mushroom') from Consultant 2.

By the measures of intensity dip (∼6.5 dB and ∼4.5 dB) and duration (127 ms and 119 ms), both of these examples fall clearly under the leftmost modes for Consultant 2's distributions. However, the production on the left has clear creaky voice, while the one on the right does not. Creak is typical of unreduced

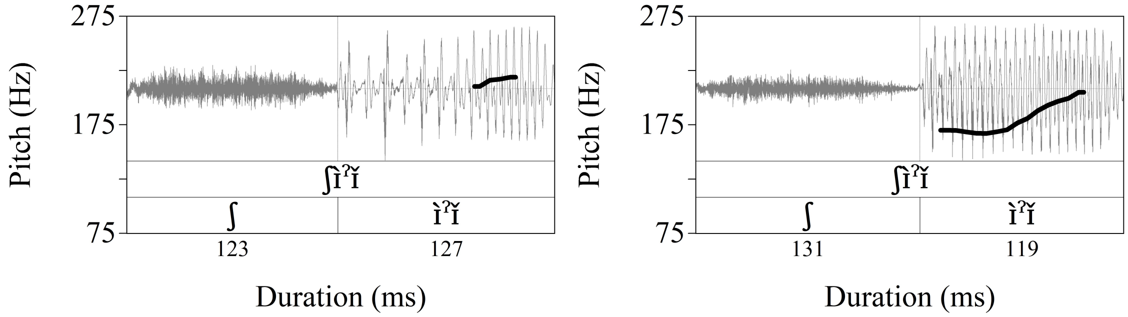



Figure 11: Two productions of the word [ʃĩ̀ˀĩ̌] ('mushroom') in the same environment by Consultant 2.

laryngealized roots, and is also relevant to whether or not the phonological reduction process described later applies to laryngealized roots: phonologically reduced roots never have visually-diagnosable creaky voice. So, though the intensity dip and duration data at least partially support the postulation of multiple acoustic categories, there is still considerable variation in intensity dips and durations within a single acoustic category, and there is also a fair amount of variation along other acoustic dimensions that are relevant for phonological reduction. Importantly, both phonologically-reduced and phonologically-unreduced roots may themselves fall under the same mode with respect to a given acoustic measure. In other words, the categories motivated by the acoustic distributions do not match up neatly with the categories motivated by the phonological reduction discussed later. Because of this, I conclude that, even with the postulation of distinct acoustic categories, laryngeal reduction is a highly gradient process.

### 3.6 Review

In this section, I have outlined various acoustic correlates of laryngeal reduction in SMPM. In general, laryngealized roots tend to have an interrupted pitch contour in their unreduced form and an uninterrupted pitch contour in their reduced form. That being said, it appears that all phonological tones are retained in reduction, since the pitch patterns of unreduced and reduced roots are qualitatively similar. Another difference between unreduced and reduced laryngealized roots is found in their intensity contour: unreduced roots have a steep dip and subsequent rise in intensity, while highly reduced roots do not. Highly reduced roots also have a much shorter duration than their unreduced counterparts, and this reduction in duration appears, at least for Consultant 1, to potentially be greater than the expected reduction due to fast speech.

Even though laryngealization has distinct acoustic correlates in unreduced and highly reduced roots, some are identical across production types: H1-H2, a cross-linguistically common cue to phonation type, is roughly equivalent between unreduced and highly reduced laryngealized roots, to the exclusion of modal vowels. This point suggests that a phonological analysis of laryngeal reduction in SMPM as the phonological deletion of laryngealization is less desirable, since at least some correlates of the contrast are robustly available in the acoustic signal. Additionally, the high degree of gradience of laryngeal reduction makes a phonological analysis that involves the categorical deletion or modification of a phonological feature more difficult. This is because, even though there is some evidence of distinct acoustic categories, there is a range of production types even within a single acoustic category, and the potential acoustic categories do not match up particularly well with the phonological categories argued for later.

That being said, some alternations that are thought of as phonological are nonetheless gradient, either in their rate of application or in their extent of application. For example, the optionality of *t*/*d*-flapping in English can be explained by making reference to potentially grammar-external factors like production planning (Wagner 2012; Kilbourn-Ceron et al. 2016; Kilbourn-Ceron 2017), and some phonologically-complete alternations are nonetheless gradiently realized, as in the case of incomplete neutralization in Chinese Tone 3 sandhi (Du & Durvasula 2020). In this light, the optionality and gradience of laryngeal reduction and the maintenance of some acoustic correlates of laryngealization in highly reduced forms do not necessarily preclude a phonological analysis. However, if it is also found that the driving factors behind laryngeal reduction are non-phonological, this would provide yet further evidence against a phonological analysis of the process. Because of this, I now turn to the conditioning environment and driving factors of laryngeal reduction.

## 4 The phonological environment and driving factors of laryngeal reduction

In this section, I examine the distribution of the application of laryngeal reduction, showing that it may apply in essentially any phonological context, though there are certain prosodic positions in which laryngealized roots are less likely to be highly reduced. Additionally, I provide evidence that one of the main driving factors behind laryngeal reduction is speech rate,[12] which is often considered to be an extra-grammatical factor not taken into account in phonological computation (McCarthy 1986:249–250; Keating 1996:263; Myers 2000:265–266; though see Kaisse 1985; Browman & Goldstein 1992 for different viewpoints). These points—the lack of a clear phonological conditioning environment and the drastic effect of speech rate on laryngeal reduction—combine to provide further evidence against a phonological analysis of the process. However, as I will argue in §5, the phonological behavior of unreduced and highly reduced laryngealized words does motivate a distinction in phonological representation between unreduced and at least some highly reduced laryngealized roots.

### 4.1 Conditioning environment

As mentioned earlier, an optional process may nonetheless be phonological (Wagner 2012; Kilbourn-Ceron et al. 2016; Kilbourn-Ceron 2017). However, the optionality of phonological processes can sometimes be linked to factors considered by many to be grammar-external, such as production planning. Kilbourn-Ceron (2017:81–123) argues that the variability of *t/d*-flapping across word boundaries in American English can be at least partially explained by variability in the size of production planning windows. The evidence comes from findings in the production-planning literature that the planning of segmental phonological material takes place in small, roughly word-sized chunks (see e.g., Sternberg et al. 1978; Wheeldon & Lahiri 1997) and that the size of these chunks may change depending on a number of factors (Konopka 2012). Interestingly, the factors that are known to affect the size of the planning window also affect the likelihood of flapping, suggesting that the two are linked. *t/d*-flapping is the process by which /t/ and /d/ can be realized as the flap [ɾ] between vowels (e.g., ‘bet’ vs ‘betting,’ ‘bed’ vs ‘bedding’). As is the case with many between-words sandhi processes, flapping is optional across word boundaries: the word ‘add’ in the phrase ‘add or subtract’ can be pronounced as [æd] or [æɾ]. But this optionality can be understood in terms of whether the entire phonological conditioning environment—in this case, the sequence /æd # o/—is contained in the same production planning window. If the entire conditioning environment is contained in the same planning window, then the process applies; if only a portion of the conditioning environment is contained in the planning window (i.e., just the word ‘add,’ with the following word ‘or’ in the next planning window), then the process does not apply.

In this light, it is worth examining whether there is a phonologically-defined conditioning environment for laryngeal reduction because, if it is the case that laryngeal reduction happens only in a given phonological environment, then an appeal to something like production planning might be made to account at least for the gradience in its rate of application, if not for the gradience in its extent of application. This section examines the various phonological environments in which laryngealized roots undergo reduction. As a preview, it appears that there is not a clear conditioning environment for laryngeal reduction, since it can happen anywhere in an utterance, though there are some prosodic tendencies.

The first point to establish is that there is no environment in which laryngeal reduction is obligatory or

[12] Word frequency is also likely to be another driving factor (Frisch 2011). Unfortunately, the lack of corpus materials for SMPM makes it difficult to quantify frequency and test this hypothesis.

near-obligatory, unlike in some other Mixtec languages (Gerfen 1996, 1999; Penner 2019). For example, in Ixtayutla Mixtec, non-initial roots in a compound lose their laryngealization and are shortened (Penner 2019). This is seen in (12), repeated from (9) above.

(12) /juˀù/ + /kúˀú$^{L}$/ = [jù-kùˀú]
'mouth' + 'bush'
'Bathroom' (Penner 2019:254)

A similar process is likely to have applied historically in SMPM, resulting in fossilized compounds like the one in (13), which involves a change in vowel quality as well as the loss of glottalization. Synchronically, the loss of laryngealization on the first member of a compound is not obligatory or near-obligatory. Instead, laryngealization is often maintained, as on the first member of the compound in (14).

(13) /βeˀe/ + /ñũˀũ̌/ → [βiñũˀũ̌]
'house' + 'earth'
'Church'

(14) ʃiˀǐ ʃã̌ˀã̀
mushroom lard
'A type of mushroom'

The second point to establish is that laryngeal reduction applies to roots of all syntactic categories, so long as they are of the shape (CV)CVˀV. The following examples show verb roots (15)–(16); noun roots (16)–(17), (20); a preposition (19); and an adjective and adverb (20) in an unreduced and reduced form. Additionally, laryngeal reduction appears to apply to roots in many different prosodic positions. The following examples show laryngeal reduction applying to utterance-initial roots (16), (20); utterance-medial roots (15)-(20); to stand-alone DPs (17)–(18); to roots that are sub-parts of a DP (16), (20); to roots that are the heads of complex DPs ([ñã̀ˀ=ĩ̂] in (21)); to roots that are separated from utterance-final position only by a weak pronoun (15), (19); and even sometimes to morphologically-complex laryngealized words ([ñã̀ˀ=ĩ̂] in (21)). These examples show that laryngeal reduction happens in all sorts of environments.

(15) nũ̀ʰnĩ̌ [tʃíˀì/tʃî] ɾà
corn plant.CONT 3M
'He is planting corn.'

(16) [sá-kʷáˀa/sá-kʷâ] nã̀ [tũ̀ˀũ/tũ̀] $^{n}$táˀβì
CAUS-go(?).CONT 3N.PL word poor
'They study Mixtec.'

(17) ʃìʰʃi [tsìmã̂ˀã̀/tsìmã̂] pã́ã̀
eat.COMPL raccoon bread
'The raccoon ate the bread.'

(18) ʃĩn=ĩ̀ [tsʲòˀo/tsʲò] konĩ
see.COMPL=1SG root yesterday
'I saw a root yesterday.'

(19) sáá kàʰtʃi ñã́ [ʃĩ́ˀĩ̀/ʃĩ̂] nã̀
SO SAY.COMPL 3F with 3N.PL
'That's what she said to them.'

(20) [loˀo/lo] [kʷéˀe/kʷê] [jùˀù/jù] péðɾo
small very mouth Pedro
'Pedro's mouth is very small.'

(21) tàʰʃĩ amígò [ñã̀ˀ=ĩ̂/ɲãĩ] [tsʲàˀá/tsʲǎ] $^{n}$tàˀ=î
give.COMPL friend POSS=1SG salsa hand=1SG
'My friend gave me salsa.'

Though reduction is relatively free in its distribution, there are two positions in which laryngealized roots are much less likely to reduce, and these are when they are utterance-final and when they are under information focus, which triggers fronting of the focused argument (Ostrove 2018; Hedding 2019a). For example, the following sentences show that a reduced laryngealized root is dispreferred utterance-finally and in a focus-fronted position.

(22) tàˀβi ʧúʰtu [kòˀǒ/#kǒ]
break.COMPL cat plate
'The cat broke the plate.'

(23) **Question**
nã̀ã́ nã̀kàβa nũ̀ʰũ̌ ñũˀũ̌?
what fall.COMPL face ground
‘What fell to the ground?’

(24) **Answer**
[βeˀe/#βe] nã̀kàβa nũ̀ʰũ̌ ñũˀũ̌
house fall.COMPL face earth
‘The *house* fell to the ground.’

However, the dispreference for laryngeal reduction utterance-finally lessens if the word in question has been previously mentioned. For example, in the following discourse, laryngeal reduction of an utterance-final root is possible:

(25) **Question**
tàˀβi ʧúʰtu [kòˀǒ]?
break.COMPL cat plate
‘Did the cat break the plate?’

(26) **Answer**
ã̀hã̌, tàˀβi ʧúʰtu [kǒ]
yes, break.COMPL cat plate
‘Yes, the cat broke the plate.’

In fact, somewhat surprisingly, laryngealized roots that are used as fragment answers may appear in a reduced form, again if the root has been previously mentioned. Note also that in this case, the laryngealized root is under information focus.

(27) **Context**
[kʷìˀi] ɾa [ʃìˀǐ] βa nĩ̀ʃìʰjǒ nũ̀ʰũ̌ maɾía
fruit and mushroom EMPH exist.COMPL face María
‘María had fruit and a mushroom.’

(28) **Question**
$^{n}$tsʲàá já ʃàʰʃi ɲã́?
which 3SG.N eat.COMPL 3SG.F
‘Which did she eat?’

(29) **Answer**
✓[kʷì]
fruit
‘Fruit.’

So, it appears that laryngealized roots may reduce in nearly every prosodic configuration, except for utterance-finally and under information focus. However, having previously mentioned the root in the discourse makes reduction possible even in these positions.

The lack of reduction in these environments might be used as evidence for an analysis of the process as prosodically-conditioned, under a line of reasoning somewhat like the following: laryngeal reduction applies whenever a laryngealized root is in a particular prosodic configuration, and doesn’t apply when the root is not in that environment. The fact that reduction does not apply to utterance-final or focus-fronted roots is evidence for this view, since these positions can be analyzed as blocking reduction because the required prosodic configuration is not present. Finally, under this account, a word that is previously mentioned in the discourse context would have a different prosodic structure than one that has not been previously mentioned, and it is this difference which allows exceptional reduction of previously-mentioned roots. Similar information-structural differences in prosodic organization have been found in, for example, Yanbian Korean (Jun & Jiang 2019). So, under this type of view, laryngeal reduction is a prosodically-conditioned phonological process that applies in a consistent environment, and never occurs outside of that environment.

I do not pursue this line of analysis for several reasons. The first is that an analysis of laryngeal reduction as applying within a specific, phonologically-defined prosodic configuration predicts that it should apply in a limited set of environments in which that specific prosodic structure is present. For instance, we might say that laryngeal reduction applies when the prosodic unit containing the laryngealized root is dependent on another prosodic unit (i.e., the root is contained in a foot that is not immediately dominated by a prosodic word). However, as we saw in (15)–(21), laryngeal reduction may apply to roots in nearly any syntactic configuration. It is difficult to imagine a syntax-prosody mapping process that allows so much variance that a subject DP like the one in (17) would be contained in a prosodic word in one utterance but not in another. However, it is precisely this kind of relationship between syntax and prosody that would be required in order to analyze laryngeal reduction as being a phonological process triggered by a specific prosodic configuration.

Instead of suggesting that reduction is triggered in particular phonological environments, the prosodic trends in the application of laryngeal reduction suggest that reduction is freely applicable, but is inhibited in particular prosodic environments, namely when utterance-final or fronted under information focus. In fact, these two environments are associated with lengthening in Yoloxóchitl Mixtec (DiCanio et al. 2018, 2020), and they are associated with the edges of fairly large prosodic constituents in many Otomanguean languages (DiCanio & Bennett 2018:9). Though I do not have the data to show that this is the case for SMPM, it does seem reasonable to suppose that words might lengthen in these contexts, given that these patterns are seen in another Mixtec language and are relatively robust cross-linguistically (Cambier-Langeveld & Turk 1999; Chen 2006; Fletcher 2010). This is important because laryngeal reduction involves the complement of lengthening, namely durational reduction. So, while there are prosodic influences on the inhibition of laryngeal reduction, it is at best very difficult—and at worst impossible—to define a phonological conditioning environment in which the process is triggered, since this requires a one-to-many syntax-to-prosody mapping.

## 4.2 Interim review

It appears, then, that laryngeal reduction in SMPM does not have a clear, phonologically-defined conditioning environment.[13] Though reduction is inhibited utterance-finally and under information focus, it remains difficult to formulate phonologically-defined factors that actively trigger laryngeal reduction. These points together make a phonological analysis of the process significantly more difficult.

The final place to investigate in order to determine whether laryngeal reduction should be viewed as phonological or phonetic is in the factors that drive it: if these driving factors also lie outside of the phonological grammar proper, then this might be another nail in the coffin of a phonological analysis. We have already seen hints that duration is correlated with reduction, and also that previous mentions appear to make reduction more likely. In the following section, I will show that speech rate appears to be the main driving factor behind laryngeal reduction, and that there is likely also an effect of previous mentions. This point is important because speech rate is often considered an extra-grammatical factor not taken into account in the phonological grammar proper.

## 4.3 The effect of speech rate

The clear effect of speech rate on laryngeal reduction, and a potential effect of previous mentions, can be seen in the results of an informal production task carried out with Consultant 1. In this task, Consultant 1 was asked to produce utterances twice, once at a slow rate of speech and once at a fast rate of speech.

[13] It is worth noting here that this fact makes a production-planning account like that of Wagner (2012) or Kilbourn-Ceron et al. (2016) less likely to be appropriate in explaining the gradience in the application of laryngeal reduction, since the essence of these proposals is that gradience in the application of external sandhi processes can be boiled down to whether the entire phonological conditioning environment for the sandhi process is present in the production planning window or not. In SMPM, where there does not appear to be a phonologically-defined conditioning environment, we cannot appeal to planning windows to derive the gradience (or, at least, all of the gradience) because there is no phonological conditioning environment for them to contain.

An example of this process is given below:

(30) **Linguist:**
I am going to ask you to translate a sentence from Spanish into Mixtec, and to say the sentence twice, the first time slowly and the second time quickly. How do you say ‘The raccoon ate the bread’?

(31) **Consultant:**

a. **Slow repetition**

| ʃìʰʃi | tsìmā́ˀā̀ | pā́ā̀ |
|---|---|---|
| eat.COMPL | raccoon | bread |

‘The raccoon ate the bread.’

b. **Fast repetition**

| ʃìʰʃi | tsìmā̂ | pā́ā̀ |
|---|---|---|
| eat.COMPL | raccoon | bread |

‘The raccoon ate the bread.’

This task tested the effects of speech rate and previous mentions on laryngeal reduction. In (31-a), the word for *raccoon* has not been previously mentioned and is given at a slow rate of speech. In (31-b), however, *raccoon* has been previously mentioned and is produced at a fast speech rate. In a subsequent elicitation session conducted a week later, the same sentence would be presented again, with the consultant asked to produce the sentence first quickly and then slowly. In this case, the first repetition would not have been previously mentioned but would be uttered at a fast rate of speech. The second repetition would have been previously mentioned but uttered at a slow rate of speech. As a result of this set-up, the effect of previous mentions and speech rate could be somewhat reliably disentangled. Half of the sentences were produced slow-then-fast in the first session and fast-then-slow in the second session, as shown in the example above. The other half of the sentences were produced fast-then-slow in the first session and slow-then-fast in the second session.

30 sentences total were used, 25 of which contained laryngealized roots and 5 fillers which did not. Each sentence was produced in both orders of speech rate (slow-then-fast and fast-then-slow, with order of speed varied), and the slow-then-fast and fast-then-slow productions of the same sentence were almost never prompted within the same elicitation session. Some sentences contained multiple laryngealized words, and only those laryngealized roots that were non-final and non-focused were analyzed, since utterance-final and narrow-focused laryngealized roots are less likely to reduce. The word [kʷéˀe] (‘very’) was also excluded from analysis, since it was used in many of the sentences and thus could not be reliably classified as not previously mentioned. Finally, one sentence containing a laryngealized root was elicited only in one of the two sessions. The result of this setup is 118 total sentence productions (30 sentences x 2 productions x 2 rates - 2 missed productions) with 98 analyzable productions of laryngealized roots.

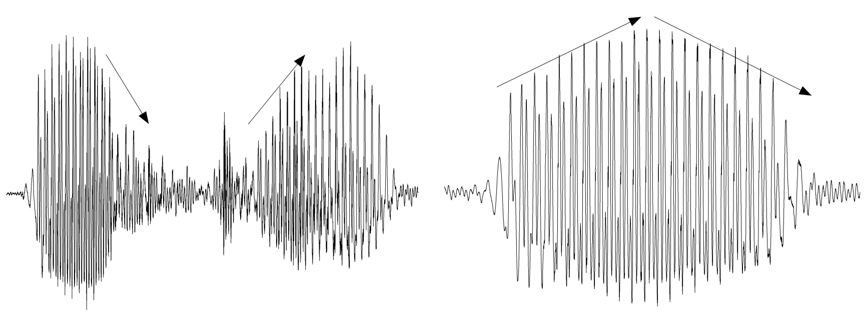


Figure 12: Unreduced (left, ∼280ms) and reduced (right, ∼140ms) forms of the laryngealized word [βeˀe] spoken in the same position by Consultant 1. Arrows indicate direction of intensity contour.

For the purposes of this task, laryngealized roots were labeled as unreduced if their amplitude showed a clear dip followed by a rise, or if there was any visible creaky voice and/or glottal closure followed by modal voice in the waveform and spectrogram, as shown in the waveform to the left in Figure 12. Words were labeled as reduced if they had no obvious dip and subsequent rise in amplitude and no visible creak followed by modal voicing, as shown in the waveform to the right. For this task, these criteria tended not to conflict.

The results of this task were telling: 26/49 laryngealized roots met the criteria for being classified as reduced in fast speech, while only 1/49 met the criteria in slow speech. It appears that whether or not a word was previously mentioned may have also had an effect on reduction rates in the fast repetition, but not in the slow production.

| | Fast production | Slow production | |
|---|---|---|---|
| Previously mentioned | 16/25 | 0/24 | 16/49 |
| Not previously mentioned | 10/24 | 1/25 | 11/49 |
| | 26/49 | 1/49 | **Total** |

Table 11: Reduction rates by production speed and previous mention.

Though the task outlined above lacks the rigorous control expected of a production study, it can be taken as suggestive that speech rate has a large effect on the probability of laryngeal reduction. Reduction is nearly categorically absent in slow speech, but prevalent in fast speech. Looking at the raw values suggests that speech rate is the main driving factor behind reduction in this task, since the difference in reduction rates between the fast and slow productions is much higher than the difference between previously-mentioned and not-previously-mentioned productions.

The task described above was able to separate the potential influence of previous mentions from an influence of speech rate, showing that speech rate appears to be the main driving factor in laryngeal reduction. Another informal production task also shows the influence of speech rate on laryngeal reduction, but does not control for previous mentions. However, it was conducted with both consultants instead of just one,[14] and it contains significantly more analyzable tokens, so it is worth reporting the results here. The task in question is the speech rate manipulation described in §3.5. In this task, both consultants produced target words in carrier sentences five times, with the first repetition being produced very slowly and each subsequent repetition being produced more quickly than the last, with the fifth and final being produced very quickly. These results provide a window into the effect of speech rate on laryngeal reduction at a more fine-grained level than that described above, since it involved changing speech rate gradually across five productions, instead of a single fast-slow binary. As stated in §3.5, Consultant 1 produced 145 tokens (29 tokens at each speed), and Consultant 2 produced 164 (32 tokens at each speed, with one set of productions thrown out because it only contained four repetitions), and there 18 distinct target words of the shape CVˀV, which varied in consonant onset and vowel quality. 10 target words were used twice for Consultant 1. For Consultant 2, 10 target words were used twice and 2 target words were used three times.[15] There were no filler items. The reduction rates are given for each consultant below:

Similarly to the previous task, reduction is categorically absent at the slowest rate of speech and prevalent at faster rates. What is more, the rate of reduction increases monotonically for both consultants as rate increases. The clear influence of rate has been shown across two tasks, then—one in which speech rate was not confounded with previous mentions, and one with more tokens and participants but in which speech rate was confounded with previous mentions (as speech rate increased, so did the number of times the target word had been previously mentioned). It is clear, then, that speech rate is at least one of the main driving factors in

[14] Consultant 1 participated in both tasks. However, the two tasks were separated from each other by about 1.5 years, so it is unlikely that taking part in the first task had a very large effect on Consultant 1's productions in the second one.

[15] It is possible that multiple uses of the same target word in the same task led to higher rates of reduction in this task, given that previous mentions of a word may increase its propensity for reduction.

| | Production Speed (slow → fast) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| **Consultant 1** | 0/28 | 3/28 | 12/28 | 20/28 | 25/28 | 60/140 |
| **Consultant 2** | 0/32 | 5/32 | 10/32 | 21/32 | 31/32 | 67/160 |
| | 0/60 | 8/60 | 22/60 | 41/60 | 56/60 | **Total** |

Table 12: Reduction rates by production speed for both consultants.

determining whether or not a laryngealized root will surface in a reduced form. That said, it is possible that speech rate's influence on reduction is mediated by another factor like changes duration (c.f. Cohen-Priva & Gleason 2020). Another potential tendency illustrated here and bolstered by the discussion in §4.1 is for laryngealized roots to be more likely to reduce when they have been previously mentioned than when they have not. This tendency is not surprising—it is common for words to be reduced if they have been previously mentioned in discourse (Bard et al. 2000; Warner 2011).

### 4.4 Review

In this section, I have argued that laryngeal reduction in SMPM does not have a clear phonologically-defined conditioning environment, and that positing one requires permitting an unusually high degree of variance in syntax-prosody mapping. Specifically, laryngeal reduction appears to apply to laryngealized roots regardless of prosodic context, and the dispreference for utterance-final and focus-fronted reduction can likely be explained by making reference to prosodic lengthening in these contexts. I have also shown that one of the most important driving factors behind laryngeal reduction is speech rate—laryngealized roots are much more likely to reduce in fast speech than in slow speech. This final point is important because sensitivity to speech rate is often used to diagnose a sound pattern as non-phonological (McCarthy 1986:249–250; Keating 1996:263; Myers 2000:265–266; c.f. Kaisse 1985). These points, taken alongside the process's gradient nature and robust maintenance of H1-H2 differences even in highly reduced roots, conspire to point toward a non-phonological analysis of the phenomenon. That is, the acoustics, conditioning environment, and driving factors behind laryngeal reduction suggest that there is no change in phonological representation between unreduced and highly reduced laryngealized roots. However, as I will show in the following section, at least some highly reduced laryngealized roots do have a distinct phonological structure from their unreduced counterparts. The evidence for this conclusion comes from the interaction of laryngeal reduction with an independent phonological process of tone sandhi.

## 5 Tone sandhi and mora deletion

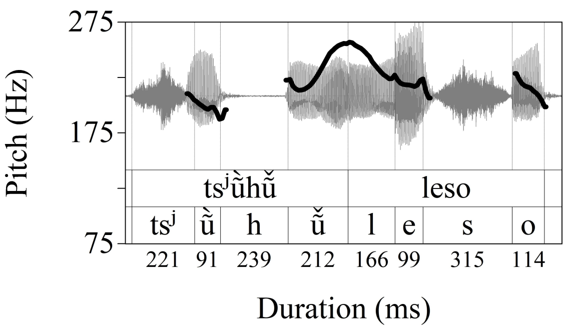
In this section, I describe a phonological process of tone sandhi in SMPM that reliably distinguishes between rising tones linked to a single mora and rising tonal melodies that span two moras. The interaction of this sandhi rule with laryngeal reduction provides evidence that at least some highly reduced laryngealized roots are mono-moraic instead of bi-moraic. This fact means that laryngeal reduction is sometimes correlated with a change to the abstract phonological representation. In order to make this point, I describe the relevant tone sandhi process as well as its interaction with laryngealized words with an L-H melody.

### 5.1 Tone sandhi

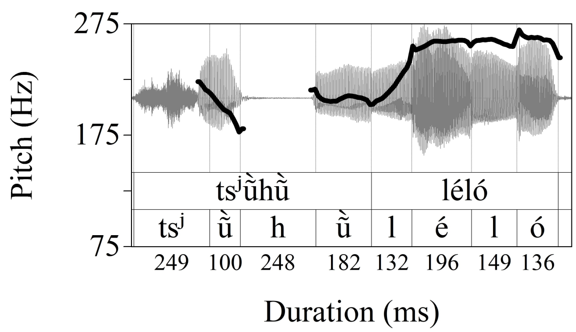
Unlike many other Mixtec languages where there is widespread evidence of floating tones and tone sandhi, relatively few instances of phonological tone sandhi have been described for SMPM. However, one process described in Hedding (2019b) is relatively robust. When a word-final LH contour tone is followed by a word-initial H tone, the word-final LH tone optionally flattens to L. This process is an example of contour simplification (Hyman & Leben 2020), and I refer to it as 'rise-flattening.' It is schematized in (32) and illustrated in the following examples. In (33), the word-final rise of [ts$^j$ũ̏hũ̌] ('turkey') surfaces faithfully. In (34), it surfaces as a flat low tone.

(32) **Rise flattening**
/LH # H/ → [L # H]

(33) **Non-application**
nĩ̀-$^n$tsì$^h$kù ts$^j$ũ̏$^h$hũ̌ le$^h$so
COMPL-chase turkey rabbit
'The turkey chased the rabbit.'

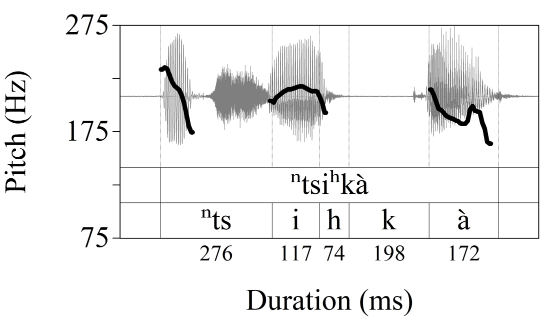



(34) **Application**
nĩ̀-$^n$tsì$^h$kù ts$^j$ũ̏$^h$ũ̏ léló
COMPL-chase turkey skunk
'The turkey chased the skunk.'

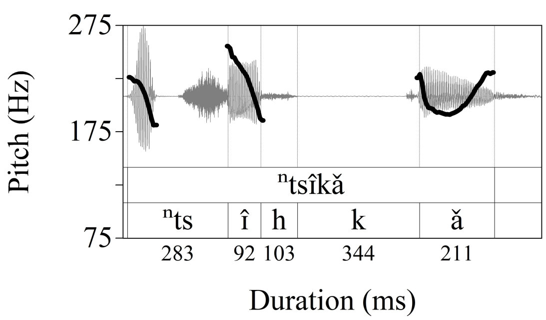



It is important to note that this tone sandhi process is phonological, not phonetic, and involves a change in abstract representation. First, it applies across speech rates—it may apply in fast and slow speech, and even when there is a pause between words. The second reason to believe that the process is phonological is that it is (at least apparently) neutralizing, collapsing the contrast between word-final L tones and word-final LH tones. This can be seen in the following examples. (35) and (36) show a near-minimal pair, with (35) having a final L tone and (36) having a final LH tone. (37) shows that the underlying final LH of 'banana' surfaces with a pitch contour very similar to that of the underlying final L in 'chest' in (35).

(35) **Underlying Final L**
$^n$tsi$^h$kà
'Chest'

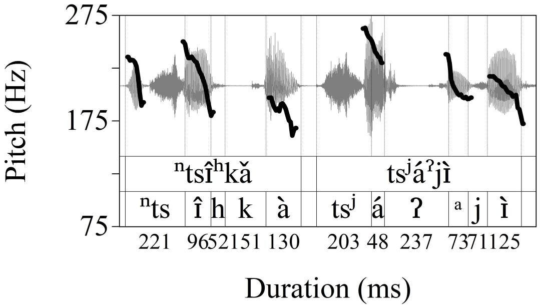



(36) **Final LH**
$^n$tsî$^h$kǎ
'Banana'



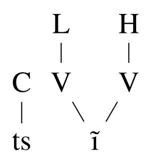
(37) **Derived Final L**

[$^{n}$tsî$^{h}$kà] ts$^{j}$á$^{ʔ}$jì
banana rotten
'A rotten banana.'




Another piece of evidence for the phonological status of tone sandhi in SMPM comes from the fact that not all *surface* rises from L to H undergo this process: when the L and H are linked to separate moras, and thus do not form a contour unit, the tone sandhi process described above does *not* take place. This can be seen clearly in words with a bi-moraic, mono-syllable template (CVV) with an L-H melody. For example, the word in (38) has a L-H melody, with the L linked to one mora and the H linked to the other (38). The tonal melody of this word is realized as rising pitch (39). As (40) shows, this rise does not flatten before an H tone:

(38) *tsĩ̀ĩ́*
'Rat'

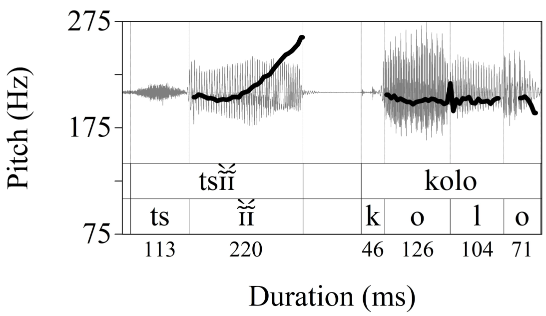


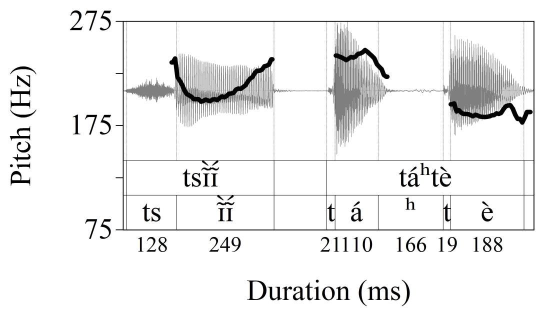

(39) **Non-application**

tsĩ̀ĩ [tsĩ̌ĩ́] kolo
COMPL.bite rat turkey
'The rat bit the turkey.'

(40) **Non-application**

tsĩ̀ĩ [tsĩ̌ĩ́] tá$^{h}$tè
COMPL.bite rat man
'The rat bit the man.'

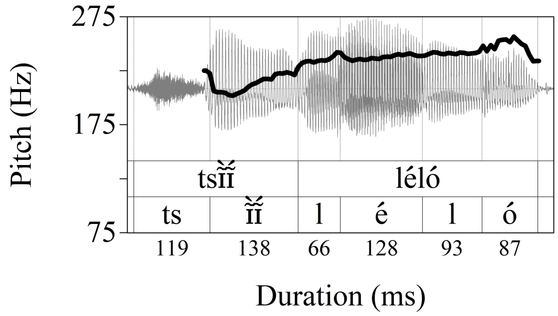



Importantly, rise flattening does not apply to bi-moraic, L-H melodies even in fast speech. This can be seen in the following example, where the rise on the word for 'rat' has about the same duration as the vowel hosting the derived L on the word for 'banana' in (37). In other words, the lack of application of rise flattening to L-H melodies on bi-moraic, mono-syllabic words is not due to the increased duration of these vowels, but rather due to their distinct phonological structure.

(41) **Non-application**

ʃĩnì tsĩ̀ĩ́ léló
see.COMPL rat skunk
'The rat saw the skunk.'




There is a clear difference, then, between LH contour tones linked to a single mora and L-H sequences linked to separate moras, illustrated by the two schematizations below. While LH contours linked to a single mora undergo H deletion, L-H sequences linked to two moras do not.

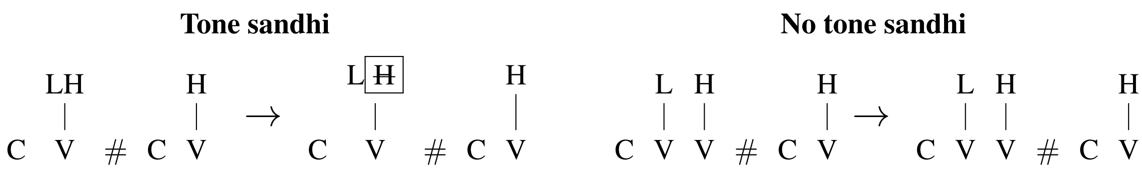



Figure 13: Illustration of application (left) and non-application (right) of tone sandhi based on tonal alignment.

## 5.2 Interim review and prediction

So far, I have argued that rise flattening is a phonological process, and that it applies to LH contour tones that are linked to a single mora, but not to L-H melodies where the L and H tones are linked to separate moras. This fact, considered alongside the phonetic nature of laryngeal reduction, leads to the following prediction: because laryngealized roots with a L-H melody have the same tonal alignment as CVV roots with a L-H melody as in Figure 14, rise flattening should not apply to laryngealized roots with a L-H melody. Additionally, because laryngeal reduction does not appear to be a phonological process, then whether or not a laryngealized root undergoes reduction should not change whether or not it undergoes tone sandhi.


Figure 14: Phonological representation of [tsʲòˀó] ('flea,' left) and [tsĩ̀ĩ́] ('mouse,' right).

However, as I will show in the following section, the facts are not so simple. While the unreduced forms of laryngealized words do not undergo tone sandhi, the reduced forms *do* often undergo sandhi. This fact suggests that the phonological representation in Figure 14 is not the only one associated with laryngealized words. Instead, words that are highly reduced can have a separate representation. The consequence of this asymmetry is that laryngeal reduction is at least sometimes correlated with phonological change, despite its purportedly phonetic nature.

### 5.3 Tone sandhi and laryngeal reduction

Laryngealized roots with an L-H melody alternate between an unreduced form, in which the L and H are separated by laryngealization, and a reduced form, which has a continuous rising contour. Figure 12 shows representative examples of this alternation for both consultants in the sentences (42) and (43), where unreduced and reduced forms of the L-H word [tsʲòˀó] (‘flea’) are in an environment that does not trigger tone sandhi. In (42), the L and H tones surface on either side of laryngealization. In (43), the L and H tones have formed a rising contour.

(42) **Non-sandhi environment**
tsĩ̀ĩ tsʲòˀó kolo
COMPL.bite flea turkey
‘The flea bit the turkey.’

(43) **Non-sandhi environment**
tsĩ̀ĩ tsʲǒ kolo
COMPL.bite flea turkey
‘The flea bit the turkey.’

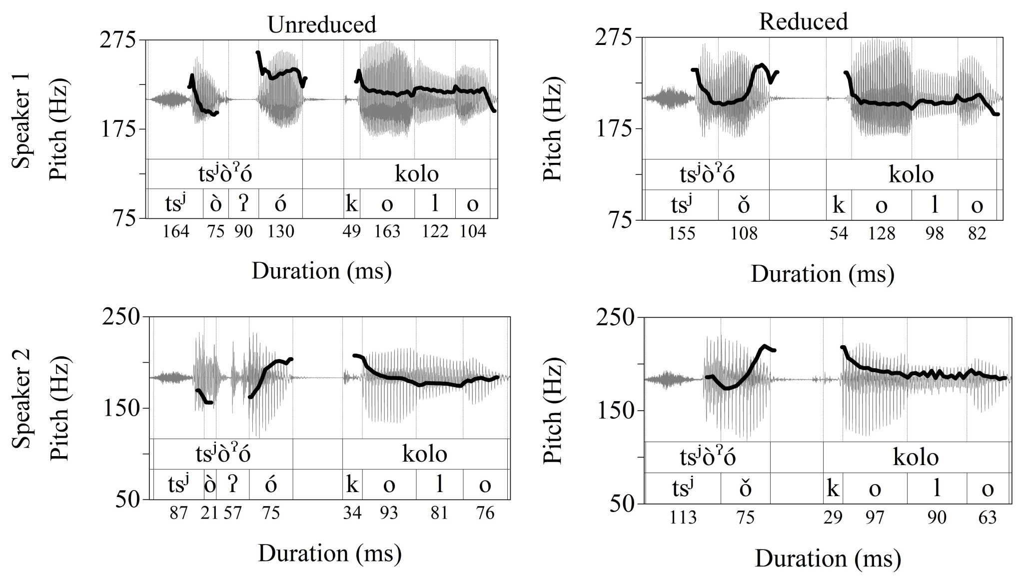



Figure 15: Representative examples of unreduced and reduced laryngealized words with an L-H melody in a non-sandhi-triggering environment for both consultants.

When the same laryngealized root with an L-H melody is placed before an H-initial word, creating the environment for tone sandhi, there is a distinction between the unreduced and reduced forms. The unreduced form surfaces faithfully, with an L and H tone separated by laryngealization. However, on the highly reduced form of the same root, the expected L-H rise surfaces as a flat L tone, showing that tone sandhi *has* taken place. Figure 13 shows representative examples of this alternation applying to the laryngealized root [tsʲòˀó] (‘flea’) in sentences (44) and (45) for both consultants. This pattern is in contrast to (40), which shows that bi-moraic L-H melodies do not undergo sandhi.

(44) **Non-application of sandhi**

tsì̃ĩ [tsʲòˀó] táʰte
COMPL.bite flea man
'The flea bit the man.'

(45) **Application of sandhi**

tsì̃ĩ [tsʲò] táʰte
COMPL.bite flea man
'The flea bit the man.'

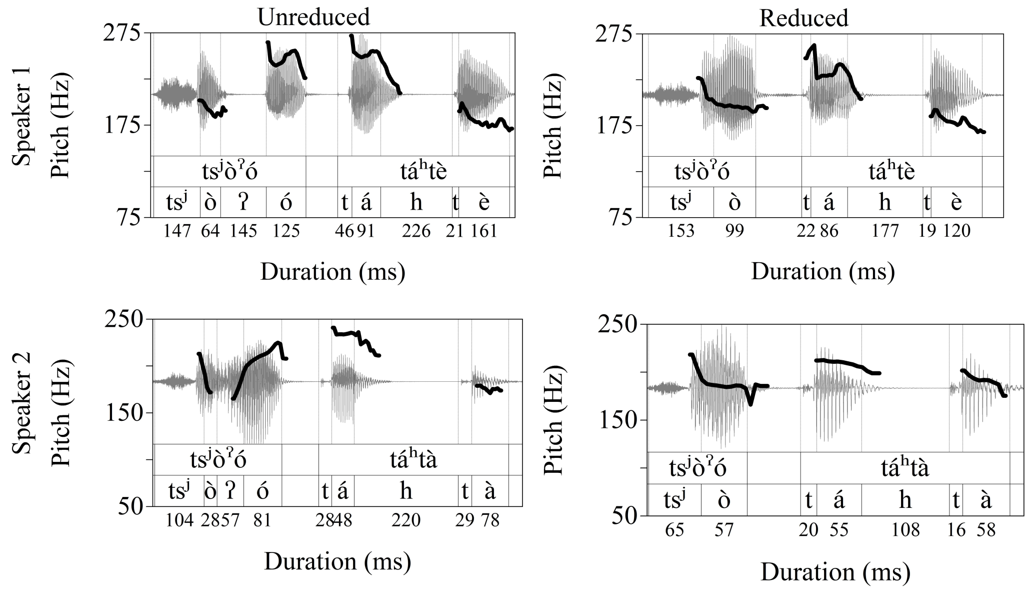



Figure 16: Representative examples of unreduced and reduced laryngealized words with an L-H melody in a sandhi environment for both consultants.

The application of rise flattening to highly reduced laryngealized roots in the sandhi-triggering environment is optional, mirroring the optionality of the process of rise flattening in general. An examination of recordings in which consultants produced highly reduced laryngealized roots before a H tone showed that rise flattening applied in 8/16 cases for Consultant 1 and in 3/8 cases Consultant 2. In a brief elicitation session, another consultant in Ahuejutla applied rise flattening to 2/3 highly reduced roots in the sandhi-triggering environment. It is also worth noting here that I have not seen any cases of rise flattening applying to an intermediate case of laryngeal reduction, such as one that has no creak but still has an amplitude dip and rise. Despite its optionality, the pattern in (44)–(45) is relatively consistent. This can be seen in the pitch plot below, which shows aggregated pitch contours from Consultant 1 for unreduced and highly reduced laryngealized roots with an L-H melody in the conditioning environment of tone sandhi. The pitch contour of highly reduced roots tracks relatively well with the pitch contour of underlying L tones in the same context.[16]

We have seen, then, that the phonological process of tone sandhi may apply to LH contour tones linked to a single mora (34), but not to a L-H melody linked to two moras (40)–(41). We have also seen that tone sandhi does not ever apply to the unreduced form of laryngealized roots that have a L-H melody. However, it is the case that sandhi applies to many highly reduced forms of roots with L-H melodies.

The fact that highly reduced and unreduced forms of laryngealized roots with an L-H melody behave differently with respect to tone sandhi shows that their phonological representation is at least sometimes categorically distinct: while unreduced roots have a melody consisting of a sequence of L and H linked to separate moras, the reduced forms of the words are apparently sometimes re-analyzed as containing an LH contour tone linked to a single mora. I take this fact as evidence that laryngeal reduction often correlates

[16]Figure 17 includes some Reduced tokens in which rise flattening was coded as not having applied. The pitch of reduced tokens is nonetheless very similar to the pitch of underlying L tones. This is likely due to the fact that several of the cases of non-application involved only very small pitch rises (∼3-5 Hz).

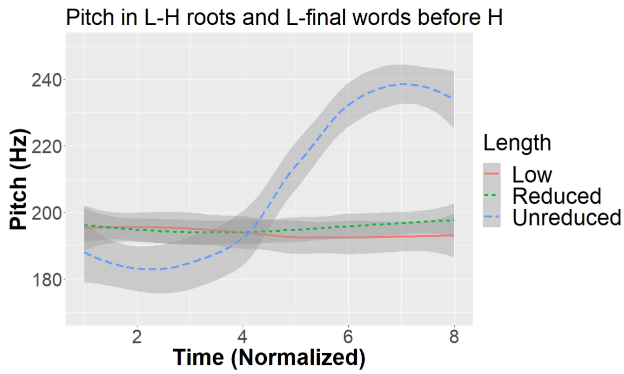



Figure 17: Pitch (Hz) before an H tone for highly reduced and unreduced productions of laryngealized roots with an L-H melody, as well as vowels with an underlying L tone (14 Long, 13 Short, 14 Low). Examples from comparable prosodic positions for Consultant 1.

with the deletion of a mora and the re-association of tone to the remaining mora. Given that laryngealization is maintained on the reduced forms of laryngealized words (§3.3), the deleted mora is the second, which is not linked to laryngealization.

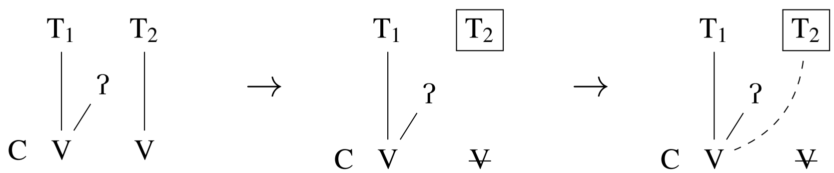



Figure 18: Illustration of mora deletion and tonal reassociation.

This result is important because it provides evidence that laryngeal reduction at least sometimes correlates with a phonological alternation: highly reduced laryngealized roots often have a different abstract, categorical representation. This is unexpected given the phonetic characteristics of the alternation outlined in §3–4.

Finally, since phonetic reduction is a gradient rather than categorical process, it is important to note the point on the continuum of reduction at which mora deletion may apply. The only laryngealized roots to which rise flattening (which is hypothesized to be triggered by mora deletion) applies are those that meet the criteria for being classified as "highly reduced" in §4.3. That is, rise flattening only applies to roots with no amplitude dip or visible creak.

## 5.4 Interim Review

In this section, I have demonstrated that laryngeal reduction is sometimes associated with a change in phonological representation, namely the deletion of a mora. The evidence for this claim comes from a phonological tone sandhi process that applies to LH contour tones linked to a single mora but not to L-H melodies spanning two moras. This process does not apply to unreduced laryngealized roots with an L-H melody, consistent with their bi-moraic nature, but does apply to many highly reduced forms of the same type of root, suggesting that they are phonologically mono-moraic. This fact is surprising when one considers the phonetic characteristics of the process laid out in §3–4. In the following section, I consider the consequences of this slate of properties for an analysis of laryngeal reduction and tone sandhi in SMPM, arguing that laryngeal reduction and mora deletion are two separate processes, the former phonetic and the latter phonological, that mirror each other in SMPM's sound system. However, given the tight relationship between the two and the phonetic conditioning of laryngeal reduction, I conclude that the phonological process of mora deletion is conditioned by the phonetic factors, such as speech rate, and thus constitutes an instance of a phonological process that is conditionied by purportedly phonetic factors.

### 5.5 Consequences

§3 showed that laryngeal reduction is a highly gradient process that does not appear to result in wholesale deletion of tone or a laryngeal feature, since H1-H2 remains reliably distinct between highly reduced laryngealized roots and modal vowels. §4 showed that laryngeal reduction cannot be clearly shown to occur in a specific, phonologically-defined environment, even if that environment is defined in terms of prosodic structure, and that it appears that speech rate is the main driving factor behind the process. These points suggest that laryngeal reduction is a phonetic process that does not reflect a change a in phonological representation.

Despite this, §5 showed that some highly reduced laryngealized roots are phonologically distinct from unreduced laryngealized roots, suggesting that laryngeal reduction is at least sometimes correlated with a change in phonological representation. In other words, a highly-gradient, speech-rate driven process of laryngeal reduction is almost certainly phonetic—it has no clear phonological conditioning environment, does not appear to result in wholesale deletion of a laryngeal feature, and is driven primarily by the purportedly phonetic factor of speech rate. However, the two ends of the continuum of laryngeal reduction (unreduced vs. highly reduced) often have distinct phonological representations, as evidenced by the their differences in behavior with respect to tone sandhi. I would like to argue that laryngeal reduction and mora deletion are two separate processes—one phonetic and one phonological—that are nonetheless correlated with each other in SMPM's sound system. They are driven by the same factors, the principal of these being speech rate. These conclusions point to mora deletion as being a phonological alternation whose driving factors lie primarily outside of the phonological grammar proper.

The parallels between the phonological process of mora deletion and the phonetic process of laryngeal reduction might be thought of as an instance of rule scattering (Bermúdez-Otero 2015), where a sound pattern exists at different levels of a language's grammar. That is, there may be both lexical and post-lexical versions of a rule, or both post-lexical and phonetic versions. An example of rule scattering is English palatalization (see, for example Holst & Nolan 1995; Nolan et al. 1996; Zsiga 2000), which exists both as a phonological rule (i.e., *press/pressure*, where the final /s/ in *press* becomes an [ʃ] in *pressure*) and as a phonetic process of coarticulation (i.e., *press your point*, where the final /s/ in *press* is coarticulated with the following [j] and is thus produced as something close to an [ʃ]). In English palatalization, the morphophonological process of palatalization (/s/ $\rightarrow$ [ʃ] / _+j) coexists with a similar phonetic process of coarticulation whereby an [s] becomes more palatal when coarticulated with a [j] across a word boundary.

However, there is a distinction between the apparent rule scattering in English palatalization and that seen in SMPM laryngeal reduction. The difference is that in English palatalization, the morphophonological rule applies categorically whenever its conditioning environment is present, regardless of speech rate. However, the phonological process of mora deletion is different in that it does not apply reliably in a well-defined environment. Instead, the main driving factors behind mora deletion do not appear to be any different than the driving factors behind laryngeal reduction—both processes appear to be conditioned mainly by speech rate, a phonetic factor.

It appears that mora reduction, then, is a phonological process whose conditioning factors lie primarily outside of the phonological grammar proper. There are several ways one might go about proposing a phonological analysis of mora deletion: one might incorporate speech rate directly into the phonological grammar, either by positing distinct grammars for different speech rates or by allowing speech rate to influence constraint ranking or weighting in a gradiently-defined constraint-based grammar. This approach has been taken, for example, in modeling the effect of speech style on phonology (van Oostendorp 1997; Boersma & Hayes 2001:Appendix C; Coetzee & Pater 2011:426–427).[17] Another type of analysis might maintain that speech rate is phonetic and as a result not taken into account in the phonological grammar, but nonetheless allow it to influence which phonological candidate ultimately makes it to surface. An example of an approach of this type is Boersma & Van Leussen's (2017) multilevel parallel constraint grammar, which incorporates two distinct levels of evaluation for phonology and phonetics but nonetheless allows the two levels to interact. In this system, speech rate can be taken into account in the phonetics, but can nonetheless influence which phonological output is ultimately chosen. Either of these approaches would be able to derive the interaction between laryngeal reduction and mora deletion in SMPM, but they are distinct in the predictions that they make about the ways that phonetic factors like speech rate may interact with the phonological grammar. Another possible phonological analysis is one that makes reference to production planning windows (Wagner 2012; Kilbourn-Ceron 2017), with the claim being that mora deletion occurs in a specific phonological context, but that that phonological context might span production planning windows. As noted earlier, an approach like this would face significant difficulty in defining just what the phonological conditioning environment for mora deletion is, since it is so tightly tied to laryngeal reduction, which has no clear phonologically-defined conditioning environment. Finally, an analysis in the framework of Articulatory Phonology might posit that the gestures associated with the second mora are gradually reduced until their size reaches zero (c.f. Hall 2010:818), triggering an apparently categorical reorganization of tonal association. Each of these approaches makes different predictions about the possible interactions between speech rate and phonological representations. It is beyond the scope of this paper to outline all of these consequences, so I leave an in-depth phonological analysis and theoretical discussion for future work.

## 6 Conclusion

In this paper, I have described and analyzed a process of laryngeal reduction in SMPM that is similar to other phonological reduction processes described in other Mixtec languages (Pike & Small 1974; Macaulay 1996; Gerfen 1999; Penner 2019). Given that this type of reduction has been analyzed phonologically in other varieties (Macaulay 1996; Gerfen 1999), but that phonologically-identical laryngealized roots may nonetheless have vastly different acoustic characteristics (Gerfen & Baker 2005), I examined the acoustic correlates, conditioning environment, and driving factors behind laryngeal reduction. Analysis of the acoustics of unreduced and highly reduced laryngealized roots in §3 showed no apparent phonological deletion of tones or laryngealization, since tonal melodies and H1-H2 values are apparently maintained even in highly reduced laryngealized roots. Additionally, it was shown that laryngeal reduction is gradient, and that even though there is some evidence for distinct acoustic categories corresponding to 'unreduced' and 'reduced,' these categories do not match up well with cases in which mora deletion has and has not applied. Then, §4 showed that there is no clear phonologically-defined conditioning environment for laryngeal reduction, since roots of this type can reduce in essentially any phonological environment, modulo the influence of prosodic lengthening. In addition to the lack of phonological conditioning environment, the main factor driving laryngeal reduction appears to be speech rate, which is often considered to be extra-phonological. This constellation of facts points to an analysis of laryngeal reduction as a phonetic process that does not reflect a change in phonological representation.

However, through an investigation of a phonological tone sandhi process in the language, §5 showed that laryngeal reduction is often correlated with a change in phonological representation, such that unreduced roots are bi-moraic, but highly reduced roots are often phonologically mono-moraic. This alternation was analyzed as a phonological process of mora deletion, and it was argued that laryngeal reduction and phono-

[17] It is worth noting here that laryngeal reduction does not appear to be a style-driven process that occurs mostly in casual speech. For example, in a relatively formal oral narrative detailing the history of Ahuejutla, a consultant regularly produced laryngealized roots in a highly reduced form.

logical mora deletion are two distinct processes that are nonetheless conditioned by largely the same factors. These factors are largely extra-grammatical, given the lack of phonological conditioning environment for laryngeal reduction alongside the speech-rate-driven and gradient nature of the process. The picture that emerges is one in which a phonological alternation is influenced primarily by factors that lie outside of the phonological grammar proper. There are a number of potential phonological analyses, each with their own theoretical implications, but I leave the issue of how exactly to implement this apparent interaction between phonology and phonetics for future research.

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