# TONE SANDHI IN COMALTEPEC CHINANTEC

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Comaltepec Chinantec tone sandhi normally consists of rightward high tone spreading from syllables with a low-high tone pattern, and almost all sandhi outputs are non-neutralizing. This sound pattern may be understood by considering articulatory, aerodynamic, acoustic, and auditory principles, in necessary combination with phonetically rooted historical forces, and the principles of contrast maintenance, economy of effort, and what is termed pattern coherence.*

1. INTRODUCTION. Kiparsky (1972) provides both synchronic and diachronic evidence that suggests the need for theoretical machinery above and beyond a rule-based generative model. For example, certain common sound patterns which a standard rule-based account cannot adequately model, let alone explain, are best accounted for by making specific reference to phonological and morphological contrast maintenance, an obvious functional consideration. Consider one example case: Labov et al. 1968 reports that certain English dialects tend to drop the past tense marker, ⟨t⟩, but do so far more often when this ⟨t⟩ redundantly encodes tense, and far less often when it is not redundant, thus $k^hip+t \rightarrow k^h\varepsilon p$ 'kept', but $p^h\text{æə}s+t \rightarrow p^h\text{æə}st$ 'passed'. That is, deletion is normally blocked when morphological information would be lost. Kiparsky argues that a strict rule-based account is forced to appeal to conspiratorial approaches, including limiting rule application to only certain eventual outputs. Kiparsky concludes that contrast maintenance often plays a decisive role in sound patterning. He suggests that generative theory might be augmented by a more functional theory: 'the concept of a "tendency," which lends functionalist discussions their characteristic unsatisfactory fuzziness, can be made more precise in terms of hierarchies of optimality, which predict specific consequences for linguistic change, language acquisition, and universal grammar. Enormous areas of vagueness obviously remain. But there is enough to show that the project is a worthwhile one' (224).[1]

In this article I offer a single example of how the notion of CONTRAST MAINTENANCE may characterize both specifics and tendencies in sound patterns, considering the tone sandhi pattern of Comaltepec Chinantec. This superficially complex tonological system would appear counterintuitive if characterized within a standard generative model, requiring tone-insertion and tone-'flop' rules in conjunction with conspiratorial rule blockage. Indeed, such complex sound patterns have been invoked in support of the view that the linguistic

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[1] Kiparsky's 1972 paper is but one of a number of attempts in its era to impose constraints on the degree of abstractness allowable within generative theory. Among other attempts are Kiparsky 1973, the work of the so-called natural generative phonologists (Vennemann 1971, Hooper 1976), and the theory of natural phonology, spearheaded by Stampe (1972, 1973).

system does not lend itself to external explanation, and is instead governed by principles peculiar to its domain (see for example S. Anderson 1981, Bromberger & Halle 1989). However, when characterized in terms of contrast maintenance and other system-external principles, and when natural historical processes are considered, the Comaltepec Chinantec tone system possesses remarkable regularity, characteristic of many cross-linguistic patterns and tendencies.

Comaltepec Chinantec (henceforth Comaltepec) tone sandhi normally consists of rightward high tone spread from syllables with a low-high tone pattern (*kwa*˩˥ *ŋih*˩ → *kwa*˩˥ *ŋih*˥˩ 'give a chayote', *kwa*˩˥ *ku:*˧ → *kwa*˩˥ *ku:*˥˧ 'give money'),[2] thus displaying at least three cross-linguistic tendencies in the patterning of tonal material (Hyman & Schuh 1974, and references therein): high tones are far more often phonologically active than low tones, in the form of spreading and/or displacement; spreading/displacement is far more often rightward than leftward; spreading/displacement is far more likely to take place when the pitch interval of a rising contour is relatively great. As with so many cross-linguistic tendencies, these patterns may be understood when considering articulatory, aerodynamic, acoustic, and auditory principles, in necessary combination with the more abstract principles of contrast maintenance, ECONOMY OF EFFORT, and, as discussed below, what I term PATTERN COHERENCE. While these principles may be viewed as independent of the linguistic system, they nonetheless constrain it in nontrivial ways. Indeed, in order to communicate effectively, salient phonetic distinctions must be maintained among contrasts. Thus strict attention must be paid to those physical systems that constrain the communication of information. I argue here that the principle of contrast maintenance plays a prominent role in phonology yet is constrained by hardwired, physically based systems. Neither the principle itself nor its physical basis is sufficient to account for linguistic sound patterns if considered alone. Instead, there is a necessary interdependence between abstraction and physicality in order to properly constrain and properly account for phonological patterns. On this point then, I agree with Anderson: 'On the one hand, we find that a great many phonological rules are tantalizingly close to some sort of phonetic explanation; but on the other, when we try to pin them down in such terms, they have evidently been transformed into something which is no longer merely "functional phonetics"' (1981:509). It is in the nature of this 'transformation' that my approach departs from Anderson's 'unnatural' rule-based phonology.

There are, in addition, both exceptional triggers and exceptional nontargets in Comaltepec tone sandhi. Certain non-LH tones trigger sandhi, and certain potential targets undergo no changes when following a sandhi trigger. Regarding the former, that sandhi is present in this non-LH environment is, by hypothesis, due to pattern coherence, whereby an allophonic realization that has origins in one context appears in additional contexts. The emergent result is that allo-

[2] For readers unfamiliar with this IPA notation, ˩˥ = LH, ˩ = L, ˥˩ = HL, ˧ = M, ˥˧ = HM, etc.

phonic variation is minimized. The hypothesized emergent phenomenon of pattern coherence is presented in 1.

(1) pattern coherence: allophony is minimized

A given contrastive value tends to be limited in its phonetic variability, as pressure applies to keep a given element similar across contexts. Therefore, all else being equal, the phonology becomes increasingly regular over time. That is, the cognitive forces which pressure for organizational simplicity (whatever they may be) may induce patterns (whatever their origin) to increasingly cohere. But of course, all else is rarely equal: increased pattern coherence may result in conflicting pressures to effect change, as pattern coherence in one environment may disrupt contrast maintenance, economy of effort, and/or pattern coherence elsewhere. Herein, of course, lies the heart of Kiparsky's conflicting 'hierarchies of optimality.' Comaltepec tonology resolves such conflicting pressures in a manner that is rather straightforwardly handled in my analysis.[3] Exceptional nontargets also may have their origins in contrast maintenance. Were sandhi to affect these potential targets, a lexical contrast would be neutralized. Here, pattern coherence of sandhi triggers is forfeited so that contrast maintenance of potential targets is maintained.

In §2 I describe the Comaltepec tonological system and in §3 I investigate the forces at work in the Comaltepec tonological system, considering in turn sandhi triggers (3.1), and sandhi targets/outputs (3.2), motivating the sandhi pattern in the terms introduced above.

2. Comaltepec Chinantec tonology described. The Chinantecan language group is a member of the Otomanguean language family, and is spoken primarily in Oaxaca, Mexico. Ex. 2 contains the segment inventory of the Comaltepec dialect (based on Anderson et al. 1990). Parenthesized forms are major allophonic or free variants.

(2) Comaltepec segment inventory

| | | | | | |
|---|---|---|---|---|---|
| consonants: | p | t | tʃ | | k |
| | $^{m}$b | $^{n}$d | $^{n}$dʒ | | $^{ŋ}$g |
| | (f) | s | (ʃ) | (ʂ) | (x) |
| | | ʐ | | | |
| | m | n | (ɲ) | | ŋ |
| | | l | | | |
| | | | j | | w |

[3] My approach is indebted to the 'self-organizational' approach to sound patterns discussed by Lindblom et al. 1984 and Ehala 1996, who in turn draw inspiration from Jantsch 1981, Haken 1981, Prigogine 1976, and Prigogine & Stengers 1984. These researchers investigate self-organizing explanations of natural patterns. In a self-organizing system, interacting and potentially conflicting subsystems which abide by primitive and general principles give rise to structures that may possess elements of symmetry, and/or may possess salient and predictable patterns. These resultant structures, note, are not in and of themselves the direct result of any such imposed goal on ultimate patterning: the potential symmetry or predictability is emergent. And given that the set of subsystems have oft-conflicting goals, the system is in a constant condition of diachronic flux, as the various subsystems are continually winning out or losing to one another.

| | | | |
|---|---|---|---|
| laryngeals: | ʔ | | |
| | h | | |
| vowels: | i | ɨ | u |
| | e | ʌ | o |
| | æ | | a |

The tones listed in 3a are attested in morphologically simplex environments. Those in 3b may be found in phonologically or morphologically derived environments. An example of each tone is presented. All data in this section are culled from the thoroughgoing descriptions in Anderson 1989, Anderson et al. 1990, and Pace 1990.

(3) a. Simplex tones
  L  hi˩  'book'
  H  l̥lloʔ˥  'pretty'
  M  ku:˧  'money'
  LM ᵑgiŋʔ˩˧  'swing'
  LH li˩˥  'tepejilote palm shoot'
b. Derived tones
  HL (kwa˩˥) to:˥˩  '(give) a banana'
  HM (kwa˩˥) ku:˥˧  '(give) money'
  MH sɨ˧˥ (kjaʔʂ˥)  'is it (his)'

Comaltepec tone sandhi is both phonologically and morphologically conditioned. Morphologically conditioned sandhi is not relevant to the present study, and is not discussed in detail.

As stated in the introduction, Comaltepec tone sandhi normally involves the rightward spreading of H tones from LH syllables. However, there are exceptional triggers of tone sandhi, and exceptional non-targets of tone sandhi. Regarding exceptional triggers, M tones in syllables lacking postvocalic laryngeals (⟨h⟩ and/or ⟨ʔ⟩) also trigger a type of sandhi, in that a H tone appears on a rightward syllable, for example, *mi:˧hi˩* → *mi:˧hi˥˩* 'I ask for a book'. This pattern is exceptional in that these M tones are the only non-LH sandhi triggers. Moreover, sandhi here cannot be viewed as the mere rightward spreading of a tone, as the trigger here is M, yet the output usually involves H. Regarding exceptional nontargets, LM tones are the only potential targets that cannot be analyzed as undergoing sandhi.

Table 1 shows the outputs when sandhi applies to a root type as given by the row and column headings. Root tonal patterns are indicated in the first column. Root rime patterns (excluding postvocalic nasals, which have no effect on sandhi) are indicated across the top row. The table interior is filled by target input and output tonal patterns. Bold-boxed cells are present only in derived contexts; they are not lexical. If a given pattern is never attested, the cell is left blank. Sandhi nontargets are shaded (all LM tones). As sandhi applies iteratively, all sandhi triggers, either lexical or derived, are italicized for clarity (these include $V^{LH}$, $V{:}h^{LH}$, $Vʔ^{LH}$, $V^{M}$, $V{:}^{M}$, $V^{MH}$, $V{:}h^{MH}$, $Vʔ^{MH}$, and $V{:}^{HM}$). Forms that may be analyzed as undergoing vacuous sandhi are indicated parenthetically. Neutralized forms are coindexed. In the remainder of this section,

**TABLE 1. Root and target patterns.**

| TONE | RIME | | | | | |
|---|---|---|---|---|---|---|
| | V | Vh | V: | V:h | V? | Vh? |
| L | L→HL | L→HL | L→HL | L→HL | L→HL | L→HL |
| M | *M* | M→ $H_x$ | *M→HM* | M→ $H_y$ | M | M→ $H_z$ |
| H | | ($H_x$→ $H_x$) | | ($H_y$→$H_y$) | (H→H) | ($H_z$→ $H_z$) |
| LM | **LM** | **LM** | | | **LM** | **LM** |
| LH | *LH→MH* | LH→MH | | *LH→MH* | *LH→MH* | |

I take the reader step by step through all the patterns indicated, so that a clear picture emerges.

Note that the $Vh^{LH}$ pattern (where ⟨h⟩ is realized as nasal devoicing in the context of postvocalic nasals) is limited to loanwords (e.g. *dih* ˩˥ 'god' < Sp. 'dios', *moŋ̊* ˩˥ 'Ramón'). It is a sandhi undergoer, but not a sandhi trigger. Regarding the absence of $V^M$ and $V?^M$ targets, Anderson et al. report that their sandhi properties 'are not known since lexical and syntactic limitations make it inappropriate for [them] to occur after a change-inducing syllable' (1990:13).

In the following subsections, I consider, in turn, sandhi triggers (2.1) and sandhi targets/outputs (2.2).

**2.1.** SANDHI TRIGGERS. As already noted, LH tones are sandhi triggers; additional examples are contained in 4.

(4) LH triggers

| INPUT | OUTPUT | |
|---|---|---|
| kwa ˩˥ to:˩ | kwa ˩˥ to:˥˩ | 'give a banana' |
| kwa ˩˥ ŋɨh˩ | kwa ˩˥ ŋɨh˥˩ | 'give a chayote' |
| kwa ˩˥ ku:˧ | kwa ˩˥ ku:˥˧ | 'give money' |
| kwa ˩˥ ⁿdʒu:˧ | kwa ˩˥ ⁿdʒu:˥˧ | 'give a jug' |

M tones on syllables which lack postvocalic laryngeals ($V^M$, $V{:}^M$ and $V{:}^{HM}$) are triggers as well. Observe that despite the quality of the triggers in 5, that is, M, targets are nonetheless realized with H tones at their left edge.

(5) M triggers

| INPUT | OUTPUT | |
|---|---|---|
| mɨ:˧hi˩ | mɨ:˧hi˥˩ | 'I ask for a book' |
| mɨ:˧moh?˩ | mɨ:˧moh?˥˩ | 'I ask for squash' |
| mɨ:˧ku:˧ | mɨ:˧ku:˥˧ | 'I ask for money' |
| mɨ:˧ˀo:˧ | mɨ:˧ˀo:˥˧ | 'I ask for papaya' |
| m̥mɨ˩ˀõ:˥˧ teh˧ | m̥mɨ˩ˀõ:˥˧ teh˥ | 'sticky soot' |

Again, these are the only M tones that trigger the process; all other triggers are LH.

Now consider phonologically complex triggers. First, MH triggers are derived from LH triggers, which themselves are subject to tone change. That is, sandhi is iterative (for example, in *ka˩ lu:h˩˥ ˀwɨ:ŋ˧* → *ka˩ lu:h˧˥ ˀwɨŋ˥˧* 'outside Ojitlán', *lu:h˩˥* undergoes morphologically triggered sandhi, and triggers phonological sandhi). Ex. 6 shows some MH triggers, whose phonological form may be the result of morphological complexity (Anderson et al. 1990:19, n.9).

(6) MH triggers

| INPUT | OUTPUT | |
|---|---|---|
| sɨ˧˥ hi˩ | sɨ˧˥ hi˥˩ | 'is it a book' |
| sɨ˧˥ to:˩ | sɨ˧˥ to:˥˩ | 'is it a banana' |
| sɨ˧˥ tũh˧ | sɨ˧˥ tũh˥ | 'is it two' |
| sɨ˧˥ $^{ŋ}$ge:h˧ | sɨ˧˥ $^{ŋ}$ge:h˥ | 'is it twenty' |
| sɨ˧˥ ku:˧ | sɨ˧˥ ku:˥˧ | 'is it money' |
| sɨ˧˥ kjaˀʂ̩˥ | sɨ˧˥ kjaˀʂ̩˥ | 'is it his' |
| sɨ˧˥ ŋi˩˥ | sɨ˧˥ ŋi˧˥ | 'is it salt' |
| sɨ˧˥ loh˩˥ | sɨ˧˥ loh˧˥ | 'is it a cactus' |

Similarly, HM triggers are derived from V:$^{M}$ triggers, which themselves are subject to sandhi. Ex. 7 contains an example of an HM trigger (whose phonological form is the result of morphologically conditioned sandhi).

(7) HM trigger

| INPUT | OUTPUT | |
|---|---|---|
| m̥mɨ˩ ˀõ:˥˧ teh˧ | m̥mɨ˩ ˀõ:˥˧ teh˥ | 'sticky soot' |

With the synchronic origins of MH and HM triggers in mind, it is now apparent that all complex sandhi triggers have their origins in simplex sandhi triggers. Two generalizations about triggers now clearly emerge; they are shown in 8.

(8)
- All LH syllables are triggers (except loan forms)
- Level M syllables are triggers, but only if they lack postvocalic laryngeals (⟨h⟩ and/or ⟨ˀ⟩)

**2.2.** SANDHI TARGETS/OUTPUTS. For clarity, I now provide examples of sandhi targets and outputs; 9 shows L targets, which change to HL.

(9) L targets

| INPUT | OUTPUT | |
|---|---|---|
| mɨ:˧hi˩ | mɨ:˧hi˥˩ | 'I ask for a book' |
| mɨ:˧ŋɨh˩ | mɨ:˧ŋɨh˥˩ | 'I ask for a chayote' |

If the target syllable is M, sandhi output is HM on V:$^{M}$, elsewhere H. The H output, notice, is neutralizing, as H is lexically present in these contexts as well. Examples are in 10.

(10) M: targets

| INPUT | OUTPUT | |
|---|---|---|
| kwa˩˥ ku:˧ | kwa ku: | 'give money' |
| kwa˩˥ $^{n}$dʒu:˧ | kwa $^{n}$dʒu: | 'give a jug' |

Other M targets

| INPUT | OUTPUT |
|---|---|
| mɨ:˧tũh˧ | mɨ:˧tũh˥ 'I ask for two' |
| mɨ:˧ᵑge:h˧ | mɨ:˧ᵑge:h˥ 'I ask for twenty' |
| kwa˩˥ ᵑge:h˧ | kwa˩˥ ᵑge:h˥ 'give twenty' |
| kwa˩˥ kjahˀʂ̩˧ | kwa˩˥ kjahˀʂ̩˥ 'give his' |

If the input is LH, then the output is MH. Note that M here may be analyzed as the result of overlapping L and H tones. Thus L and H merge to produce an M output; 11 contains examples of LH targets.[4]

(11) LH targets

| INPUT | OUTPUT |
|---|---|
| mɨ:˧ŋi˩˥ | mɨ:˧ŋi˧˥ 'I ask for salt' |
| mɨ:˧loh˩˥ | mɨ:˧loh˧˥ 'I ask for a cactus' |

Contrast this output with that of L targets: acquired H on a lexical LH syllable is realized M(H), while acquired H on a lexical L is realized H(L).

To summarize, LH syllables, as well as level M syllables lacking postvocalic laryngeals, are sandhi triggers. All tone patterns except LM are subject to sandhi, and all targets have allophonic outputs, except M tones other than $V{:}^{M}$, which neutralize with H.

3. Comaltepec Chinantec tonology explained. Comaltepec tonology displays a number of remarkable properties. First, the Comaltepec tonal inventory is comparatively rich, with five lexical tonal patterns, and several allophonic and morphologically complex variants. Moreover, Comaltepec words are normally monosyllabic, while verbal inflection usually involves tone modification. Given both the relative syllabic impoverishment of the Comaltepec word, as well as the tonal richness of the lexical and morphological systems as wholes, it might be predicted that tone sandhi, if present at all, should be extremely limited in scope. Whence this prediction? Unlike in polysyllabic languages, in Comaltepec, if a lexical tonal pattern is even minimally categorially altered—the defining property of tone sandhi—then the tonal pattern of the entire word is altered, as words are usually both monosyllabic and polymorphemic, and have their inflectional properties marked tonally. Therefore, rampant tone sandhi greatly runs the risk of neutralizing contrastive values, as sandhi outputs are likely to neutralize with lexical tonal patterns, or produce phonemic overlap. Yet Comaltepec tone sandhi is indeed rampant, regularly taking place both word-internally (upon encliticization, and in rare polysyllabic roots) and across word boundaries (Anderson et al. 1990:13). It is impeded only by a pause, or by a topic-comment boundary (Pace 1990:26). Remarkably however, sandhi outputs almost never neutralize with lexical tonal patterns, and never produce phonemic overlap. That is, almost all sandhi outputs are allophonic,

[4] This merging refers to a phenomenon in which two conflicting and potentially overlapping gestures are blended towards an intermediate value. One model that is particularly successful at graphically representing blending is the gestural score model employed in the theory of articulatory phonology (Browman & Goldstein 1986, 1989, 1990a, 1990b, 1992).

and not neutralizing, and thus lexical contrasts are fully recoverable despite surface distortion. It is my contention that the allophonic character of tone sandhi is no accident. As the primary function of a phonology is to communicate information effectively, a phonology evolves such that its contrasts are normally maintained: allophony (as opposed to neutralization) preserves contrastive information. I thus posit the principle in 12.

(12) contrast maintenance: contrastive values are maintained

According to 12, an element that functions contrastively should maintain this function in all environments.[5] In this section I argue that this principle, in necessary combination with the additional principles discussed in §1, may be employed to explain the Comaltepec sandhi pattern. Specifically, I address the questions listed in 13.

(13)
- Why does sandhi consist of rightward H spread from LH syllables?
- Why do level M tones lacking postvocalic laryngeals trigger the appearance of a rightward H tone?
- Why do level H tones never trigger sandhi?
- Why does sandhi never affect potential LM targets?
- Why do M targets with postvocalic aspiration neutralize with H?
- Why do LH targets become MH, whereas L targets become HL?

I consider, in turn, the origins of sandhi triggers (3.1), and sandhi targets/outputs (3.2).

**3.1.** THE ORIGIN OF SANDHI TRIGGERS. In the basic Comaltepec tone sandhi pattern, H tones sometimes expand their temporal duration to affect the first part—or, in some cases, the entirety—of a following vowel. I now investigate the reasons why.

Sundberg (1973, 1979), and Ohala and Ewan (1973) find that speakers are able to produce a falling pitch over a given pitch interval much faster than a rising pitch over the same interval. This physiological constraint, then, is fully consistent with the observations of Hyman and Schuh (1974) that high tones spread more often than low tones, that tone spreading is far more often rightward than leftward, and that spreading is much more likely when the lower-to-higher pitch differential is relatively great. Indeed, Ohala (1978:31) hypothesizes that since pitch falls may be accomplished more quickly, they might be less likely to 'spill over' onto a following syllable. Rising pitch contours, however, as they take longer to implement, would indeed be predicted more likely to spill over on to a following syllable. My claim is that the patterning of LH tones in Comaltepec exemplifies this spillover effect.

Consider a situation in which contrastive lower pitch is immediately followed by contrastive higher pitch. The necessary change in articulatory configuration

[5] I should point out that a principle of maintaining contrastive values is in no way related to the Pragueian notion of 'functional load', explored in detail by Martinet (1952) and argued against by King (1967), primarily with Germanic data. Functional load arguments refer to the statistical prevalence of a given contrastive value, and the supposed negative correlation between this prevalence and the tendency toward merger. Contrast maintenance has nothing to say about a supposed negative correlation between statistical prevalence and the tendency toward diachronic merger.

takes longer to implement than does a change in the opposite direction (i.e. from H to L). When considering the accompanying supralaryngeal gestures, the potential for H spread becomes apparent. The laryngeal musculature is relatively sluggish in achieving the configuration necessary for producing a higher pitch when immediately preceded by a lower pitch. Supralaryngeal musculature, however, apparently does not suffer from a similar sluggishness. Therefore, as a higher pitch is ultimately achieved, the supralaryngeal articulators may already be implementing a following consonant. Thus high pitch is achieved only at the very end of the first vowel, and may actually overlap with the following consonant-vowel sequence.[6] I thus suggest that it is due to physiological constraints on the achievement of higher pitch in this context that H is realized into a following vowel. And as its duration is increased upon overlapping with a following vowel, the perception of this higher pitch becomes salient, and the contrast is maintained. In time, this pattern has phonologized as rightward tone 'spread'.

In summary then, H tone spread has its origins in physiological constraints, and over time has phonologized, since the contrastive H is clearly distinguishable upon overlapping with a following vowel. It is my hypothesis then, that Comaltepec tone sandhi has its origins in this context.

Now, recall that pattern coherence is, also by hypothesis, an emergent pressure on the phonology to minimize allophonic variation, pressuring towards organizational simplicity. Thus, a given contrastive value optimally possesses similar cues in all contexts, except where these cues would be readily confused with those of another contrastive value. In such cases, allophony may be the only recourse if neutralization is to be avoided.

However, once allophony is triggered in one context as a result of the principle of contrast maintenance, the independent principle of pattern coherence may begin to exert additional force on the system; that is, a contextual realization whose phonetic properties are altered by the pressure to maintain a contrast may appear to apply pressure toward this allophonic realization in additional contexts, and especially those contexts in which contrast maintenance would not be forfeited.

In order to make these ideas more clear to the reader, I now place them in

[6] Upon overlap with an obstruent consonant, the likelihood of saliently transmitting pitch is diminished. Due to the constriction which defines a consonant, oral airflow is potentially impeded. This impedance potentially disrupts both the frequency and the amplitude of vocal fold vibration. Regarding frequency, a downstream obstruent constriction results in a reduction in transglottal airflow. This reduction in transglottal flow increases the likelihood of pitch lowering, as rate of transglottal flow may influence rate of vocal fold vibration (Ohala 1978, and references therein). In the limiting case, the vocal folds may cease to vibrate. Voiceless consonants, of course, induce the cessation of a pitch percept. Regarding amplitude, a downstream constriction reduces energy, thus potentially disrupting the pitch percept: the higher pitch is robustly realized only at the very end of its syllable of origin, and for an extra-short duration. For these reasons, tone is not reliably produced and transmitted when overlapped with obstruent constrictions. Sonorants, by definition, do not significantly inhibit transglottal flow, and consequently, have little if any effect on pitch, though they surely reduce amplitude; although syllable-final sonorants are perfectly adequate tone-bearers, intervocalic sonorants, perhaps due to their shorter duration, have never been observed to be tone bearing.

the context of Comaltepec tone sandhi. I have argued that the H component of an LH syllable is achieved late in its syllable of origin because of physiological constraints. This phonetic pattern ultimately phonologizes as rightward spreading onto a following vowel, as its cues are now effectively transmitted to the listener. Now the phonology involves a pattern that is a result of contrast maintenance, something like, 'H spreads rightward from LH syllables'. At this point, the phonology has two realizations of a single contrastive value: sometimes H tones spread (in the context of a tautovocalic leftward L), but elsewhere, H tones do not spread. This, then, is an example of allophonic variation resulting from contrast maintenance, but is also exactly the context in which the forces of pattern coherence may apply new pressures on the system. With two allophonic variants, the contrastive value is now subject to the further pressures of pattern coherence, in order to achieve greater regularity.

So what might happen? First, the system might simply stabilize at this point, that is, the pressures of pattern coherence and contrast maintenance may achieve a sort of parity in this context. Second, H spread may be lost. This would result in a fully coherent pattern, but of course, H in LH syllables would again be jeopardized, and thus would again potentially be subject to the pressures of contrast maintenance, culminating in a diachronic loop. Alternatively, H may be lost altogether in this context, resulting in merger. A final possibility must be considered, however. Pattern coherence may exert additional force, pressuring toward allophonic H-spreading in additional environments. The extent of this force is surely mediated by the counterforce of contrast maintenance. That is, the sound pattern may be pressured in a particular direction so that it coheres more fully, but contrast maintenance curtails the power of pattern coherence. Where would the forces of pattern coherence encounter the least resistance? After H spreads rightward from LH syllables, one extremely likely extension of the environments affected might be characterized as 'H spreads rightward from (all) H-final syllables'. In this way, pattern coherence gains ground without applying any pressure on contrast maintenance: the pattern increasingly coheres, and contrast maintenance remains stable. Table 2 outlines this hypothesized diachronic scenario.

| PROCESS | MOTIVATION |
|---|---|
| 1. H spills onto a following vowel from LH syllables | physiological forces |
| 2. H spreads rightward from LH syllables | contrast maintenance |
| 3. H spreads rightward from (all) H-final syllables | pattern coherence |

TABLE 2. Hypothesized diachrony of H sandhi triggers.

But in fact, sandhi does not take place from all H-final syllables: H NEVER spreads from level H syllables. Instead, certain level M syllables are sandhi triggers ($V^M$, $V{:}^M$). Thus, while contrast maintenance might motivate LH-triggered sandhi, the principle of pattern coherence fails to account for these other sandhi patterns. What then motivates sandhi in these M syllables? Viewed in exclusively synchronic terms, the answer to this question is surely 'nothing': there is no synchronic motivation for the appearance of a rightward H in this context, for M tones are fully recoverable in their syllable of lexical origin, and an added rightward H violates pattern coherence, and sometimes violates the contrast maintenance of targets. As it turns out, however, M tones in long syllables lacking postvocalic laryngeals are historically derived from *H, according to Rensch (1968, 1976, 1989). This, notice, would account for the absence of H tones on syllables lacking postvocalic laryngeals in present-day Comaltepec (see Table 1). Moreover, Rensch does not reconstruct *M in proto-Chinantec, and thus this hypothesized sound change was not neutralizing. So consider the forms in 14. In the first column I present examples of present-day nouns which possess level M: in open syllables (from Anderson 1989, Anderson et al. 1990, and Pace 1990). In the second column I present these same nouns' reconstructed proto-Chinantec forms (from Rensch 1968, 1989). (As pointed out by Rensch (1968:102), since verbs are necessarily inflected with tonal material, their reconstruction is far more difficult. I ignore for present purposes the segmental changes.)

| | | |
|---|---|---|
| (14) | Present-day Comaltepec | Reconstructed Proto-Chinantec |
| | ku:˧ | *ku:˥ 'money' |
| | $^{n}$dʒœ:˧ | *dʒu:˥ 'earthen jar/jug' |
| | ˀwɨ:ŋ˧ | *ˀwɨ:˥ 'Ojitlán' (a large Chinantec village) |

Compare the forms in 14 to those in 15. Here, historic *H followed by a laryngeal is retained in present-day Comaltepec.

| | | |
|---|---|---|
| (15) | Present-day Comaltepec | Reconstructed Proto-Chinantec |
| | lih˥ | *lih˥ 'flower' |
| | hu:h˥ | *hu:h˥ 'word' |
| | hu:hˀ˥ | *hu:ˀ˥ 'pineapple' |

Why should this historical change have applied asymmetrically? I suggest that the aerodynamic requirements of syllables with H that lack postvocalic laryngeals may be such that historic H tones were not implemented with the consequent degree of pitch height found in their postaspirated and/or checked counterparts. Why might this have been the case?

Upon implementing a postvocalic glottal stop, vocal fold constriction and tensing take place. If respiratory muscular flexion is held more or less constant, then the same force acts to push air through an increasingly small glottal opening, and increasingly tensed vocal folds. This may give rise to a pitch increase which, in time, may be phonemicized in place of the glottal closure. Indeed, Hombert (1978) reports that syllable-final glottal stops have been replaced by rising tones in several East Asian languages, including Vietnamese (Haudricourt 1954, Matisoff 1973) and Middle Chinese (Mei 1970).

Syllable-final aspiration, however, has sometimes been rephonemicized as a falling tone. Hombert again cites Vietnamese (Haudricourt 1954, Matisoff 1973) and Middle Chinese (Pulleyblank 1962) as two examples. The vocal fold abduction and laxing associated with ⟨h⟩ may lead to a pitch fall if respiratory muscular flexion is not increased to compensate for the laryngeal gesture. A noncontrastive pitch fall that is associated with a postvocalic ⟨h⟩ may in time be phonemicized in place of aspiration.[7] In Comaltepec however, postvocalic aspiration is accompanied by a pitch rise, not a pitch fall. In Silverman 1994, 1997a and b, I go into detail about the phonetic origins of this pitch increase. Briefly, as postvocalic aspiration is aerodynamically, acoustically, and auditorily weak, extra respiratory muscular flexion in the context of postvocalic aspiration serves to increase transglottal flow, which in turn increases acoustic energy, culminating in a more robust response at the level of the peripheral auditory system. A byproduct of this increased transglottal flow is a moderate pitch increase on the latter portion of the vowel, around the onset of aspiration.[8] Perhaps then, syllables which lacked postvocalic laryngeals originally marked H were not implemented with quite the degree of pitch height as their postaspirated and/or glottally checked counterparts, and, consequently, have evolved into present-day M. We might tentatively conclude that an additional pressure on sound patterning enforces economization of articulatory effort.[9]

(16) economy of effort: articulatory effort is saved

And while the phonetically natural triggering environment has been lost in Comaltepec, the process of tone sandhi itself nonetheless remains. Thus these M tones appear to trigger the appearance of a rightward H.

But, even given the historical origins of M triggers, was this ever a likely sandhi environment? Why should tone sandhi have ever been present in open H syllables? Surely, these historic H tones, unlike the H of LH, are fully recoverable in their syllable of origin. It is here, of course, where pattern coher-

[7] I have hypothesized elsewhere (Silverman 1997a, b, pace Noyer 1991) that Huave is in the process of such a rephonemicization, and have additionally hypothesized that the Ojitlán and Usila dialects of Chinantec have evolved similarly (Silverman 1997a, b, pace Rensch 1976).

[8] In Silverman 1997a, b, I provide spectrographic evidence for this pitch increase, and also discuss evidence for similar phenomena in other languages, such as increases in respiratory muscular activity during word-initial h in English (Ladefoged 1968), hypothesized increases in respiratory muscular activity during breathy vowels in Gujarati (Fischer-Jørgensen 1970), free and dialectal variation between postvocalic aspiration and a high tone in Jeh (Gradin 1966), and a diachronic shift from postvocalic aspiration to high tone in Quiotepec Chinantec (Robbins 1961, 1968, Rensch 1976, Gardner & Merrifield 1990).

[9] The motivation for a principle of least effort as applied to sound systems derives especially from the work of Lindblom (1983), who applies general principles of motor behavior to the speech mechanism in an attempt to motivate, for example, patterns of coarticulation and vowel reduction. There are, in fact, many documented cases which lend themselves to a characterization in which a principle of least effort is weighted more heavily than contrast maintenance. See, for example, Jun 1995, and Steriade 1995, which discuss a least effort principle in synchronic terms, and, again, Lindblom 1983, which presents a computational model which weights a pressure for perceptual distinctness against a pressure for least effort. Alternatively, consider the ongoing research of Ohala (e.g. 1981, 1992), who argues that patterns of both neutralization and allophony are listener-based, having nothing to do with a speaker-based principle of least effort. In this context, see for example Kuhl 1991, which discusses a so-called perceptual magnet effect in the context of phoneme recognition, and also, Frisch 1996a, b, which quantifies phonemic similarity and shows that phonotactic constraints are quantitatively sensitive to them. Both these lines of research investigate numerical modeling of perceived sound similarity, and both may potentially be applied to patterns of neutralization from Ohala's listener-based perspective.

ence enters the picture. Instead of limiting the sandhi context to H tones in only certain environments (i.e. preceding tautovocalic L), sandhi generalizes toward affecting all H tones, and thus the organization of the sound pattern is pressured toward symmetry in this context: 'H spreads rightward from all H-final syllables'. But in particular, level H tones that are not followed by laryngeals are the most likely candidates to succumb to the pressures of pattern coherence, because the laryngeal configuration may quite naturally perseverate into a following vowel as no conflicting laryngeal gesture (⟨h⟩ and/or ⟨ʔ⟩) intervenes: 'H spreads rightward from all H-final syllables, except when a laryngeal immediately follows level H'.

Consider now the environment in which no spreading takes place, when ⟨h⟩ and/or ⟨ʔ⟩ follow. As distinct and perhaps conflicting demands are made of the laryngeal musculature in order to implement a following laryngeal, the tendency to expand the tone-based gesture is inhibited.

To summarize the story so far, I offer the hypothesized diachrony of sandhi triggers in Table 3.

| PROCESS | MOTIVATION |
|---|---|
| 1. H spills onto a following vowel from LH syllables | physiological forces |
| 2. H spreads rightward from LH syllables | contrast maintenance |
| 3. H spreads rightward from (all) H-final syllables | pattern coherence |
| 4. H spreads rightward, except when a laryngeal immediately follows level H | pattern coherence |
| 5. level H without postvocalic laryngeals lowers to M; sandhi remains | aerodynamic forces; economy of effort |

TABLE 3. Hypothesized diachrony of M sandhi triggers.

3.2. AN ACCOUNT OF SANDHI TARGETS/OUTPUTS. I have thus far offered an account of the behavior of sandhi triggers. But what of sandhi targets? Should not the realization of H on a following vowel disrupt, and thus potentially neutralize this vowel's lexical tone pattern, thus negating any functional gain made by sandhi? In theory, yes. But observe that sandhi involving L, $V{:}^{M}$, and LH targets results in allophonic outputs. Regarding HL and HM, both retain their lexical character (that is, L and M, respectively), and MH is not a lexical pattern. Therefore, no lexical contrasts are neutralized upon sandhi here. Consequently, this allophonic process maintains the target contrast while enhancing the trigger contrast, and thus contrasts are maintained through allophony. That is, the cues of the trigger H tone are enhanced, with a negligible loss of cues for the target. Table 4 summarizes this allophonic process.

| PROCESS | MOTIVATION |
|---|---|
| L → HL | contrast maintenance of trigger (while contrast maintenance of target is not jeopardized) |
| $V{:}^{M} \rightarrow V{:}^{HM}$ | |
| LH → MH | |

TABLE 4. Allophonic sandhi outputs.

Now consider potential LM targets, which, recall from Table 1, are the only potential targets that may not be analyzed as undergoing sandhi. If sandhi were to alter LM tones, what might the output be? One possibility is that upon tone sandhi here, the target would possess three tonemes, HLM. Too many tones crowded onto a single syllable, however, would not be realizable in a salient fashion, as the duration of each is decreased as crowding increases. With this increased crowding, the tone pattern may not be recoverable. In theory, H might spread onto LM, merge with L, and be realized as M, in another case of blending. Indeed, in the case of MH sandhi outputs (derived from LH), blending straightforwardly accounts for the pattern. But in the case of LM inputs, a blended output would neutralize with lexical M, thus indeed confounding any overall functional gain made by the salient transmission of the H cues. Thus, if blended, the expansion of H onto LM would result in the neutralization of contrastive values, and if not blended, undue articulatory effort would be required to maintain all contrastive cues. In fact, even if all pitch contours are implemented here, they would likely suffer from perceptual nonsalience. So while the non-sandhi-triggering H tone here is short in duration, it is nonetheless the most satisfactory output, as neutralization would quite likely result upon sandhi. That is to say, when the salience of all contrasts can be improved upon H spreading, H spreads. However, if spreading here would neutralize another contrast, it is blocked, and the H tone resides on its syllable of origin, thus being realized in a fashion that maintains (though does not optimize) its contrastive cues, without obliterating other contrastive cues. Stated another way, pattern coherence of sandhi triggers is violated so that target cues are maintained. This type of apparent 'conspiracy' effect, in which contrastive values behave differently depending on their tendency to neutralize, is exactly the sort discussed by Kiparsky (1972), and is exactly the sort of pattern that purely synchronic characterizations have such great difficulty motivating.

But if the phonology is organized to avoid neutralization, how do we account for those M targets that neutralize with lexical H upon sandhi? This pattern represents the only instance of a neutralizing sandhi output. Specifically, $Vh^{M} \rightarrow Vh^{H}$, $V{:}h^{M} \rightarrow V{:}h^{H}$, and $Vh?^{M} \rightarrow Vh?^{H}$ are neutralizing outputs, as $Vh^{H}$, $V{:}h^{H}$, and $Vh?^{H}$ are lexically contrastive. Why should neutralization occur in this context, whereas in all other contexts the output of sandhi is either nonneutralizing or the entire process is blocked, as neutralization would otherwise result? When considering additional facts and generalizations, a possible answer emerges. First, this neutralization in Comaltepec occurs only in postaspirated syllables. Non-postaspirated syllables involve a nonneutralized output, HM. Now, recall that postaspirated syllables in Chinantec involve pitch increases toward their right edge. Consequently, it is exactly in postaspirated syllables where moderate pitch falls should be difficult to effectively implement and maintain. I suggest that implementing so many subtle pitch changes within such a short temporal domain is simply not worth the articulatory effort to produce all these contrastive values. And again, even if all pitch contours are implemented here, they would suffer from perceptual nonsalience, and the listener would likely conclude that the tone sequence was actually a level H tone.

Therefore, in contexts where V(:)h$^{HM}$ might be the expected sandhi output, V(:)h$^{H}$ is observed instead. Consequently, M targets in postaspirated syllables neutralize with lexically contrastive H tones. Here, again, the sound pattern seems to be influenced by a principle of least effort, this time at the expense of contrast maintenance.

Table 5 provides an outline of the argument when applied to the Comaltepec pattern. In this—and only this—context then, pattern coherence of triggers is maintained (sandhi takes place, and thus allophonic variation is pressured toward minimization), and effort is economized (not all contrastive pitch contours are implemented), at the expense of contrast maintenance of targets (the target is neutralized).

| TONE | GOODNESS OF CONTRAST | CONSEQUENCE |
|---|---|---|
| LM | good contrast with other lexical/derived values | sandhi blocked |
| Hh<br>Mh<br>HMh | not-so-good lexical/derived contrasts | sandhi neutralizes output to Hh |

TABLE 5. Neutralized sandhi outputs.

4. SUMMARY AND CONCLUSION. Comaltepec tone sandhi is hypothesized to have its origins in LH syllables, which, unless the following tone pattern is LM, spill over their H component onto a following vowel, because of articulatory constraints in combination with the principle of contrast maintenance. This may account for why sandhi consists of rightward H spread from LH syllables.

Historic H tones may have been next to fall in line with the pattern, but only when no postvocalic laryngeals intervene. This generalizing tendency is a first step toward pattern coherence. These tones are argued to have rather naturally evolved into present-day M. While this modern reflex is no longer a likely sandhi trigger, the process still takes place. This may account for why level M tones lacking postvocalic laryngeals trigger the appearance of a rightward H tone, and for why level H tones (which all possess postvocalic laryngeals) never trigger sandhi.

Pattern coherence and contrast maintenance of targets exerts the greater force in the context of potential LM targets, for sandhi here might result in neutralization. This may account for why sandhi never affects potential LM targets. By contrast, M targets possessing postvocalic aspiration indeed neutralize with lexical H. Given the pitch rise present in this particular environment, neutralization with H is more likely. Here then, pattern coherence of the triggering environment, and/or economy of effort in the target environment, takes precedence over contrast maintenance of the target. This may account for why M targets with postvocalic aspiration neutralize with H. Finally, excessive tone cramming is avoided so that recoverability is not jeopardized. Consequently, certain overlapping pitch values may blend toward an intermediate value. This may account for why LH targets become MH, whereas L targets become HL.

The primary function of a phonological system is to keep meaningful elements distinct. There are, however, always environments in which neutralization is the only reasonable recourse, and the pressures of pattern coherence inevitably interact in mutually confounding ways. As phonology is a system of 'hierarchies of optimality', optimization in one area inevitably leads to conflict elsewhere. This, indeed, is the fundamental insight of Kiparsky (1972), explored more recently in the context of optimality theory. But in the approach to phonological explanation I adopt here, unlike generative theories such as optimality theory, there are no inherently linguistic principles to which sound patterns must conform; there is no convention which restricts phonological systems by such theoretical constructs as a synchronically active ban on adjacent identical elements (Leben 1973), synchronically imposed locality conditions (Goldsmith 1979), faithfulness conditions (McCarthy & Prince 1993), or limiting comparisons to input-output relations (Halle 1962, Chomsky & Halle 1968).

Instead, through direct reference to proximal phonetic forces, in conjunction with sound change, as well as the more abstract pressures of contrast maintenance, economy of effort, and pattern coherence, sound patterns may be characterized in a far more compelling way. For example, the optimality-theoretic notion of 'faithfulness', formalized in recent work with correspondence theoretic constraints (McCarthy & Prince 1995) requires identity between inputs (lexical forms) and outputs (surface forms). But why? Apart from capturing the mere fact that hypothesized inputs and outputs tend to be identical, what fundamental linguistic truth is expressed by this theory, motivating, in the words of McCarthy and Prince 'a correspondence-sensitive grammar' (1995: 262)? In my approach, input-output correspondence is a mere epiphenomenon. Contrastive values typically do not neutralize, since doing so would override their primary function. Also, allophonic variation is minimized by the emergent strength of pattern coherence. These two independent principles thus severely limit the window of variation for a given contrastive value. Consequently, since the mental organization of the incoming sound signal can be posited only from surface patterning, learners (and linguists) never stray far from surface patterning when imposing order on the incoming data: the observed correspondence between some hypothesized input and the output thus comes at no cost.

Finally, I must reiterate that the hypothesized forces at work on phonological systems are not synchronically encoded in the mental grammar. Rather, the synchronic system is the natural result of evolutionary forces acting upon the linguistic system. These forces are Darwinian, not Lamarckian. Phonological ontogeny does not recapitulate phonological phylogeny; the synchronic grammar does not recapitulate the forces which have determined its shape, because, unless compelling evidence is offered to the contrary, its physical shape and its mental organization are assumed to be determined by wholly different principles. This, again, departs from the generative model, which often conflates history, synchrony, and acquisition, by rule ordering (Chomsky & Halle 1968), or, somewhat indirectly, through constraint ranking (McCarthy & Prince 1993, Prince & Smolensky 1993). Rather, characterizing the acquisition and synchronic organization of the grammar should be pursued in cooperation with computer scientists, cognitive scientists, learning theorists, and even evolutionary biologists, who might apply their theories to the data corpus. Approaches to explanation in phonology that refer to these fields include the functional arguments advanced by Kiparsky 1972, Liljencrants & Lindblom 1972, and Lindblom 1983, 1986, 1989, 1990a, 1990b; the evolutionary biological approaches of Lindblom 1984 and Nettle 1996; the self-organizing principles advanced by Lindblom et al. 1984, and Ehala 1996, the quantitative models advanced in many places by Lindblom and his associates (Lindblom & Sundberg 1969, 1971, Liljencrants & Lindblom 1972), and the general cognitive models advanced by Kuhl 1991, Kluender 1994, Frisch 1996a,b, and by Ohala 1981, 1990, and 1992. It is thus hoped that linguists actively seek to wed their theories of language with these other fruitful areas of science. This will undoubtedly result in major progress towards our understanding of the forces that shape and change the mental organization of linguistic sound systems.

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