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Phasing and Recoverability

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For my family--Bob, Phyllis, Ethan, Jerry, Shaheen, Arif, and Nadim

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Acknowledgements

My mother loves telling the story of how, in 1986, soon after I returned to Shanghai, fresh from hitch-hiking through the mountains of Guizhou and Yunnan, she was standing in the driveway one day talking with Barry and Donca, listening to them tell her how if I like Chinese and the minority regions so much, I should maybe study linguistics, and they mentioned UCLA in particular as a department that might suit my interests. "Maybe you two want to starve to death studying that crazy stuff, but why on earth do you think Danny would want to?" she thought to herself behind her polite smile...

...Donca Steriade is not only a great linguist and a great teacher. Truly, she is a great person. Throughout my graduate career, Donca has always been there to support and encourage me both academically and personally, to demand my best work and never let me get away with my natural laziness, and to constantly remind me that she's not my mother. She will always be my teacher.

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ABSTRACT OF THE DISSERTATION

Phasing and Recoverability

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This dissertation is an investigation into the phasing relationships that render contrastive values optimally recoverable, and establishes a functional link between recoverability and markedness.

The primary function of a phonological system is to keep meaningful elements distinct. Realizing this function involves optimizing the recoverability of contrastive values. Articulatory timing, or *phasing* relationships may ensure the auditory salience of these contrasts. These phasing relationships take four forms. First, one gesture may be *temporally sequenced* with respect to another, ensuring a salient realization of both. Second, a gesture may be *temporally expanded*, such that it both precedes and follows other gestures, again, ensuring the salience of both. Third, a gesture may be *temporally truncated* with respect to another gesture. Finally, to the extent that gestures *can* overlap, they *do* overlap. Thus *parallel production* of contrastive information is preferred, but only up to the recoverability of contrastive values.

Chapter One
Introduction

1.0 Introduction

The primary function of a phonological system is to keep meaningful elements distinct. Since calculating distinctness across *every form* in a lexicon is too great a task, phonological systems evolve to ensure the salient distinction of one contrastive configuration from another. These contrastive configurations combine with each other in various ways to encode lexical distinctions.

The phonology may be viewed as a conflict between two forces: **(1)** maximizing articulatory ease, and **(2)** maximizing perceptual salience. In this dissertation I investigate this second force. Particular *Timing relationships* between distinctive values ensure their perceptual salience. These timing, or *phasing* patterns take four forms. First, one distinctive value--one gesture--may be *temporally sequenced* with respect to another, ensuring a salient realization of both. Second, a gesture may be *temporally expanded*, such that it both precedes and follows other contrasts, again, ensuring the salience of both. Third, a gesture may be *temporally truncated* with respect to an overlapping gesture. Finally, to the extent that gestures *can* overlap, they *do* overlap. Thus *parallel production* of contrastive information is preferred, but only up to the recoverability of contrastive values.

This dissertation is an investigation into the phasing relationships that render contrastive values optimally recoverable, and explores the intimate relationship that recoverability bears to markedness.

1.1 Auditory Salience

Both contrastive laryngeal gestures (laryngeal abductions, laryngeal constrictions, voicing, and tone) and contrastive supralaryngeal gestures (a constriction at a particular place, and of a certain degree, with or without velic lowering) are potentially subject to perceptual obscuring. Now, laryngeal gestures and supralaryngeal gestures are functionally independent, and therefore may, in theory, be implemented simultaneously. Thus, for example, a voiceless aspirated stop consists of an oral occlusion as well as a laryngeal abduction. However, were the phonetic realization of the two gestures strictly simultaneous, the laryngeal abduction would not be perceived as such by the listener. Assuming for the moment that the acoustic goal of a laryngeal abduction is to achieve broadband noise across a large portion of the sound spectrum, the speech signal possesses insufficient energy at this crucial instant to encode this contrastive laryngeal gesture. Stated simply, the full closure here reduces the acoustic output to zero. With zero acoustic energy, no laryngeal contrast is perceivable. A listener can tell that there is either voicing or no voicing, but cannot recover more specific information regarding the state of the glottis during oral closure. (1) presents a schematic representation of this unattested realization of an aspirated labial

stop.

(1) unattested realization of an aspirated "p":

SL (supralaryngeal): labial stop: ■

L (laryngeal): abduction: ▨

p

Throughout this dissertation, "■" represents a saliently encoded gesture. "▨" represents an auditorily unencoded--though articulatorily implemented--gesture. Finally, "▤" represents a gesture that is auditorily encoded, though not optimally so.

(2) ■ = auditorily optimally encoded gesture

▤ = auditorily sub-optimally encoded gesture

▨ = auditorily unencoded gesture

Now, before, going on, I am fully aware that "salience" and "optimal" and "sub-optimal" auditory encoding are rather vague notions. In this dissertation, I begin to move toward a proper notion of salience and auditory optimality by considering certain properties of the peripheral auditory system. Specifically, the salience of a given gesture is argued to correlate with the degree of auditory nerve response. In short, the greater the firing rate of the auditory nerveat the relevant characteristic frequency, the more salient I assume the percept to be, and, consequently, the more highly valued--the closer to "optimal"--a given phasing pattern is. This idea is considered in greater detail in Chapter Two.

A phonological system fulfills its primary function by maximizing auditory salience. In the case at hand, due to the temporal sequencing of the two gestures, the otherwise obscured gesture is rendered salient. Maximal laryngeal abduction is realized at or around the interval of release of the oral occlusion, for example in English (Yoshioka, Löfqvist, Hirose, and Collier 1986), Danish (Fukui and Hirose 1986), Hindi (Dixit 1989), and Korean (Kim, Hirose, and Niimi 1992). As the maximally abducted larynx is phonetically realized across the transition from the stop into the following, more sonorous gesture, sufficient acoustic energy is present to encode this contrastive information. The resulting phonetic string consists of two perceptually salient elements ordered in time.

(3) optimal realization of an aspirated"p":

SL: labial stop: ■

L: maximal abduction: ▨■

p^h

Kingston (1985, 1990), echoing the electromyographic and fiberscopic studies of Hirose, Lee, and Ushijima (1974), Löfqvist (1980), Löfqvist and Yoshioka (1980),

and Yoshioka, Löfqvist, and Hirose (1981), posits that laryngeal articulations are more tightly "bound" to the release of a stop than to the release of a continuant. It should be noted that the transition around the offset of a stop, unlike that of a continuant, is an acoustically salient event particularly well-suited to encode contrastive information. Continuants, however, are more or less acoustically uniform from onset to offset (Kingston 1990, Goldstein 1990).

As discussed in Chapter Two, for various reasons stop onsets are not as salient as stop releases. Therefore, as the laryngeal abduction is not as saliently encoded when it precedes the stop closure, pre-aspirated stops constitute a sub-optimal realization.

(4) phonetically sub-optimal realization of an aspirated "p":

SL: labial stop: ■

L: maximal abduction: ▤▨

$^h p$

It should also be noted that laryngeal abductions are common concomitants of phonologically *plain* stops. Here, the abduction is indeed phased more or less simultaneously with the oral occlussion. The function of a laryngeal abduction in this context may be to ensure voicelessness during oral closure; it is surely *not* the case that the acoustic goal of this gesture is bradband noise. Thus oral closures may be simultaneous with either vocal fold vibration, resulting in a voiced stop, or non-vibration, resulting in a voiceless stop. However, it is not possible to make finer distinctions during oral closure: when the vocal folds are vibrating, different modes of vibration cannot be distinguished. When the vocal folds are not vibrating, it cannot be reliably determined whether this is due to a laryngeal abduction or a laryngeal constriction. For this reason, aspiration is optimally sequenced to *follow* a stop closure, and sub-optimally sequenced to *precede* a stop closure.

Due to pressure to maximize the number of contrasts (see Flemming 1995), when the system of contrasts exhausts the set of phonetically optimal phasing relations, or when more stringent morphological and/or phonotactic constraints are enforced, phonetically sub-optimal phasing patterns may be employed. Some of these sub-optimal realizations are discussed in subsequent chapters of this dissertation.

Now, it is usually the case that implementing a phonetically sub-optimal phasing pattern comes at a compensatory articulatory cost. That is to say, given the tendency toward non-recoverability here, additional articulatory effort is required to increase the likelihood of encoding the contrastive information. For example, post-aspirated plosives are salient due to their aerodynamic and auditory properties. Pre-aspirated stops do not enjoy these phonetic advantages. Consequently, it is quite likely that pre-aspirates are implemented with increases in respiratory muscular activity, in order to increase the energy of the speech signal here, thus increasing the likelihood of their recoverability (see Ladefoged 1958, 1968 concerning instrumental evidence for increased respiratory muscular activity accompanying word-initial aspiration--that is, h-

initial words--in English).

Given their auditory and aerodynamic advantages, post-aspirates possess unmarked status in the world's languages, while pre-aspirates are marked. That is to say, if one contrastive phasing pattern between stops and abductions is present in a system, it involves post-aspiration. Moreover, the presence of pre-aspiration in a system implies the presence of post-aspiration. Indeed, throughout this dissertation I establish links between auditory optimality and patterns of markedness: the greater the auditory nerve response, the less marked.

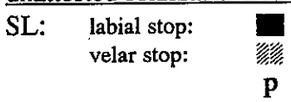
In the remaining sections of this introductory chapter, I consider gestural sequencing (1.2), gestural expansion (1.3), and gestural truncation (1.4); three different ways of achieving the recoverability of contrastive values. I continue with a brief discussion of parallel production and serial production (1.5), and formalism (1.6).

1.2 Gestural Sequencing

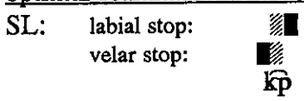
As discussed in 1.1, the optimal realization of aspirated stops involves temporally sequencing the maximal laryngeal gesture to be phased at or around the transition period between stop and vowel.

Another example of maximizing recoverability involving temporal sequencing is the complex labio-velar stop. Maddieson (1994) shows that these doubly-articulated segments in Ewe are phased such that their velar gesture slightly precedes their labial gesture. As Maddieson argues, this sequencing results in the perceptual salience of both components of the stop.

(5) a. unattested realization of a labio-velar stop:

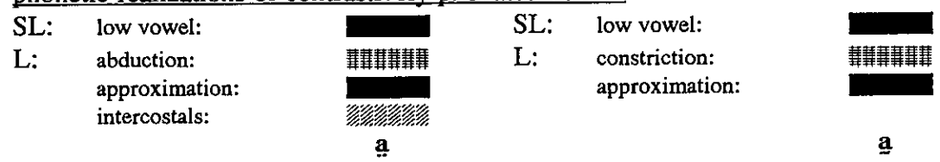


b. optimal realization of a labio-velar stop:



A third case of temporal sequencing that is especially relevant for the present investigation involves solely laryngeal gestures. Vowels, with maximum sonority, contain sufficient acoustic energy so that a contrastive laryngeal gesture may be phonetically simultaneous with the supralaryngeal constriction. Thus breathy vowels are found in, for example Oriya (Dhall 1966), and Gujarati (Fischer-Jorgensen 1970), and creaky vowels are found in, for example, Sedang (Smith 1968).

(6) phonetic realizations of contrastively phonated vowels:[1]



However, in certain languages, contrastive phonation gestures of vowels are phased such that they are realized in a part-modal, part-non-modal fashion. Sequencing of contrastive phonation gestures with respect to modal voicing is limited primarily to tonal languages. As I discuss in Chapter Five, tone may be obscured if phased in parallel with non-modal phonation. Upon sequencing the contrastive laryngeal gestures--tone and non-modal phonation--the likelihood of recoverability is increased: tone is encoded. I refer to languages (and vowels) which cross-classify tone and phonation as "laryngeally complex".

The Otomanguean languages of Oaxaca, Mexico and environs employ this method of maximizing auditory recoverability. I especially concentrate on the Comaltepec dialect of Chinantec. Chinantec possesses a lexical and morphemic contrast traditionally referred to as "ballistic accent" (term in this context originally from Merrifield 1963). Ballistically accented syllables are reportedly articulated more forcefully than "controlled" (non-ballistic, or plain) syllables, affecting pitch, amplitude, and phonation. In (7) are some examples.

(7)

ballistic:		controlled:		
lo:h^{LH}	lime	**lo:**^{H}	skin	(Comaltepec dialect (Anderson 1990))
mah^{H}	food	**na**^{H}	now	(Palantla dialect (Merrifield 1963))
ty:h^{M}	blind	**ty:**^{M}	Peter	(Quiotepec dialect (Robbins 1968))

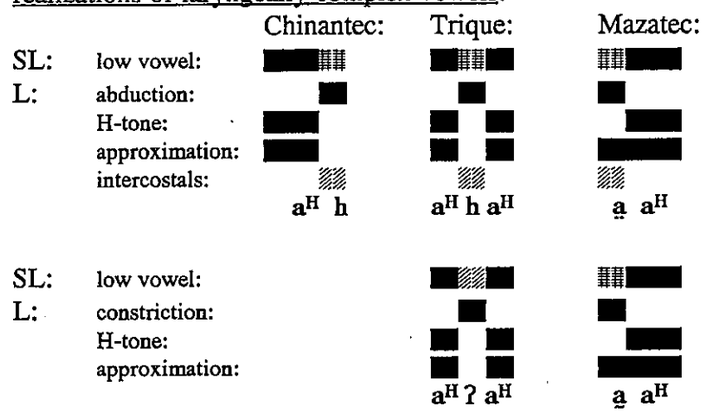
Ballisticity has traditionally been considered a stress-based property of syllables (Merrifield 1963, Bauernschmidt 1965, Rensch 1978). In Chapter Five I instead argue that ballisticity is laryngeally-based, involving a laryngeal abduction, with a concomitant increase in respiratory muscular activity. As my notation in (7) indicates, the laryngeal abduction in ballistic syllables is realized post-vocalically.

The peculiar realization of ballistic syllables ultimately derives from a complex combination of phonetic, phonological, and morphological factors. As these vowels possess both lexical and morphemic laryngeal contrasts involving both tone and phonation, these gestures are sequenced in order to maximize the salience of all contrastive information: tone is most reliably perceived and most reliably produced with modal voice. I provide supporting evidence for this approach to laryngeally

[1] The presence of "intercostals" here is discussed at length in later chapters.

complex vowels from the related Otomanguean languages of Trique and Mazatec. While vocalic phonation contrasts are phonetically postvocalic in Chinantec (**Vh**), they "interrupt" the vowel in Trique (**VhV**, **V?V**), and are prevocalic in Mazatec (**V̰V**, **V̰V**). In Trique in particular, there is ample phonological evidence that interrupted vowels pattern as single nuclei. In Mazatec, as well as in Chinantec, there is distributional evidence supporting this same conclusion. Thus Chinantec, Trique, and Mazatec realize their vocalic non-modal phonatory gestures in three distinct ways. (8) displays these realizations, employing a high-toned low vowel with a laryngeal abduction, and a laryngeal constriction, respectively.[2]

(8) <u>realizations of laryngeally complex vowels</u>:



This and other examples of gestural sequencing are explored in detail in later chapters.

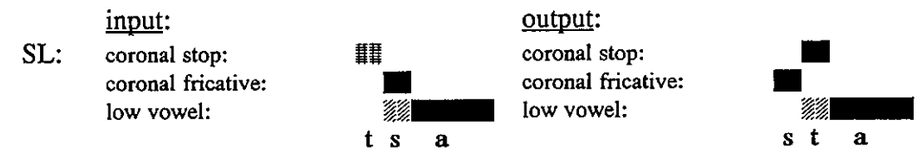
Now consider gestural *re*-sequencing, or metathesis, exemplified by the so-called **hitpaʃel** pattern in Hebrew. Here, a prefix-final coronal stop metathesizes with a root-initial consonant, but only if this root consonant is a sibilant (**s,ʃ,ts,dz**).

What motivates re-sequencing in this environment? First, stop consonants are most salient when released into a vowel, and coronals in particular are dependent upon this release for a salient realization. Second, sibilants, more than any other class, are cued primarily by their target constriction, and only secondarily are cued by the onset and offset of the gesture. Consequently, these two gestures are re-sequenced such that the coronal stop is released into a vowel, thus optimizing its salience, while the sibilant, now re-sequenced to precede the stop closure, does not suffer any significant loss of its major acoustic cues. Moreover, if not re-sequenced, fricative-stop clusters

[2]The gestural discontinuity of voicing and tone in Trique laryngeally complex vowels ("▇ ▇") is due to the articulatory incompatibility of these gestures with a strong laryngeal abduction. This incompatibility is discussed in detail in Chapter Five.

(e.g., **t+s**) would neutralize with affricate onsets (e.g., **ts**). Upon re-sequencing, all contrasts are maintained and enhanced (e.g., **st**).

(9)



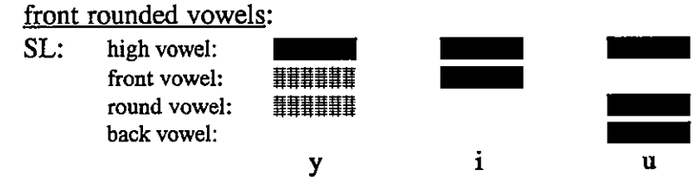
See Sherman 1994 for a detailed discussion of this pattern.

1.3 Gestural Expansion

Gestures which may be superimposed on vowel quality without obliterating vocalism may be implemented across a gestural expanse--across more than one gesture--in order to enhance their salience: increasing temporal exposure to contrastive values results in a more salient percept (Kaun 1995, Flemming 1995). Most importantly, expanding gestures through intervening consonantal constrictions results in more formant transitions, serving to better encode the expanded gesture. Gestures which may expand in this fashion include nasalization (e.g., Guarani), lip-rounding (e.g., Turkish), tongue body gestures (e.g. Yawelmani), pharyngealization (e.g. Arabic), tonal gestures (e.g. Chaga), and, rarely, anteriority (e.g. Tahltan).

For example, front rounded vowels are often subject to temporal expansion, or spreading, such that this contrastive configuration both precedes and follows other contrasts. Why should this be the case? Such vowels (for example, **y**) include a tongue-fronting gesture, which serves to raise F2. But these vowels also possess a lip-rounding gesture, which serves to *lower* F2. These distinct gestures thus influence F2 in opposite directions, which potentially results in an acoustic signal which cannot be reliably distinguished from **i** or **u**.

(10) <u>front rounded vowels</u>:



How might languages overcome this potential non-recoverability? One method of achieving salience here, discussed at length in Kaun (1995), involves spreading the potentially opaque gesture across a larger temporal domain. By expanding the temporal duration of these acoustically "bad vowels" across distinct gestures (terminology from Kaun), the likelihood of recovering their composition is increased, and thus the possibility of perceptual neutralization is mitigated.

(11) round harmony:

a. sub-optimal:

SL: coronal stop:
high vowel:
front vowel:
round vowel:

b. possible optimal:

SL: coronal stop:
high vowel:
front vowel:
lip-rounding:

Kaun notes that in non-high front rounded vowels, lip rounding is often less pronounced than in their high counterparts. As the degree of lip-rounding correlates with the degree of F2 lowering, this contrastive gesture is less robustly encoded than its high vowel counterpart. Consequently, roundness is more likely to spread here. Kaun reports that, for example, Eastern Mongolian dialects and Tungus languages display this pattern: roundness spreads from non-high front rounded vowels, but not from high front rounded vowels.

(12) round harmony:

a. sub-optimal:

SL: coronal stop:
mid vowel:
front vowel:
round vowel:

b. possible optimal:

SL: coronal stop:
mid vowel:
front vowel:
round vowel:

A second method of increasing the likelihood of recoverability in these vowels involves the temporal sequencing of their constituent components; the tongue-fronting gesture and the lip-rounding gesture. As these gestures are no longer phonetically simultaneous upon sequencing, the mismatch between F2 quality and articulatory positioning is not encountered, and acoustic transparency is achieved.

For example, Andersen (1971) discusses a historic process in Slovak whereby an original front-rounded word-final glide **y:** has evolved into an **iu** sequence. Despite the temporal sequencing of fronting and rounding, many modern dialects reportedly still treat the **iu** sequence as a single syllabic nucleus, while other dialects have phonemicized the sequence (**iju, iju:**).

(13) possible optimal:

SL: high vowel:
front vowel:
round vowel:
back vowel:

In fact, many of the diachronic diphthongization processes presented by Andersen may be analyzed along these lines.

Now consider a second source of temporal expansion. Sometimes, a contrastive value may possess intrinsic auditory distinctness. However, due to its sequencing with respect to another contrastive value, non-recoverability may result.

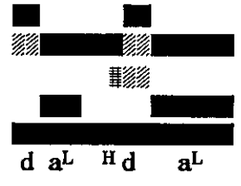
For example, Comaltepec Chinantec **H** tones spread to a following vowel if immediately preceded by a tautosyllabic **L** tone (Anderson, Martinez, and Pace 1990, Pace 1990, Silverman 1995). While linguistically significant higher pitch is surely auditorily distinct from linguistically significant lower pitch, spreading occurs in this environment in order to increase salience. Why should this be so?

Sundberg (1973) provides instrumental evidence showing that pitch rises take much longer to initiate than do pitch falls of the same distance.[3] Therefore, in a syllable with a **LH** tone pattern, the **H** tone might be implemented only at the very end of the vowel. In (14) I show this pattern with a voiced coronal stop and a low vowel followed by a low-toned vowel.

(14) unattested realization of Comaltepec Chinantec **LH** pattern:

SL: coronal stop:
low vowel:

L: H-tone:
L-tone:
approximation:

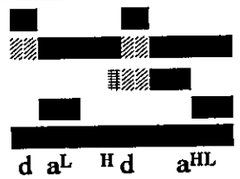


[3]Some languages accommodate to this physiological constraint by *reducing* the pitch differential in phonological upglides; in such languages, phonological pitch falls undergo a greater absolute pitch change than phonological pitch rises do (for discussion, see Ohala 1978).

In (14) observe that the **H** tone is implemented only at the very end of the first vowel, and actually overlaps with the following consonant. In this environment, the **H** tone is potentially non-recoverable. Due to the oral constriction which defines a consonant, oral airflow is potentially impeded. In Silverman 1995, this impedence is argued to disrupt both the frequency and the amplitude of the **H** tone.

Thus the **H** component of a Comaltepec Chinantec **LH** contour tone regularly spreads from its syllable of origin on to a following vowel. (15) shows this configuration.

(15) optimal realization of Comaltepec Chinantec **LH** pattern:

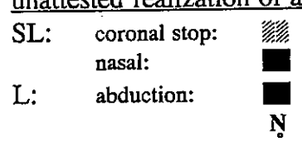


As its duration is increased upon spreading to overlap with a following vowel, this higher pitch becomes more salient. Its reliable encoding in the speech signal ensures its recoverability.

1.4 Gestural Truncation

Some languages' nasal series cross-classifies with contrastive phonation (aspiration and/or laryngealization). These combinations of gestures may render place of articulation non-recoverable. The simultaneity of laryngeal gestures and velic lowering may obscure the acoustic encoding of an accompanying oral occlusion. For example, as shown by Dantsuji (1984, 1986, 1987), a laryngeal abduction occurring with a nasal stop greatly reduces intensity, dramatically obscuring the nasal formant structure. Consequently, nasal place of articulation might not be discernible.

(16) unattested realization of a coronal nasal with a contrastive laryngeal abduction:

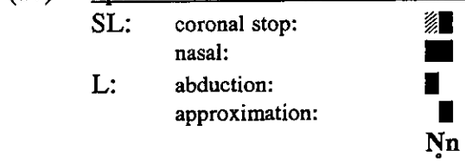


Therefore, the temporal duration of the contrastive laryngeal gesture is truncated with respect to the accompanying supralaryngeal gestures, sequenced to precede voicing. A portion of the supralaryngeal gesture is thus realized with modal voice, rendering its formant structure recoverable.[4] Usually, voicelessness is realized during

[4]I could just as readily consider this strategy an *expansion* of the supralaryngeal value. However, in this dissertation, the term *gestural expansion* refers to values which flank

the first portion of the nasal.

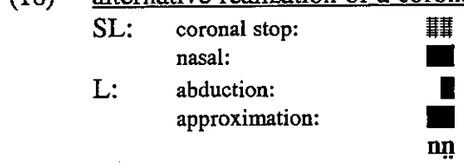
(17) optimal realization of a coronal nasal with a contrastive laryngeal abduction:



Burmese "voiceless nasals" are an example. According to Dantsuji (1984), these segments consist of two portions: a voiceless nasal portion, followed by a voiced (plain) nasal portion.

Alternatively, in some languages, the laryngeal abduction may occur during the second portion of the nasal in the form of *breathy*--not *voiceless*--phonation.

(18) alternative realization of a coronal nasal with a contrastive laryngeal abduction:



In Chapter Four I discuss the reasons for the articulatory asymmetry between these distinct phasing relationships.

1.5 Parallel Production and Serial Production

To the extent that gestures *can* overlap without obscuring contrastive information, they *do* overlap. (See, for example, Liberman, Cooper, Shankweiler, and Studdert-Kennedy 1967 and Mattingly 1981; see Marchal 1987, Nolan 1992, Zsiga 1992, Byrd 1992, and Silverman and Jun 1994 for evidence of gestural overlap which may result in neutralization; Byrd 1994 shows that speech rate, place, manner, and gestural environment affect the degree of overlap in English consonant clusters. This non-contrastive timing variability is discussed in Chapter Two.) Indeed, Liberman, Cooper, Shankweiler, and Studdert-Kennedy (1967) argue that the speech perception mechanism is especially designed for decomposing an informationally complex speech signal, and is less adept at decoding isolated speech sounds. Consequently, *parallel production* of contrastive information may be optimal, but only, of course, up to the recoverability of contrastive values. For the purposes of this dissertation, parallel production refers to the *temporally simultaneous* implementation of more than one contrastive gesture. For example, in the case of (non-tonal) breathy or creaky vowels,

other values. For this reason, I refer to the process presently under discussion as *gestural truncation* of one gesture relative to another.

both the laryngeal and supralaryngeal configurations may be implemented fully simultaneously, as no contrasts are jeopardized.

When gestural overlap would otherwise result in a diminished contrast, *serial production* is sometimes implemented in order to avoid neutralization. In this dissertation, serial production refers to the *temporally sequenced* implementation of contrastive gestures, which may nonetheless result in the *parallel transmission* of contrastive information (see especially Liberman, Cooper, Shankweiler, and Studdert-Kennedy 1967, and Mattingly 1981 for discussion here). Thus, for example, in the case of aspirated stops, were supralaryngeal closure and laryngeal abduction implemented in full parallel, the laryngeal abduction would not be encoded in the speech signal. Consequently, their serial production is observed: maximal laryngeal abduction occurs at or around stop release and the immediately following interval. Thus the transient between the stop and the vowel is an informationally rich segment of the signal: random noise here encodes the laryngeal abduction, and formant transitions encode both the place of stop closure, and the place of the following vowel. This pattern thus exemplifies how serial production may yield parallel transmission.

1.6 Formalism

The conflict between *maximizing articulatory ease* and *maximizing perceptual salience* may be expressed as ranked, violable constraints in the framework of Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993). Recall, however, that this dissertation is concerned with only the latter. Therefore, conflicting constraints are employed to model gestural realization, resulting in either the parallel production or serial production of contrastive values, that is, in the phasing relationship which *optimizes recoverability*. These constraint families are presented in (19).

(19)

(a) phase *employ/do not employ particular phasing patterns*	**(b) recover** *maximize auditory recoverability, otherwise maintain auditory recoverability*	**(c) economize** *maximize articulatory ease*	**(d) overlap** *maximize gestural overlap*

That is, the phonology values the overlap of contrastive gestures in order to increase speaking rate **(d)**, but also values articulatory ease **(c)**. But in order to maintain the encoding contrastive gestures, these constraints are not as highly valued as auditory recoverability **(b)**. However, as discussed in later chapters, there are systems in which maximal auditory nerve response is forfeited in order maintain a(n auditorily sub-optimal) lexical phasing pattern **(a)**. For example, Huautla Mazatec possesses optimal **tʰ**, but also possesses sub-optimal **ʰt**. In such cases, all contrastive gestures are recoverable, but auditory response is not always optimal (as in the case of **ʰt**). As I show in later chapters, these constraint families may be re-ranked in order to account for cross

linguistic patterning, while also reflecting major cross-linguistic trends in gestural phasing. However, given that this dissertation focusses on contrasts at the lexical level, **phase** is an undominated constraint; in morphologically complex environments, **phase** may indeed be dominated.

The various phasing patterns are relations between the gestures themselves. These are indicated throughout with the shorthand symbols listed in (20).

(20) schematic of possible phasing patterns:

phasing patterns		schematic examples:		gloss:
parallel	(⇧)	**a⇧b**	a: b: **a͡b**	phase a and b strictly simultaneously
sequence	(⇨)	**a⇨b**	a: b: **a b**	phase a to precede b
expand	(⇧)	**a⇧b⇨c**	a: b: c: **a a͡b a͡c**	phase a to precede b, but also in parallel with b and c
truncate	(⇩)	**a⇩b**	a: b: **a͡b b**	phase a to the first portion of b

This notation is intended to make more explicit the involved phasing patterns. I also spell out in prose the phasing pattern which a given notation characterizes. So **parallel**, indicated by the vertical birectional arrow, indicates two gestures phased strictly simultaneously. **sequence**, with a right-pointing arrow, means the involved gestures are temporally sequenced in the order shown. **expand** with an upward pointing arrow, indicates that one gesture both precedes and follows another. **truncate**, indicated by the downward-pointing arrow, represents phasing one gesture in parallel with only a portion of another gesture.

And the actual contrastive gestures are listed in (21), abstracting away from place of articulation.

(21) gestures: SL: **stop, fricative, nasal, liquid, glide, vowel**
L: **abduction, constriction, approximation, tone**

Thus, for example, a breathy vowel involves **vowel⇧approximation⇧abduction**: phase the vowel and the abduction in parallel. An aspirated stop involves **stop⇨abduction**: sequence the maximal abduction to around stop release, as parallel production here would render the abduction unencoded.

1.7 Conclusion, and Outline of the Dissertation

The primary function of a phonological system is to keep meaningful elements

distinct. Realizing this function involves optimizing the salience of contrastive values. Phasing relationships between gestures are organized to maximize recoverability, while also maintaining gestural overlap and articulatory ease up to recoverability. These relationships involve temporal sequencing, temporal expansion, temporal truncation, and parallel production. The specific phasing pattern employed is determined by the oft-conflicting goals of maximizing gestural recoverability, maximizing articulatory ease, and maximizing gestural overlap. The achievement or non-achievement of auditory salience involves the complex interdependence between articulatory phonetics, aerodynamics, acoustic phonetics, auditory phonetics, and the systems of contrasts and morphology. All of these components are herein shown to play major roles in the structures and patterning of phonological systems.

Chapter Two reviews the relevant literature on which subsequent discussion is based. This includes Browman and Goldstein 1986, 1989, 1990, 1992, Kingston 1985, 1990, Bladon 1986, Mattingly 1981, and Steriade 1992, 1993, 1994, and the literature on gestural overlap. Chapter Three discusses the interaction of obstruents and laryngeal gestures, presenting a formal account of their patterning. Chapter Four investigates the interaction of sonorant consonants and laryngeal gestures, presenting a formal account of their patterning. Chapter Five discusses the interaction of vowels and laryngeal gestures.

Chapter Two
Previous Work, and Formalism

2.0 Introduction

The present investigation owes much to Browman and Goldstein's theory of Articulatory Phonology (1986, 1989, 1990, 1991, 1992), Kingston's binding generalizations, (1985, 1990), as well as Bladon's generalizations on auditory phonetics (1986), and Mattingly's discussion of parallel transmission (1981). It is additionally inspired and influenced by Steriade's work on aperture positions (1992, 1993, 1995), Zsiga's approach to lexical versus post-lexical processes (1993), and Byrd's (1994) and Jun's (1995) work on gestural overlap and reduction. In this chapter I present and critique the foundations of these areas of research.

I conclude this chapter with a discussion of Optimality Theory (McCarthy and Prince 1993, Prince and Smolensky 1993).

2.1 Browman and Goldstein (1986, 1989, 1990, 1991, 1992)

This dissertation employs a version of Browman and Goldstein's theory of Articulatory Phonology.[1] In this theory, phonological primitives consist of temporally arranged (or "phased") gestures, where a gesture is an autonomous and abstract structure consisting of the onset, target, and offset of a constriction at a particular location and of a particular degree. As the authors point out, "...the gestures for a given utterance, together with their temporal patterning, perform a dual function. They characterise the actual observed articulator movements (thus obviating the need for any additional implementation rules), and they also function as units of contrasts (and more generally capture aspects of phonological patterning)" (1989:210). In certain incarnations (1986, 1991) the gestural approach permits the phonology free access to timing information, thus potentially allowing many system-internal contrasts in timing alone: "There is a potential continuum [of gestural overlap] ranging from complete synchrony...through partial overlap...to minimal overlap...there are no *a priori* constraints on intergestural organization within the gestural framework. The relative 'tightness' of cohesion among particular constellations of gestures is a matter of continuing research" (1991:319, quoted in Byrd 1994:139). In other incarnations, phasing rules have access to only three *landmark regions*: the onset, target, and offset of a gesture (Browman and Goldstein 1990).

Byrd (1994) argues against a strict interpretation of Browman and Goldstein's timing, or "phasing" rules. She further rules out the landmark approach, regarding it "empirically overly constrained and theoretically unprincipled. Why would exactly these three phase angles and no others...exist for timing rules?" (p.139). In fact, there are very

[1]Many of the basic notions and devices of this theory, including gestural primitives, gestural score-like displays, phasing rules, and synchronic and diachronic phonological motivation, are prefigured in Henderson 1985.

well motivated reasons why the phonology should exploit these three landmarks. As I discuss in detail in later chapters, primary and secondary acoustic cues reside in onsets/offsets (e.g., formant transitions), and steady states (e.g., fricative constrictions, secondary place cues in nasal consonants), and the timing of laryngeal gestures is indeed coordinated with these three articulatory/acoustic/auditory landmarks.

I note here, and this is very important, that I employ gestural notation despite the fact that I am arguing for these gestures' *auditory* relevance. That is, gestures and their phasing are simply means to achieve auditory ends. The reader is encouraged to keep in mind my underlying claim that phasing patterns are good to the extent that they are *auditorily* good. Stated simply, *a particular gestural phasing pattern is employed to achieve a particular auditory goal or goals.* For this reason, I take a more concrete approach to articulatory gestures, describing their pre-theoretical *physical articulatory* characteristics. Thus, it is only for expository clarity that I employ gestural score notation, as the portrayal of temporally arranged auditory goals renders the visual presentation too far removed from intuition. I do, however, enrich the system by providing gross information regarding auditory recoverability. The indicated recoverability of a given gesture should be considered a cover term for the acoustic cue or cues that are auditorily recoverable from the particular gesture in the portrayed timing configuration.

The gestural model arranges gestures in "articulatory tiers," thus grossly distinguishing consonantal gestures from vocalic gestures, as well as making finer distinctions which correlate more or less to the "articulator nodes" employed in the theory of feature geometry (Clements 1985, Sagey 1986, McCarthy 1989).

(1) <u>tiers in Articulatory Phonology</u>:

```
V-tier:     a     b     c
           / \   / \   / \
C-tier:    e f   g h   i j
```

I also recognize the functional independence of distinct articulatory subsystems. Thus laryngeal and supralaryngeal configurations are by and large independently manipulable, as is the velum. Consequently, in my notation, I divide the speech mechanism into laryngeal and supralaryngeal subsystems, affording the velum independence as well.

(2) <u>functional independence of articulatory subsystems</u>:

```
supralaryngeal:   oral:    ▮   etc.
                  nasal:   ▮   etc.
laryngeal:                 ▮   etc.
```

It should nonetheless be noted that this presentation represents the *functional* distinction between these subsystems, and not their phonological independence. That is,

the laryngeal system and the supralaryngeal system may in theory be physically manipulated independently from one another. Nonetheless, phonologically, they pattern in a highly interdependent manner. Indeed, over and over again in later chapters I discuss how their interaction is crucial for the auditory encoding of a given contrast. For this reason, my segregating these subsystems in a tier-like, vertical fashion is for expository clarity only: no theoretical significance is intended by this notation. Gestural scores, then, merely *display* timing relations.

Finally, in the articulatory model, gestures are modeled according to a 360 degree cycle, in which gestural onset, target and offset phase angles are lexically specified, and supposedly invariant across contexts. In the present approach however, only *relative* gestural target durations are modelled (for example, contrastive length; see Browman and Goldstein for a discussion of gestural representations which encode prosodic positions); interpolation between target durations is left unspecified (see also Keating 1990). I do not, however, overlook the informational richness of these dynamic portions of the speech signal. Indeed, they usually provide a richer source of information than do static targets (see, for example, Liberman, Cooper, Shankweiler, and Studdert-Kennedy 1967, Mattingly 1981, Bladon 1986). Moreover, specific intergestural timing relationships are accounted for by their effect on the auditory nerve. Thus, for example, a laryngeal abduction is coordinated with voiceless stop release because this timing relationship optimizes the salience of the contrastive material. The resulting temporal stability of oral closure-then-laryngeal abduction is a consequence of this optimal coordination of gestures.

To summarize, in this dissertation I employ a version of Articulatory Phonology, in that I present gestural scores involving gestural primitives. However, I view particular gestural configurations as mere means to achieve particular auditory goals. Indeed, I enrich the gestural score model by indicating the relative degree of auditory salience of a given gesture. Gestures are phased with respect to one another in a manner which optimizes auditory salience, while interpolation across target gestures is left articulatorily unspecified, although is often of primary auditory importance.

2.2 Kingston (1985, 1990)

Kingston's articulatory binding generalizations observe that laryngeal articulations tend to be realized at (that is, are "bound" to) the release of a stop consonant. Unlike a voiceless stop closure, the transition interval from a voiceless stop into a following vowel is an acoustically salient event which involves the pressurized expulsion of air that has been trapped behind the oral occlusion. This pressurized expulsion of air results in a high level of acoustic energy which is especially well-suited to bear contrastive information. Because of its salience, it is a preferred site for the realization of linguistically significant articulatory events. Laryngeal articulations thus gravitate toward this site so that they may be realized with maximal acoustic salience.

The present approach broadens Kingston's conclusions by placing them in the context of the more general pattern of phasing and recoverability. In particular, I argue that many phenomena fall under the same rubric as articulatory binding: contrastive information is rendered salient, either through its sequencing (as in laryngeally contrastive stops), temporal truncation, or temporal expansion.

The binding generalizations observe two asymmetries in the patterning of laryngeal articulations with respect to oral ones. They are paraphrased in (3).

(3) paraphrase of Kingston's binding generalizations:

(1) Voiceless plosives are much more likely to contrast for glottal articulations than voiced plosives, fricatives, or sonorants.

(2) Contrastive glottal articulations in voiceless plosives are more frequently realized as modifications of the release of the oral closure than of its onset.

A full supralaryngeal occlusion unaccompanied by vocal fold approximation (voicing) possesses negligible acoustic energy. However, a laryngeal abduction or laryngeal constriction that is implemented during closure, and continues beyond the stop release, is realized in an especially salient fashion. This transition interval, then, is especially suited to encode laryngeal contrasts.

For example, a glottal abduction allows air to pass across the glottis at a fairly rapid rate. With a downstream closure, the oral cavity fills to capacity quite quickly. Now, around the interval of oral release, the glottal abduction is maintained, and actually increases in magnitude around the transition from stop to vowel (Hirose, Lee, and Ushijima 1974, Löfqvist 1980, Löfqvist and Yoshioka 1980, Yoshioka, Löfqvist, and Hirose 1981). The pressure build-up behind the oral closure is thus released with a salient burst. Moreover--and this is especially important--phasing the maximal laryngeal abduction with the transition from stop closure to vowel results in maximal airflow during this critical interval, and thus the laryngeal abduction is saliently encoded in the speech signal.

For ejective stops, which involve a glottal constriction, the laryngeal gesture is obviously quite different. An ejective stop involves a glottal closure during which transglottal flow ceases. As there is no transglottal flow, the volume of air within the supraglottal cavity remains constant. Here, unlike the case of the aspirated stop, transglottal flow does not serve to increase intraoral pressure. Instead, additional laryngeal gestures obligatorily accompanies the glottal constriction, serving to raise oral pressure.

In ejective stops, the glottis shuts, the larynx raises, the pharyngeal cavity may be constricted, and the pharyngeal walls stiffened, thus reducing the size of the oral cavity, consequently raising intraoral pressure (Kingston 1985, MacEachern, in prep.). Now, at stop release, as the compressed air rushes through the mouth. The accompanying laryngeal constriction is saliently encoded during this interval. As Kingston states, "The acoustic character of the burst at once depends on and cues the state of the glottis" (1990:408).

A continuous stream of nasal airflow characterizes a nasal stop. Therefore, these articulations possess a less forceful release than either voiced or voiceless oral stops. Continuants also possess a less pronounced oral release: like nasals, their offsets are virtual mirror-images of their onsets. Therefore, according to Kingston, contrastive laryngeal articulations do not bear a special timing relationship with respect to this type of oral constriction: laryngeal gestures are less likely to be realized around a continuant release, and more likely to be unfixed in time with respect to the supralaryngeal constriction.[2]

Goldstein (1990) formulates two criticisms of Kingston's approach. He interprets Kingston's binding generalizations to be based on the hypothesis that a glottal abduction is implemented to increase intraoral pressure during closure, which consequently results in an aspirated stop's characteristic burst. He notes that Dixit and Brown (1978) find that in phonologically plain plosives in Hindi, peak intraoral pressure is equivalent with that found in voiceless aspirated stops. This is most likely due to the fact that, even in plain stops, the larynx is abducted during the oral closure, in part to avoid voicing, and thus the intraoral cavity fill to capacity quite quickly. Based on this finding, Goldstein questions Kingston's conclusions regarding the force of aspirated releases: unaspirated releases should be just as forceful as aspirated releases.

However, one must consider the state of the larynx *during the transition interval itself*. In a number of languages, it is reported that in phonologically unaspirated stops, the larynx adducts somewhat before release is achieved, for example in English (Yoshioka, Löfqvist, Hirose, and Collier 1986), Danish (Fukui and Hirose 1986), Hindi (Dixit 1989), and Korean (Kim, Hirose, and Niimi 1992). This results in less airflow at the transient interval between stop and vowel. That is, in unaspirated stops, despite elevated intraoral pressure during closure, the same volume of air is not expelled with the same amount of force upon release. In aspirated stops, however, the vocal folds *are maximally abducted at the interval immediately preceding and immediately following release*. Given the timing of this maximal abduction, more air is flowing through the glottis at the transition from stop to vowel. Therefore, air is forced out more rapidly during this interval, resulting in a greater amount of acoustic energy.

As laryngeal phasing distinctions and degree of abduction are the critical differences between plain and contrastively aspirated stops, Goldstein's criticism of the binding generalizations, that a glottal abduction is implemented in order to increase intraoral pressure during closure, rests on an incorrect assumption. Consequently, it is not a legitimate strike against the binding generalizations.

Additionally, Goldstein states the following (1990:449):

> "It is not the case that stops demand coordination of glottal events with their releases, but it is the case that coordinating peak glottal opening with

[2]In Chapters Three and Four I show that this aspect of Kingston's approach is not quite accurate.

different phases of a stop produces very different acoustic consequences (thereby allowing stops to show the variety of voicing/aspiration contrasts that languages show) [...] (C)oordinating glottal gestures (opening or constriction) with different phases of an approximant (for example, /l/), would be expected to produce fairly similar acoustic consequences--the only difference would be one of temporal order *per se*. It is more likely, therefore, that such approximant patterns could be confused with one another by listeners than it would be for the comparable stop patterns."

Goldstein is surely correct regarding the perceptual distinctness between pre-aspirated and pre-glottalized stops, plain stops, and their post-aspirated and post-glottalized counterparts, in contrast to the relative non-distinctness of similarly specified continuants. However, his observation does not necessarily render Kingston's binding generalizations incorrect. When stops are implemented simultaneously with small laryngeal abductions (as is often the case in plain prevocalic stops), or laryngeal constrictions (as is often the case in postvocalic stops), these laryngeal gestures are not implemented in order to produce aspiration in the relevant environment. However, when aspiration or glottalization are contrastive in a system, they are almost always realized at stop release. In fact, pre-aspirates (though not always pre-glottals) are only attested in systems that additionally possess their their post-aspirated and post-glottalized counterparts (see especially Kingston 1990, and Steriade 1993a). Thus, the canonical realization of an aspirated plosive does indeed involve acoustic modification at release--and this, recall, is exactly what the binding generalization observes.

I conclude that Kingston's binding generalizations thus far withstand the criticisms that have been launched against it.

2.3 Steriade (1992, 1993, 1995)

Although Steriade's work on aperture-related phenomena originates out of an investigation of segment-internal contours (see Steriade 1989), her more recent work (Steriade 1992, 1993, 1995) may be interpreted as a phonological response to Kingston's binding generalizations. As laryngeal contrasts may either precede or, usually, follow a stop closure, Steriade argues for a bipartite structure of plosives, involving linguistically relevant Closure and Release A(perture)- positions. As plosives and only plosives are bipositional, they may phonologically encode temporal precedence relations between laryngeal and supralaryngeal features: while Closure accommodates supralaryngeal features, Release usually accommodates laryngeal articulations. For example, p^h would have the following partial surface structure.

(4) $\underline{p}^{\underline{h}}$:

A_0 A_{max}
| |
p [spread]

(where A_0 = Closure, A_{max} = (approximant) Release)

And as aperture positions are phonological entities, Steriade accounts for system-internal contrasts between pre- and post-aspirated plosives.

(5) $\underline{p}^{\underline{h}}$: $^{\underline{h}}\underline{p}$:

A_0 A_{max} A_0 A_{max}
| | / \
p [spread] p [spread]

Note in particular that continuants, possessing a single A-position, are correctly predicted not to be able to contrast in this fashion.

(6) $\underline{s}^{\underline{h}}$:

A_f
/ \
s [spread]

Regarding laryngeal gestures and A-positions, Steriade's principal language of investigation is the Huautla de Jimenez dialect of Mazatec (henceforth Huautla).

Drawing on data from Pike and Pike (1947), Steriade determines that Huautla onset clusters involving laryngeals consist of the two- and three-member groups in (7):

(7)

pre-aspirated stops:	pre-glottalized stops:
ht hk hts htʃ htʂ	
hm hn hɲ	**ʔm ʔn ʔɲ**
hnt hnk hnts hntʃ hnʂ	**ʔnt ʔnk ʔnts ʔntʃ ʔnt**
post-aspirated stops:	post-glottalized stops:
th kh tsh tʃh tʂh	**tʔ kʔ tsʔ tʃʔ tʂʔ**
nth nkh ntsh ntʃh nʂh	**ntʔ nkʔ ntsʔ ntʃʔ nʂʔ**
post-aspirated continuants:	post-glottalized continuants:
vh mh nh sh ʂh	**vʔ yʔ mʔ nʔ ɲʔ sʔ ʂʔ lʔ**

Regarding the patterning of aspiration and glottalization, Steriade observes that **(1)** with certain systematic though presently irrelevant exceptions, nasals, plosives, and nasal-

plosive clusters may be pre-aspirated/pre-glottalized, provided no ʔ follows, and (2) plosives and continuants may be post-aspirated/-glottalized.[3]

Thus, Steriade observes, most stops (oral or nasal) may contrast pre-and post-aspiration/-glottalization. However, continuants may only be post-aspirated/post-glottalized, never pre-aspirated/-glottalized.

Steriade argues that this patterning supports the hypothesis that stops possess two A-positions, while continuants possess but one. Pre-aspirated/pre-glottalized plosives are represented with aspiration/glottalization associated to Closure position. Working in a theory of privative laryngeal features, Steriade employs [spread] and [constricted] to represent, respectively, the laryngeal abduction and the laryngeal constriction.

(8)

pre-aspirated stop:		pre-glottalized stop:	
place		place	
|		|	
A_0	A_{max}	A_0	A_{max}
|		|	
[spread]		[constricted]	

Post-aspirated/post-glottalized plosives and nasals, however, are represented with [spread] or [constricted] associated to stop Release.

(9)

post-aspirated stop:		post-glottalized stop:	
place		place	
|		|	
A_0	A_{max}	A_0	A_{max}
	|		|
	[spread]		[constricted]

Finally, a plain stop possesses no contrastive laryngeal feature.

(10)

plain stop:	
place	
|	
A_0	A_{max}

Given their monopositional status, continuants either possess or lack a [spread]/[constricted] feature associated to their single A-position.

[3]Another relevant observation is that plosives may be pre-aspirated, but not pre-glottalized. This pattern is discussed in Chapter Three.

(11)

plain continuant:	aspirated continuant:	glottalized continuant:
place	place	place
|	|	|
A_f	A_f	A_f
	|	|
	[spread]	[constricted]

Steriade's representation of plosives is related to the phonetic character of their release: "...I choose to represent stop releases only when accompanied by audible bursts...audible either because accompanied by a burst or because it is released with audible friction" (1993:402-403) Now, while oral stops indeed involve a salient burst, to which Kingston argues laryngeal articulations may bind, nasal stops usually do not involve such a burst. Given a nasal's steady stream of (nasal) airflow, its release is similar to that of a continuant in that its offset is usually a virtual acoustic mirror image of its onset; there is no appreciable build-up of pressure, and usually there is no plosion. Thus, at least in these acoustic and aerodynamic terms, nasals pattern with continuants, and not with plosives. It would thus seem difficult to maintain this aerodynamic-/acoustic-based account of the hypothesized structural similarity between plosives and nasals.

Steriade's approach rests on the fact that stops involve a marked, localized, decrease-then-increase in acoustic energy. And in fact, like the offsets of stops, the offsets of nasals also involve a marked acoustic discontinuity: nasal offsets involve an abrupt increase in energy in the region of their characteristic nasal zero, in particular in the vowel F2 frequency region (see especially Fant 1960). This transition from vowel to nasal, and from nasal to vowel thus involves a sharp, localized decrease-then-increase in acoustic energy, which is both acoustically and auditorily prominent. Modification of these dynamic transitional components therefore leads to salient disruptions of the signal. For this reason, nasals may fall in line after stops as being the most likely class to accommodate laryngeal augmentation at both onset and offset.[4]

Continuants also involve a salient decrease-then-increase in acoustic energy at the lower frequency levels. Thus f, s, and ʃ involve negligible energy below 2500 Hz. (Ladefoged 1975:184), which is approximately in vocalic F3 region. Why then do

[4]Kingston (1994) points out that diachronic coda attrition in Chinese follows this same order. He implicates the crucial import of oral stop releases, and the secondary import of nasal releases--both disallowed in Chinese--in accounting for this diachronic patterning. Chen (1973) employs the comparative method to reconstruct this process: first p and t merged with k, which then became ʔ. A later process involved the merger of m and n with ŋ, followed by loss of closure and concomitant phonemicization of vowel nasalization (see also Trigo 1988, and Hura, Lindblom, and Diehl 1992). Kingston argues that without release, stop cues are most greatly affected, while nasal cues are next in line. I show in Chapter Five that Jalapa Mazatec constitutes a counter-example to this trend, as sonorants possess contrastive phasing relationships involving laryngeals, while stops do not.

fricatives rarely possess laryngeal contrasts apart from voicing (see Maddieson 1984)? As I discuss in Chapter Three, fricatives possess a *redundant* laryngeal abduction, in order to maintain downstream frication. Consequently, *contrastive* laryngeal abductions here--sequenced with respect to the fricative--are not readily discriminable from a plain fricative constriction. Consequently, fricatives are less likely to possess as many contrastive phasing relationships involving laryngeal abductions as are plosives; this is exactly what we find in Huautla and elsewhere.

In summary, Steriade shows that laryngeal gestures may be sequenced either to follow or to precede a stop closure within a single system. This patterning has a direct explanation in the present approach to gestural patterning. I do not investigate whether or not these phasing contrasts require the prosodic constituents posited by Steriade.

2.4 Bladon (1986), and Mattingly (1981)

Above and beyond aerodynamic considerations, there are independent *auditory* reasons why aspiration is preferably realized on a stop release, as opposed to a stop onset.

Bladon (1986) proposes some of the major principles of auditory phonetics. For present purposes, his principles (3), (4), and (5) are most relevant. These are quoted in full in (12) (1986:5).

(12) **(3)** On/off response asymmetry: spectral changes whose response in the auditory nerve is predominantly an onset of firing are much more perceptually salient than those producing an offset (Tyler, Summerfield, Wood, and Fernandes 1982).

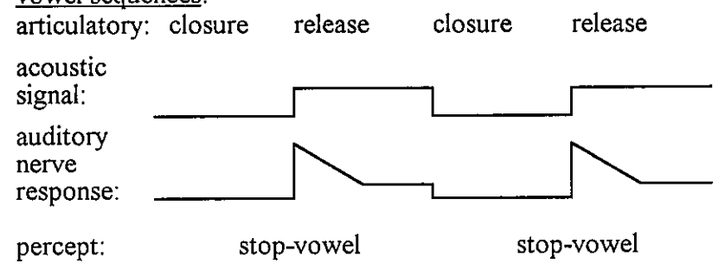
(4) Short-term adaptation: after a rapid onset of auditory nerve discharge at a particular frequency, there is a decay to a moderate level of discharge, even though the same speech sound is continuing to be produced (Delgutte 1982).

(5) Neural recovery: silent intervals in speech sounds give rise to a rapid, high-amplitude discharge when interrupted (Delgutte 1982).

Summarizing, auditory nerve firing does not seem to respond exclusively to absolute levels of acoustic energy. Instead, it responds in part to local *changes* in acoustic energy. Consequently, the same gesture may evoke a greater response, that is, be more salient, when in one gestural environment than when in another. Thus, a given phasing of gestures results in a more or less salient percept. For example, stop releases involve a sharp increase in auditory nerve firing rate, which decays to a moderate level through the following vowel. Given the heightened auditory response at stop release (Principle **5**), and the rapid decay of response across the steady state of a following vowel (Principle **4**), it should not be viewed as coincidental that **CV** transitions (and, by necessary extension, **CV** sequences) are especially valued.

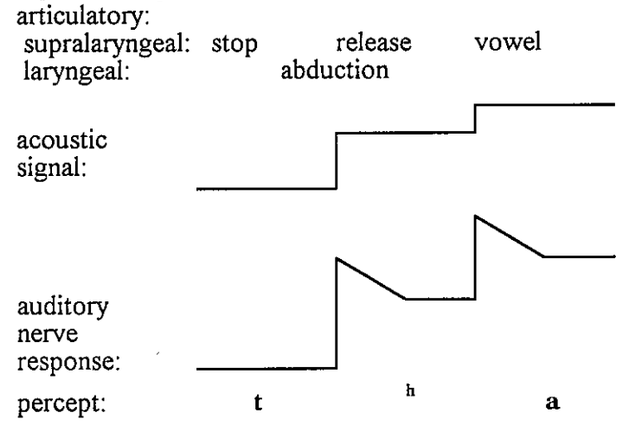
The schematic in (13) displays in gross terms the distorting effect that the auditory nerve imparts on the incoming acoustic signal in this context.

(13) gross schematic of articulatory, acoustic, and auditory characteristics of stop-vowel sequences:



Now, if aspiration is sequenced to *follow* a stop closure, the sound spectrum changes abruptly from silence to burst and random noise. After the period of silence which auditorily characterizes the stop closure, spectral activity is reintroduced into the signal. Consequently, neural activation is heightened due to the re-implementation of the stimulus (Principle **5**). Consequently, the aspiration of post-aspirated stops are auditorily salient.

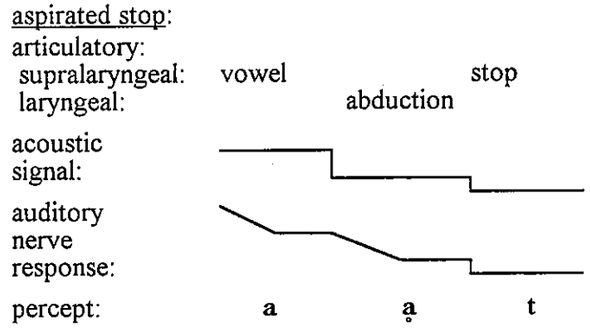
(14) gross schematic of articulatory, acoustic, and auditory characteristics of post-aspirated stop:



Now, compare post-aspirated stops with pre-aspirated stops. Here, Bladon notes that aspiration is realized as a devoicing of the latter portion of the previous vowel. Thus there is little spectral shift in the transition from modal vowel to voicelessness. Consequently, the auditory nerve undergoes short-term adaptation (Principle **4**): neural discharge decays throughout the vowel-**h** sequence. Moreover, the transition which encodes aspiration here is dependent on aspiration's offset; from **h** to the following stop. Since auditory response is much greater for the onset of spectral activity as opposed to its

offset, the likelihood of recovery here is quite low (Principle **3**). As Bladon concludes, "...given that preaspiration suffers from an accumulation of auditory handicaps, it would not be a risky prediction that languages would rarely make use of this auditory-phonetic dinosaur" (p.7). Bladon's prediction, of course, is correct.

(15) gross schematic of articulatory, acoustic, and auditory characteristics of pre-aspirated stop:



I should point out that Mattingly (1981) motivates certain gross aspects of syllable structure in similar terms. He argues, along the lines of Liberman, Cooper, Shankweiler, and Studdert-Kennedy (1967), that the speech perception mechanism is especially designed to decode a signal involving the simultaneity of cues, and is less adept at decoding a signal consisting of discrete, non-overlapping cues. Specifically, alternating greater degrees of stricture with lesser degrees of stricture--in serial fashion--may result in a speech signal in which contrastive information is transmitted in parallel, during stricture transition intervals. That is, the transitions from **C** to **V**, and from **V** to **C** are the most informationally rich components of the speech signal.

But note that implicating transition periods *per se* is insufficient to isolate those components of the speech signal that are *most* successful in encoding information. Rather, transitions from periods of greater stricture (**C**s) to periods of lesser stricture (**V**s) are optimal, at least at the level of the peripheral auditory system. As auditory theory provides a straightforward account of the primacy of **CV** transitions--even over **VC** transitions--an auditory-based approach may be regarded as better underlying motivation for gross gestural organization.

To summarize, abrupt, incremental rises in amplitude result in maximal auditory nerve response. Moreover, amplitude plateaus result in the rapid decay of auditory nerve response. Consequently, phasing patterns are optimal to the extent that amplitude increases incrementally and frequently.

2.5 Zsiga (1993), Byrd (1994), and Jun (1995)

Zsiga (1993) addresses the observation that lexical phonological processes are typically categorial in nature, while post-lexical phonetic processes are typically gradient in nature. She argues that lexical rules are best modeled in the theory of Autosegmental

Phonology (Goldsmith 1976), in which input and output structures differ categorially. However, post-lexical processes are best modeled in the theory of Articulatory Phonology, which, unlike autosegmental theory, directly captures the gradient character of phonetic realization.

It is well known that linguistically relevant articulatory configurations are not produced discretely, one after the other, in sequence. Instead, these configurations overlap a great deal, in a form of *parallel production*.

Now, as stated in section 2.1, in this dissertation I describe sound patterns in terms of articulatory gestures. Nonetheless, Zsiga's model--in which simultaneity is modelled in a (n auto-) segmental framework, while phasing detail is expressed in gestural terms--captures one aspect of the distinction between parallel and serial production.

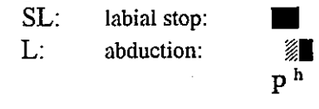
Specifically, a segmental formalism best models the parallel production of tautosegmental features, and the serial production of heterosegmental features: assuming for the moment that segments are phonologically relevant, and that the most faithful implementation of a segment is that which mirrors the phonological simultaneity of the involved features, then the parallel realization of segmental material is optimal. For example, a fully faithful realization of an aspirated stop involves the full simultaneity of all features. Zsiga might thus model the phonological nature of an aspirated stop in segmental terms, in which the features representing the supralaryngeal closure are not timed with respect to that representing the laryngeal abduction. That is, the features which combine to produce an aspirated stop are represented in parallel.

(16) unordered autosegmental model of an aspirated "p" (abbreviated):

```
        root
       /    \
[labial stop]  [abduction]
```

However, as I have already shown, parallel production may lead to the non-recoverability of contrastive information. Consequently, phasing relationships which stray from parallel implementation are often employed. Here, at the phonetic level, maximal laryngeal abduction is typically realized at or around oral release. The gestural model, unlike the segmental model, is able to capture this temporal detail.

(17) gestural model of aspirated "p":



Zsiga's model then, reflects this tug of war between parallel and serial production. I do not, however, adopt this approach. A multi-staged model is not motivated unless explicit evidence is presented that requires reference to a lexical, or a segmental stage, as well as a post-lexical, or gestural stage. In fact, many patterns are fully expressible

exclusively in gestural terms, while a segment-based approach--at any stage--often fails to satisfactorily account for the data (see especially Henderson 1985, and Browman and Goldstein 1989); I have not found patterns that *require* a segmental analysis.

Moreover, Zsiga argues that a strict interpretation of Articulatory Phonology allows for the possibility of lexical contrasts involving minuscule distinctions in phasing. She argues that Autosegmental Phonology correctly constrains lexical representations by eliminating the possibility of such negligible timing contrasts. Indeed, a gestural model based exclusively on articulation may be subject to Zsiga's argument. However, a gestural model in which gestures are a means to auditory ends does not encounter such criticism. Specifically, only when phasing contrasts are sufficiently *auditorily* distinct from each other may they play their fundamental role of defining the system of contrasts itself.

Before concluding this section, recall that Byrd (1994) shows that gestural overlap in English consonant sequences is influenced by gestural environment, place and manner of articulation, and rate of speech. However, this variation in phasing is never contrastive in and of itself. Jun (1995) shows that there is a correlation between the degree of gestural overlap and the concomitant degree of gestural reduction. Thus the degree of overlap of **A** by **B** correlates with the degree of reduction of **A**. In such overlap/reduction situations, the acoustic payoff of **A** is obviously reduced, more so due to reduction than to overlap. This reduction in acoustic payoff may, in time, lead to eventual deletion of **A**. This diachronic tendency is schematized in (18).

(18) evolution of gestural deletion:

	articulatory:	acoustic:
1.	overlap up to, but not exceeding, critical degree	all cues present
2.	reduction and overlap fluctuate around critical perceptual degree	cues sporadic
3.	reduction exceeds critical degree, overlapped gesture reduced	cues fully opaque
4.	gestural deletion	(no cues)

As this dissertation focuses on the *maintenance* of contrasts rather than their neutralization, I do not investigate further this critical point where overlap and reduction lead to neutralization, although, formally, neutralization may be expressed by a simple re-ranking of the involved constraint families.

I now turn to the relevant constraint families.

2.6 Prince and Smolensky (1993), and McCarthy and Prince (1993)

The sytem of contrasts is optimized by abiding by the four constraint families, presented in left to right order, reflecting their usual value to the grammar, in (19) (Prince and Smolensky 1993, McCarthy and Prince 1993).

(19) constraints which determine gestural phasing relationships:

(a) phase	(b) recover	(c) economize	(d) overlap

Consider first the **overlap** family. The parallel production of contrasts results in a *faster* rate of speaking than serial production. This is especially the case when the involved gestures do not employ the same articulator. I thus operate under the assumption that the phonology is designed such that articulatory configurations are produced in parallel, but only up to the recoverability of contrastive values, in order to maximize parallel production. That is, to the extent that gestures *can* overlap without jeopardizing contrasts, they *do* overlap.

(20)

overlap	***maximize parallel production in order to increase speaking rate***

Now consider **economize**.

(21)

economize	***maximize articulatory ease in order to conserve energy***

There is a long tradition of viewing the phonology as a struggle between articulatory ease and perceptual salience (for example, Martinet 1952, Lindblom 1990). In the present approach of course, this struggle is directly encoded in the grammar itself; it *is* the grammar. In certain circumstances, **economize** is more highly valued than other considerations, although this cannot true when the goal is to maximize salience of contrastive values.

Instead, when encoding a contrast (as opposed to neutralizing a contrast) languages place a higher value on maximizing auditory response than they do maximizing articulatory ease. As **economize** does not necessarily meet this more highly valued goal, gestures are normally phased such that they are auditorily optimal, in that auditory nerve response is maximized. **economize** is thus usually outranked by **recover**, which ensures auditory recoverability.

(22)

recover	***maximize auditory recoverability of contrastive cues, otherwise maintain auditory recoverability of contrastive cues***

Finally, when the same gestures are employed to encode more than one contrastive phasing relationship, an auditorily sub-optimal phasing is employed, one which, though sub-optimal, nonetheless renders all contrasts recoverable. In such cases, maximal recoverability is forfeited so that lexically contrastive phasing patterns are maintained.

(23)

phase	*employ/do not employ particular phasing patterns*

Thus lexical representations may value **phase**, even over maximizing auditory recoverability. This constraint becomes highly valued when systems possess lexical gestural configurations that differ only in their phasing.

Upon morpheme concatenation, gestural environments may change. Here, lexical phasing may be forfeited; phasing patterns may be alterred so that recoverability is *maintained*, though not necessarily maximized. Alternatively, if too much articulatory effort is required to maintain recoverability of contrasts, neutralization results, and thus **economize** outranks both **phase** and **recover**. But again, this dissertation is primarily concerned with the system of lexical contrasts.

Interestingly, additional articulatory effort is often required in order to ensure recoverability of auditorily sub-optimal phasing patterns; it is surprisingly often the case that the auditorily optimal phasing pattern is identical to the most articulatorily economical phasing pattern. Consequently, implementing an auditorily sub-optimal phasing pattern (in order to maintain contrasts) often entails a violation of **economize**, as additional articulatory maneuvers may be necessary to ensure salience.

To illustrate how the constraint families work, consider now one example case. After plain stops, languages may allow post-aspirates, because post-aspirates maximize auditory nerve response to the involved contrasts at little articulatory cost. After post-aspirates, languages may then, and only then, allow pre-aspirates. Pre-aspirates are least preferred, as they require additional articulatory effort in order to achieve auditory recoverability, and are not optimally salient. Finally, no language allows the full **overlap** of stops and contrastive abductions implemented with the acoustic goal of aspiration, as this phasing pattern renders the cues fully non-recoverable, resulting in neutralization with plain stops.

(24) stops and aspiration:

auditorily optimal aspirated stop	t^h	implies the presence of **t**
auditorily sub-optimal aspirated stop	^ht	implies the presence of **t** and t^h
stop and simultaneous aspiration	t̥	unattested

First, no system allows aspirated stops implemented in parallel. I thus regard this phasing pattern as a lexical impossibility; both remaining possibilities are *potential* candidates. So consider the table in (25). Here, both possible permutations are compared against **recover**.

(25)

1	2
recover {stop, abduction}	recover {stop, abduction}
t^h stop abduction	^ht stop *abduction
^ht stop *abduction	t^h stop abduction

(24) constitutes what I term possible "system expansions." By "system expansion," I mean that a given system may expand its inventory of contrasts only in the columnar order shown. Here, the two possible system expansions are considered against **recover**. **recover** violations are indicated with stars (*). When a gesture is optimally recoverable ("▉"), it receives no stars. When a gesture is recoverable, though not optimally so ("▒"), it receives a single star (*). Finally, when a gesture is unrecoverable ("▒"), it receives two stars.

Only one system (25.1) expands in accordance with **recover**. That is, only (25.1) decreases in recoverability as the system of contrasts expands; the other system does not expand in this fashion.

(26) **recover**: t^h << ^ht

Consequently, as a system increases the number of contrasts involving stops and/or laryngeal abductions, only (25.1) correctly constrains the order of expansion; all other possible system expansions violate **recover**. This is indicated by shading.

Now consider system expansions constrained by **economize**. Since the most economical sound pattern involves no sound whatsoever, every gesture here entails a violation (*). In (27), the two possibilites are considered.

(27)

1	2
economize	economize
t^h *stop *abduction	^ht *stop *abduction *intercostals
^ht *stop *abduction *intercostals	t^h *stop *abduction

Here, again, only one system expansion, (27.1) is consistent with **economize**.

(28) **economize**: t^h << ^ht

Finally, consider **overlap**.

(29)

1 overlap	2 overlap
*t^h	*^ht
*^ht	*t^h

As full overlap is not a possible phasing pattern when the acoustic goal is an aspired stop, and as both remaining candidates equally violate **overlap**, it is predicted that no system will attribute a high value to **overlap** in this context.

What then are the explicit phasing patterns which give rise to a particular auditory nerve response? As discussed in Chapter One and throughout this dissertation, gestures may be implemented in **parallel**, may be **sequenced**, **expanded**, or **truncated**, such that the constraint families in (19) are abided by or violated.

So, for example, the tables in (30) characterize the markedness ranking of stops and/or laryngeal abductions, with phasing patterns expressed in shorthand. With three contraints, six (3!) permutations are possible. Each permutation is given a number, appearing in the upper left cell. In the next cell are the contrastive gestures that are being considered. In the **recover** column, optimally recoverable cues are given a black square, and no violative stars. Recoverable, but sub-optimal cues are given dark gray squares and a single star (*). Non-recoverable gestures are given a light gray square and two stars (**). In the **economize** column, all involved gestures are repeated and starred (*), since every implemented gesture involves a violation of this constraint. Finally, each contrastive gesture which does not fully overlap with the maximally expanded gesture receives a star (*). Candidates are presented in descending order according to **recover**, which, as will be seen, is the primary determinant of lexically contrastive phasing patterns.

(30) aspirated stops:

1	{stop, abduction}	recover {stop, abduction}	economize	overlap
a.	**stop⇨abduction** stop: abduction: t h	stop abduction	*stop *abduction	*
b	**abduction⇧intercostals⇨stop** stop: abduction: intercostals: h t	stop *abduction	*stop *abduction *intercostals	*

2	{stop, abduction}	recover {stop, abduction}	overlap	economize
a.	t^h	stop abduction	*	*stop *abduction
b	^ht	stop *abduction	*	*stop *abduction *intercostals

3	{stop, abduction}	economize	recover {stop, abduction}	overlap
a	t^h	*stop *abduction	stop abduction	*
b	^ht	*stop *abduction *intercostals	stop *abduction	*

4	{stop, abduction}	economize	overlap	recover {stop, abduction}
a	t^h	*stop *abduction	*	stop abduction
b	^ht	*stop *abduction *intercostals	*	stop *abduction

5	{stop, abduction}	overlap	recover {stop, abduction}	economize
a	t^h	*	stop abduction	*stop *abduction
b	^ht	*	stop *abduction	*stop *abduction *intercostals

6	{stop, abduction}	overlap	economize	recover {stop, abduction}
a	t^h	*	*stop *abduction	▉stop ▉abduction
b	^ht	*	*stop *abduction *intercostals	▉stop ▤*abduction

Thus, given the free ranking of constraints, the six system expansions in (30) are theoretically possible. However, two weighting conditions must be considered.

(1) Systems normally value **recover** more highly than **economize**, and in turn, value **economize** more highly than **overlap**. This is simply a formal way of characterizing the fact that a phonology's primary function is to keep meaningful elements distinct while easing articulatory effort.

(31) **recover >> economize >> overlap**

Thus, in (30), system expansions are presented in their order of likelihood.

(2) Within a given system expansion, the farther down the list one goes, the less likely that a given pattern is allowable, i.e., the more marked the system and the phasing pattern are.

The likelihood of a given constraint ranking characterizing a given system thus decreases in the order shown in (32).

(32)

less likely ↓ less likely ↓ less likely	→→→→→less likely→→→→→less likely→→→→less likely						
	systems→ contrasts↓	1	2	3	4	5	6
	1	t^h	t^h	t^h	t^h	t^h	t^h
	2	^ht	^ht	^ht	^ht	^ht	^ht

Note that the free ranking of constraints still yields only one possible system expansion in the case of aspirated stops. This, of course, is the correct prediction, as no system allows pre-aspirates to the exclusion of post-aspirates. In later chapters, I show that cross-linguistic variability with respect to the timing of other gestures is correctly predicted in the present approach.

Now, to characterize specific phasing patterns within a specific language, the three constraint families in (30) are dominated by **phase**, as shown in (33). The possible phasing patterns now become candidates, to be matched up against the constraints. In (33), the candidates are compared to a t^h lexical pattern.

(33) aspirated stops:

1	phase optimal	recover {stop, abduction}	economize	overlap
a ☞	**stop⇨abduction** stop: ▉ abduction: ▨▉ t h	▉stop ▉abduction	*stop *abduction	*
b	**abduction⇳intercostals⇨stop** stop: ▉ abduction: ▉▨ intercostals: ▨▨ h t	▉stop ▤*abduction	*stop *abduction *intercostals	*

-or-

2	phase optimal	recover {stop, abduction}	overlap	economize
a ☞	t^h	▉stop ▉abduction	*	*stop *abduction
b	^ht	▉stop ▤*abduction	*	*stop *abduction *intercostals

-or-

3	phase optimal	economize	recover {stop, abduction}	overlap
a ☞	t^h	*stop *abduction	▉stop ▉abduction	*
b	^ht	*stop *abduction *intercostals	▉stop ▤*abduction	*

-or-

4	phase optimal	economize	overlap	recover {stop, abduction}
a ☞	t^h	*stop *abduction	*	▉stop ▉abduction
b	^ht	*stop *abduction *intercostals	*	▉stop ▤*abduction

-or-

5	phase optimal	overlap	recover {stop, abduction}	economize
a ☞	t^h	*	▉stop ▉abduction	*stop *abduction
b	^ht	*	▉stop ▤*abduction	*stop *abduction *intercostals

-or-

6	phase optimal	overlap	economize	recover {stop, abduction}
a ☞	t^h	*	*stop *abduction	▮stop ▮abduction
b	^ht	*	*stop *abduction *intercostals	▮stop ▮▮*abduction

And, of course, t^h is the optimal phasing pattern.

2.7 Conclusion

In the following chapters, I place the work of Browman and Goldstein, Kingston, and Bladon, in the broader context of phasing and recoverability.

Chapter Three
Obstruents and Laryngeal Gestures

3.0 Introduction

In this chapter I discuss in detail the interaction of obstruents and laryngeal gestures. I first consider the interaction of oral closures with laryngeal abductions and laryngeal constrictions (section 3.1). I conclude that contrastive laryngeal abductions and constrictions are optimally sequenced to *follow* the stop closure. However, there are cases in which phonological, morphological and/or phonotactic constraints prohibit access to this optimal position. In such cases, auditory optimality is forfeited so that lexical contrasts may be recovered. I follow with a brief discussion of the interaction of fricatives and laryngeal gestures (section 3.2). Due to the laryngeal abduction that obligatorily accompanies a fricative, and due to a fricative's less pronounced oral constriction, these are rarely modified by contrastive laryngeal abductions or laryngeal constrictions.

3.1 Stops and Laryngeal Gestures

In this section I examine the interaction of supralaryngeal closures and laryngeal abductions (3.1.1) and constrictions (3.1.2), discussing, in turn, phasing patterns in Huautla de Jimenez Mazatec and Chong, with brief reference to Korean and Sanskrit as well. I conclude that the optimal phonetic realization of such stops involves a laryngeal constriction or abduction following the stop release. This phasing pattern produces the optimal auditory nerve response. A phonetically sub-optimal phasing relationship between contrastive laryngeal gestures and oral stops involves modification of the stop onset. The relevant phasing patterns appear in (1).

(1) supralaryngeal closures and laryngeal abductions/constrictions:

a	**stop⇨laryngeal**	phase maximal laryngeal gesture at or around stop release interval
b	**laryngeal⇨stop**	phase maximal laryngeal gesture to precede stop closure

3.1.1 Stops and Laryngeal Abductions

In this section I discuss auditorily optimal and sub-optimal realizations of oral stops modified by contrastive laryngeal abductions. Given the nature of a full supralaryngeal closure, a laryngeal abduction must be sequenced with respect to the occlusion, in order for its recoverability to be guaranteed.

As discussed in Chapter Two, the canonical realization of aspirated stops involves aspiration on release. Languages as diverse as Mandarin, Bulgarian, Tamang, Dakota, Georgian, and Somali possess contrastively aspirated stops in their consonant inventories (Maddieson 1984).

Also discussed in Chapter Two, post-aspirated stops are so prevalent because of both the nature of their release, which renders them articulatorily economical, as well as their effect on the auditory nerve, which serves to increase perceptual salience of the contrastive information. It might then be the case that if release is unavailable or non-

salient, aspirated stops might be realized as pre-aspirates. This phasing relationship is *articulatorily* sub-optimal, since, unlike stop onsets do not possess a free build-up of pressure preceding the abduction. Moreover, pre-aspirated stops are *auditorily* dispreferred as well (Bladon 1986). Given these deficits, pre-aspirates may involve additional articulatory effort in order to ensure their reliable transmission. As I argue in this chapter, auditorily sub-optimal pre-aspirates come at an articulatory cost: respiratory muscular activity (flexion of the internal intercostals) is likely to be increased here in order to enhance the otherwise non-salient laryngeal abduction.

Both optimal and sub-optimal phasing relations are lexically contrastive in Huautla Mazatec.

Case Study: Huautla Mazatec

In at least some systems, the presence of phonetically sub-optimal pre-aspirates is partially explained when considering morphological and phonotactic constraints. One instance of pre-aspirated stops which lends itself to such an analysis is Huautla de Jimenez Mazatec, as mentioned in Chapter Two. I now discuss in more detail the Huautla pattern.

Even when fully inflected, Mazatec words are usually quite short (usually either mono- or bi-syllabic). The system of contrasts must consequently resort to phonetically sub-optimal phasing relationships in order to encode all the contrasts required of fully inflected stems: the Huautla dialect is unique in Mazatecan in that it maintains contrasts involving aspiration both *preceeding* and *following* oral stop closures. Some examples of both pre-aspirated and post-aspirated stops in Huautla Mazatec words are presented in (2) (from Pike and Pike 1947).

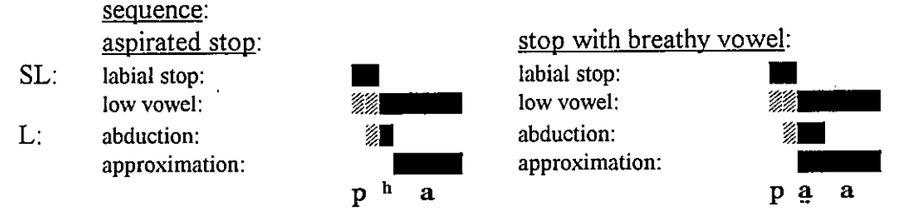
(2)

pre-aspirated stops:		post-aspirated stops:	
^{h}ti^{4}	fish	t^{h}a^{4}	light in weight
^{h}tse^{13}	a sore	ts^{h}e^{43}	clean
^{h}tʃi^{4}	small	tʃ^{h}a^{4}	brother-in-law
^{h}ka^{34}	stubble	k^{h}ã^{3}	bad smelling

A certain amount of exposition is required to account for this peculiar contrast. First, as I discuss in detail in Chapter Five, some dialects of Mazatec possess breathy vowels in which breathiness is manifested primarily on the first portion of the vowel; the latter portion of the vowel tends toward modal (actually, *near*-modal) phonation (see Kirk, Ladefoged, and Ladefoged 1993, Silverman, Blankenship, Kirk, and Ladefoged 1995 and Chapter Five for a discussion of the Jalapa dialect). This peculiar phonation change--heavy breathy phonation followed by light breathy phonation--enhances the encoding of tonal contrasts. However, plosive-breathy vowel sequences (for example, **pa̤a**) do not minimally contrast with post-aspirated plosives (for example, **p^{h}a**). Only the latter is attested in Mazatec. This restriction is presumably due to difficulty of maintaining

the necessary gestural timing and aerodynamic distinction between these two gestural configurations.

(3) unattested contrast involving an oral closure-laryngeal abduction-vowel sequence:

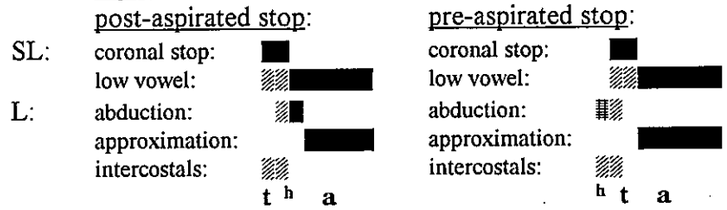


(3) schematically models the distinction between an aspirated stop (**p^{h}a**), and a plain stop followed by a breathy-then-modal vowel (**pa̤a**). In an aspirated stop, a strong puff of air follows stop release, which in turn is followed by voicing. In the unattested plain stop-breathy vowel sequence, the stop release would be accompanied by a small glottal abduction, a weaker flow of air, and the immediate onset of voicing. This would be followed by a reduction in glottal aperture. As the phasing distinction between the two is so meager, it is small wonder that this contrast is unattested. Indeed, since stop releases accompanied by voiceless aspiration render all contrastive information acoustically salient, it is almost always the case that languages opt for this realization, and avoid a combination of gestures involving a plain stop followed by a voiced, breathy release (for example, most Mazatec dialects, and Oriya (Dhall 1966)).

As contrastive laryngeal abductions precede modally phonated vowels here, Huautla expands its system of contrasts by implementing a phasing relationship which maximizes perceptual distinctness (pre-aspiration versus post-aspiration) at the expense of maximizing recoverability.

Moreover, given the risk of non-recoverability in pre-aspirates, it is quite likely that this phasing pattern is accompanied by an increase in respiratory muscular activity, in order to increase aspiration's salience (see Ladefoged 1958, 1968 for discussion of increased internal intercostal activity in **h**-initial words in English; to my knowledge, no instrumental studies have been done on Huautla Mazatec). Thus, implementing an auditorily sub-optimal phasing pattern comes at an articulatory cost. With two counts against them (auditory and articulatory costs), it is hardly surprising that pre-aspirates are marked.

(4) aspiration contrasts in Huautla de Jimenez Mazatec stops:



In Huautla then, pre-aspirated plosives do indeed render all contrasts auditorily recoverable, although at an articulatory cost. Two phasing relationships account for the attested patterning of laryngeal abductions here.

First, post-aspirated stops are characterized by phasing the laryngeal abduction to the period around the release of the oral closure. As discussed in Chapter Two, one possible way of formally characterizing this pattern is: **stop⇨abduction**, or, more completely, **phase maximal laryngeal abduction at or around stop release**.

Second, *pre*-aspirated stops are characterized such: **⟨abduction⇳intercostals⟩⇨ stop**, or, **phase the laryngeal abduction to precede stop closure, and increase respiratory muscular activity**.

(5) supralaryngeal closures and/or laryngeal abductions:

stop⇨abduction	phase maximal laryngeal abduction at or around stop release interval
⟨abduction⇳intercostals⟩⇨stop	phase maximal laryngeal abduction to precede stop closure, and increase respiratory muscular activity

In (6), both t^h and ^ht lexical phasing patterns are characterized.

(6) aspirated stops in Huautla Mazatec:

1	phase optimal	recover {stop, abduction}	economize	overlap
a ☞	**stop⇨abduction** stop: abduction: t h	stop abduction	*stop *abduction	*
b	**abduction⇳intercostals⇨stop** stop: abduction: intercostals: h t	stop *abduction	*stop *abduction *intercostals	*

-or-

2	phase optimal	recover {stop, abduction}	overlap	economize
a ☞	t^h	stop abduction	*	*stop *abduction
b	^ht	stop *abduction	*	*stop *abduction *intercostals

-or-

3	phase optimal	economize	recover {stop, abduction}	overlap
a ☞	t^h	*stop *abduction	stop abduction	*
b	^ht	*stop *abduction *intercostals	stop *abduction	*

-or-

4	phase optimal	economize	overlap	recover {stop, abduction}
a ☞	t^h	*stop *abduction	*	stop abduction
b	^ht	*stop *abduction *intercostals	*	stop *abduction

-or-

5	phase optimal	overlap	recover {stop, abduction}	economize
a ☞	t^h	*	stop abduction	*stop *abduction
b	^ht	*	stop *abduction	*stop *abduction *intercostals

-or-

6	phase optimal	overlap	economize	recover {stop, abduction}
a ☞	t^h	*	*stop *abduction	stop abduction
b	^ht	*	*stop *abduction *intercostals	stop *abduction

-and-

1	phase *optimal	recover {stop, abduction}	economize	overlap
a	**stop⇨abduction** stop: abduction: t h	stop abduction	*stop *abduction	*
b ☞	**abduction⇳intercostals⇨stop** stop: abduction: intercostals: h t	stop *abduction	*stop *abduction *intercostals	*

-or-

2	phase *optimal	recover {stop, abduction}	overlap	economize
a	t^h	stop abduction	*	*stop *abduction
b ☞	^ht	stop *abduction	*	*stop *abduction *intercostals

-or-

3	phase *optimal	economize	recover {stop, abduction}	overlap
a	t^h	*stop *abduction	stop abduction	*
b ☞	^ht	*stop *abduction *intercostals	stop *abduction	*

-or-

4	phase *optimal	economize	overlap	recover {stop, abduction}
a	t^h	*stop *abduction	*	stop abduction
b ☞	^ht	*stop *abduction *intercostals	*	stop *abduction

-or-

5	phase *optimal	overlap	recover {stop, abduction}	economize
a	t^h	*	stop abduction	*stop *abduction
b ☞	^ht	*	stop *abduction	*stop *abduction *intercostals

-or-

6	phase *optimal	overlap	economize	recover {stop, abduction}
a	t^h	*	*stop *abduction	stop abduction
b ☞	^ht	*	*stop *abduction *intercostals	stop *abduction

Both optimal and non-optimal phasing patterns are contrastive in Huautla. Thus, the Huautla expansion system is consistent with all six constraint rankings, although, as discussed in Chapter Two, system (6.1) is the most likely.

Before concluding this case study of Huautla, recall from Chapter Two an additional asymmetry in the patterning of laryngeal gestures with respect ot supralaryngeal gestures here: while plosives may be either post-aspirated or pre-aspirated, they may only be post-glottalized, and never pre-glottalized. (7) repeats the relevant patterns.

(7) <u>pre-aspirated stops</u>: **ht hk hts htʃ hʈʂ** **hm hn hɲ** **hnt hnk hnts hntʃ hnʈʂ**

<u>pre-glottalized stops</u>: **ʔm ʔn ʔɲ** **ʔnt ʔnk ʔnts ʔntʃ ʔnt**

Whence this asymmetry? While the bulk of my discussion of laryngeal constrictions and stops awaits the next section, I briefly address this pattern.

Given the acoustic quality of aspiration (random noise across a large portion of the frequency range), the cues are recoverable even when preceding a voiceless stop, especially if the necessary gesture implemented with greater articulatory effort. The same, however, cannot be said of a laryngeal constriction. In a voiceless context (for example, in isolation, or preceding a word-initial voiceless stop), a laryngeal constriction involves only silence: without the benefit of a preceding or following voiced sonorant, a glottal constriction possesses no acoustic payoff, regardless of articulatory effort. Consequently, while Huautla allows pre- and post-glottalized nasals, contrastively pre-glottalized voiceless plosives are unattested.

In summary, the optimal realization of contrastively aspirated stops involves phasing the laryngeal abduction at or around stop release, e.g. t^h. When the system of contrasts possesses an additional phasing configuration involving supralaryngeal closures and laryngeal abductions, **economize** is violated, but **recover** is only partially violated (*) in comparison to neutralization (**). Consequently, this additional contrast is implemented as a laryngeal abduction with extra internal intercostal flexion followed by a supralaryngeal closure, or **⟨abduction⇳intercostals⟩⇨stop**, e.g. ^ht.

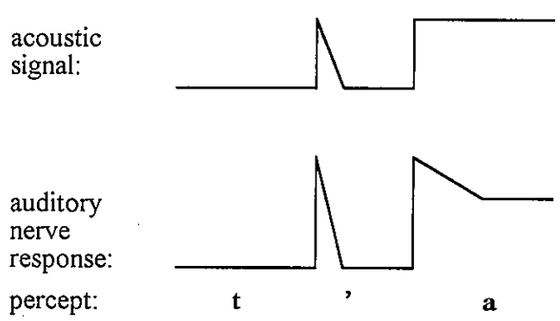
3.1.2 Stops and Laryngeal Constrictions

In this section I investigate laryngeal constrictions and their interaction with supralaryngeal occlusions.

Ejectives, the most salient type of glottalized stop, involve a glottal constriction with concomitant larynx raising, and possibly pharyngeal constriction and pharyngeal wall hardening all implemented during an oral closure (Kingston 1985). Tzeltal, Jaqaru, Haida, and Kefa are some languages which possess ejectives (Maddieson 1984). Indeed, the additional articulatory gestures in this context are crucial for the salient encoding of the contrastive laryngeal constriction. Were the larynx not raised and the pharynx not constricted, the air in the intraoral cavity would not be compressed, and thus would lack its characteristic pop at release. After oral release, glottal closure is released as well. Were glottal release simultaneous with oral release, the glottal constriction would not be acoustically encoded, as oral pressure would be reduced to the equivalent of that which results from a plain oral closure. Thus, glottal release is sequenced to follow oral release.

(8) gross schematic of articulatory, acoustic, and auditory characteristics of ejective stop:

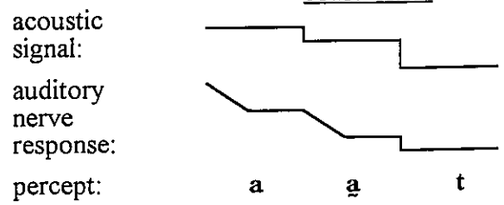
articulatory:
supralaryngeal: stop release vowel
laryngeal: glottal closure glottal release



Now compare post-glottalized stops with pre-glottalized stops. Recall that since supraglottal wall hardening, pharyngeal constriction, and larynx rasing would offer negligible acoustic payoff in this context, glottalization here is realized as a mere creaking of the latter portion of the previous vowel. Thus there is much less spectral shift in the transition from modal vowel to voicelessness; the onset of creakiness on the vowel affords far less change in spectral activity; neural response, hence auditory salience, suffers as a consequence.

(9) gross schematic of articulatory, acoustic, and auditory characteristics of pre-glottalized stop:

articulatory:
supralaryngeal: vowel stop
laryngeal: approx. approx. constriction



Note also that larynx raising in conjunction with a laryngeal constriction is only relevant in the context of an obstruent constriction, especially a supralaryngeal occlusion. With a lesser degree of constriction, larynx raising produces little aerodynamic--hence acoustic--effect, since air in the intraoral cavity may freely escape from the mouth or nose.

(10) stops and contrastive laryngeal constrictions (ejectives, creaks):

auditorily optimal glottalized stop:	t'	implies the presence of t
auditorily sub-optimal laryngealized stop:	Vt	implies the presence of t
stop and simultaneous ejectivity/creakiness:	t	unattested

As with asprated stops, stops involving a laryngeal constriction in which the intended goal involves encoding the constriction itself cannot be realized with the laryngeal constriction phased simultaneosuly with the oral closure. Consequently, I do not consider this impossible configuration. Now consider system expansions constrained by **recover**.

(11)

1	2
recover {stop, constriction}	recover {stop, constriction}
t'	Vt
▮stop	▮stop
▮constriction	▮*constriction
Vt	t'
▮stop	▮stop
▮*constriction	▮constriction

Only one system expansion, (11.1), fully abides by **recover**.
The same may be said of **economize**, shown in (12).

(12)

1 economize	2 economize
t' *stop *constriction *larynx raising *etc.	Vt *stop *constriction *approximation
Vt *stop *constriction *approximation	t' *stop *constriction *larynx raising *etc.

And as wsith aspirated stops, no system expnasion fully abides by **overlap**.

(13)

overlap	overlap
*t'	*Vt
*Vt	*t'

And (14) presents six possible permutations of constraint ranking, which account for all attested system expansions.

(14) stops and laryngeal constrictions:

1	{stop, constriction}	recover {stop, constriction}	economize	overlap
a	**stop⇨constriction** stop: constriction: larynx raising: t'	stop constriction	*stop *constriction *larynx raising *etc.	*
b	**constriction⇨stop** stop: constriction: approximation: V t	stop *constriction	*stop *constriction *approximation	*

2	{stop, constriction}	recover {stop, constriction}	overlap	economize
a	t'	stop constriction	*	*stop *constriction *larynx raising *etc.
b	Vt	stop *constriction	*	*stop *constriction *approximation

3	{stop, constriction}	economize	recover {stop, constriction}	overlap
a	Vt	*stop *constriction *approximation	stop *constriction	*
b	t'	*stop *constriction *larynx raising *etc.	stop constriction	*

4	{stop, constriction}	economize	overlap	recover {stop, constriction}
a	Vt	*stop *constriction *approximation	*	stop *constriction
b	t'	*stop *constriction *larynx raising *etc.	*	stop constriction

5	{stop, constriction}	overlap	recover {stop, constriction}	economize
a	t'	*	stop constriction	*stop *constriction *larynx raising *etc.
b	Vt	*	stop *constriction	*stop *constriction *approximation

6	{stop, constriction}	overlap	economize	recover {stop, constriction}
a	V̲t	*	*stop *constriction *approximation	stop *constriction
b	t'	*	*stop *constriction *larynx raising *etc.	stop constriction

The relevant phasing patterns are glossed in (15).

(16) stops and laryngeal constrictions:

stop⇨⟨constriction⇕larynx raising, etc.⟩	phase maximal laryngeal constriction and larynx raising etc. at or around stop release
constriction⇨stop	phase maximal laryngeal constriction to precede stop closure

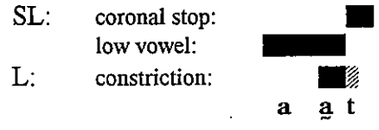
Thus, in pre-glottals, the laryngeal constriction is recoverable, though not maximally so (*).

Moreover, an ejective stop needs several extra articulatory gestures in order to be effectively implemented (**). Pre-glottals involve the simultaneity of laryngeal constriction and laryngeal approximation. I argue in Chapter Five that the parallel production of gestures involving the same articulator comes at an articulatory expense, and, consequently, pre-glottals violate **economize** (*).

Finally, both ejectives and pre-glottals violate **overlap** (*).

As predicted by (15), there are cases in which laryngealization is realized *preceding* the oral occlusion, overlapping with a preceding vocalic gesture. This phasing pattern is phonetically sub-optimal, as auditory nerve response is not maximal.

(17) phonetically sub-optimal realization of laryngealized stops:



This non-canonical realization may sometimes be explained when considering both phonotactic and morphological influences on phasing relationships, as I now show by investigating creaky and breathy vowels in Chong.

Case Studies: Chong, Korean, and Sanskrit

Chong is a Mon-Khmer language spoken by approximately 8000 people in Cambodia and Thailand (Grimes 1988). All data in this section are culled from Thonkum (n.d.), who reports on the Krathing dialect. Chong possesses both breathy and creaky

vowels. But while breathy vowels enjoy a relatively free distribution with respect to other elements of the root syllable, creaky vowels may be present *only* when a supralaryngeally-articulated coda consonant is present as well. Moreover, while creakiness overlaps with post-vocalic sonorants, it is purely vocalic in the context of a post-vocalic stop; vowel laryngealization here may be viewed, in effect, as the realization of a glottalized stop. I explain this unusual distribution by considering language-particular syllabic and morphological constraints, in conjunction with the principles of phasing and recoverability. In Chong, obligatory unrelease of root-final stops, combined with its non-suffixing nature, explains the peculiar patterning of its root-final laryngealized stops. Yet when otherwise disallowed root-final stop release is made available through suffixation, laryngeal contrasts may indeed be canonically realized. I show that Korean and Sanskrit implement two variations of this general pattern. I conclude that morphological patterning can and does exert an influence on the realization of contrastive information.

(18) shows the Krathing Chong segment inventory.

(18) Chong segment inventory:

p	t	c	k	i(:)	ɯ(:)	u(:)
pʰ	tʰ	cʰ	kʰ	e(:)	ɤ(:)	o(:)
b	d			ɛ(:)	ə	ɔ(:)
	s				a(:)	
m	n	ɲ	ŋ			
	l,r					
w		j				
h,ʔ						

Thonkum reports that Chong contains four contrastive "registers," listed in (19).

(19) Chong registers:

R(egister) **1**:	clear voice, high pitch, relatively higher F1
R2:	clear-creaky voice, high-falling pitch, relatively higher F1
R3:	breathy voice, lower pitch, relatively lower F1
R4:	breathy-creaky voice, low-falling pitch, relatively lower F1

I depart from Henderson's (1952) original usage of the term "register" to account for these particular contrasts, in that I do not view register *per se* as a phonological primitive, but instead as a cover term for a number of co-occuring phonetic properties that may or may not be phonological primitives in and of themselves. Indeed, in related Mon-Khmer languages, the primary feature of so-called register may be pitch-based (i.e., tone), as Thonkum reports for the Chamkhlo' dialect of Chong, or tongue-root based, as discussed at length by Gregerson (1976). According to Thonkum's instrumental analyses, the most stable feature of register in Krathing Chong is phonation, that is, vowel

breathiness, and/or creakiness which resides on the latter portion of the vowel, and on any post-vocalic sonorant. Examples of each register are in (20).[1]

(20) examples of Chong registers:

R1:	c^hih^1	**c^hih**	to dry in the sun
	puk^1	**puk**	rotten smell
	sii^1	**siː**	head louse
	p^hoʔ^1	**p^hoʔ**	to dream
R2:	kəsut^2	**kəsuu̯t**	to come off
	t^ham^2	**t^haa̯m̯**	crab
	kəp^{h}aŋ^2	**kəp^{h}aa̯ŋ̯**	scraps, chips
	kəpɯt^2	**kəpɯɯ̯t**	to wear (skirt, trousers)
R3:	puut^3	**puːt**	to speak
	kəlaa^3	**kəla̤ː**	ear
	pɔh^3	**pɔ̤h**	ashes
	kəcaai^3	**kəca̤ːj**	nine
R4:	luuc^4	**luːu̯c**	soft
	kəlaai^4	**kəla̤ːa̯j**	loose
	cam^4	**ca̤a̯m̯**	bruised
	krɤt^4	**krɤ̤ɤ̤t**	to leak

Possible codas are presented in (21), along with an example of each.

[1]Transcriptions are based on Thonkum's descriptions. Vowels with laryngeal contours are transcribed with doubled vowels, since typographic limitations prohibit the indication of a partially-creaked vowel, e.g., krɤt^4 **krɤ̤ɤ̤t** (to leak), luuc^4 **luːu̯c** (soft), t^ham^2 **t^haa̯m̯** (crab); laryngeal contours on codas are not indicated.

(21) Chong codas:

stops:	**p**	kəkɛɛp^1	**kəkɛːp**	to cut (with scissors)
	t	peet^3	**peːt**	plague
	c	kənooc^2	**kənoːo̯c**	nipple
	k	lɛɛk^1	**lɛːk**	chicken
nasals:	**m**	cum^4	**cṳu̯m̯**	vine, climber
	n	k^hiin^2	**k^hiːi̯n̯**	guard
	ɲ	(no examples given)		
	ŋ	kəlɛɛŋ^2	**kəlɛːɛ̯ŋ̯**	floor
glides:	**j**	luj^4	**lṳu̯j̯**	earthworm
	w	ŋɛw^2	**ŋɛɛ̯w̯**	curved
laryngeals:	**ʔ**	rəkoʔ^1	**rəkoʔ**	tips (of climbers and creepers)
	h	pah^3	**pa̤h**	dry

(21) shows that all plain stops, as well as the nasals, the glides and the laryngeals may close the syllable in Chong.

Breathy vowels (registers **3** and **4**) are free to occur with any syllable type. However, one notable exception to this otherwise free distribution involves the set of obstruents that possess a pronounced laryngeal abduction. This set includes all aspirated plosives, as well as the fricative **s**. Thus, like all languages which possess both aspirated plosives and breathy vowels, the two do not co-occur.

The distribution of creaky registers is far more limited, however: creaky registers may occur only when a coda is present. Moreover this coda consonant must be supralaryngeally articulated. Finally, only the latter portion of the vowel is creaked; the initial portion may be either plain or breathy.

Thus, post-vocalic **ʔ** and **h** never occur with creaky registers, though are free to occur with so-called breathy registers. Such forms involve either a plain or a breathy vowel, followed by a laryngeal abduction or laryngeal constriction, as shown in (22).

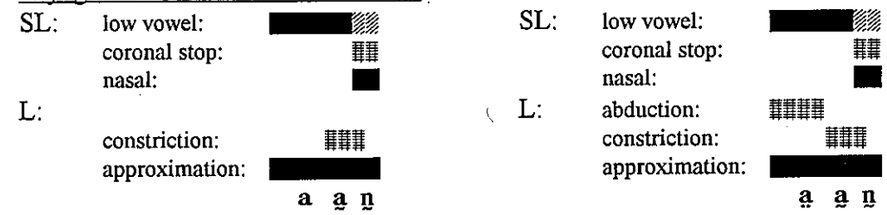
(22) h and ʔ codas:

examples:	kəpɔh[1]	kəpɔh	thread
	ʔih[1]	ʔih	not
	pɔh[3]	pɔ̰h	ashes
	kɔh[3]	kɔ̰h	to knock

examples:	kəloʔ[1]	kəloʔ	skin
	leʔ[1]	leʔ	kind of hat
	klɔʔ[3]	klɔ̰ʔ	to vomit
	peʔ[3]	pḛʔ	delicious

However, laryngealization may phased with the latter portion of the vowel and into sonorant codas. These supralaryngeal gestures possess sufficient acoustic energy to encode all of the relevant contrasts. Although not emphasized by Thonkum, she briefly mentions that creaky registers trail away toward the end of sonorant codas, and assumes that the concomitant pitch fall here helps to encode the contrast. Indeed, as discussed in Chapter 4, this partially modal realization of creaked nasals allows place of articulation to be more saliently encoded, and is thus the cross-linguistic norm.

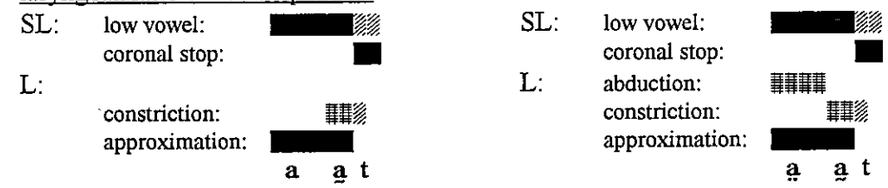
(23) laryngealization with sonorant codas:



examples:	ɲɯɯj[2]	ɲɯ̰ɯ̰j	kind of mushroom
	cum[4]	cṵṵm̰	vine, climber

Most importantly for present purposes, those forms with creaky registers and post-vocalic stops manifest their creakiness exclusively on the latter portion of the vowel. That is, when a laryngeal constriction is accompanied by a supralaryngeal closure, creakiness is phased to precede the closure, realized co-extensively with the final portion of the vowel.

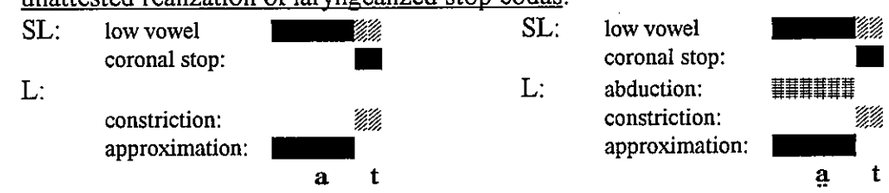
(24) laryngealization with stop codas:



examples:	kɤɤt[2]	kɤ̰ɤ̰t	shallow
	lɔɔp[4]	lɔ̰ɔ̰p	gadfly

Recall that voiceless oral occlusions possess no acoustic energy. Consequently, unlike vowels and sonorants, they cannot encode this contrastive laryngeal constriction.

(25) unattested realization of laryngealized stop codas:

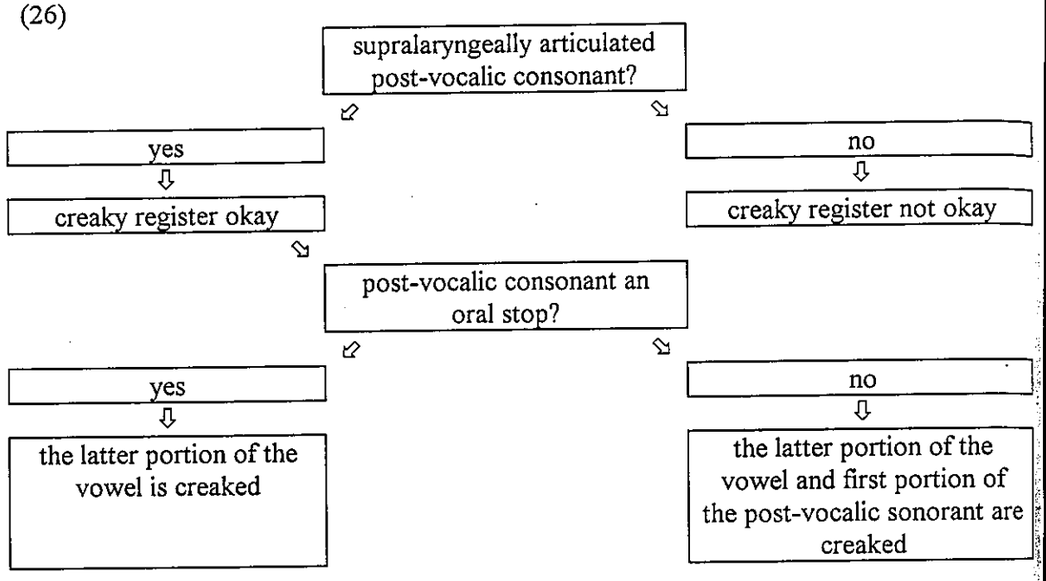


Therefore, the laryngeal gesture is phased to precede the stop closure, so that the otherwise unencoded gesture is rendered recoverable.

Summarizing the Chong data, in the context of a following stop closure, creaky registers are implemented on the vowel exclusively. Moreover, only this vowel's latter portion is creaked. If this vowel is breathy, then creaky phonation follows the period of breathiness. Additionally, post-vocalic sonorants may be partially creaked, or a glottal closure may stand alone in post-vocalic position.

The flowchart in (26) summarizes the distribution of creakiness in Chong.

(26)



I now turn my attention to the important role that Chong syllabic and morphological structure plays in the realization of laryngealized coda stops.

Chong words are very short. Most roots are monosyllabic. Bisyllabic roots possess either **kə** or **rə** as the first syllable. Furthermore, syllable structure is quite simple. These short syllables consequently are likely to exploit non-canonical phasing patterns in order to accommodate the number of contrasts that is required of the open class categories. Root-final laryngeal contrasts thus serve to expand the inventory of contrastive root types, though are in and of themselves auditorily sub-optimal.

But why should laryngealization here be phased to *precede* stop closures, and not phased to *follow* stop closures, which is the auditorily optimal pattern? There are two independent aspects of the Chong grammar that pressure forms to be realized in this non-canonical fashion. **(1)** Chong coda stops are unreleased, as is the norm for related Mon-Khmer and areal languages. Unrelease is indicated in Thonkum's instrumental records, which do not typically possess the small, post-closure energy hump that is characteristic of final stop releases. **(2)** Mon-Khmer languages are strictly non-suffixing. That is, lexical morphological complexes are created primarily through prefixation, secondarily through infixation, but never through suffixation (Nghia 1976). Therefore, despite the noted

preference for realization at stop release, any contrast in post-vocalic position that is auditorily endangered must be sequenced to *precede* the offending gesture if it is to avoid complete neutralization. As root-final stops are unreleased, and as no lexical morphological complex involves material following the root, there is no lexical environment in which contrastive information may be encoded *following* the root. Thus contrastive laryngealization in roots with final plosives is realized on the tautosyllabic, or, more to the point, tauto*morphemic* vowel.

It is exceedingly rare for languages to realize word-final laryngeal contrasts at stop release (Yurok is an example (Gensler 1986)). This is most likely due to the non-salience of this particular release position: as release here does not necessarily involve the re-implementation of voicing, laryngeal contrasts here are not salient. For example, a word final aspirated stop may be followed by a voiceless plosive-initial word. In this context, voicing is not re-implemented at the word boundary. Consequently, this position is not well suited to encode laryngeal contrasts.

(2) As ejectives are so salient, it might be predicted that the laryngeal constriction be realized root-*initially*. Why is this pattern unattested in Chong?

First, recall that vowels in Chong may be breathy. Now, just as contrastively aspirated stop-breathy vowel sequences are universally unattested (for example, ***tʰa̤**), it also seems to be the case that ejective stops-breathy vowel sequences are unavailable (for example, ***t'a̤**). The impossibility of this pattern is surely due to the difficulty in maintaining the required control over the articulatory and aerodynamic systems. That is, reliably realizing a breathy vowel after a forceful ejective release is articulatory difficult. Realizing the laryngeal constriction in this position would consequently allow for fewer contrastive configurations.

Second, recall that, though auditorily optimal, ejectives come at a high articulatory cost. Consequently, languages may value saving articulatory effort more highly than maximizing recoverability.

Consider now the formal characterization of the Chong laryngeal pattern. First, undominated constraints disallow both coda release and suffixation. Laryngealized stops are consequently not realized in the phonetically optimal fashion: release is unavailable. Instead, they are realized around stop closure, primarily on the preceding vowel, thus partially violating **overlap**. Also, given this necessarily phonetically sub-optimal realization, **recover** is partially violated as well.

(27) laryngeal constrictions and stops in Chong:

3	economize	recover {stop, constriction}	overlap	phase optimal
a ☞	*stop *constriction *approximation	▮stop ▤*constriction	*	**constriction⇨stop** stop: ▮ constriction: ▤ approximation: ▮ V̲ t
b	*stop *constriction *larynx raising *etc.	▮stop ▮constriction	*	**stop⇨constriction** stop: ▮ constriction: ▨▮ larynx raising: ▨ t '

-or-

4	economize	overlap	recover {stop, constriction}	phase optimal
a ☞	*stop *constriction *approximation	*	▮stop ▤*constriction	V̲t
b	*stop *constriction *larynx raising *etc.	*	▮stop ▮constriction	t'

-or-

6	overlap	economize	recover {stop, constriction}	phase optimal
a ☞	*	*stop *constriction *approximation	▮stop ▤*constriction	V̲t
b	*	*stop *constriction *larynx raising *etc.	▮stop ▮constriction	t'

The Chong system is consistent with constraint rankings (3), (4), and (6), that is, with any of the system expansions is which pre-glottals are allowed before post-glottals.

In summary, the distribution of laryngeal gestures within the Chong syllable indicates that vowel laryngealization is, in effect, the realization of glottalized stops in coda position. That is, glottalized coda stops in Chong are realized as pre-glottals in order to achieve auditory recoverability. Independent morphological and phonological constraints which are more highly valued in the grammar account for this auditorily sub-optimal phasing pattern.

If Chong *were* a suffixing language, root-final laryngeally contrastive stops could indeed be realized at stop release, provided these suffixes were vowel-initial. Two languages which display variants of this pattern are Korean and Sanskrit.

Kim-Renaud (1991) reports that obstruents (either plain, glottalized [tense], or aspirated) are neutralized syllable-finally in Korean, due to "unrelease". Thus, for example, all coronal obstruents (**t**, **tʰ**, **t'**, **tʃ**, **tʃʰ**, **tʃ'**, as well as **s**, and **s'**) require release in order to encode their contrastive status within the coronal class; upon unrelease, all neutralize to **t**. This occurs in word-final position, as well as upon the attachment of a consonant-initial suffix. Upon vowel-initial suffixation however, root-final obstruents may possess any laryngeal contrast.

(28)

k'otʃʰ + i	→	**k'otʃʰi / k'oʃi**[2]	flower (nom.)
k'ot˺			flower
supʰ + i	→	**supʰi**	wood (nom.)
sup˺			wood
pak' + ɨro	→	**pak'ɨro**	outside (loc.)
pak˺			outside

Due to the rich suffixation system in Korean, the proper lexical environment for stop release is commonplace, and so laryngeal contrasts may be recovered. Consequently, Korean need not resort to a sub-optimal phasing pattern, even in the context of a word-final or pre-consonantal stop; neutralization in such contexts is not complete.

I note anecdotally that Sun Ah Jun informs me that free roots which display laryngeal contrasts upon suffixation come from a rather small set. Usually, only bound roots have root-final laryngeal contrasts, which are manifested *only* upon vowel-initial suffixation. She and I surmise that this distinction is primarily historical in origin. Free roots tend to be nouns, many of which are Chinese loans. Since Chinese did not possess coda obstruent laryngeal contrasts, none is present in Korean either. In contrast, roots. which may possess final laryngeal contrasts are typically native Korean verbs. But most importantly, laryngeal neutralization does indeed occur upon consonant-initial suffixation of these roots. The Korean pattern thus fully supports the present approach to phasing and recoverability: a laryngeal contrast in root-final stops may survive in canonical form (historically, if not in every synchronic alternation) *only* if the stop is released in *some* lexical environment.

Sanskrit took a rather more circuitous route to avoid complete neutralization in similar circumstances. As in Korean, Sanskrit possessed root-final aspirates. Also, as in Chong and Korean, root-final stops are presumed by some to have been obligatorily

[2]Sun Ah Jun tells me that either of these pronunciations is acceptable here.

unreleased (see Collinge 1985 and references therein for analyses which seem to rely on this assumption). Now, for fully independent reasons, Sanskrit permitted the realization of only one aspirate per root. (Ohala 1992 offers some intriguing perceptually-based speculations on the origins of this pattern.). In roots with two voiced stops in which the first was non-palatal, aspiration could be realized in canonical fashion--that is, at stop release, but *only* if this release was followed by a vocoid or nasal (Whitney 1885, 1889). Root-initial aspirates were thus freely allowed, since they were necessarily followed by vocoids. However, root final aspirates *required* suffixation involving release into a vocoid or nasal. (29) provides some examples from Whitney (1889).

(29)	√**dag^h**	reach to	**dag^{h}iṣjanti**	(Fut.)
	√**bud^h**	know, wake	**bod^{h}i**	(Aor.)
	√**dab^h**	harm	**dab^{h}ati**	(Pres.)

As is well known, this pattern is part of a much more complicated process eponymously known as Bartholomae's Law (Collinge 1985, and references therein).

When these roots were unsuffixed, or suffixed by forms that did not permit root-final release into a vocoid or nasal, root-final stops were realized without aspiration or contrastive voicing. Thus far, the Sanskrit pattern would seem to bear a striking resemblance to that present in Korean. But Sanskrit departs from the Korean pattern in that these unsuffixed or inappropriately suffixed forms realized aspiration root-*initially*, thus salvaging the otherwise neutralized aspiration.

(30)	√**dag^h**	reach to	**d^{h}ak**	(root noun, nom. sing.)
	√**bud^h**	know, wake	**b^{h}ut**	(root noun, nom. sing.)
	√**dab^h**	harm	**d^{h}ap**	(root noun, nom. sing.)

This pattern is well known as Grassman's Law (again, see Collinge 1985, and references therein). The intimate interaction of Bartholomae's and Grassman's Laws, which produced a sizeable array of non-neutralized allomorphs, may thus be seen as a consequence of unrelease. That is, the generalization seems to hold that was necessary for the realization of aspiration.[3]

But in Chong, unlike in Korean or Sanskrit, neither root-final release nor suffixation is *ever* available. Moreover, unlike Sanskrit, laryngeally contrastive onsets here are free to occur with laryngeally contrastive codas. Therefore, onset position cannot serve as a reliable site for the realization of laryngeals that suffer from root-final unrelease. Consequently, the language must resort to sub-optimal pre-laryngealization in order to accommodate root-final laryngealized stops, for coda neutralization here would indeed be complete.

[3]But see Lombardi (1991) for a purely formal account of the Sanskrit pattern.

The exceptionality of the Chong pattern may be understood when considering the effect of a given phasing pattern on the peripheral auditory system: those timing relations which evoke a stronger response at the level of the peripheral auditory system are better than those which evoke a weaker response, since a more robust neural response is likely to be more perceptually salient. Laryngealization in Chong may thus be viewed as the exception which proves the rule.

I have motivated this exceptional patterning by appealing to language-specific constraints on syllabic and morphological structure. As Chong root-final stops are unreleased, and as the language is strictly non-suffixing, no lexical environment exists which would allow the canonical realization of laryngealized stops. If complete neutralization is to be avoided here, root-final laryngealization must precede stop closure.

In contrast, due to their suffix-taking behavior, Korean and Sanskrit may avoid the auditorily sub-optimal realization of word-final and pre-consonantal laryngeal contrasts, as the proper lexical environment and/or the proper root constraints elsewhere exist to avoid complete neutralization while enjoying optimal realization. The distinct behaviors of root-final laryngeals in Chong, Korean, and Sanskrit also indicate that morphological patterning *can* and *does* exert an influence on the realization of contrastive information.

3.2 Laryngeal Gestures and Fricatives

Unlike plosive releases, fricative releases are virtual mirror images of their onsets. As air continually flows across the glottis and out the mouth, apart from stridents no appreciable build-up of air pressure takes place, and consequently, there is no burst on to which a laryngeal may "bind". Consequently, modifying a fricative release affords little acoustic payoff. Moreover, fricatives are necessarily accompanied by abducted vocal folds. This laryngeal abduction results in sufficient airflow to induce turbulence at the constriction site, thus giving rise to the fricative's characteristic noise (Ohala 1990). For these reasons, laryngeal contrasts in fricatives are comparatively rare.

In those rare instances of aspirated fricatives, aspiration usually both co-occurs with the fricative (in order to maintain frication) and is maintained upon oral release (in order to saliently encode the contrastive aspiration).

(31) a. <u>unattested realization of contrastively aspirated fricative</u>:

SL: coronal fricative: ■

L: abduction: ▨

s

b. <u>optimal realization of contrastively aspirated fricative</u>:

SL: coronal fricative: ■

L: abduction: ▨▤

s h

Burmese is a language with post-aspirated fricatives (Dantsuji 1986, 1987).

Given the redundant laryngeal abduction involved in fricatives, laryngeally constricted fricatives are rare as well. Such gestural combinations require both a brief laryngeal abduction (in order to maintain downstream frication) as well as a contrastive laryngeal constriction. Here, larynx raising is employed to increase airflow, resulting in a louder (and often lengthier) percept. Hausa, Siona, and Wapishana are three of the few languages which possess laryngealized fricatives (Maddieson 1984).

3.3 Conclusion

The auditorily optimal realization of laryngeally contrastive stops involves phasing the contrastive laryngeal gesture to stop release. Both laryngeal abductions and laryngeal constrictions are optimally phased with this position.

The patterning of laryngeal gestures in Huaulta de Jimenez Mazatec and Chong show that morphological and/or phonotactic contraints may prohibit access to this optimal phasing location. In such cases, laryngeal contrasts may be phased sub-optimally, *preceding* the supralaryngeal closure.

In Huautla, additional articulatory cost may be involved in implementing phonetically sub-optimal pre-aspirates. By contrast, Chong foregoes paying the additional articulatory cost of implementing ejectives, and instead settles for auditorily sub-optimal pre-glottalization. Indeed, given phonotactic and morphological constraints here, pre-glottalization is the only option.

Chapter Four
Sonorants and Laryngeal Gestures

4.0 Introduction

In this chapter I explore the phasing relationships between sonorant consonants and laryngeal gestures, considering in turn nasals (section 4.1), laterals (section 4.2), and glides (section 4.3). In sonorants, contrastive laryngeal gestures are optimally phased such that the laryngeal gesture is truncated with respect to the supralaryngeal gesture, and sequenced with respect to voicing, involving non-modal phonation followed by modal phonation. In this fashion, gestures are optimally encoded in the speech signal.

Less often, the contrastive laryngeal gesture is phased with the latter portion of the sonorant. Here, laryngeal abductions and constrictions are implemented in parallel with voicing, in order to better encode formant transitions between the sonorant and the following vowel.

4.1 Nasals and Laryngeal Gestures

In this section I investigate both modal and non-modally phonated nasals. Modal nasals involve a full oral occlusion and velum lowering. Non-modal nasals superimpose a laryngeal abduction or constriction on this supralaryngeal gestural configuration. I first consider how place of articulation is encoded in modally phonated nasals (4.1.1). I then investigate nasals with accompanying laryngeal abductions (4.1.2), and constrictions (4.1.3). Non-modal phonation is shown to induce the non-recoverability of nasal place-of-articulation information. Consequently, the laryngeal gesture is typically truncated with respect to the supralaryngeal gesture--sequenced with respect to voicing--so that the nasal is partially realized with modal voice. The optimal site of the truncated laryngeal gesture is the first portion of the nasal. In this fashion, nasal place of articulation is saliently encoded in the speech signal.

4.1.1 Modally Phonated Nasals

Modally phonated nasals convey place of articulation information in two ways. First, and most importantly, modal phonation at nasal onset, and especially nasal offset results in saliently encoded formant transitions between the nasal and a neighboring vowel (Fant 1960, Fujimura 1962, Recasens 1983, Bhaskararao and Ladefoged 1991). Fujimura: "[T]here is no doubt that the formant transitions of the adjacent vowels often play a [...] dominant role in the recognition of [...] individual nasals" (p.1875). And given that auditory response is heightened at the onset of spectral activity, CV formant transitions are primary, while VC transitions are only secondary.

Second, nasal place cues are encoded during the nasal murmur itself (Fant 1960, Dantsuji 1984,86,87, Kurowski and Blumstein 1984), as each nasal has its distinctive

resonances and anti-resonanaces.[1] Fant (1960), in his discussion of the acoustic characteristics of nasals, reports the following:

> "...nasal sounds contain fairly fixed formants essentially depending on the nasal tract and the pharynx...There are also formants that depend on the oral cavities, but they are severely weakened, owing to the close proximity of [nasal-D.S.] zeros." (pp.147-148)

Recasens (1983) summarizes the distinct role of dynamic versus steady-state cues to nasal place of articulation in Catalan. Corroborating other reports, the conclusions of his experiment on place cues in word-final nasals in Catalan indicate that transitions provide more effective cues than murmurs, but that murmurs indeed contribute significantly, more so at some places of articulation, less so at others.

-Either **m** transition structure or **m** murmur structure is a sufficient cue
-**n** transition structure is a more powerful place cue than **n** murmur structure
-**ɲ** transition structure, but not **ɲ** murmur structure, is a sufficient place cue
-**ŋ** transitions, murmur, and release are needed for a satisfactory place identification with **æ**, but only murmur with **a** (p.1347)

To summarize, the primary cues for nasal place of articulation are encoded at the dynamic formant transitions into and, especially, out of the nasal. Secondary cues are encoded during the steady-state nasal murmur.

4.1.2 Nasals and Laryngeal Abductions

A laryngeal abduction occuring with a nasal stop involves a dramatic decrease in acoustic energy in comparison with its voiced counterpart. Ladefoged and Maddieson (1995) hypothesize that the reduced energy associated with voiceless nasals may obscure formant transitions between the nasal and a neighboring vowel.[2] These formant transitions, recall, are primary in determining nasal place of articulation. Therefore, a voiced transition between a phonologically voiceless nasal and a neighboring (modal) vowel serves to better encode these transitions, thus increasing the likelihood of conveying place-of-articulation information.

[1]The reader is cautioned that the term "murmur", when employed in conjunction with nasals, refers to the auditory impression of a *modally phonated* nasal. This use contrasts with that employed in conjunction with vowels. Here, "murmur" is by and large synonymous with breathy phonation (Fischer-Jørgensen 1970, Ladefoged 1975).
[2]Nasal offsets are distinct from stop offsets in that they do not usually involve bursts; they thus do not readily encode any characteristic burst frequencies, nor are they well-suited to encode laryngeal abductions simultaneously with formant transitions.

vowel serves to better encode these transitions, thus increasing the likelihood of conveying place-of-articulation information.

The dramatic decrease in acoustic energy associated with voiceless phonation may also result in obscured nasal formant structure (Ladefoged 1971, Ohala 1975, Dantsuji 1984, 1986, 1987, Ladefoged and Maddieson 1995). Again, without a salient formant structure, nasal place-of-articulation may not be saliently encoded in the acoustic signal. Ohala (1975) reports that since the nostrils cannot be constricted very much, and since there are no resonance cavities in front of the nostrils, voiceless nasals possess diffuse and low intensity noise. Moreover, due to their decreased energy, no nasal zero, or anti-resonance, will be acoustically encoded. Therefore, if a nasal stop is voiceless throughout, it is unlikely that oral place-of-articulation will be encoded in the signal.

Consequently, in order to saliently encode all contrastive information in the speech signal, the laryngeal abduction is truncated with respect to the nasal, and sequenced with respect to voicing, such that the latter portion of the nasal is realized with modal voice.

In (4) are tables indicating all possible rankings of constraints, characterizing the possible phasing patterns between nasal stops and laryngeal abductions.

(1) nasals and/or contrastive laryngeal abductions:

auditorily optimal voiceless nasal	**N̥n**	implies the presence of **n** and **h**
auditorily sub-optimal voiceless nasal	**nn̥**	implies the presence of **n** and **h**
simultaneous nasal and contrastive abduction	**n̥**	neutralizes place

Since place of articulation is fully obscured by the parallel implementation of voicelessness and a nasal stop, this phasing pattern is not considered in subsequent discussion. Thus only two possible system expansions are possible, though only one system expansion fully abides by **recover**.

(2) **recover**: nasals and laryngeal abductions:

1 recover {stop, nasal, abduction}	2 recover {stop, nasal, abduction}
N̥n stop nasal abduction	**nn̥** *stop nasal abduction
nn̥ *stop nasal abduction	**N̥n** stop nasal abduction

Similarly, only one system expansion abides by **economize**.

(3) **economize**: nasals and/or laryngeal abductions:

1 economize	2 economize
Nn *stop *nasal *abduction *intercostals *approximation	**nn** *stop *nasal *abduction *intercostals *approximation
nn *stop *nasal *abduction *intercostals *approximation	**Nn** *stop *nasal *abduction *intercostals *approximation

Finally, only one system expansion abides by overlap.

(4) **overlap**: nasals and/or laryngeal abductions:

overlap	overlap
****Nn**	***nn**
***nn**	****Nn**

With three constraints then, six system expansions are possible.

(5) stops, nasal, and/or laryngeal abductions:

1	{stop, nasal, abduction}	recover {stop, nasal, abduction}	economize	overlap
a	**⟨stop⇧nasal⟩⇧** **⟨abduction⇧intercostals⇨approximation⟩** stop: nasal: abduction: intercostals: approximation: **Nn**	 stop nasal abduction	 *stop *nasal *abduction *intercostals *approximation	**
b	**⟨stop⇧nasal⇧approximation⟩⇩abduction** **⇧intercostals** stop: nasal: abduction: intercostals: approximation: **nn**	 *stop nasal abduction	 *stop *nasal *abduction *intercostals *approximation	*

2	{stop, nasal, abduction}	recover {stop, nasal, abduction}	overlap	economize
a	**Nn**	stop nasal abduction	**	*stop *nasal *abduction *intercostals *approximation
b	**nn**	*stop nasal abduction	*	*stop *nasal *abduction *intercostals *approximation

3	{stop, nasal, abduction}	economize	recover {stop, nasal, abduction}	overlap
a	**Nn**	*stop *nasal *abduction *intercostals *approximation	stop nasal abduction	**
b	**nn**	*stop *nasal *abduction *intercostals *approximation	*stop nasal abduction	*

4	{stop, nasal, abduction}	economize	overlap	recover {stop, nasal, abduction}
a	**N̥n**	*stop *nasal *abduction *intercostals *approximation	**	stop nasal abduction
b	**nn̤**	*stop *nasal *abduction *intercostals *approximation	*	*stop nasal abduction

5	{stop, nasal, abduction}	overlap	recover {stop, nasal, abduction}	economize
a	**nn̤**	*	*stop nasal abduction	*stop *nasal *abduction *intercostals *approximation
b	**N̥n**	**	stop nasal abduction	*stop *nasal *abduction *intercostals *approximation

6	{stop, nasal, abduction}	overlap	economize	recover {stop, nasal, abduction}
a	**nn̤**	*	*stop *nasal *abduction *intercostals *approximation	*stop nasal abduction
b	**N̥n**	**	*stop *nasal *abduction *intercostals *approximation	stop nasal abduction

(6) presents in prose form the phasing patterns mentioned in (5).

(6) nasals and laryngeal abductions:

a	**nasal⇧⟨abduction⇧intercostals⇨approximation⟩**	phase voicelessness to first portion of nasal
b	**⟨nasal⇧approximation⟩⇩abduction⇧intercostals**	phase breathiness to latter portion of nasal

The laryngeal abduction may be sequenced to the left of voicing, resulting in early voicelessness followed by late modal phonation: **N̥n**. This phasing pattern incurs no **recover** violation, as recoverability is optimal: acoustic energy increases incrementally. It does, however, twice violate **overlap** (**).

Alternatively, the laryngeal abduction may be realized at the latter portion of the voiced nasal (resulting in early modal phonation followed by late *breathiness*). This phasing pattern incurs one **recover** violation, as oral place of articulation is recoverable, but not optimally so (*). This phasing pattern comes at an articulatory cost, as voicing and breathiness are implemented in parallel (*). As two distinct gestures are required simultaneously of the laryngeal musculature, this configuration involves extra effort, and is normally avoided. Also, a single violation of **overlap** is incurred, as the abduction does not persists for theduration of voicing, stop closure, and nasality.

As I now show, voiceless nasals involving early voicelessness are optimal (**N̥n**), hence their unmarked status relative to **nn̤**.

So consider the table in (7).

(7)

less likely	➔➔➔➔➔less likely➔➔➔➔➔less likely➔➔➔➔less likely						
⬇ less likely	systems➔ contrasts⬇	1	2	3	4	5	6
⬇ less likely	1	**N̥n**	**N̥n**	**N̥n**	**N̥n**	**nn̤**	**nn̤**
less likely	2	**nn̤**	**nn̤**	**nn̤**	**nn̤**	**N̥n**	**N̥n**

The present analysis thus captures the fact that it is far more likely that a language posseses **N̥n** than **nn̤** (Henderson 1985).

I now investigate Burmese in detail, which is a system that optimally phases nasals and laryngeal abductions.

Case Study: Burmese

Burmese contrasts voiced and voiceless nasals (Bhaskararao and Ladefoged 1991).

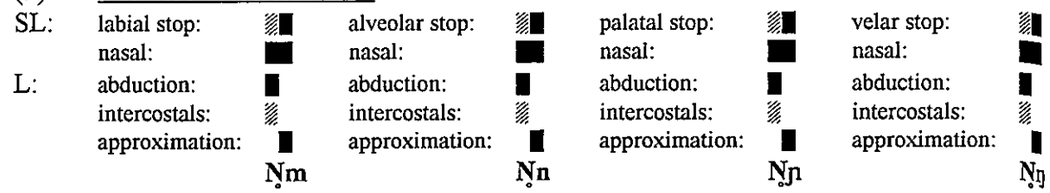
(8)

voiced nasals:		voiceless nasals:	
mâ̰	lift up	**m̥â̰**	from
na	pain	**n̥a**	nose
ɲa	right	**ɲ̥a**	considerate
ŋâ	fish	**ŋ̥â**	borrow

Bhaskararao and Ladefoged present aerodynamic evidence indicating the sequencing of the supralaryngeal and laryngeal components in Burmese voiceless nasals: first aspiration, then voicing, both of which occur simultaneously with velic lowering and

oral occlusion. The authors refer to a "low level phonetic rule inserting the voicing toward the end" (p.80). In this fashion, modal phonation and voiced formant transitions into a following vowel provide acoustically salient cues to nasal place-of-articulation.

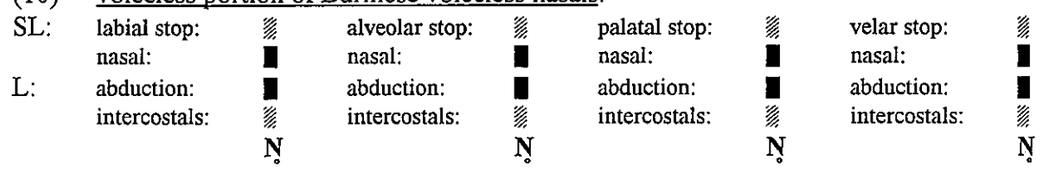
(9) Burmese voiceless nasals:



As Bhaskararao and Ladefoged note, this prevocalic voicing makes clear the place of articulation of the nasal. As shown experimentally by Dantsuji (1986, 1987), the murmured portions alone of Burmese voiceless nasals possess sufficient cues for listeners to determine their place of articulation.

Dantsuji additionally reports that he could not find significant differences in the spectral characteristics within the voiceless portion of Burmese voiceless nasals made at the labial, alveolar, and velar places of articulation. Without their distinctive spectral characteristics, place of articulation may be indiscriminible.

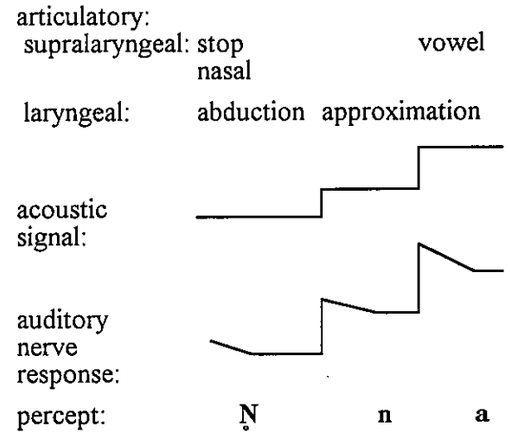
(10) voiceless portion of Burmese voiceless nasals:



As early phasing of the laryngeal abduction guarantees that the modal nasal murmur abuts a following vowel, I conclude that this constitutes the canonical realization of a voiceless nasal.

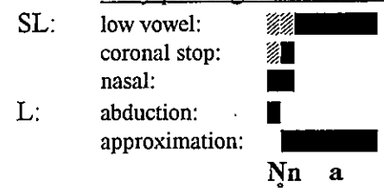
Additionally, I have discussed the fact that the auditory nerve is more responsive to the *onset* of spectral activity than to the *offset* of spectral activity. If voiceless nasals are implemented with voicelessness *preceding* the nasal murmur, which in turn precedes modal vocalism, then the auditory encoding of the signal is optimal, as spectral energy increases incrementally from voiceless nasality, to nasal murmur, to orality.

(11) gross schematic of articulatory, acoustic, and auditory characteristics of early voicelessness in nasals:



Indeed, rightward laryngeal truncation in voiceless nasals is far more prevalent than leftward truncation (Henderson 1985).

(12) early phasing of voiceless nasal:



Note finally that the canonical realization of voiceless nasals is distinct from the canonical realization of aspirated stops. While aspirated stops normally involve the *late* sequencing of the laryngeal gesture, voiceless nasals normally involve the *early* realization of the laryngeal gesture.

Morpho-phonological patterning in Burmese is consistent with this generalization. Dantsuji (1984) reports that synchronic morphophonemic alternations exist between voiced and voiceless nasals in Burmese. Prefixing a laryngeal abduction to certain verbs results in a transitive or causative reading. When plain obstruents undergo the process, they are post-aspirated. This, recall, is the optimal realization of an aspirated obstruent. However, when plain nasals undergo causativization, voiceless nasality precedes nasal modal voice (data from Okell 1969).

(13) obstruent-initial:

pi	be pressed	**pʰi**	press, compress
pe	break off, be chipped	**pʰe**	break off (a piece)
po	appear	**pʰo**	reveal
ceʔ	be cooked	**cʰeʔ**	cook
puʔ	fall, be situated	**cʰaʔ**	drop, throw, put
sowʔ	be torn, shabby	**sʰowʔ**	tear
suʔ	be damp	**sʰuʔ**	moisten, make damp
kwe	be split, separated	**kʰwe**	split, separate

nasal-initial:

mjin	be high, tall	**m̥mjin**	raise, make higher
niʔ	be submerged, sink	**n̥niʔ**	submerge, sink
ne	be loose	**n̥ne**	loosen (in socket, etc.)
naʔ	be completely cooked	**n̥naʔ**	complete cooking

Thus, whether prefixed to a nasal-initial root or to a stop-initial root, prevocalic laryngeal abductions are always realized optimally.

Formally, laryngeal abductions in Burmese involve **nasal⇧⟨abduction⇨voice⟩**, This phasing relationship partially satisfies **overlap,** and fully satisfies **economize** and **recover**. Truncating the abduction with respect to the supralaryngeal gesture results in optimizing recoverability while simultaneoulsy maximizing gestural overlap up to recoverability. Moreover, the truncated abduction is implemented to the left of modal voice, so that all contrasts are optimally encoded.

(14) Nasals and laryngeal abductions in Burmese:

1	recover {stop, nasal, abduction}	economize	overlap	phase optimal
a☞	▮stop ▮nasal ▮abduction	*stop *nasal *abduction *intercostals *approximation	**	**⟨stop⇧nasal⟩⇧⟨abduction⇧intercostals⇨approximation⟩** stop: ▨▮ nasal: ▮▮ abduction: ▮ intercostals: ▨ approximation: ▮ **N̥n**
b	▮▮*stop ▮nasal ▮abduction	*stop *nasal *abduction *intercostals *approximation	*	**⟨stop⇧nasal⇧approximation⟩⇩abduction⇧intercostals** stop: ▮▮▮ nasal: ▮▮ abduction: ▮ intercostals: ▨ approximation: ▮ **nn̥**

-or-

2	recover {stop, nasal, abduction}	overlap	economize	phase optimal
a☞	▮stop ▮nasal ▮abduction	**	*stop *nasal *abduction *intercostals *approximation	**N̥n**
b	▮▮*stop ▮nasal ▮abduction	*	*stop *nasal *abduction *intercostals *approximation	**nn̥**

-or-

3	economize	recover {stop, nasal, abduction}	overlap	phase optimal
a☞	*stop *nasal *abduction *intercostals *approximation	▮stop ▮nasal ▮abduction	**	**N̥n**
b	*stop *nasal *abduction *intercostals *approximation	▮▮*stop ▮nasal ▮abduction	*	**nn̥**

-or-

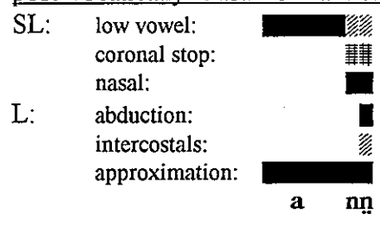
4	economize	overlap	recover {stop, nasal, abduction}	phase optimal
a☞	*stop *nasal *abduction *intercostals *approximation	**	stop nasal abduction	Nn
b	*stop *nasal *abduction *intercostals *approximation	*	*stop nasal abduction	nn

Case Study: Sukuma

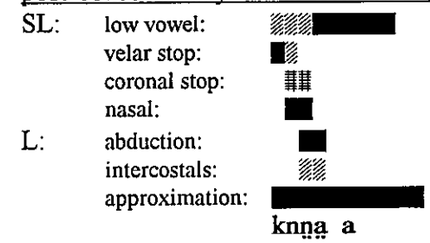
Despite the cross-linguistic preference for leftward realization of the laryngeal abduction in voiceless nasals, sometimes languages nonetheless implement their laryngeally contrastive nasals with non-modal phonation *following* modal phonation, as in the Eastern Bantu language Sukuma (Maddieson 1991).

In this environment there is no guarantee of a leftward vowel providing the optimal environment for encoding formant nasal structure (15a), as such nasals may be post-consonantal (15b) or post-pausal (15c). Consequently, this phasing relationship involves *breathy* phonation, as opposed to voicelessness. Given their increased spectral energy in comparison to voiceless formant transitions, formant transitions which occur with breathy phonation are more likely to be encoded in the speech signal. Recall, however, that this phonetically sub-optimal phasing pattern comes at an articulatory cost, as the vocal folds must implement a voicing gesture and an abduction simultaneously.

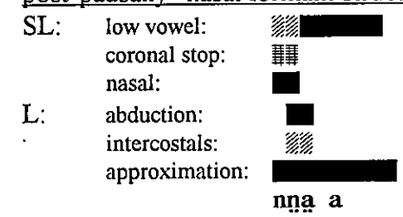
(15) a. early truncation of voiceless nasal:
post-vocalically--nasal formant structure reasonably salient:



b. post-consonantally--nasal formant structure potentially non-salient:

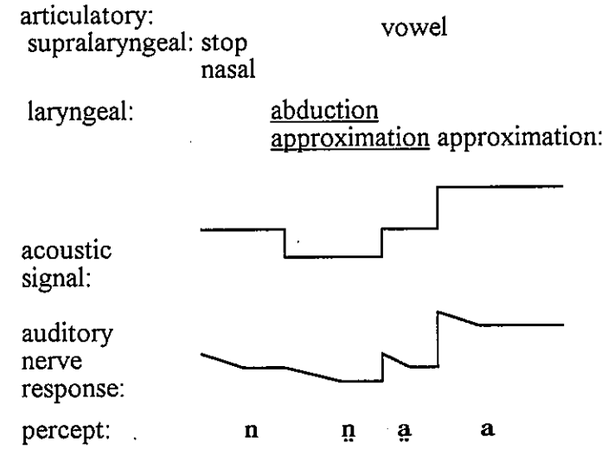


c. post-pausally--nasal formant structure potentially non-salient:



Finally, spectral energy *decreases* in the transition from nasal murmur to breathiness, thus *reducing* auditory discharge at the point of spectral change.

(16) gross schematic of articulatory, acoustic, and auditory characteristics of late breathiness in nasals:



Maddieson (1991) reports that the production of "aspirated nasals" in Sukuma usually involves the following sequence of events:

(17) **(1)** voicing, oral closure, and velic lowering. This results in a plain nasal stop.

(2) intraoral pressure and nasal airflow increase, along with continued voicing. This indicates that a glottal abduction has been added to the configuration.

(3) oral closure is released, while nasality and breathy phonation persist into the following vowel.

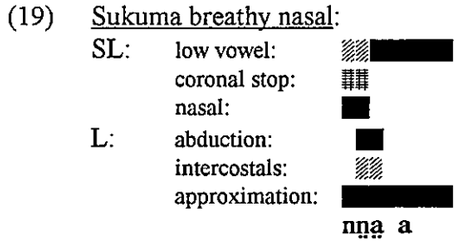
In (18) are some examples. These nasals are represented orthographically by a digraph nasal+"h".

(18) Sukuma breathy nasals:

ndɩnhɔɔ	**ndɩnn̤ɔɔ**	ladle
mhala	**mm̤aala**	gazelle
mhala nhaale	**mm̤aala nn̤aale**	small gazelle
mhayɔ	**mm̤aajɔ**	word

Note in particular that murmured nasals in Sukuma involve a salient modally phonated nasal component, as schematized in (19).

(19) Sukuma breathy nasal:



As already noted, were laryngeal abduction, place of articulation, and velic lowering fully simultaneous, the location of the supralaryngeal constriction would be unrecoverable. Upon truncation of the laryngeal gesture, all contrastive information is reliably encoded in the speech signal, thus resulting in recoverability.

Note finally that although the realization of Sukuma murmured nasals is sub-optimal in terms of direction of truncation, true voicelessness is never implemented. Instead, the transition from nasal to vowel is accompanied by breathy phonation. In this manner, formant transitions are more likely to be encoded in the signal, as energy is not reduced to the degree found in true voiceless nasals. I suggest that in those cases where, for whatever reason, the laryngeal abduction is sub-optimally encoded--that is, at the nasal's right edge--breathy voice is implemented in order to increase the likelihood of recoverability. Conversely, when the laryngeal abduction is optimally encoded--that is, at

the nasal's left edge--true voicelessness may be implemented, thus maximizing the salience of the abduction without jeopardizing formant transition cues.

Sukuma is thus in violation of cross-linguistic tendencies, but is nonetheless formally predicted to exist, given the free ranking of constraints. (20) shows this quite clearly: only the unlikely system expansions (20.5) and (20.6) properly characterize the Sukuma pattern.

(20) nasals and laryngeal abductions in Sukuma:

5	overlap	recover {stop, nasal, abduction}	economize	phase optimal
a ☞	*	*stop nasal abduction	*stop *nasal *abduction *intercostals *approximation	**⟨stop⇧nasal⇧approximation⟩⇩abduction ⇧intercostals** stop: nasal: abduction: intercostals: approximation: **nn̤**
b	**	stop nasal abduction	*stop *nasal *abduction *intercostals *approximation	**⟨stop⇧nasal⟩⇧ ⟨abduction⇧intercostals⇨approximation⟩** stop: nasal: abduction: intercostals: approximation: **Nn̤**

-or-

6	overlap	economize	recover {stop, nasal, abduction}	phase optimal
a ☞	*	*stop *nasal *abduction *intercostals *approximation	*stop nasal abduction	**nn̤**
b	**	*stop *nasal *abduction *intercostals *approximation	stop nasal abduction	**Nn̤**

Thus, there is a trade-off relation between contrastive gestures in the realization of contrastively phonated nasals. Specifically, strong non-modal phonation requires right-truncation, so that formant transitions from the nasal into a following vowel are modally phonated. This is the Burmese pattern. However, if non-modal phonation is sufficiently weakened--in the form of *breathy* phonation--the laryngeal abduction may yet be co-

extensive with the formant transitions from nasal to vowel. The abduction is thus encoded as breathiness, as simultaneous voicing during the supralaryngeal transition increases the likelihood of encoding oral place of articulation. Additionally, the laryngeal abduction is truncated such that the initial portion of the nasal is modally phonated. This, again, provides secondary cues to the nasal's oral configuration. Both of these possible phasing patterns, as well as a gross characterization of their likelihood, are correctly predicted by the present approach to phasing and recoverability.

Case Study: Comaltepec Chinantec

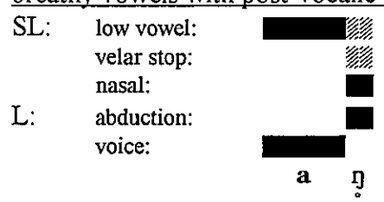
In Comaltepec Chinantec, as in Burmese, the first portion of contrastively phonated nasals possess non-modal phonation. The latter portion of such nasals in Chinantec are modally phonated.

(21)	m̥miː^{L}	water
	n̥ɲœː^{L}	green beans
	n̥ŋajɲʔ^{LM}	he kills

However, in post-vocalic position, a different phasing pattern is present. Consider the post-vocalic nasal, and its interaction with ballisticity. In section 5.5 I argue that ballisticity is best treated as a laryngeally-based phenomenon, consisting of a post-vocalic laryngeal abduction. Now, in ballistic syllables with a post-vocalic nasal element, several authors, discussing a variety of dialects, report that this nasal is normally devoiced. Merrifield (1963:3) reports that ballistic syllables in the Palantla dialect involve a "tendency to loss of voicing of post-vocalic elements." Anderson, Martinez, and Pace (1990) describe in identical terms this interaction in Comaltepec.

Thus the abduction is implemented co-extensively with the post-vocalic nasal.

(22) <u>breathy vowels with post-vocalic nasal</u>:



But notice that in this environment, the place of this nasal is rendered unrecoverable: as voicelessness is phonetically coextensive with nasality, nasal formant structure and formant transitions are potentially missing. How to explain this patterning?

An explanation emerges upon investigating in greater detail the phonological properties of the postnuclear nasal. As it turns out, the place of articulation of the post-vocalic nasal is fully predictable.

Anderson, Martinez, and Pace (1990:7) discuss the phonetic realization of the Comaltepec post-vocalic nasal in a variety of environments. In (23) I quote directly from these authors, although notation has been changed into standard IPA.

(23) "(a) The postnuclear nasal is [...] alveolar preceding **n** within the word, or preceding any alveolar consonant across a word boundary.

ka^{L}w̥weṇʔ^{LM}neʔ^{L}	the animal was frightened
j̥juːṇ^{HLH}la^{HL}	this child
j̥juːṇ^{HLH}zeʔ^{MH}	sick child

(b) Preceding a labial consonant, within the word or across a word boundary, the postnuclear nasal is labial.

pimʔ^{H}	(<..Nʔ + p)	he is tiny
j̥juːm̥^{HLH}piŋʔ^{H}		small child

(c) Preceding a velar or laryngeal consonant, or pause, the postnuclear nasal is velar.

j̥juŋ^{HLH}kʌŋʔ^{MH}	big children
w̥wiŋʔ^{H}	black child
j̥juːŋ̊^{HLH}haŋʔ^{MH}	perverse child

(d) Preceding ʐ within a word, the postnuclear nasal assimilates the ʐ and actualizes as a fronted velar with a nonsyllabic high front vocoid onglide.

ni^{L}l̥lejn̥^{M}	(<..N̥ + ʐ)	he will tremble
ʔʌjn̥^{LM}	(<..N̥ + ʐ)	he pulls (him)"

As the place of articulation of the post-nuclear nasal is wholly determined by context, it is not crucial for its formant structure to be encoded in the speech signal. Therefore, aspiration may be phonetically implemented co-extensively with the nasal. In this way, all contrastive information is recoverable.

Thus Comaltepec Chinantec allows for the canonical phasing pattern between nasals and laryngeal abductions in pre-vocalic position, but also allows the full parallel production of nasality and laryngeal abductions in post-vocalic position, as place of articulation here is contextually determined here.

(24) nasality and laryngeal abductions in Comaltepec:

1	recover {nasal, abduction}	economize	overlap	phase optimal
a☞	▮nasal ▮abduction	*nasal *abduction *intercostals		**nasal⇧abduction⇧intercostals** nasal: ▮ abduction: ▮ intercostals: ▨ **N̥**
b	▮nasal ▮abduction	*nasal *abduction *intercostals *approximation	**	**nasal⇧** **⟨abduction⇧intercostals⇨ approximation⟩** nasal: ▮ abduction: ▮ intercostals: ▨ approximation: ▮ **N̥n**
c	▮nasal ▮abduction	*nasal *abduction *intercostals *approximation	*	**⟨nasal⇧approximation⟩⇩abduction ⇧intercostals** nasal: ▮ abduction: ▮ intercostals: ▨ approximation: ▮ **nn̤**

-or-

2	recover {nasal, abduction}	overlap	economize	phase optimal
a☞	▮nasal ▮abduction		*nasal *abduction *intercostals	**N̥**
b	▮nasal ▮abduction	*	*nasal *abduction *intercostals *approximation	**nn̤**
c	▮nasal ▮abduction	**	*nasal *abduction *intercostals *approximation	**N̥n**

-or-

3	economize	recover {nasal, abduction}	overlap	phase optimal
a☞	*nasal *abduction *intercostals	▮nasal ▮abduction		**N̥**
b	*nasal *abduction *intercostals *approximation	▮nasal ▮abduction	**	**N̥n**
c	*nasal *abduction *intercostals *approximation	▮nasal ▮abduction	*	**nn̤**

-or-

4	economize	overlap	recover {nasal, abduction}	phase optimal
a☞	*nasal *abduction *intercostals		▮nasal ▮abduction	**N̥**
b	*nasal *abduction *intercostals *approximation	*	▮nasal ▮abduction	**nn̤**
c	*nasal *abduction *intercostals *approximation	**	▮nasal ▮abduction	**N̥n**

-or-

5	overlap	recover {nasal, abduction}	economize	phase optimal
a☞		▮nasal ▮abduction	*nasal *abduction *intercostals	**N̥**
b	**	▮nasal ▮abduction	*nasal *abduction *intercostals *approximation	**N̥n**
c	*	▮nasal ▮abduction	*nasal *abduction *intercostals *approximation	**nn̤**

-or-

6	overlap	economize	recover {nasal, abduction}	phase optimal
a☞		*nasal *abduction *intercostals	▮nasal ▮abduction	N̥
b	**	*nasal *abduction *intercostals *approximation	▮nasal ▮abduction	N̥n
c	*	*nasal *abduction *intercostals *approximation	▮nasal ▮abduction	nn̥

This gestural configuration is thus optimal: gestural overlap is maximal, and all contrasts are maximized. I conclude that in those rare situations when only nasality and laryngeal abductions are contrastive, such gestures are optimally phased in parallel.

4.1.3 Nasals and Laryngeal Constrictions

Like voiceless nasals, glottalized nasals are normally implemented with modal phonation for part of their duration. Also like voiceless nasals, leftward laryngealization is preferred to rightward laryngealization.

(25) nasals and laryngeal constrictions:

a	**nasal⇧⟨constriction⇨approximation⟩**	phase a glottal constriction with the first portion of the nasal
b	**⟨nasal⇧approximation⟩⇩constriction**	phase creakiness to latter portion of nasal

Why should this be the case?

A heavy glottal constriction may result in sufficient aperiodicity, or jitter, to disrupt the acoustic encoding of a salient nasal formant structure. Given the brevity of the formant transition from vowel to nasal or nasal to vowel, it is particularly important that a stable F0 is present for the duration of these excursions: if glottal pulse (quasi-) periodicity is markedly slow--a common result of creakiness--insufficient energy is present during the crucial transition period; transitions may take place during the relatively long periods of glottal closure. Consequently, forant transitions may be rendered unrecoverable.

(26) heavily constricted nasals:

SL:	labial stop:	▨	alveolar stop:	▨	velar stop:	▨
	nasal:	■	nasal:	■	nasal:	■
L:	constriction:	■	constriction:	■	constriction:	■
	approximation:	■	approximation:	■	approximation:	■
		N̥		N̥		N̥

In the limiting case, a full glottal closure reduces airflow to zero. With zero airflow, of course, no acoustic energy is present to encode a downstream constriction.

(27) nasals with glottal closure:

SL:	labial stop:	▨	alveolar stop:	▨	velar stop:	▨
	nasal:	▨	nasal:	▨	nasal:	▨
L:	constriction:	■	constriction:	■	constriction:	■
		ʔ		ʔ		ʔ

Consequently, the laryngeal gesture is truncated so that nasal place of articulation may be recovered. Usually, a glottal creak or closure is simultaneous with the first portion of the nasal. A modally phonated nasal then ensues.

(28) optimal realization of laryngealized nasal:

SL:	coronal stop:	▨▮	coronal stop:	▨▮
	nasal:	■	nasal:	■
L:	constriction:	▮	constriction:	▮
	approximation:	▮	approximation:	■
		ʔn		nn̥

The free ranking of the three constraints yields the possible system expansions in (29).

(29) nasals and laryngeal constrictions:

	{stop, nasal, constriction}	recover {stop, nasal, constriction}	economize	overlap
a	**stop⇧nasal⇧⟨constriction ⇨approximation⟩** stop: nasal: constriction: approximation: ʔn	 stop nasal constriction	 *stop *nasal *constriction *approximation	**
b	**⟨stop⇧nasal⇧approximation⟩ ⇩constriction** stop: nasal: constriction: approximation: nn	 *stop nasal constriction	 *stop *nasal *constriction *approximation	*

2	{stop, nasal, constriction}	recover {stop, nasal, constriction}	overlap	economize
a	ʔn	stop nasal constriction	**	*stop *nasal *constriction *approximation
b	nn	*stop nasal constriction	*	*stop *nasal *constriction *approximation

3	{stop, nasal, constriction}	economize	recover {stop, nasal, constriction}	overlap
a	ʔn	*stop *nasal *constriction *approximation	stop nasal constriction	**
b	nn	*stop *nasal *constriction *approximation	*stop nasal constriction	*

4	{stop, nasal, constriction}	economize	overlap	recover {stop, nasal, constriction}
a	ʔn	*stop *nasal *constriction *approximation	**	stop nasal constriction
b	nn	*stop *nasal *constriction *approximation	*	*stop nasal constriction

5	{stop, nasal, constriction}	overlap	recover {stop, nasal, constriction}	economize
a	nn	*	*stop nasal constriction	*stop *nasal *constriction *approximation
b	ʔn	**	stop nasal constriction	*stop *nasal *constriction *approximation

6	{stop, nasal, constriction}	overlap	economize	recover {stop, nasal, constriction}
a	nn	*	*stop nasal constriction	*stop *nasal *constriction *approximation
b	ʔn	**	stop nasal constriction	*stop *nasal *constriction *approximation

(30) presents in prose the phasing patterns employed in (29).

(30)

stop⇧nasal⇧⟨constriction⇨approximation⟩	phase a glottal stop with the first portion of the nasal
⟨stop⇧nasal⇧approximation⟩⇩constriction	creak the latter portion of the nasal

In (30), **ʔn** is the optimally recoverable phasing pattern, as nasality, oral place of articulation, and the contriction are all saliently encoded. Moreover, energy increases incrementally here. Moreover, **overlap** is violated, as the laryngeal constriction is truncated (*). This is the canonical realization of laryngealized nasals, found, for example, throughout Otomanguean, as well as in Hausa.

nn incurs a **recover** violation, as place of articulation is not optimally recoverable, but recoverable nonetheless.

4.2 Liquids and Laryngeal Gestures: The Exceptional Case of Laterals

Voiceless laterals present a special case of phasing and recoverability, in that they may be readily realized in two distinct ways from language to language:

(1) The abduction may be implemented strictly simultaneously with a constricted lateral gesture, resulting in a lateral fricative (e.g. Zulu ɬ) (Ladefoged 1975).

(2) The abduction is truncated with respect to the lateral gesure (e.g. Chinantec l̥l) (Anderson, Martinez, and Pace 1990).

Why should languages allow this relative freedom of realization? As I now show, the answer to this question lies in a combination of two factors:

(1) The relative articulatory and acoustic similarity found within the class of laterals, which explains why languages do not often possess place contrasts within the lateral class, and

(2) The relative acoustic distinctness between laterals and non-laterals, in particular, the distinctness between voiceless laterals and voiceless nasals.

I consider these two factors in turn.

(1) Unlike, say, nasals or stops, laterals are almost exclusively coronal articulations, for the tongue tip and blade possess sufficient flexibility to initiate simultaneous central contact and lateral opening--the defining characteristics of a lateral (I ignore velar laterals for present purposes, which are extremely rare (Ladefoged and Maddieson 1995)). Given these articulatory constraints, it is rarely the case that a language possesses more than a single place of articulation here: articulatory similarity within the class of possible laterals results in acoustic similarity, and acoustically similar contrasts are usually avoided.

Let us then briefly consider the acoustic quality of laterals. Bladon (1979) reports on palatalized dentals (French and Irish l̪), pharyngealized alveolars (English ɫ), retroflexes (Tamil, Swedish ɭ), and palatals (Castilian Spanish ʎ). He finds that F1 in laterals is always low, with little difference across places. F2, by contrast, is higher in laterals with a shorter back cavity (e.g., ɫ), lower in laterals with a longer back cavity (e.g., ʎ). F3 is often obliterated due to a lateral zero present in this spectral range. However, the retroflex and palatal laterals may possess a relatively prominent F3. F4 varies with front cavity length.

Between F1 and F2, at about 1000 Hz., is the first lateral zero. This is true for all laterals investigated. Finally, the second zero, which often overlaps with F3, displays only minimal variation across places.

With their often obliterated F3, their similar Z1, and their only minor variability in their other formants and Z2, laterals at distinct places, unlike other classes of constrictions, display comparatively minor acoustic distinctness. Consequently, place contrasts within this class are dispreferred (see Maddieson 1984).

(2) However, since laterals *as a class* are articulatorily and acoustically distinct from other classes of constrictions, a given lateral does not run a major risk of being confused with any non-lateral. This holds for not so much for plain laterals (which may be confused with alveolar nasals)[3], but does hold for voiceless laterals. In particular, voiceless laterality is quite distinct from voiceless nasality. Thus, when a system possesses a contrast between a plain and a voiceless lateral, the articulatory and acoustic distinctness of this class remains sufficient so that recoverability of the contrast is readily maintained. Consequently, a voiceless lateral should enjoy a relatively free and varied realization across languages. Indeed this combination of gestures is implemented in at least two ways, yielding two rather different acoustic effects.

(a) The lateral gesture is sufficiently constricted, so that oral frication results, culminating in a voiceless lateral fricative ɬ, as in Zulu.

(31) Zulu laryngeally abducted lateral:

SL: lateral fricative: ■
L: abduction: ■
ɬ

(b) Alternatively, the laryngeal gesture may be truncated relative to the oral gesture, l̥l. The laryngeally constrastive laterals of Otomanguean--both abducted and constricted--are implemented in this second fashion, l̥l, l̰l.

(32) Otomanguean laryngeally abducted lateral:

SL: lateral approximant: ■
L: abduction: ▮
approximation: ▮
l̥l

Otomanguean laryngeally constricted lateral:

SL: lateral approximant: ▨■
L: constriction: ▮
approximation: ▮
l̰l

Let us briefly compare the system of laterals with the system of nasals. Nasal systems usually possess maximal oral dispersion (m,n,ŋ), whether or not laryngeal contrasts are available. With full laryngeal cross-classification, six more nasal contrasts become available (m̥,m̰,n̥,n̰,ŋ̥,ŋ̰). As I discuss in section 4.1, fully voiceless nasals run a

[3]For example, in certain central Chinese dialects (e.g., Shashi), laterals and alveolar nasals are in free variation.

great risk of neutralizing with each other. Therefore, the abduction is obligatorily truncated here so that all contrasts are recoverable.

But as the class of laterals rarely posseses oral contrasts, and since, regardless of their implementation, laryngeally contrastive laterals are acoustically distinct from other classes, the oral constriction here enjoys a relative freedom of aperture and timing with respect to the laryngeal abduction, and the attested variation results.

Formally, we may express the phasing relationships between laterals and laryngeal abduction as **lateral fricative⇕abduction**, as in Zulu, and **⟨abduction⇨voice⟩⇕lateral approximant**, as in Otomanguean.

Finally, I predict the extreme rarity of systems which cross-classify lateral place contrasts with laryngeal contrasts. Indeed, the only language in Maddieson 1984 to possess such a system is Diegueño, which possesses both voiced and voiceless laterals at both the dental and alveolar places of articulation (l̪,l̪,ɬ̪,ɬ̪). Tellingly, according to Langdon (1970:31), the acoustic distinction between the apical and laminal lateral fricatives are, "even after long exposure (...) still very hard for [her] to differentiate."[4]

So consider the tables in (34), which freely rank the constraint families.

(33)

	{lateral, abduction}	recover {lateral, abduction}	economize	overlap
a	**lateral⇕⟨abduction⇕intercostals⇨ approximation⟩** lateral: ▇ abduction: ▮ approximation: ▮ intercostals: ▒ l̪l̪	▇lateral ▮abduction	*lateral *abduction *approximation *intercostals	**
b	**lateral⇕abduction⇕intercostals** lateral: ▇ abduction: ▇ intercostals: ▒▒ ɬ̪	▇lateral ▮abduction	*lateral *abduction *intercostals	
c	**⟨lateral⇕approximation⟩⇩abduction** lateral: ▇▤ abduction: ▮ approximation: ▮ abduction: ▒ l̪l̪	▤*lateral ▮abduction	*lateral *abduction *approximation *intercostals	*

[4]In some languages, such as Spanish, place contrasts between laterals involve alveolarity versus palatality. This contrast may be enhanced by sequencing the palatal gesture to the release of the lateral, resulting in a lateral-glide sequence.

2	{lateral, abduction}	recover {lateral, abduction}	overlap	economize
a	ɬ̪	▇lateral ▮abduction		*lateral *abduction *intercostals
b	l̪l̪	▇lateral ▮abduction	**	*lateral *abduction *approximation *intercostals
c	l̪l̪	▤*lateral ▮abduction	*	*lateral *abduction *approximation *intercostals

3	{lateral, abduction}	economize	recover {lateral, abduction}	overlap
a	ɬ̪	*lateral *abduction *intercostals	▇lateral ▮*abduction	
b	l̪l̪	*lateral *abduction *approximation *intercostals	▇lateral ▮abduction	**
c	l̪l̪	*lateral *abduction *approximation *intercostals	▤*lateral ▮abduction	*

4	{lateral, abduction}	economize	overlap	recover {lateral, abduction}
a	ɬ̪	*lateral *abduction *intercostals		▇lateral ▮abduction
b	l̪l̪	*lateral *abduction *approximation *intercostals	**	▇lateral ▮abduction
c	l̪l̪	*lateral *abduction *approximation *intercostals	*	▤*lateral ▮abduction

5	{lateral, abduction}	overlap	recover {lateral, abduction}	economize
a	ɬ		▮lateral ▮abduction	*lateral *abduction *approximation *intercostals
b	l̥l	*	▮▮*lateral ▮abduction	*lateral *abduction *approximation *intercostals
c	l̥l	**	▮lateral ▮abduction	*lateral *abduction *intercostals

6	{lateral, abduction}	overlap	economize	recover {lateral, abduction}
a	ɬ		*lateral *abduction *intercostals	▮lateral ▮abduction
b	l̥l	*	*lateral *abduction *approximation *intercostals	▮▮*lateral ▮abduction
c	l̥l	**	*lateral *abduction *approximation *intercostals	▮lateral ▮abduction

Phasing patterns (33) are glossed in (34).

(34)

lateral⇧⟨abduction⇧intercostals⇨ approximation⟩	sequence voicelessness and voicing, in parallel with laterality
lateral⇧abduction⇧intercostals	implement laterality and voicelessness in full parallel
⟨lateral⇧approximation⟩⇩⟨abduction ⇧intercostals⟩	phase breathiness to latter portion of lateral

l̥l is optimally recoverable, though incurs one **economize** violation (*), as well as two **overlap** violations (**). As ɬ implements laterality and the abduction in full parallel, the laryngeal gesture is perhaps less salient than its truncated realization. For this reason I impart a single violation of **recover** here, although, indeed, this is surely a moderate violation, as this gestural configuration has little possibility of neutralizing with another. finally, l̥l does not optimally encode laterality, as formant transitions between the lateral and the following vowel are breathy, not voiced.

Thus, l̥l and ɬ are most favored, and l̥l is least favored. However, as stated, given their similar acoustic properties, it is extremely unlikely that a language possesses more than one phasing pattern here.

4.3 Glides and Laryngeal Gestures

Like nasals, laryngeally contrastive glides normally realize their laryngeal gesture early.

I show in Chapter Five that vowels which possess contrastive non-modal phonation (V̤,V̰) may simultaneously implement their laryngeal and supralaryngeal gestures, provided that tone and non-modal phonation do not cross-classify. I show that breathy and creaky vowels possess sufficient acoustic energy to simultaneously encode both the supralaryngeal gesture and the laryngeal gesture, in parallel fashion. If glides possess a similar degree of stricture as do high vowels, then why should not non-modally phonated glides pattern similarly? That is, why are not the laryngeal and supralaryngeal gestures implemented simultaneously here as well?

The answer lies in both **(1)** the durational difference between glides and vowels, and **(2)** the energy difference between glides and vowels.

(1) As glides are by definition non-syllabic, they are of a shorter temporal duration than their vocalic counterparts. This makes it difficult to saliently encode both oral and laryngeal contrasts simultaneously here.

(2) Moreover, as glides are often implemented with a slightly greater degree of constriction than their corresponding high vowels, the energy level of glides is significantly reduced relative to these vowel: glides show significant reduction in amplitude in their higher frequencies--at the F2 region and above--in comparison to their vocalic counterparts (Bordon and Harris 1984). Thus, indeed, despite a minute increase in degree of constriction between high vowels and glides, amplitude levels may diminish significantly. These decreases in energy, of course, make it difficult to simultaneously encode oral and laryngeal contrasts in glides.

(35) glide versus vowel:

palatal glide: ▮ j high front vowel: ▮ i

labial glide: ▮ w high rounded vowel: ▮ u

With their shorter duration and reduced energy in comparison to vowels, it is less likely that all contrastive information is reliably encoded if produced in parallel. Therefore, in such contexts, the truncation of non-modal phonation is observed, so that all contrastive information is recoverable from the speech signal. As in the case of contrastively phonated nasals, the canonical realization of laryngeally contrastive glides

involves the early phasing of the laryngeal gesture. In this fashion, salient formant transitions are guaranteed between the glide and a following vowel. In (36) are examples of labial and palatal glides with an abduction and a constriction.

(36)

	optimal realization:		sub-optimal realization:		unattested realization:	
SL:	palatal glide:		palatal glide:		palatal glide:	
L:	abduction:		abduction:		abduction:	
	intercostals:		intercostals:		intercostals:	
	approximation:		approximation:		approximation:	
		j̥ j		j j̲		j j̥
SL:	labial glide:		labial glide:		labial glide:	
L:	abduction:		abduction:		abduction:	
	intercostals:		intercostals:		intercostals:	
	approximation:		approximation:		approximation:	
		w̥w		ww̲		ww̥
SL:	palatal glide:		palatal glide:			
L:	constriction:		constriction:			
	approximation:		approximation:			
		ʔj		j j		
SL:	labial glide:		labial glide:			
L:	constriction:		constriction:			
	approximation:		approximation:			
		ʔw		ww̲		

I am unaware of any language which sub-optimally implements contrastively phonated glides to the exclusion of optimally phased contrastively phonated glides; Jalapa Mazatec, in fact, possesses both patterns.

English is an example of a language with early-phased voiceless glides (in those dialects in which possess a voiced-voiceless glide contrast). In (38) are some examples of each.

(37)

English palatal voiceless glide:		English labial voiceless glide:	
ˈj̥jumən	human	ˈw̥wɪtʃ	which
ˈj̥jʊtʃ	huge	ˈw̥wɛn	when

I forego a complete presentation of cross-linguistic patterns here, leaving it to the reader to piece together the patterns based on my discussion of nasals and laterals.

4.4 Conclusion

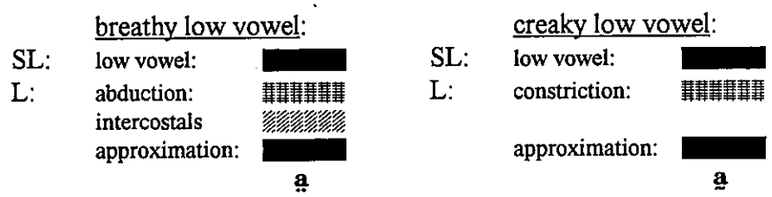
To optimize recoverability, sonorant consonants are realized with laryngeal gestures phased to the early portion of the supralaryngeal configuration, and thus are transmitted in a part parallel-part serial fashion. When phased to the latter portion of the sonorant, voicing is added to the configuration at an articulatory cost, in order to mitigate the potential non-salience of formant transitions into a following vowel.

Chapter Five
Vowels and Laryngeal Gestures

5.0 Introduction

In this chapter I explore the interaction between vowels and laryngeal gestures. With maximum acoustic energy, vowels are able to accommodate the parallel production of oral gestures and contrastive laryngeal gestures--abduction, constriction, or of course, tone. As airflow may persist relatively unimpeded for the duration of a vowel, sufficient energy is present to allow the full simultaneity of laryngeal and supralaryngeal gestures, without the risk of obscuring either component. Indeed, the existence of breathiness or creakiness accompanying any and all vowel qualities confirms this (Dhall 1966, Smith 1968, Fischer-Jørgensen 1970, Maddieson 1984). Here, breathiness or creakiness persists for the duration of the vowel.

(1)



Also, obviously, vowels are ideally suited to accommodate contrastive pitch levels, or tones. Sonorant consonants may also be tone-bearing (for example, in Cantonese). However, obstruents may not. Obstruents may induce non-contrastive pitch perturbations on adjacent tones (for example, in Zulu (Cope 1960, 1970, Traill, Khumalo, and Fridjhon 1987)) which may lead to tonogenesis (for example, in Cantonese (Karlgren 1926)). However, obstruents may not bear linguistically significant pitch values. The pronounced oral constriction which defines an obstruent makes it difficult to reliably encode contrastive F0 values. In the limiting case, an oral occlusion induces the full cessation of voicing. Without voicing, no periodic vocal vibration is present to manipulate, and hence no F0 is produced. I discuss in greater detail the interaction between F0 and downstream constrictions momentarily.

The story becomes rather more complex when considering vowels that possess both contrastive phonation *and* contrastive tone. Such vowels, which I term "laryngeally complex," are attested throughout Otomanguean. As I argue in this chapter, tone is most salient when occurring with modal voice. Consequently, in laryngeally complex vowels tone and non-modal phonation are sequenced--produced serially--so that tone may be realized with modal voice.

In section 5.1 I discuss the breathy vowels of Gujarati, in section 5.2 I examine the creaky vowels of Sedang, and in section 5.3 I discuss phonation contrasts in tonal languages. Laryngeally "interrupted" vowels in Trique, breathy and creaky vowels in

Jalapa Mazatec, and post-vocalic aspiration in Chinantec, are all shown to support the hypothesis that tone and non-modal phonation are sequenced in laryngeally complex class languages so that all laryngeal contrasts achieve salience.

In section 5.4 I consider both real and apparent exceptions to my claims regarding laryngeally complex vowels.

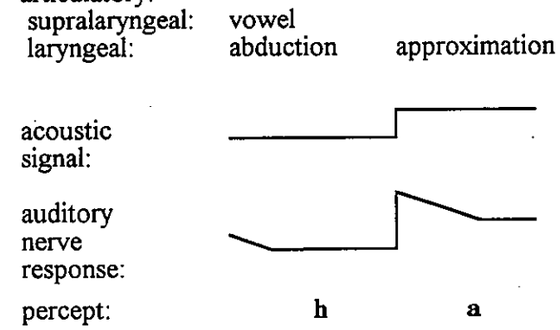
5.1 Breathy Vowels as a Sub-Optimal Phasing Pattern

In this section I show that breathy vowels, which consist of the parallel production of a laryngeal abduction and a supralaryngeal vocalic gesture, constitute an auditorily sub-optimal phasing pattern.

Possible phasing patterns between vowels and laryngeal abductions include pre-aspiration (**ha**), post-aspiration (**ah**), and breathiness (**a**). So consider these three possible phasing patterns with respect to the three constraint families **recover**, **economize**, and **overlap**. For **recover**, **ha** renders all contrasts maximally recoverable, as energy increases at the transition from voicelessness to voicing.

For **ha** energy increases at the onset of voicing, triggering a sudden excitation of the auditory nerve.

(2) gross schematic of articulatory, acoustic, and auditory characteristics of h-V sequences:



And while both **a** and **ah** suffer a loss of cues, neither risks non-recoverability. For **a**, energy is constant throughout; auditory nerve response diminishes and stabilizes.

(3) gross schematic of articulatory, acoustic, and auditory characteristics of **V**:

sequences:
articulatory:
supralaryngeal: vowel
laryngeal: approximation
abduction

acoustic signal:

auditory nerve response:

percept: **a̤**

Finally, for **ah**, auditory nerve response diminishes at the transition from voicing to voicelessness.

(4) gross schematic of articulatory, acoustic, and auditory characteristics of **V-h**

sequences:
articulatory:
supralaryngeal: vowel
laryngeal: approximation abduction

acoustic signal:

auditory nerve response:

percept: **a** **h**

I thus impart a single **recover** violation to both.
(5) shows all possible system expansions constrained by **recover**.

(5)

recover {vowel, abduction}	recover {vowel, abduction}	recover {vowel, abduction}	recover {vowel, abduction}	recover {vowel, abduction}	recover {vowel, abduction}
ha vowel abduction	**ha** vowel abduction	**ah** vowel *abduction	**ah** vowel *abduction	**a̤** vowel *abduction	**a̤** vowel *abduction
ah vowel *abduction	**a̤** vowel *abduction	**ha** vowel abduction	**a̤** vowel *abduction	**ha** vowel abduction	**ah** vowel *abduction
a̤ vowel *abduction	**ah** vowel *abduction	**a̤** vowel *abduction	**ha** vowel abduction	**ah** vowel *abduction	**ha** vowel abduction

Thus, only two possible system expansions (5a and 5b) abide by **recover**.

Regarding **economize**, since the simultaneity of voicing annd abduction is articulatorily difficult, only two systems are viable expansions (6a and 6c).

(6)

economize	economize	economize	economize	economize	economize
ha *vowel *abduction *intercostals *approximation	**ha** *vowel *abduction *intercostals *approximation	**ah** *vowel *abduction *intercostals *approximation	**ah** *vowel *abduction *intercostals *approximation	**a̤** *vowel *abduction *intercostals *approximation	**a̤** *vowel *abduction *intercostals *approximation
ah *vowel *abduction *intercostals *approximation	**a̤** *vowel *abduction *intercostals *approximation	**ha** *vowel *abduction *intercostals *approximation	**a̤** *vowel *abduction *intercostals *approximation	**ha** *vowel *abduction *intercostals *approximation	**ah** *vowel *abduction *intercostals *approximation
a̤ *vowel *abduction *intercostals *approximation	**ah** *vowel *abduction *intercostals *approximation	**a̤** *vowel *abduction *intercostals *approximation	**ha** *vowel *abduction *intercostals *approximation	**ah** *vowel *abduction *intercostals *approximation	**ha** *vowel *abduction *intercostals *approximation

Finally, only two system expansions---those headed by **a̤**--abide by **overlap**.

(7)

overlap	overlap	overlap	overlap	overlap	overlap
a̤	**a̤**	***ha**	***ha**	***ah**	***ah**
***ha**	***ah**	**a̤**	***ah**	**a̤**	***ha**
***ah**	***ha**	***ah**	**a̤**	***ha**	**a̤**

Despite the acceptability of two system expansions for each of the three constraints, I limit all subsequent discussion to the first acceptable pattern, for ease of exposition.

(8) shows the free-ranking of constraints, indicating possible system expansions. But as breathy vowels are never allowed to the exclusion of **hV** sequences, **overlap** is never valued most highly in a system. That is to say, **hV** sequences are always preferred to V̤. Actually, given the prevalence of **h** in segment inventories, combined with the rarity of breathy vowels, this generalization follows almost trivially. For example of the 453 languages in the UCLA Phonetic Segment Inventory database (UPSID), only five possess breathy vowels: Bruu, Dinka, Nyah Kur, Parauk, and Tamang. Of these five languages, Nyah Jur, Bruu, Parauk, and Tamang also possess **h**, while Dinka is claimed to lack **h**. However, I show in 5.4.2 that Dinka actually possesses a *pharyngeal* contrast, not breathiness, as implied by certain researchers. Therefore the generalization that **hV** sequences are always preferred to V̤ appears to hold.[1] For this reason such systems are excluded from consideration.

[1]Note that the presence of **a̤** almost guarantees the presence of **ha**; pattern (iiia) actually predicts the existence of counter-examples, although, as stated above, I am aware of none.

(8) phasing of laryngeal abductions, voicing, and vowels:

1	{vowel, abduction}	recover {vowel, abduction}	economize	overlap
a	**vowel⇧⟨abduction⇧intercostals⇨ approximation⟩** vowel: abduction: intercostals: approximation: **h a**	vowel abduction	*vowel *abduction *intercostals *approximation	*
b	**vowel⇧⟨approximation⇨abduction⇧ intercostals⟩** vowel: abduction: intercostals: approximation: **a h**	vowel *abduction	*vowel *abduction *intercostals *approximation	*
c	**vowel⇧abduction⇧intercostals⇧ approximation** vowel: abduction: intercostals: approximation: **a̤**	vowel *abduction	*vowel *abduction *intercostals *approximation	

2	{vowel, abduction}	recover {vowel, abduction}	overlap	economize
a	**ha**	vowel abduction	*	*vowel *abduction *intercostals *approximation
b	**a̤**	vowel *abduction		*vowel *abduction *intercostals *approximation
c	**ah**	vowel *abduction	*	*vowel *abduction *intercostals *approximation

3	{vowel, abduction}	economize	recover {vowel, abduction}	overlap
a	**ha**	*vowel *abduction *intercostals *approximation	vowel abduction	*
b	**ah**	*vowel *abduction *intercostals *approximation	vowel *abduction	*
c	**a̤**	*vowel *abduction *intercostals *approximation	vowel *abduction	

4	{vowel, abduction}	economize	overlap	recover {vowel, abduction}
a	**ha**	*vowel *abduction *intercostals *approximation	*	vowel abduction
b	**ah**	*vowel *abduction *intercostals *approximation	*	vowel *abduction
c	**a̤**	*vowel *abduction *intercostals *approximation		vowel *abduction

The unfamilar cover terms in (8) represent the phasing patterns in (9).

(9) phasing patterns between vowels and laryngeal abductions:

⟨abduction⇨approximation⟩⇳vowel	phase voicelessness to the first portion of the vowel
vowel⇳abduction⇳approximation	phase the vowel, the laryngeal abduction, and approximation in parall
⟨approximation⇨abduction⟩⇳vowel	phase voicelessness to the latter portion of the vowel

Thus, only when a language employs the phonetically optimal phasing relationship between two gestures, may it resort to a phonetically *sub*-optimal--though recoverable--phasing relationship if it is to further exploit the involved gestures.[2] Consequently, after a language allows **hV** sequences, it might only then allow the phonetically sub-optimal **V̤** (8b).

[2]Chamicuro apparently allows post-vocalic laryngeals to the exclusion of pre-vocalic laryngeals (Parker 1994), and thus constitutes a counter-example to this claim.

Case Study: Gujarati

As discussed in great in detail by Fischer-Jørgensen (1970) Gujarati possesses breathy vowels with any and all vowel qualities. Breathy vowels involve the parallel production of voicing, laryngeal abduction, and vocalism.

In (10) is the Gujarati segment inventory (from Taylor 1985).

(10) Gujarati segment inventory:

p	t	tʃ	ʈ	k	i	u
pʰ	tʰ	tʃʰ	ʈʰ	kʰ	e	o
b	d	dʒ	ɖ	g	a	
bʰ	dʰ	dʒʰ	ɖʰ	gʰ		
v	s	ʃ	ʂ			
m	n	ɲ	ɳ	ŋ		
	r,l		ɭ			
		j				
h						

Vowels is Gujarati may be plain or breathy. In (11) are some examples of breathy vowels (from Fischer-Jørgensen 1970) (no glosses available).

(11) Gujarati breathy vowels:

tʃi̤r	**mo̤r**	**dṳd**
bi̤	**do̤ɾ**	**pe̤lo**
se̤dʒ	**ko̤ɾ**	**ta̤ro**
me̤k	**ko̤**	**wa̤li**
ba̤r	**po̤r**	**ke̤ɾi**

According to Patel and Mody (1961) breathy vowels are limited in their distribution to the first syllable of the word, although this is only a trend. More importantly, however, any consonant may precede a breathy vowel except those listed in (12).

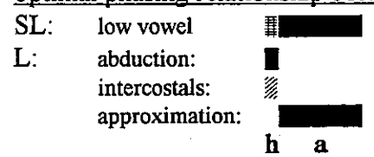
(12) onsets disallowed with breathy vowels:

pʰ	tʰ	tʃʰ	ʈʰ	kʰ
bʰ	dʰ	dʒʰ	ɖʰ	gʰ
		ɲ	ɳ	
			ɭ	
h				

Thus breathy vowels may follow any onset except those involving aspiration. Moreover, class-internal coronal sonorants do not contrast before breathy vowels.

Now, as indicated in (2), in terms of recoverability, the optimal phasing relationship between a laryngeal abduction, voicing and a vocalic gesture involves the truncation of the laryngeal abduction with respect to vowel quality, and the sequencing of the laryngeal abduction and voicing. This results in an **h**-vowel sequence.

(13) optimal phasing relationship between abductions, voicing, and vowels:



This phasing relationship is optimal because voiceless aspiration is followed by modal voicing: auditory nerve response is consequently maximal, as acoustic energy increases incrementally over the course of the sequence. Moreover, sequencing aspiration and voicing is articulatorily easier than implementing voicing and abduction in parallel.

In (14) then, I consider candidates in Gujarati system.

(14) phasing of laryngeal abductions, voicing, and vowels in Gujarati:

2	phase optimal	recover {vowel, abduction}	overlap	economize
a ☞	**vowel⇧⟨abduction⇧intercostals⇨ approximation⟩** vowel: abduction: intercostals: approximation: h a	vowel abduction	*	*vowel *abduction *intercostals *approximation
b	**vowel⇧abduction⇧intercostals⇧ approximation** vowel: abduction: intercostals: approximation: a	vowel *abduction		*vowel *abduction *intercostals *approximation
c	**vowel⇧⟨approximation⇨abduction⇧ intercostals⟩** vowel: abduction: intercostals: approximation: a h	vowel *abduction	*	*vowel *abduction *intercostals *approximation

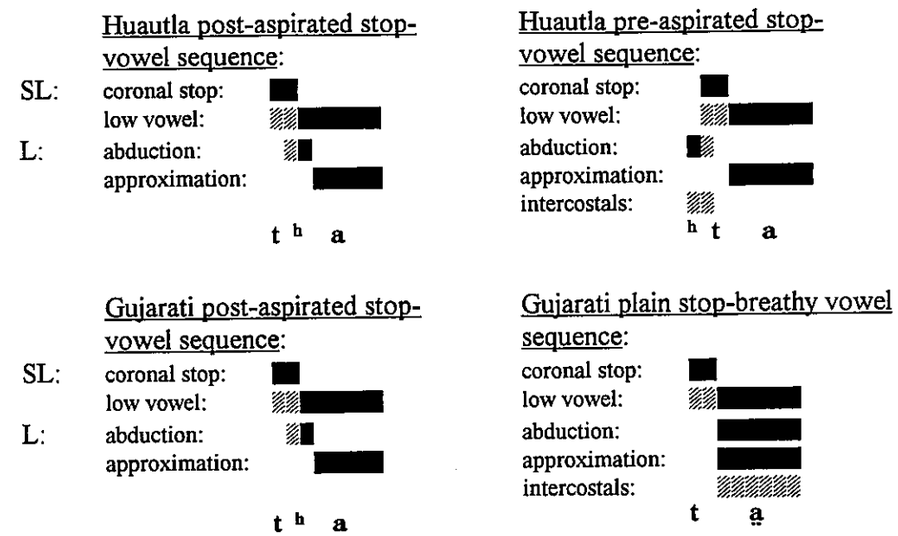
-and-

2	phase *optimal	recover {vowel, abduction}	overlap	economize
a	**vowel⇧⟨abduction⇧intercostals⇨ approximation⟩** vowel: abduction: intercostals: approximation: **h a**	vowel abduction	*	*vowel *abduction *intercostals *approximation
b ☞	**vowel⇧abduction⇧intercostals⇧ approximation** vowel: abduction: intercostals: approximation: **a̤**	vowel *abduction		*vowel *abduction *intercostals *approximation
c	**vowel⇧⟨approximation⇨abduction⇧ intercostals⟩** vowel: abduction: intercostals: approximation: **a h**	vowel *abduction	*	*vowel *abduction *intercostals *approximation

Now consider a further observation: despite the existence of **hV-V̤** contrasts, it is exceedingly rare for languages to possess aspirated plosive-plain vowel sequences that contrast with plain plosive-breathy vowel sequences. For example, **tʰa** very rarely contrasts with **ta̤**. Gujarati (Patel and Mody 1960) and Chong (Huffman 1985) are two of the very few languages which possess this contrast. The rarity of this contrast is most likely a consequence of the difficulty in maintaining a sufficiently salient distinction between the two configurations.

Recall now, however, the Huautla Mazatec pattern discussed in Chapter Three. Here, unlike in Gujarati, aspirated stops do not contrast with post-plosive breathy vowels, but they *do* contrast with *pre*-aspirated stops. How can the phasing contrasts in Huautla Mazatec versus those in Gujarati be accounted for? That is, why should Huautla expand its inventory of contrasts by allowing **ʰta** in addition to **tʰa**, while Gujarati expand its inventory of contrasts by allowing **ta̤** in addition to **tʰa**?

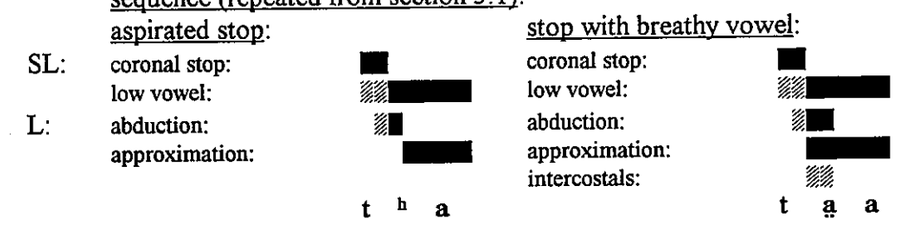
(15)



The answer is found by analyzing contrastiveness within the context of the systems as wholes. I consider, in turn, **(1)** Mazatec, and **(2)** Gujarati.

(1) Huautla Mazatec is a laryngeally complex language. That is, its vowels possess both phonation and tonal contrasts. As I discuss in detail in section 5.3, non-modal phonation in the Jalapa dialect of Mazatec is phased to the first portion of the vowel, so that tonal contrasts may be saliently encoded on the vowel's latter portion. Consequently, in a language like Jalapa Mazatec, the phasing distinction between an aspirated stop (**tʰa**) versus a plain followed by breathy phonation (**ta̤a**) would be extremely meager indeed. In fact, as discussed in Chapter Three, the major distinction between the two would be the presence versus absence of voicing during the laryngeal abduction.

(16)



Now, I am unaware of any instrumental analyses of the Huautla dialect of Mazatec. I assume, however, that post-consonantal laryngeal phasing patterns in Huautla are more or less equivalent to those of Jalapa, which *have* been analyzed (Kirk,

Ladefoged, and Ladefoged 1993, Silverman, Blankenship, Kirk, and Ladefoged 1995). Assuming this, the maximally contrastive phasing pattern available *within the Huautla system* is pre- versus post-aspiration.

(2) In contrast, in Gujarati, which does not possess tones, breathy phonation persists for the duration of the vowel. Consequently, here, the contrast between aspirated stop-plain vowel sequences (**tʰa**), and plain stop-breathy vowel sequences (**ta̤**) involves both gestural overlap *and* gestural duration differences: in the case of breathy vowels, the abduction is implemented simultaneously with voicing, and is implemented in full parallel with the entire vowel. In contrast, aspirated stops involve a voiceless puff of aspiration followed by a modal vowel. For this reason, the attested contrast is maximal, again, *within the Gujarati system*.

Before concluding, recall that, within a given class, coronal sonorants do not contrast before breathy vowels. Now, Patel and Mody are not fully explicit as to whether coronal nasals and laterals are exclusively dental in this context (**na̤, la̤**), or whether they are in free variation with non-dental coronals (**na̤ ~ ɲa̤ ~ ɳa̤, la̤ ~ ɭa̤**). Either way though, place patterning here supports my claim in Chapter Four regarding breathy phonation implemented simultaneously with CV formant transitions. Since contrasts are limited here, and importantly, are *not* limited in systems with early voicelessness (for example, Burmese), it is clear that formant transitions here are not as readily recoverable as their modally phonated counterparts. Thus, the Gujarati pattern lends strong support to the present claims regarding phasing and recoverability: those patterns which are more readily recoverable are unmarked, while those patterns that are less readily recoverable are more marked.

In conclusion, breathy vowels involve phonetically sub-optimal phasing relations among the relevant gestures. The system of contrasts may exploit this phonetically sub-optimal configuration, but only after employing the optimal phasing pattern. Whether or not breathy vowels indeed constitute the maximally contrastive phasing relation with **hV** sequences depends on the nature of the system in question.

5.2 Creaky Vowels

Like the phasing relations between abductions and vowels, the optimal pattern of constrictions and vowels consists of the early realization of a laryngeal constriction, followed by a modal vowel. That is, the constriction is truncated with respect to the vowel, phased to its initial portion: **vowel⇧⟨constriction⇩approximation⟩**or **ʔa**. Indeed, languages perhaps always allow for this phasing pattern of the involved gestures before allowing for others.

Now, in contrast to the abduction-vowel pattern, languages seem to allow glottal stop codas before they allow true creaky vowels: **vowel⇧⟨approximation⇩**

constriction⟩or **aʔ**. Thai is but one of many languages which possesses glottal stop codas, but does not possess contrastively creaked vowels. This is most likely due to both the articulatory ease and relative salience of implementing a post-vocalic glottal stop: unlike a post-vocalic abduction, there is little risk of non-recoverability here, and no extra muscular effort is needed to reliably encode the gesture.

(17) phasing of laryngeal constrictions and vowels:

1	{vowel, constriction}	recover {vowel, constriction}	economize	overlap
a	**vowel⟨⇧constriction⇨approximation⟩** vowel: constriction: approximation: ʔ a	vowel constriction	*vowel *constriction *approximation	*
b	**vowel⇧⟨approximation⇨constriction⟩** vowel: constriction: approximation: a ʔ	vowel *constriction	*vowel *constriction *approximation	*
c	**constriction⇧vowel⇧approximation** vowel: constriction: approximation: a	vowel *constriction	*vowel *constriction *intercostals *approximation	

2	{vowel, constriction}	recover {vowel, constriction}	overlap	economize
a	**ʔa**	vowel constriction	*	*vowel *constriction *approximation
b	**a**	vowel *constriction		*vowel *constriction *intercostals *approximation
c	**aʔ**	vowel *constriction	*	*vowel *constriction *approximation

3	{vowel, constriction}	economize	recover {vowel, constriction}	overlap
a	ʔa	*vowel *constriction *approximation	▮vowel ▮constriction	*
b	aʔ	*vowel *constriction *approximation	▮vowel ▮▮*constriction	*
c	a̲	*vowel *constriction *intercostals *approximation	▮vowel ▮▮*constriction	

4	{vowel, constriction}	economize	overlap	recover {vowel, constriction}
a	ʔa	*vowel *constriction *approximation	*	▮vowel ▮constriction
b	aʔ	*vowel *constriction *approximation	*	▮vowel ▮▮*constriction
c	a̲	*vowel *constriction *intercostals *approximation		▮vowel ▮▮*constriction

The cover terms in (17) represent the phasing patterns in (18).

(18) phasing patterns of vowels and laryngeal constrictions:

vowel⇕⟨constriction⇨approximation⟩	phase the laryngeal constriction to the first portion of the vowel
vowel⇕⟨approximation⇨constriction⟩	phase the laryngeal constriction to the latter portion of the vowel
vowel⇕constriction⇕approximation	phase the laryngeal constriction in parallel with approximation and the vowel

Four possible systems are listed in (17). Usually, **ʔa** is allowed, followed by **aʔ**, and finally **a̲**. It is also predicted, however, that **a̲** should be allowed before **ʔa**, but rarely. Indeed, I am aware of no language that employs the constraint rankings which characterize such a system.

Case Study: Sedang

Sedang is a Mon-Khmer language spoken by approximately 40,000 people in Vietnam (Grimes 1988). It is like Chong in that it possesses phonetically creaked vowels. However, in Sedang, unlike in Chong, the distributional patterning of vowel creakiness with respect to other elements of the syllable clearly shows that laryngealization is always

phased in full parallel with the vowel, and never phased to only one portion of the vowel. Moreover, Sedang possesses both pre-vocalic and post-vocalic ʔ. In this subsection, I consider in detail the distributional patterning of laryngeal gestures within the Sedang syllable.

In (19) is the Sedang segment inventory (all data from Smith 1968).[3]

(19) Sedang segment inventory:

p	**t**	**tʃ**	**k**		**i** **u**
ᵐb	**ⁿd**	**ⁿdʒ**	**ᵑg**		**e** **o**
	s	**ʃ**			**ɛ** **ɔ**
m	**n**	**ɲ**	**ŋ**		**a**
	l,r				
w		**j**			
h,ʔ					

Voiced stops are redundantly pre-nasalized. Syllables in Sedang are of the form **C(C/G)V(C)**. For present purposes, onset clusters are irrelevant. Permissible codas are listed in (20).

(20) **p,t,k,m,n,ŋ,j,w,h,ʔ**

The voiceless stops, three of the nasals, the glides, and the laryngeals may close the syllable. The voiced stops, the fricatives, the liquids, and the alveopalatals may not close the syllable. Restrictions on coda distribution involving the laryngeals are discussed below.

In (21) I present the distribution of laryngeal gestures in Sedang onsets.

[3]Note that **w** is **v** in onset position.

(21) a. Sonorants, as well as the voiced stops may be pre-glottalized. When voiced stops are glottalized they lose their nasal component.

plain:		glottalized:	
lo	to go out	**ʔlo**	there also
mot	to enter	**ʔmot**	to hunt with a dog
ᵐbo	opening	**ʔbok**	honorific address

b. Sonorants may be voiceless.

plain:		voiceless:	
rej	root	**r̥re**	small animal in sewage
no	mango	**n̥no**	village name

c. Voiceless stops may be aspirated.

plain:		aspirated:	
kja	grave	**kʰi**	wind

d. Laryngeals may stand alone.

ho.ɣvã̰	right (hand)
ʔi.jja̰	little

Regarding (21a), glottalized sonorants are implemented as pre-glottals. This, recall, is the optimal realization of laryngeally modified sonorants.

(22) Sedang laryngealized sonorant:

SL: coronal liquid:
L: constriction:
approximation:
ʔr

Now consider laryngeal abductions in onsets (21b,c). The laryngeal abductions in voiceless sonorants (21b) are phased to overlap with only the first portion of the supralaryngeal configuration. This of course is the canonical realization of a voiceless sonorant, resulting in the phonetically salient realization of the supralaryngeal constriction, while simultaneously affording the laryngeal abduction a salient realization. Also, the forms in (21c) represent the canonical realization of aspirated stops, in that the laryngeal abduction is manifested at the release of the supralaryngeal occlusion.

(22) a. Sedang voiceless sonorant:

SL: coronal liquid:
L: abduction:
approximation:
r̥ r

b. Sedang aspirated stop:

SL: coronal stop:
L: abduction:
t ʰ

Thus, just as in Burmese, laryngeal gestures are phased optimally with respect to prevocalic consonantal gestures.

Vowels in Sedang may be either plain or creaky. (With nasalization cross-classifying, this results in four vowel classes.) Smith reports that "a laryngealized vowel is a vowel during which there is simultaneous voicing and trillization [glottalization (D.S.)]," and that "(i)n closed syllables, the trillization continues through the final consonant" (p.60).

Only the nasals and the glides may close syllables with creaky vowels; voiceless stops and the laryngeals--otherwise acceptable codas--are unattested in this environment.

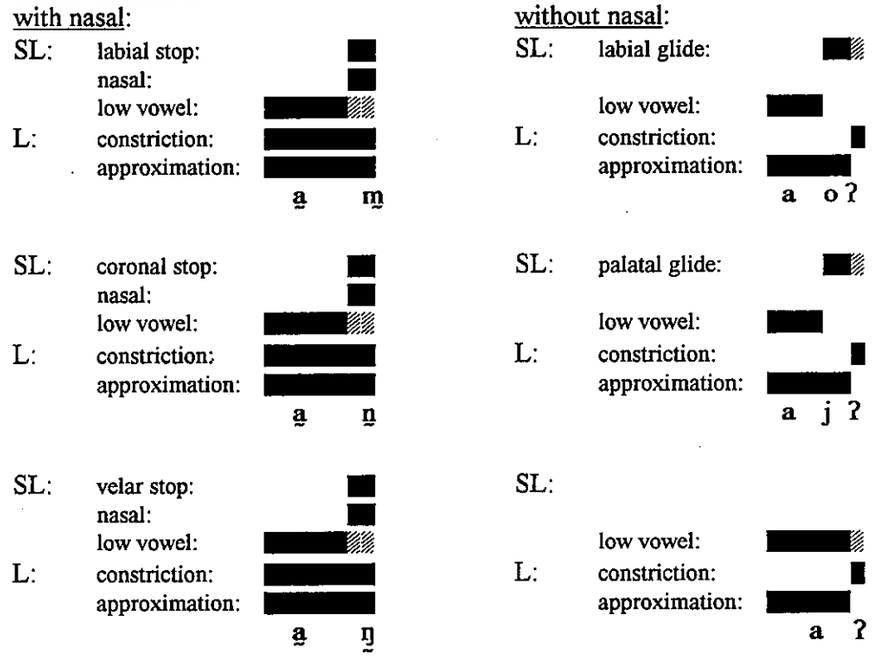
In some syllables with nasal codas, creaky vowels vary freely with modal vowels followed by a post-vocalic glottal stop, with concomitant loss of the coda nasal. Moreover, certain forms displaying this free variation additionally undergo diphthongization. This process is termed "de-laryngealization" by Smith. However, a more accurate name might be "denasalization," as laryngealization survives in the form of glottal checking, while nasality is lost. Examples are in (23).

(23)

	tum̰	~	**twoʔ**	all
	ren̰	~	**rejʔ**	to bite
	ʃaŋ̰	~	**ʃaʔ**	bitter
	tʃaŋ̰	~	**tʃaʔ**	fish fin
	r̥rin̰	~	**r̥rjɔʔ**	hundred
but	**mim̰**			plump baby
	prwaŋ̰			a name

The observed free variation may be analyzed as nasal deletion, with concomitant retention of a vocalized oral component, resulting in diphthongization in some cases. Thus the loss of nasality and oral closure from **m** leaves a labialized offglide, **o**. Loss of nasality and oral closure from **n** leaves a fronted glide **j** or **e**. Finally, loss of nasality and oral closure from **ŋ** usually results in complete loss of the supralaryngeal gesture.

(24) Sedang "de-laryngealization":



Smith suggests that de-laryngealization is indicative of a sound-shift in progress: certain laryngealized vowels are neutralizing with syllables closed by ʔ, along with vocalic augmentation in some instances.

(25)	tʃa̰ŋ̰	~	tʃaʔ	fish fin
			tʃaʔ	sword
	ra̰ŋ̰	~	raʔ	arrow
			raʔ	dried (wood)

Now consider the following distributional pattern: creaky vowels may be present in either open syllables, or syllables closed by sonorants (see 19), and, most significantly, "final glottal stop contrasts with [vowel--D.S.] laryngealization in open syllables" (p.60).

(26)	V:		V̰:		Vʔ:	
	o	young sibling	o̰	very	oʔ	daughter's husband
	cʰa	basket	cʰa̰	wild cat	cʰaʔ	gate

(26) shows two sets of minimal triplets involving plain, creaked, and checked vowels. Now, were creaky vowels only present in closed syllables, it might be concluded that Sedang is like Chong, in that phonetically creaked vowels involve a post-vocalic laryngeal gesture. But as vowel creakiness is not necessarily dependent upon the presence of a coda consonant, and as open syllables with creaky vowels contrast with glottally checked plain vowels, it may be safely concluded that the laryngeal constriction may be contrastively phased with respect to the vowel: if the laryngeal constriction is phased to follow the vowel, it is implemented as a post-vocalic glottal stop: **Vʔ**. If the laryngeal constriction is phased simultaneously with the vowel, it is implemented as vowel creakiness: **V̰**. In short, the laryngeal constriction is always realized optimally, depending on its lexical phasing with respect to vocalism.

Finally, Smith reports that "(i)nitial consonants have no restrictive effect on [vowel--D.S.] laryngealization" (p.60) (no examples given). When recalling that onsets may be either glottalized or aspirated, it becomes clear that vowel creakiness cannot be affiliated with *pre*-vocalic position: pre-vocalic glottalization (and aspiration) is fully independent of vowel creakiness.

In (27) is a summary of the distribution of laryngeal gestures within the Sedang syllable.

(27) syllable position:	example:	
onset:		
- plain	**kja**	grave
- abduction	**ho.v̰va̰**	right (hand)
	kʰja	wind (n)
	r̥re	small animal in sewage
- constriction	**ʔi.j̰ja**	little
	l̰lo	there also
nucleus:		
- plain	**kwa**	pipe
- constriction	**cʰa̰**	wild cat
coda:		
- plain	**po.lwam**	spider
- abduction	(no examples given)	
- constriction	**lḛm̰**	good
	ho.raʔ	to stay awake

(27) shows that plain, aspirated, or laryngealized consonants are allowed in onset position. Furthermore, **ʔ** and **h** are allowed in this position as well. Nuclei may be plain or

creaked. Codas may be plain, creaked, or **h**. Finally codas may also be **ʔ**, but this is only contrastive in the context of a plain vowel.

In (28) the Sedang system is formally characterized.

(28) phasing of laryngeal constrictions, voicing, and vowels in Sedang:

1	phase optimal	recover {vowel, constriction}	economize	overlap
a ☞	**vowel⟨⇳constriction⇨approximation⟩** vowel: constriction: approximation: ʔ a	▮vowel ▮constriction	*vowel *constriction *approximation	*
b	**vowel⇳⟨approximation⇨constriction⟩** vowel: constriction: approximation: a ʔ	▮vowel ▮▮*constriction	*vowel *constriction *approximation	*
c	**constriction⇳vowel⇳approximation** vowel: constriction: approximation: a	▮vowel ▮▮*constriction	*vowel *constriction *intercostals *approximation	

-or-

2	phase optimal	recover {vowel, constriction}	overlap	economize
a ☞	ʔa	▮vowel ▮constriction	*	*vowel *constriction *approximation
b	a	▮vowel ▮▮*constriction		*vowel *constriction *intercostals *approximation
c	aʔ	▮vowel ▮▮*constriction	*	*vowel *constriction *approximation

-or-

3	phase optimal	economize	recover {vowel, constriction}	overlap
a ☞	ʔa	*vowel *constriction *approximation	▮vowel ▮constriction	*
b	aʔ	*vowel *constriction *approximation	▮vowel ▮▮*constriction	*
c	a	*vowel *constriction *intercostals *approximation	▮vowel ▮▮*constriction	

-or-

4	phase optimal	economize	overlap	recover {vowel, constriction}
a ☞	ʔa	*vowel *constriction *approximation	*	▮vowel ▮constriction
b	aʔ	*vowel *constriction *approximation	*	▮vowel ▮▮*constriction
c	a	*vowel *constriction *intercostals *approximation		▮vowel ▮▮*constriction

-and-

1	phase *optimal	recover {vowel, constriction}	economize	overlap
a	**vowel⟨⇳constriction⇨approximation⟩** vowel: constriction: approximation: ʔ a	▮vowel ▮constriction	*vowel *constriction *approximation	*
b ☞	**vowel⇳⟨approximation⇨constriction⟩** vowel: constriction: approximation: a ʔ	▮vowel ▮▮*constriction	*vowel *constriction *approximation	*
c	**constriction⇳vowel⇳approximation** vowel: constriction: approximation: a	▮vowel ▮▮*constriction	*vowel *constriction *intercostals *approximation	

-or-

2	phase **optimal	recover {vowel, constriction}	overlap	economize
a	ʔa	▮vowel ▮constriction	*	*vowel *constriction *approximation
b	a̲	▮vowel ▤*constriction		*vowel *constriction *intercostals *approximation
c ☞	aʔ	▮vowel ▤*constriction	*	*vowel *constriction *approximation

-or-

3	phase *optimal	economize	recover {vowel, constriction}	overlap
a	ʔa	*vowel *constriction *approximation	▮vowel ▮constriction	*
b ☞	aʔ	*vowel *constriction *approximation	▮vowel ▤*constriction	*
c	a̲	*vowel *constriction *intercostals *approximation	▮vowel ▤*constriction	

-or-

4	phase *optimal	economize	overlap	recover {vowel, constriction}
a	ʔa	*vowel *constriction *approximation	*	▮vowel ▮constriction
b ☞	aʔ	*vowel *constriction *approximation	*	▮vowel ▤*constriction
c	a̲	*vowel *constriction *intercostals *approximation		▮vowel ▤*constriction

-and-

1	phase **optimal	recover {vowel, constriction}	economize	overlap
a	**vowel⇨⟨constriction⇧approximation⟩** vowel: constriction: approximation: ʔ a	▮vowel ▮constriction	*vowel *constriction *approximation	*
b	**vowel⇧⟨approximation⇨constriction⟩** vowel: constriction: approximation: a ʔ	▮vowel ▤*constriction	*vowel *constriction *approximation	*
c ☞	**constriction⇧vowel⇧approximation** vowel: constriction: approximation: a̲	▮vowel ▤*constriction	*vowel *constriction *intercostals *approximation	

-or-

2	phase *optimal	recover {vowel, constriction}	overlap	economize
a	ʔa	▮vowel ▮constriction	*	*vowel *constriction *approximation
b ☞	a̲	▮vowel ▤*constriction		*vowel *constriction *intercostals *approximation
c	aʔ	▮vowel ▤*constriction	*	*vowel *constriction *approximation

-or-

3	phase **optimal	economize	recover {vowel, constriction}	overlap
a	ʔa	*vowel *constriction *approximation	▮vowel ▮constriction	*
b	aʔ	*vowel *constriction *approximation	▮vowel ▤*constriction	*
c ☞	a̲	*vowel *constriction *intercostals *approximation	▮vowel ▤*constriction	

-or-

4	phase **optimal	economize	overlap	recover {vowel, constriction}
a	ʔa	*vowel *constriction *approximation	*	▮vowel ▮constriction
b	aʔ	*vowel *constriction *approximation	*	▮vowel ▮*constriction
c ☞	a̰	*vowel *constriction *intercostals *approximation		▮vowel ▮*constriction

It may be safely concluded that the laryngeal constriction of Sedang creaky vowels is contrastively phased in parallel with the vowel itself, and may expand into the post-vocalic domain. Also, of course, the constriction must be implemented simultaneously with voicing. Were voicing not present, vowel quality would be obliterated.

5.3 Phonation Contrasts in Tonal Languages

Some languages with phonation contrasts on vowels also possess tonal contrasts. In a subset of this group, phonation may fully cross-classify with tone. That is, tone and non-modal phonation may both be present on a single vowel. In this subset, the temporal sequencing of the tonal and the non-modal phonatory gestures may be observed. As I now argue, tone is optimally recoverable when the obscuring effects of non-modal phonation are not present.

There is evidence that the listener does not attend solely to the fundamental frequency during pitch perception, but instead attends to the harmonics which accompany the fundamental, as discussed in Plomp (1967), Ritsma (1967), Remez and Rubin (1984, 1993), and Stagray, Downs, and Sommers (1992). These researchers provide experimental evidence suggesting that the fundamental frequency is not a necessary component for accurate pitch perception. Even when the fundamental frequency is masked, it may be recovered from the pulse period and the surviving harmonics. Regarding the harmonics, given an F0 between 100 and 400 Hz., the frequency range between 400 and 1000 Hz. is the most important for pitch perception, provided amplitude exceeds a minimum of 10dB above threshold (Ritsma 1967). This region roughly corresponds to the third through the fifth harmonics, or approximately the first formant region (Remez and Rubin 1984, 1993). This is shown schematicallly in (27), employing an F0 of 125 Hz., in which the shaded bar indicates this region.

(29) optimal pitch source during modal phonation:

modal vowel:		
Formant:	Harmonic:	Frequency:
	...	...
	H9	1125
	H8	1000
	H7	875
	H6	750
F1	H5	625
	H4	500
	H3	375
	H2	250
	H1	125

In some cases, tonal contrasts may cross-classify with phonation contrasts. This is the laryngeally complex class of languages (laryngeally *simplex* languages are those which do not cross-classify tone and phonation). In the laryngeally complex class, a wide array of laryngeal contrasts may exist. Consider the case of Comaltepec Chinantec. In Silverman 1995 I show that this language possesses **H**, **M**, **L**, **LM**, and **LH** tones. Comaltepec Chinantec also possesses a phonation contrast involving a laryngeal

abduction. Cross-classifying tone and phonation, the possible vocalic laryngeal contrasts in (28) emerge.

(30) predicted laryngeal contrasts in Comaltepec Chinantec:

tone→ phonation↓	H	M	L	LM	LH
V	V^{H}	V^{M}	V^{L}	V^{LM}	V^{LH}
V̤	$V̤^{H}$	$V̤^{M}$	$V̤^{L}$	$V̤^{LM}$	$V̤^{LH}$

Ten nuclear laryngeal contrasts are predicted to exist in Comaltepec Chinantec. In Silverman 1995 I argue that most of these contrastive states in fact do exist. However, tone and the laryngeal abduction are sequenced in laryngeally complex vowels. In Comaltepec Chinantec, the abduction is sequenced to follow the tone, resulting in a modally phonated toned vowel followed by voicelessness.

(31) laryngeal contrasts in Comaltepec Chinantec:

tone→ phonation↓	H	M	L	LM	LH
V	V^{H}	V^{M}	V^{L}	V^{LM}	V^{LH}
Vh	Vh^{H}	Vh^{M}	Vh^{L}	Vh^{LM}	Vh^{LH}

In the following subsections, after discussing laryngeally simplex systems, I discuss the phonetic motivation for the serial production of tone and non-modal phonation in laryngeally complex systems. I then investigate the cross-linguistic patterning of laryngeally complex languages.

5.3.1 Subtypes of Laryngeally Simplex Languages

Most languages do not cross-classify tone and phonation. That is, most languages are laryngeally simplex.

Laryngeally simplex languages fall into four subtypes.

(1) neither contrastive tone nor contrastive phonation (e.g., English)
(2) contrastive tone, but no contrastive phonation (e.g., many African languages)
(3) contrastive phonation, but no contrastive tone (e.g., Gujarati, Sedang)
(4) contrastive tone and contrastive phonation which do not cross classify (e.g. Hmong, Vietnamese)

Subtypes **(1)-(3)** present no problems.

In subtype **(4)** languages, tonal contrasts exist, and phonation contrasts exist. However, contrastive tone and contrastive phonation never occur on a single vowel. Put another way, subtype **(4)** languages do not possess tonal contrasts on vowels that bear

non-modal phonation. However, a full array of tonal contrasts exists on modally phonated vowels.

Consider the case of Vietnamese (Nguyen 1965; no glosses available). The southern dialect possesses five tones which may contrast on plain vowels, plus a "constricted" (creaky) tone. The table in (32) provides examples of both tonal and phonatory contrasts in Vietnamese.

(32)

Level tone	**la˥**
Rising tone	**la˧˥**
Falling tone	**la˨˩**
Falling rising tone	**la**
Low rising tone	**la˩˧**
Low constricted tone	**la̰˩**

Consider next Hmong (Lyman 1974, Smalley 1976, Huffman 1987, Ratliff 1992). White Hmong possesses five tones that may be realized on plain vowels. Vowels bearing non-modal phonation--creakiness or breathiness--never contrast in tone. These phonation contrasts are traditionally labelled "creaky tone" and "breathy tone," respectively.[4] The table in (31) (adapted from Huffman) exemplifies these tonal contrasts.

(33)

High	**tau^{55}**	pumpkin
Rising	**tau^{35}**	to dam up (water)
Low	**tau^{22}**	axe
Mid (normal)	**tau^{33}**	to be able
Falling (normal)	**tau^{42}**	sp. of grass
Creaky	**tau^{31}**	bean
Breathy	**tau^{32}**	to follow

Corroborating the hypothesis that the so-called breathy tone is in fact a phonation contrast, not a tonal contrast, Ratliff (1992), in the context of a lengthy discussion of White Hmong fossilized tonal morphology, reports that the breathy tone bears different pitch patterns for male versus female speakers. For male speakers, the breathy tone is implemented as a low, whispered pitch fall: $V̤^{31}$. For female speakers, the breathy tone is implemented as a high, whispered fall: $V̤^{53}$. Ratliff: "...(M)y perception of the difference

[4]Lyman (1974) considers creaky-toned vowels creaked. However, Smalley (1976) and Huffman (1989) describe them as glottally checked. Ratliff (1992) reports that David Strecker, among others, observes free variation between checking and creakiness.

leads me to believe that the phonation contrast is the primary phonetic cue, fundamental frequency change ("contour") the secondary phonetic cue, and fundamental frequency itself ("pitch") only the tertiary phonetic cue for this tone" (p.12). That is, the relative pitch of the breathy tone is not crucial to the lexical contrast, as it varies with respect to other pitch patterns. Instead, the reliable and constant cue to the contrast is its breathy quality.

Edward Flemming (personal communication) suggests that phonatory contrasts in subtype **(4)** languages may be viewed as phonetic enhancers of a tonal contrast. Thus, despite the presence of a non-modal phonatory gesture, phonation is not itself contrastive here. While this approach certainly cannot explain, for example, the Hmong pattern, certain instances of superficial phonation contrasts do indeed lend themselves to this approach.

Consider the case of Mandarin in this light. Mandarin possesses four tones, in addition to tonelessness.

(34)	high level	$t^h an^{H}$	greedy
	high rising	$t^h an^{MH}$	deep
	dipping	$t^h an^{MLH}$	perturbed
	high falling	$t^h an^{HL}$	spy

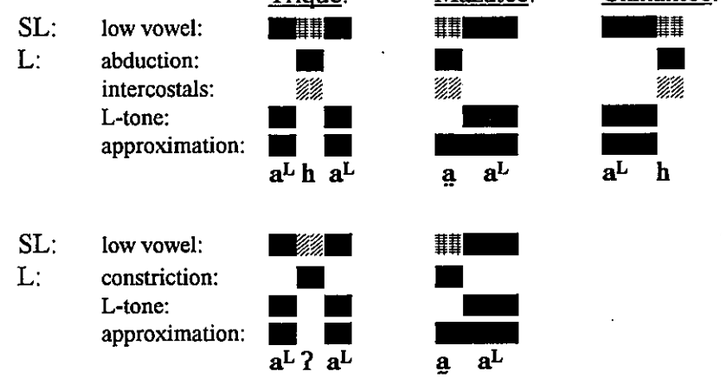
The dipping tone is in fact a level low tone in most contexts (**L**). Phrase-finally, it is realized **MLH**, and before another dipping tone, it is realized as a high rising tone (**MH**). For all these realizations--except **MH**--a laryngeal creak may optionally accompany the tone pattern. Thus **L** freely varies with **L̰**, and **MLH** freely varies with **M̰L̰H**. This non-contrastive creak may be viewed as an enhancement of the dipping tone.

In summary, laryngeally simplex languages are those in which tone and non-modal phonation do not cross-classify. By far, the majority of languages fall into this category.

5.3.2i Laryngeally Complex Languages

In laryngeally complex languages non-modal phonation cross-classifies with tone. Otomanguean languages, which are laryngeally complex, employ three distinct phasing patterns involving tone and phonation: late sequencing of non-modal phonation (exemplified by Mazatec), early sequencing of non-modal phonation (exemplified by Chinantec) and vocalic "interruption," in which the vowel is intruded upon by its non-modal component (exemplified by Trique). In all these cases, tone is realized on the modal portion of the vowel.

(35) laryngeally complex class (e.g., Otomanguean):



I now discuss in detail the motivation for sequencing tone and non-modal phonatory gestures in laryngeally complex languages, considering, in turn, **(1)** acoustic phonetics and **(2)** articulatory phonetics.

(1) First, consider acoustics. The perception of pitch during modal phonation bears a correlative (though non-linear) relationship with the frequency at which the vocal folds vibrate. During modal phonation, as the frequency of vocal fold vibration increases, perceived pitch increases as well. A reliable and stable pitch percept which derives from glottal vibration may be disrupted during non-modal phonation. While breathy phonation may disrupt the encoding of the periodic glottal vibration, creaky phonation may result in glottal wave quasi- or a-periodicity. I consider each of these in turn. Anticipating my conclusion, when a periodic glottal wave is either obscured or not present, the acoustic signal does not saliently encode a pitch source.

Acoustic analyses of breathy vowels indicate that the fundamental frequency is enhanced relative to the lower harmonics (Bickley 1982, Huffman 1987, Ladefoged, Maddieson, and Jackson 1988, Cao and Maddieson 1992). While this enhanced fundamental might be argued to provide a salient pitch percept, recall that when analyzing pitch the auditory system is less attuned to the fundamental frequency than to its accompanying third through fifth harmonics (Plomp 1967, Ritsma 1967, Remez and Rubin 1984,1993), as well as the pitch period. Note now that the harmonic structure possesses increased bandwidths during breathy phonation, as well as an overall increase in noise, which in some cases has been shown to largely obscure the harmonic structure (Silverman 1994a, Silverman, Blankenship, Kirk, and Ladefoged 1995). Consequently, the frequency of the glottal vibration may be unrecoverable in breathy vowels.

(36) schematic of weakened harmonic structure characteristic of breathy vowels:

breathy vowel:		
Formant:	Harmonic:	Frequency:
	...	...
	H9	1125⇕
	H8	875⇕
	H7	750⇕
	H6	750⇕
F1	H5	500⇕
	H4	375⇕
	H3	375⇕
	H2	250⇕
	H1	125⇕

Moreover, Kirk, Ladefoged, and Ladefoged (1993) provide waveforms of the breathy portion of breathy vowels in Jalapa Mazatec: "The breathy vowel is characterized by an onset of indiscernible pulses" (p.445).

Given both the obscured harmonic structure and the indiscernible pulses that may accompany breathy phonation, tone is not reliably encoded in the speech signal when implemented with breathy voice. It is therefore predicted that languages which possess tonal and breathy phonation contrasts on a given vowel will sequence the contrastive laryngeal gestures, so that both tone and phonation are recoverable, since tone is most reliably encoded during modal phonation.

Creaky vowels also possess a potentially unanalyzable harmonic structure. This is due to the aperiodic and/or unstable glottal vibration that results from vocal fold constriction (Kirk, Ladefoged, and Ladefoged 1993, Ladefoged and Maddieson 1995).

For example, Kirk, Ladefoged, and Ladefoged (1993) compare glottal pulse patterns in creaky versus modal vowels in Jalapa Mazatec. These researchers provide waveforms of creaky phonation in Jalapa Mazatec: "creaky vowels have speech jitter (irregularly spaced pulses)" (p.445). The mean variance for creaky vowels is reported to be 9.1 msecs, while that for modal vowels is .08 msec (p.448).

Now note that Rosenberg (1966), and Cardozo and Ritsma (1968) find that when a pulse period varies, or jitters, by more than 10%, a stable pitch is not reliably discernible.

(37) schematic of jittered pitch source characteristic of creaky vowels:

creaky vowel:		
Formant:	Harmonic:	Frequency:
	...	...
	H9	1125↑↓↑↓
	H8	875↑↓↑↓
	H7	750↑↓↑↓
	H6	750↑↓↑↓
F1	H5	500↑↓↑↓
	H4	375↑↓↑↓
	H3	375↑↓↑↓
	H2	250↑↓↑↓
	H1	125↑↓↑↓

It is therefore predicted that languages which possess tone on creaky vowels--such as Jalapa Mazatec--may sequence their tonal and non-modal phonatory gestures, so that both contrastive tone and contrastive phonation are recoverable. Below, I show that this prediction is correct.

(2) I now turn my attention to articulatory considerations. I consider, in turn, tone production with modal phonation, and tone production with non-modal phonation. I show that pitch targets are most reliably achieved when implemented with modal phonation. Note that the conflicts discussed here are *articulatory* in nature, not acoustic. However, their articulatory incompatability indeed results in non-recoverability, as the inability to achieve a particular articulatory configuration may result in the non-achievement of the intended acoustic goal.

Ohala (1978) provides an excellent summary of the interacting muscular, articulatory, and aerodynamic factors involved in pitch production.

Briefly, pitch is determined by rate of vocal fold vibration, which is controlled primarily by tensing (stretching) and laxing of the vocal folds via the crycothyroid muscle. Provided that a steady transglottal airstream is maintained, tensing the vocal folds increases rate of vibration (hence increasing pitch), while laxing the folds decreases rate of vibration (hence reducing pitch).

However, there are additional ways in which pitch may be more moderately influenced.

First, subglottal pressure affects pitch: increases in subglottal pressure through increased respiratory muscle activity (the internal intercostal muscles) have been shown to have moderate effects on rate of vocal fold vibration. All else held constant, the higher the subglottal pressure, the higher the rate of vocal fold vibration; as transglottal flow is increased, vocal fold vibration increases as well.

Additionally, larynx height correlates with pitch: raising the larynx is associated with pitch increases, while lowering the larynx is associated with pitch falls.

Glottal aperture may also affect pitch, interacting in complex ways with airflow, subglottal pressure, and supraglottal stricture. All else being equal, a more open glottis may result in faster trans-glottal airflow, hence higher pitch. However, the consequent reduction in subglottal pressure may lead to a pitch *fall*.

Given the primary muscular correlate to pitch production (crycothyroid activity), along with the possible enhancing mechanisms just mentioned, the ideal configuration for a given pitch (tonal) target, either higher pitch or lower pitch may be determined. This configuration is presented in tabular form in (38).

(38) tone (with modal phonation):		H:	L:
primary gesture:			
vocal fold tension:	higher:	■	
	lower:		■
enhancing gestures:			
glottal aperture:	higher:	■	
	lower:		■
intercostal flexion:	higher:	■	
	lower:		■
larynx height:	higher:	■	
	lower:		■

That is, implementing a high tone primarily involves tensing the vocal folds. Secondarily, glottal aperture should be increased. Subglottal pressure, of course, should remain high throughout. Finally, the larynx should be raised.

A low tone primarily involves laxing the vocal folds. Lowness may be enhanced if glottal aperture is decreased; subglottal pressure should remain reduced. Finally, the larynx is lowered.

Now consider the interaction of tone and non-modal phonation. While the primary articulatory correlates to pitch and phonation type are in theory independently manipulable, these potentially distinct laryngeal configurations make conflicting demands on their respective enhancing mechanisms.

Consider first breathy voice. Breathy voice is implemented primarily through abducting the vocal folds. Additionally, vocal fold laxing may enhance the salience of breathiness, allowing the folds to flap freely, thus increasing random noise. Subglottal pressure increases may also enhance breathiness, as increased airflow increases acoustic energy. Finally, there may be a correlation between breathy phonation and a moderate lowering of the larynx (Henderson 1952, Gregerson 1976, Thonkum 1987a). The source of this larynx lowering is not fully clear; it may simply be an automatic muscular by-product of glottal abduction.

(39) breathy phonation:		V̲:
primary gesture:		
glottal aperture:	higher:	■
	lower:	
enhancing gestures:		
vocal fold tension:	higher:	
	lower:	■
intercostal flexion:	higher:	■
	lower:	
possible automatic concomitant:		
larynx height:	higher:	
	lower:	■

Now consider what would happen if a speaker were to simultaneously encode lexically contrastive breathiness and lexically contrastive higher pitch. For breathiness, glottal aperture is increased. For higher pitch, vocal fold tension is increased. These two configurations are, at least in theory, independent of each other. However, consider the accompanying enhancements. For breathiness, vocal fold tension should be decreased. This conflicts with the increased tension necessary to implement pitch increases. Similarly, glottal aperture might be reduced for pitch increases. However, breathiness requires vocal fold abduction. Finally, while higher pitches involve pronounced larynx raising, breathiness is accompanied by larynx lowering.

Now consider lower pitch and breathiness. Both are implemented with lax, non-abducted vocal folds, and larynx lowering. However, while lowness is enhanced by *reducing* subglottal pressure, breathiness is enhanced by *increasing* subglottal pressure.

(40) tone with breathy phonation:		V^H:	V̲:		V^L:	V̲:
vocal fold tension:	higher:	■		higher:		
	lower:		■	lower:	■	■
glottal aperture:	higher:	■	■	higher:		■
	lower:			lower:	■	
intercostal flexion:	higher:	■	■	higher:		■
	lower:			lower:	■	
larynx height:	higher:	■		higher:		
	lower:		■	lower:	■	■

The degree of supralaryngeal stricture may serve to complicate this picture somewhat. Certain laryngeal configurations may influence pitch in one direction toward the beginning of a syllable, but in the opposite direction toward the end of a syllable. For example a post-stop laryngeal abduction may increase pitch, because airflow is very high at stop release. Post-vocalically, aspiration is potentially weakened (see also Bladon 1986). Moreover, a laryngeal abduction here may reduce pitch, as the vocal folds are necessarily slackened, and the larynx is perhaps somewhat lowered (Ohala 1978). It might consequently be predicted that, if a preceding supraglottal closure is unavailable, aspiration should be implemented with an increase in subglottal pressure (implemented by internal intercostal muscular contraction), in order to facilitate the acoustic encoding of aspiration in this otherwise weak position.

I briefly digress and consider three possible realizations of post-vocalic aspiration: **(1)** post-vocalic aspiration may be accompanied by an increase in intercostal flexion, giving rise to a pitch increase as well, **(2)** post-vocalic aspiration may not be accompanied by an increase in intercostal flexion, thus giving rise to a pitch fall, and **(3)** post-vocalic aspiration may not be accompanied by an increase in intercostal flexion, thus neutralizing the aspiration contrast. Jeh, Huave, and Arawakan exemplify these three patterns. I briefly consider each in turn.

Case Studies: Jeh, Huave, and Arawakan

(1) Consider first the case of Jeh. Jeh is a Mon-Khmer language spoken in Kontum province, Vietnam (Gradin 1966). Gradin reports on the Dak Wak dialect, spoken in the Dak Sut area. This dialect possesses a peculiar phenomenon that Gradin terms "consonantal tone." While Jeh is otherwise non-tonal, certain open syllables are characterized as possessing "a level tone followed by sharp rise. The main vowel remains level for the duration of a regular short vowel, and there is never any friction or occlusion succeeding the sharp rise in pitch". However, "The sharp rise in pitch can cause the vowel to be broken up by a non-contrastive glottal stop"(p.42).

Gradin additionally reports that neighboring languages, including certain other northern Jeh dialects, possess **h** in place of this pitch increase.

(41)	Dak Wak:	other northern dialects:	
	tɛ:ʃ	**tɛh**	to scythe
	dajʃ	**dajh**	loud

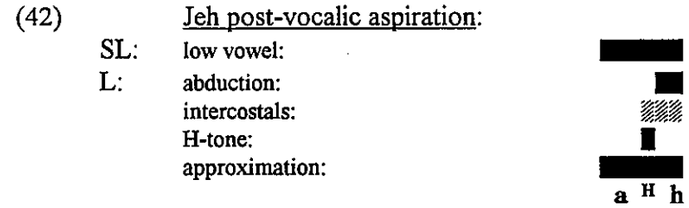
In still other northern dialects syllable final **h** reportedly freely varies with a rising tone (p.45).

Based on the cross-dialectal patterns presented by Gradin, I suggest that post-vocalic aspiration in certain Jeh dialects is being rephonemicized as a pitch rise late in the vowel. Why is this happening? Perhaps Jeh post-vocalic aspiration, as it is in danger of weakening, is implemented with a concomitant increase in subglottal pressure and airflow,

originating in increased internal intercostal flexion, intended to enhance its perceptual salience. Now, as I have reported, an increase in subglottal pressure may give rise to a moderate pitch increase as well.

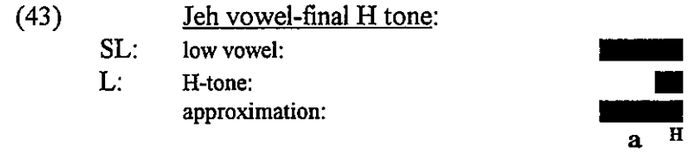
Now, apart from the phenomenon under scrutiny, Jeh is a non-tonal language. Therefore, a respiratory gesture implemented to enhance the perceptual salience of post-vocalic aspiration is free to precede the laryngeal abduction--in anticipatory fashion--without disrupting any contrastive pitch information. That is, subglottal pressure increases may slightly precede the laryngeal abduction, thus resulting in a moderate pitch increase during the modally phonated vowel. Thus, if subglottal pressure and airflow increases precede the glottal abduction in an anticipatory fashion, a pitch increase would occur during modally phonated portion of the vowel.

(42) Jeh post-vocalic aspiration:



And so in time, the system of contrasts may evolve such that the pitch rise cues the contrast, rather than the post-vocalic aspiration. Ultimately, aspiration may be lost altogether, and the pitch rise is the sole cue to the contrast, as in Dak Wak.

(43) Jeh vowel-final H tone:



If this speculation is on the right track, Jeh offers an example of enhancement gone awry: a gesture implemented in order to enhance the salience of a particular contrast instead gives rise to a rephonemicization--this, indeed, is a common source of diachronic change.

(2) Without an increase in internal intercostal flexion, aspiration in post-vocalic position is in danger of being replaced by pitch *lowering*. Let us briefly consider the case of Huave in this light.[5] Huave is a tonal language of indeterminate affiliation, spoken by approximately 13,000 people in Oaxaca, Mexico (Grimes 1989). Noyer (1991) reports

[5]Thanks to Rolf Noyer for suggesting that I examine his Huave data.

that long vowels in Huave alternate with **Vh** sequences. He presents several different arguments in favor of this underlying representation.

(1) Geminate vowels alternate with **Vh** (underlined), conditioned by stress. Closed final syllables are stressed (italicized).

(44) a. ...**à** ***pé<u>ee</u>d*** he cuts
b. ...**àpè<u>h</u>** ***tíʌ̃w*** they cut

Stress-shift off the derived penult in (1b) results in surface **Vh**.

(2) "In environments which are always stressless, **Vh** always occurs and **VV** never does. Such an environment is the penultimate syllable when the final syllable is closed.

(45) **-VVCV(V)C#**

In such an environment the sequence **Vh** is abundantly represented" (p.10).

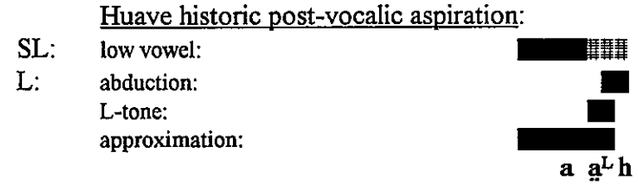
(46) **wahtat** sawfish
ʃehken dull
tehpɛay washtub

(3) Some dialects possess geminate vowels where others possess **Vh** sequences. Moreover, in emphatic speech, long vowels **VV** may be realized with h-interruption (**VhV**).

(4) Most significantly, these alternating long vowels are always realized with *falling tones.*

How might the Huave facts be interpreted in accordance with the present theory? I claim that long, falling-toned vowels have their historic origins in vowels followed by aspiration.

(47) <u>Huave historic post-vocalic aspiration</u>:



Given its weak position, this aspiration would seem a prime candidate for deterioration and ultimate loss, were subglottal pressure and flow not sufficiently increased. Thus, without these increased, a weakening of the noise associated with aspiration results, in addition to a lowering of pitch that is associated with a glottal

abduction unaccompanied by subglottal pressure and flow increases: the vocal folds are slackened, and the larynx is lowered. The result is a long vowel with a falling pitch--exactly what is found in most environments in Huave today.

(48) <u>Huave vowel-final low tone</u>:

I thus speculate that Huave is in the process of losing its post-vocalic aspiration, replacing it with a vowel length contrast that possesses a pitch fall. Presently, the two bear an allophonic relationship. Whether a length distinction or tonal distinction ultimately evolves into the contrastive value remains to be seen.

(3) I have thus far argued that a post-vocalic laryngeal abduction accompanied by an increase in internal intercostal flexion may evolve into a pitch rise, as in Jeh, or, if not accompanied by an increase in internal intercostal flexion, may evolve into a pitch fall. One final possibility here is the total loss of the contrast: post-vocalic aspiration may neutralize with its absence. Payne (1991), and Parker (1994) discuss this diachronic process in certain Arawakan languages.

In summary, these case studies provide evidence that language-specific conventions concerning how a particular contrastive gestural configuration is implemented may, in time, lead to divergent systems of contrasts.

5.3.2ii Laryngeally Complex Languages

I now return to the discussion of laryngeally complex vowels. I have thus far considered the interaction of breathy voice and tone. Consider now creaky vowels. Creakiness is realized primarily with a reduction in glottal aperture. Increases in vocal fold tension serves to enhance creakiness. Subglottal pressure increases may increase the perceptual salience of creakiness. And just as larynx lowering is a concomitant of breathiness, larynx raising is an attested (and perhaps automatic) concomitant of creaky phonation (Thonkum 1987a, Kirk, Ladefoged, and Ladefoged 1993).

(49) creaky phonation: V̲:

primary gesture:		
glottal aperture:	higher:	
	lower:	■
enhancing gestures:		
vocal fold tension:	higher:	■
	lower:	
intercostal flexion:	higher:	■
	lower:	
possible automatic concomitant:		
larynx height:	higher:	■
	lower:	

Creakiness is largely compatible with higher pitch, although a conflict in glottal aperture may result: glottal aperture is optimally initially higher for a high tone, while glottal aperture is necessarily low for a laryngeal constriction. However, were creakiness to occur with lower pitch, conflicts would result. First, low pitch involves decreased vocal fold tension, while creakiness is enhanced by *increasing* vocal fold tension. Also, creakiness is enhanced by increasing subglottal pressure, while lowness is enhanced by reducing subglottal pressure. Finally, low tones involve pronounced larynx lowering, while creakiness may be accompanied by larynx raising.

(50) tone with creaky phonation:

		V^H:	V̲:		V^L:	V̲:
vocal fold tension:	higher:	■	■	higher:		■
	lower:			lower	■	
glottal aperture:	higher:	■		higher:		
	lower:		■	lower:	■	■
intercostal flexion:	higher:	■	■	higher:		■
	lower:			lower:	■	
larynx height:	higher:	■	■	higher:		■
	lower:			lower:	■	

Interestingly, creakiness has been observed as a concomitant of pitch *lowering* as well (for example, in Chong and Mandarin). Creaky phonation here may have somewhat distinct origins from that which derives from an active decrease in glottal aperture. Instead, creakiness which accompanies lower pitch may be a consequence of reducing subglottal pressure and transglottal flow. With these reduced, the vocal folds may more readily seal the subglottal chamber, and thus are only intermittently blown apart by eventual subglottal pressure increases. This slow and irregular glottal pulse may give rise to creakiness. For this reason, creakiness implemented late in the syllable may in fact occur with a pitch lowering.

The observed conflicts in phonetic enhancing strategies between breathiness and pitch targets, and creakiness and pitch targets, if considered one by one, might not appear to be sufficiently incompatible to greatly disrupt the achievement of a given acoustic goal. However, when considering the rapidity with which the laryngeal musculature must be adjusted--going from pitch target to pitch target, and from phonation target to phonation target--the difficulty in simultaneously achieving the articulatory demands of both acoustic dimensions (pitch and phonation) becomes apparent. Thus, while it is not necessarily difficult to implement a given gestural configuration involving tone and phonation, it may be difficult to implement many distinct configurations in sequence. And of course, given this articulatory difficulty, acoustic cues to contrastive information may suffer.

By hypothesis then, it is for these acoustic and articulatory reasons that contrastive tone and phonatory gestures may be sequenced in laryngeally complex languages.

So consider laryngeally complex vowels with respect to constraints and system expansions. For all three constraints, there are two possible system expansions, as shown in (51).

(51) vowels, abductions and tones:

1 recover {vowel, abduction, tone}	2 recover {vowel, abduction, tone}	3 recover {vowel, abduction, tone}	4 recover {vowel, abduction, tone}	5 recover {vowel, abduction, tone}	6 recover {vowel, abduction, tone}
ha^L ▮vowel ▮tone ▮abduction	ha^L ▮vowel ▮tone ▮abduction	a^Lh ▮vowel ▮tone ▮▮*abduction	a^Lh ▮vowel ▮tone ▮▮*abduction	a^L ▮vowel ▮▮*tone ▮abduction	a^L ▮vowel ▮▮*tone ▮abduction
a^Lh ▮vowel ▮tone ▮▮*abduction	a^L ▮vowel ▮▮*tone ▮abduction	ha^L ▮vowel ▮tone ▮abduction	a^L ▮vowel ▮▮*tone ▮abduction	ha^L ▮vowel ▮tone ▮abduction	a^Lh ▮vowel ▮tone ▮▮*abduction
a^L ▮vowel ▮▮*tone ▮abduction	a^Lh ▮vowel ▮tone ▮▮*abduction	a^L ▮vowel ▮▮*tone ▮abduction	ha^L ▮vowel ▮tone ▮abduction	a^Lh ▮vowel ▮tone ▮▮*abduction	ha^L ▮vowel ▮tone ▮abduction

1 economize	2 economize	3 economize	4 economize	5 economize	6 economize
ha^L *vowel *tone *abduction *intercostals	**ha^L** *vowel *tone *abduction *intercostals	**a^{L}h** *vowel *tone *abduction *intercostals	**a^{L}h** *vowel *tone *abduction *intercostals	**a̤^{L}** *vowel *tone *abduction *intercostals	**a̤^{L}** *vowel *tone *abduction *intercostals
a^{L}h *vowel *tone *abduction *intercostals	**a̤^{L}** *vowel *tone *abduction *intercostals	**ha^L** *vowel *tone *abduction *intercostals	**a̤^{L}** *vowel *tone *abduction *intercostals	**ha^L** *vowel *tone *abduction *intercostals	**a^{L}h** *vowel *tone *abduction *intercostals
a̤^{L} *vowel *tone *abduction *intercostals	**a^{L}h** *vowel *tone *abduction *intercostals	**a̤^{L}** *vowel *tone *abduction *intercostals	**ha^L** *vowel *tone *abduction *intercostals	**a^{L}h** *vowel *tone *abduction *intercostals	**ha^L** *vowel *tone *abduction *intercostals

1 overlap	2 overlap	3 overlap	4 overlap	5 overlap	6 overlap
**ha^L	**ha^L	**a^{L}h	**a^{L}h	**a̤^{L}**	**a̤^{L}**
**a^{L}h	**a̤^{L}**	**ha^L	**a̤^{L}**	**ha^L	**a^{L}h
a̤^{L}	**a^{L}h	**a̤^{L}**	**ha^L	**a^{L}h	**ha^L

But recall that no language allows breathy vowels to the exclusion of **hV** sequences. Consequently, it cannot be the case that **overlap** is the most highly valued constraint in a system. So, employing only one possible expansion for each of the three constraints, the possible system expansions in (52) emerge.

(52) system expansions of laryngeally complex vowels involving abductions:

1	{vowel, abduction, tone}	recover {vowel, abduction, tone}	economize	overlap
a	**vowel⇳⟨abduction⇳ intercostals⇨tone⟩** vowel: tone: abduction: intercostals: h a^L	vowel tone abduction	*vowel *tone *abduction *intercostals	**
b	**vowel⇳⟨tone⇨ abduction⇳intercostals⟩** vowel: tone: abduction: intercostals: a^L h	vowel tone *abduction	*vowel *tone *abduction *intercostals	**
c	**vowel⇳tone⇳abduction⇳ intercostals** vowel: tone: abduction: intercostals: a̤^{L}	vowel *tone abduction	*vowel *tone *abduction *intercostals	

2	{vowel, abduction, tone}	recover {vowel, abduction, tone}	overlap	economize
a	**ha^L**	vowel tone abduction	**	*vowel *tone *abduction *intercostals
b	**a̤^{L}**	vowel *tone abduction		*vowel *tone *abduction *intercostals
c	**a^{L}h**	vowel tone *abduction	**	*vowel *tone *abduction *intercostals

3	{vowel, abduction, tone}	economize	recover {vowel, abduction, tone}	overlap
a	**ha**^{L}	*vowel *tone *abduction *intercostals	▌vowel ▌tone ▌abduction	**
b	**a**^{L}**h**	*vowel *tone *abduction *intercostals	▌vowel ▌tone ▌▌*abduction	**
c	**a̲**^{L}	*vowel *tone *abduction *intercostals	▌vowel ▌▌*tone ▌abduction	

4	{vowel, abduction, tone}	economize	overlap	recover {vowel, abduction, tone}
a	**ha**^{L}	*vowel *tone *abduction *intercostals	**	▌vowel ▌tone ▌abduction
b	**a**^{L}**h**	*vowel *tone *abduction *intercostals	**	▌vowel ▌tone ▌▌*abduction
c	**a̲**^{L}	*vowel *tone *abduction *intercostals		▌vowel ▌▌*tone ▌abduction

And the free ranking of constraints involving constrictions yields (53).

(53) vowels, constrictions, and tone:

1 recover {vowel, constriction, tone}	2 recover {vowel, constriction, tone}	3 recover {vowel, constriction, tone}	4 recover {vowel, constriction, tone}	5 recover {vowel, constriction, tone}	6 recover {vowel, constriction, tone}
?a^{L} ▌vowel ▌tone ▌constriction	?a^{L} ▌vowel ▌tone ▌constriction	a^{L}? ▌vowel ▌tone ▌▌*constriction	a^{L}? ▌vowel ▌tone ▌▌*constriction	a̲^{L} ▌vowel ▌▌*tone ▌constriction	a̲^{L} ▌vowel ▌▌*tone ▌constriction
a^{L}? ▌vowel ▌tone ▌▌*constriction	a̲^{L} ▌vowel ▌▌*tone ▌constriction	?a^{L} ▌vowel ▌tone ▌constriction	a̲^{L} ▌vowel ▌▌*tone ▌constriction	?a^{L} ▌vowel ▌tone ▌constriction	a^{L}? ▌vowel ▌tone ▌▌*constriction
a̲^{L} ▌vowel ▌▌*tone ▌constriction	a^{L}? ▌vowel ▌tone ▌▌*constriction	a̲^{L} ▌vowel ▌▌*tone ▌constriction	?a^{L} ▌vowel ▌tone ▌constriction	a^{L}? ▌vowel ▌tone ▌▌*constriction	?a^{L} ▌vowel ▌tone ▌constriction

1 economize	2 economize	3 economize	4 economize	5 economize	6 economize
?a^{L} *vowel *tone *constriction	?a^{L} *vowel *tone *constriction	a^{L}? *vowel *tone *constriction	a^{L}? *vowel *tone *constriction	a̲^{L} *vowel *tone *constriction	a̲^{L} *vowel *tone *constriction
a^{L}? *vowel *tone *constriction	a̲^{L} *vowel *tone *constriction	?a^{L} *vowel *tone *constriction	a̲^{L} *vowel *tone *constriction	?a^{L} *vowel *tone *constriction	a^{L}? *vowel *tone *constriction
a̲^{L} *vowel *tone *constriction	a^{L}? *vowel *tone *constriction	a̲^{L} *vowel *tone *constriction	?a^{L} *vowel *tone *constriction	a^{L}? *vowel *tone *constriction	?a^{L} *vowel *tone *constriction

1 overlap	2 overlap	3 overlap	4 overlap	5 overlap	6 overlap
**?a^{L}	**?a^{L}	**a^{L}?	**a^{L}?	a̲^{L}	a̲^{L}
**a^{L}?	a̲^{L}	**?a^{L}	a̲^{L}	**?a^{L}	**a^{L}?
a̲^{L}	**a^{L}?	a̲^{L}	**?a^{L}	**a^{L}?	**?a^{L}

In (54) are the possible system expansions of laryngeally complex vowels involving constrictions, again, exclusing the possibility of **overlap** being the most highly valued constraint.

(54) system expansions of laryngeally complex vowels involving constrictions:

1	{vowel, constriction, tone}	recover {vowel, constriction, tone}	economize	overlap
a	**vowel⇕(constriction⇨tone)** vowel: constriction: tone: ʔ a^L	vowel constriction tone	*vowel *constriction *tone	**
b	**vowel⇕(tone⇨constriction)** vowel: constriction: tone: a^L ʔ	vowel *constriction tone	*vowel *constriction *tone	**
c	**vowel⇕tone⇕constriction** vowel: constriction: tone: $\underline{a}^L$	vowel constriction *tone	*vowel *constriction *tone	

2	{vowel, constriction, tone}	recover {vowel, constriction, tone}	overlap	economize
a	ʔa^L	vowel constriction tone	**	*vowel *constriction *tone
b	$\underline{a}^L$	vowel constriction *tone		*vowel *constriction *tone
c	a^Lʔ	vowel *constriction tone	**	*vowel *constriction *tone

3	{vowel, constriction, tone}	economize	recover {vowel, constriction, tone}	overlap
a	ʔa^L	*vowel *constriction *tone	vowel constriction tone	**
b	a^Lʔ	*vowel *constriction *tone	vowel *constriction tone	**
c	$\underline{a}^L$	*vowel *constriction *tone	vowel constriction *tone	

4	{vowel, constriction, tone}	economize	overlap	recover {vowel, constriction, tone}
a	ʔa^L	*vowel *constriction *tone	**	vowel constriction tone
b	a^Lʔ	*vowel *constriction *tone	**	vowel *constriction tone
c	$\underline{a}^L$	*vowel *constriction *tone		vowel constriction *tone

The argument, then, is that tonal contrasts are best perceived and best produced when phonetically occurring with modal voice. Consequently, tone and non-modal phonatory gestures are sequenced in laryngeally complex vowels of this type. As I now show, in Mazatec, non-modal phonatory gestures are phased early in the toned vowel (**V̰V**, **V̤V**) (Kirk, Ladefoged, and Ladefoged 1993, Ladefoged, Maddieson and Jackson 1988, Ladefoged and Maddieson 1995, Silverman, Blankenship, Kirk, and Ladefoged 1995). In Trique, they interrupt the toned vowel (**VhV**, **VʔV**) (Longacre 1957, Gudschinsky 1959, Hollenbach 1977). In Chinantec, aspiration is phased late in the toned vowel (**Vh**).

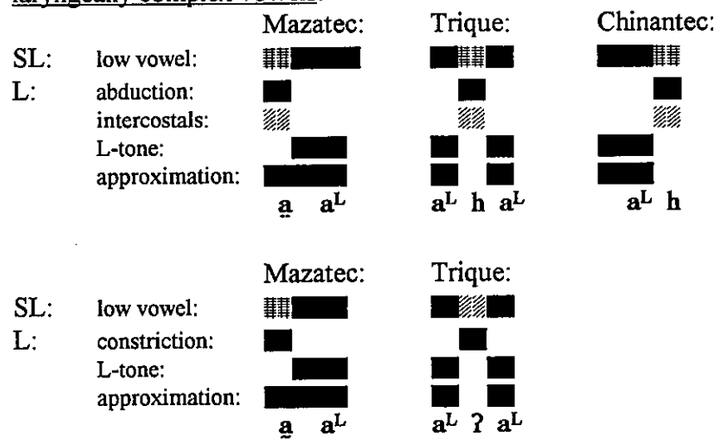
5.3.3 Gestural Sequencing in Laryngeally Complex Languages

In this section, I investigate the laryngeally complex Otomanguean languages of Mazatec, Trique, and Chinantec.

Mazatec realizes laryngeally complex vowels with early breathiness and early glottalization, while Trique possesses so-called "interrupted" vowels. Interrupted vowels are claimed below to be single vowels containing a laryngeal interruption (either **h** or **ʔ**). Interrupted vowels indeed pattern as single vowels in the phonology of Trique; here, the abduction or constriction is phased to the mid portion of the vowel. Finally, Chinantec possesses post-vocalic aspiration.

I employ a low vowel with a high tone in the example in (55).

(55) laryngeally complex vowels:



Case Study: Jalapa Mazatec

Jalapa Mazatec (Pike and Pike 1947, Kirk 1966, Bull 1983, 1984, Steriade 1992, Silverman 1994a, Kirk, Ladefoged, and Ladefoged 1993, Silverman, Blankenship, Kirk, and Ladefoged 1995) is spoken by 10-15,000 people in the states of Oaxaca and Veracruz, Mexico, and is a member of the Popolocan branch of Otomanguean.

Jalapa Mazatec contains the segment inventory shown in (56) (from Silverman, Blankenship, Kirk, and Ladefoged 1995).

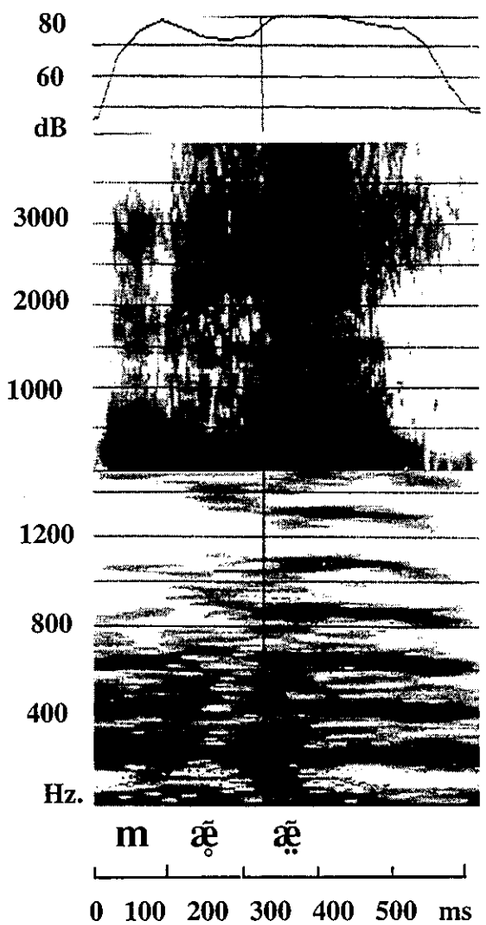
(56) Jalapa Mazatec segment inventory:

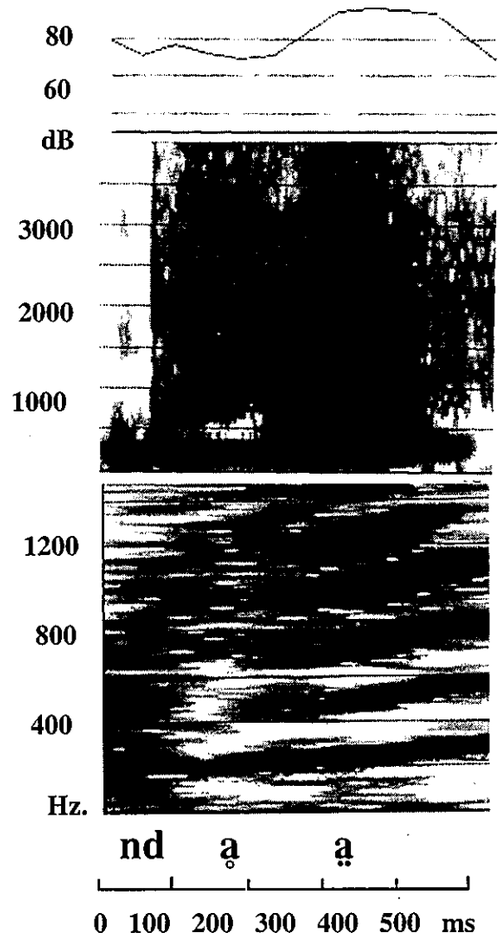
(p)	t	ts	tʃ	k	i	u
(pʰ)	tʰ	tsʰ	tʃʰ	kʰ		o
(ᵐb)	ⁿd	ⁿdz	ⁿdʒ	ᵑg	æ	a
	s		ʃ			
m	n		ɲ	ŋ		
	(l)					
w		j				
h,ʔ						

(parenthesized segments are limited to loanwords)

Tone, nasality, and length contrasts greatly expand the vowel inventory. Mazatec posseses three level tones (**H**, **M**, **L**), as well as a series of tonal contours (**LM**, **LH**, **ML**, **MH**, **HL**, **HM**, **LML**, **LHL**, **MHL**; Kirk 1966).

Breathiness or creakiness may accompany Mazatec vowels. In either case, non-modal phonation is realized primarily in the first portion of the vowel. The second portion of the vowel usually possesses severely weakened breathiness or creakiness, verging on modal phonation. In (57) and (58) are examples of both wideband and narrowband spectrograms of breathy vowels, along with energy contours (taken from Silverman, Blankenship, Kirk, and Ladefoged 1995). The narrowband spectrograms show that noise during strong breathy phonation often weakens the harmonic structure by increasing harmonic bandwidths. During their latter, less-breathy portion, harmonic structure is often strengthened, indicated by harmonic bandwidth narrowing. Under the assumption that overall energy is greater during less-breathy phonation than during more-breathy phonation, the energy contour may help to determine the onset of less-breathy voicing: an increase in energy should accompany the transition from more-breathy voice to less-breathy voice. This assumption is confirmed by those narrowband spectrograms in which harmonic structure reveals strong breathiness, as the onset of a salient harmonic pattern coincides with an increase in overall energy. Note finally that the onset of less-breathy voice is often accompanied by a moderate increase in fundamental frequency: as breathy phonation involves a laxing of the vocal folds, the moderate tensing involved in shifting to modal phonation may induce a moderate increase in rate of fold vibration.


80
60
dB
3000
2000
1000
1200
800
400
Hz.
m
æ̰
æ̤
0 100 200 300 400 500 ms


80
60
dB
3000
2000
1000
1200
800
400
Hz.
nd
a̰
a̤
0 100 200 300 400 500 ms

As discussed by Silverman, Blankenship, Kirk, and Ladefoged (1995), creaky vowels, like breathy vowels, manifest their non-modal phonation primarily during the first portion of the vowel.

The sonorants consonants and glides of Jalapa Mazatec are perhaps unique in that laryngeal contrasts may either precede or follow modal phonation. When the laryngeal contrast precedes the modally phonated sonorant, the transition from onset to nucleus is modally phonated. Some contrasts are shown in (59) (from Silverman, Blankenship, Kirk, and Ladefoged 1995).

(59)	aspirated nasals and glides:		laryngealized nasals and glides:	
	m̥ma^{M}	black	**ti**^{H}**ʔmæ**^{M}	he is sick
	n̥næ^{M}	he falls	**ʔna**^{M}	shiny
	ɲ̥ɲa^{M}	growth, bush	**ʔɲa**^{L}	chills
	j̥ju^{M}	peace	**ʔja**^{L}	ants
	w̥wa^{L}	Juán	**ʔwV**	(no examples)

These laryngeally contrastive sonorants are optimally realized, in that the laryngeal gesture precedes modal phonation.

When the laryngeal contrast follows the modally phonated sonorant, it is primarily the vowel which is laryngeally modified. As shown above, the first portion of the vowel bears strong non-modal phonation, and the second portion of the vowel bears nearly modal phonation. Some examples are in (60).[6] Doubled vowel symbols here do not indicate length, but instead indicate partially creaked or breathy phonation.

(60)	breathy vowel:		creaky vowel:	
	mæ̤æ̤:^{ML}	wants	**mo̰o**^{M}**sḛe**^{M}	eviction
	na̤a^{MH}	my tongue	**næ̰æ**^{M}	he says
	ɲV̤V	(no examples)	**ɳV̰V**	(no examples)
	jæ̤æ^{L}	boil	**jwa̰aj**^{M}**tsẽ:j**^{M}	he remembers
	wV̤V	(no examples)	**wV̰V**	(no examples)

In these cases, it is the vowel that bears the primary burden of encoding the laryngeal gesture. However, as Jalapa Mazatec vowels are laryngeally complex--bearing tone as well as non-modal phonation--the laryngeal gesture is phased such that it is realized primarily on the first portion of the vowel.

[6]Breathy and creaky vowels may also occur with the plain and voiced plosives, as well as the fricatives. As is always the case, aspirated plosives may not occur with breathy vowels (but see footnote 7).

Observe additionally that Jalapa Mazatec is analyzed as possessing a series of aspirated voiceless plosives (see 56). The following question now arises: as all other instances of immediately pre-vocalic non-modal phonation are analyzed as nuclear in affiliation, why should aspiration following the voiceless plosives be analyzed as *pre-nuclear* in affiliation? The answer to this question stems from the fact that aspirated stops are the only pre-vocalic laryngeal contrasts that may occur with a vocalic laryngeal contrast. Specifically, aspirated stops may occur with creaky phonation on the vowel, whereas no other syllable pattern possesses more than one instance of non-modal phonation. Some examples are in (61).

(61)	aspirated stops with creaky vowels in Jalapa Mazatec:	
	tj̰õõ^{M}	fifteen
	t̰i^{M}**k**^{h}**a̰a**^{H}	get (carry)
	tʃ^{h}**a̰a**^{L}	spoon

This unique distribution is acceptable due to the abrupt discontinuity of the acoustic signal that aspiration induces at stop releases. While the interval following stop releases are acoustically salient--that is, markedly distinct from their surrounding environment--the same cannot be said of aspiration in other environments. I have already argued that a laryngeal abduction intervening between a sonorant and a vowel is optimally implemented as breathiness ("murmur"), in order for formant transitions to be encoded. Given the phonetic co-occurence of voicing and breathiness here, a laryngeal abduction in this context does not provide as pronounced a discontinuity of the speech signal. Given this relative non-salience, it is far less likely that aspiration here may be followed by an additional laryngeal contrast.

Note finally that the Jalapa contrasts *creaky* phonation following aspirated stops, but does not contrast *breathy* phonation in this context, as breathy phonation would not provide a salient contrast in the context of an aspirated stop. Thus, for example **t**^{h}**a** does not provide a salient contrast with **t**^{h}**a̤a**, but is sufficiently contrastive with **t**^{h}**a̰a** Indeed, I am aware of no language which contrasts breathy phonation in the context of a preceding aspirated stop.[7]

The phasing patterns in (62) and (63) formally characterize the laryngeally complex vowels of Jalapa Mazatec.

[7]Huffman (1985) reports a single possible exception in the Ban Thung Saphan dialect of Chong--**c**^{h}**a̰ak**, foot--in which both aspiration at stop release and breathy phonation on the vowel are contrastive with their absence. However, he considers the datum "suspect" (p.361), as no other word in the language patterns similarly.

(62) vowels, abductions, and tone in Jalapa Mazatec:

1	recover {vowel, abduction, tone}	economize	overlap	phase optimal
a ☞	vowel tone abduction	*vowel *tone *abduction *intercostals	**	**vowel⇧⟨abduction⇧intercostals⇨tone⟩** vowel: tone: abduction: intercostals: h a^L
b	vowel tone *abduction	*vowel *tone *abduction *intercostals	**	**vowel⇧⟨tone⇨abduction⇧intercostals⟩** vowel: tone: abduction: intercostals: a^L h
c	vowel *tone abduction	*vowel *tone *abduction *intercostals		**vowel⇧tone⇧abduction⇧intercostals** vowel: tone: abduction: intercostals: a^L

-or-

3	economize	recover {vowel, abduction, tone}	overlap	phase optimal
a ☞	*vowel *tone *abduction *intercostals	vowel tone abduction	**	ha^L
b	*vowel *tone *abduction *intercostals	vowel tone *abduction	**	a^Lh
c	*vowel *tone *abduction *intercostals	vowel *tone abduction		a^L

-or-

4	economize	overlap	recover {vowel, abduction, tone}	phase optimal
a ☞	*vowel *tone *abduction *intercostals	**	vowel tone abduction	ha^L
b	*vowel *tone *abduction *intercostals	**	vowel tone *abduction	a^Lh
c	*vowel *tone *abduction *intercostals		vowel *tone abduction	a^L

(63) vowels, constrictions, and tones in Jalapa Mazatec:

1	recover {vowel, constriction, tone}	economize	overlap	phase optimal
a ☞	vowel constriction tone	*vowel *constriction *tone	**	**constriction⇨⟨vowel⇧tone⟩** vowel: constriction: tone: ʔ a^L
b	vowel *constriction tone	*vowel *constriction *tone	**	**vowel⇧⟨tone⇨constriction⟩** vowel: constriction: tone: a^L ʔ
c	vowel constriction *tone	*vowel *constriction *tone		**vowel⇧tone⇧constriction** vowel: constriction: tone: a^L

-or-

2	recover {vowel, constriction, tone}	overlap	economize	phase optimal
a ☞	vowel constriction tone	**	*vowel *constriction *tone	$ʔa^L$
b	vowel constriction *tone		*vowel *constriction *tone	a^L
c	vowel *constriction tone	**	*vowel *constriction *tone	$a^Lʔ$

-or-

3	economize	recover {vowel, constriction, tone}	overlap	phase optimal
a ☞	*vowel *constriction *tone	vowel constriction tone	**	ʔa^{L}
b	*vowel *constriction *tone	vowel *constriction tone	**	a^{L}ʔ
c	*vowel *constriction *tone	vowel constriction *tone		a̰^{L}

-or-

4	economize	overlap	recover {vowel, constriction, tone}	phase optimal
a ☞	*vowel *constriction *tone	**	vowel constriction tone	ʔa^{L}
b	*vowel *constriction *tone	**	vowel *constriction tone	a^{L}ʔ
c	*vowel *constriction *tone		vowel constriction *tone	a̰^{L}

ha represents the phonetically optimal phasing relationship between abductions, toned vowels. This pattern is available when aspiration either stands alone with respect to a (toned) vowel, or when aspiration and a preceding consonant are phased with respect to a (toned) vowel. In the context of a preceding voiceless stop, aspiration is voiceless; in the context of a preceding sonorant, aspiration is implemented simultaneously with voicing, that is, as breathy phonation. These patterns are conflated in the table in (71). **ʔa** represents the phonetically optimal phasing relation between constrictions and toned vowels. Indeed, this is the only phasing pattern between vowels, constrictions, and tone which is attested in Jalapa.

In summary, Jalapa Mazatec nuclei possess both tone and phonation contrasts, that is, are laryngeally complex. Therefore, the non-modal phonatory gesture is phased to precede the tonal gesture, so that all contrastive information is recoverable.

Case Study: Trique

I have thus far shown that laryngeally complex vowels are realized with early non-modal phonation in Jalapa Mazatec. I now show that Trique implements a second realization of laryngeally complex vowels. In addition to pre-vocalic and post-vocalic laryngeals, Trique also possesses laryngeally interrupted vowels, in which the laryngeal

gesture intrudes upon the central portion of the otherwise modal vowel, a phasing which is maximally distinct from elsewhere-attested pre-vocalic and post-vocalic laryngeals.

The word in Trique normally consists of a bisyllabic root and sub-syllabic inflectional material (consisting of tone, length, ablaut, and/or consonantism). This morphological complex is called a "couplet" (foot) by Longacre (1957), in his discussion of Trique in the context of Proto-Mixtecan. A couplet's first and second syllables are referred to as "penultima" and "ultima," respectively.

The San Juan Copala dialect of Trique possesses the segment inventory listed in (64).

(64) San Juan Copala Trique segment inventory:

p	t				k		i	ɨ	u
b	d				g		e		o
		tʃ	cç	ʈʂ				a	
s	ʃ		ʂ						
	z	ʒ							
				ɾ					
m	n								
	l								
			j		w				

ʔ, h

(p and b occur only in loans)

The San Juan Copala dialect possesses eight contrastive tonal patterns, shown in (65).

(65). **21, 32, 3, 34, 35, 4, 5, 53**
(where **1** is highest, **5** is lowest)

Vowels may be contrastively nasalized.

In Trique, couplets are stress-final, accompanied by lengthening of open ultimas, with a freer distribution of consonants in ultimas than in penultimas. Only the laryngeals (ʔ and **h**) may close syllables, and only ultimas may be closed. Examples of lengthened

open ultimas are presented in (66), from the various dialects discussed by Longacre (1957).[8]

(66)	**ma^{4}re:^{3}**	red
	gu^{3}na:^{23}	to remain
	ra^{3}ʔa:^{3}	hand
	ri^{3}o:^{43}	trough, manger

Examples of laryngeal codas are presented in (67).

(67)	**waʔ^{5}**	the right	**ʒu^{2}kwah^{1}**	to be twisted
	jaʔ^{34}	teeth	**jah^{3}**	ashes
	ni^{5}kaʔ^{5}	five	**rah^{21}**	to grind

In Trique, ultima vowels may be laryngeally interrupted, in which **h** or **ʔ** intrude on the vowel (i.e., **VhV**, **VʔV**). Interruption is exemplified in (68).

(68)	**ga^{3}tuʔu^{43}**	incense-burner[9]
	ri^{3}uhu^{53}	hollow reed
	na^{3}ʔaha^{43}	conversation

Longacre presents six reasons to interpret interrupted vowels as laryngeal gestures phased to interrupt a single vocalic gesture, rather than a phased sequence involving two distinct vowel gestures.

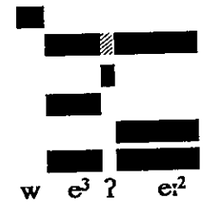
(1) interrupted vowels are distinguished from true sequences of vowel-laryngeal-vowel, in that interrupted forms do not undergo final lengthening. Thus **weʔe^{3}** (house) is monosyllabic, while **we^{3}ʔe:^{2}** (beautiful) is bisyllabic.

[8]Longacre does not actually provide phonetic transcriptions which indicate length, but reports that "non-phonemic stress and non-phonemic lengthening of unchecked vowels occur regularly on the final syllable..." (p.15).

[9]While Longacre does not discuss the phonetic interaction of tone and interruption, I assume that each toneme manifests itself on one half of the interrupted vowel, thus *tuʔu^{43}* = **tu^{4}ʔu^{3}**.

(69) interrupted vowel:

true V-ʔ-V sequence:



Longacre hypothesizes that since interrupted vowels manifest their vocalism on either side of the laryngeal, each half is a single mora in length. Therefore, lengthening under stress does not apply. Trique thus possesses an inviolable constraint: **stressed open syllables are bimoraic**. Further examples are presented in (70). While not explicitly discussed by Longacre, it seems that only the glottal stop may contrast in this fashion; true **V-h-V** sequences seem unattested.

(70)	interrupted vowels:		true vowel-laryngeal-vowel sequences:	
	jaha^{3}	flower	**da^{3}ʔa:^{34}**	cord, root
	joʔo^{3}	year	**jo^{3}ʔo:^{53}**	the gummy deposit made by smoke from a wood fire
	na^{3}kihi^{43}	atole		
			ʔu^{5}ʔu:^{5}	five

(2) Longacre shows that interrupted forms lose their second vocalic component in phrasal contexts:

(71)	**jaha^{3}**	but	**jah^{3} zi^{3}ŋa^{2}**	nasturtiums
	joʔo^{3}	but	**joʔ^{3} ga^{3}ci^{23}**	the past year
	nakihi^{43}	but	**nakih^{4} ru^{4}ne^{43}**	bean-atole

This elision is not reported for true **V-ʔ-V** sequences.

(3) Interrupted vowels often appear in otherwise canonical bisyllabic words, whereas true trisyllabic words are quite rare.

(72)	**na^{4}kihi^{3}**	atole	**ga^{3}uʔu^{43}**	incense burner
	gi^{3}ʔjaha^{43}	holy day, festival	**re^{3}kaʔa^{43}**	stick
	na^{2}nihi^{54}	open	**re^{3}keʔe^{43}**	splinter
	da^{3}kuhu^{54}	ascent		

(4) Tonal sequences occurring on interrupted forms are limited to those which occur on single vowels.

(5) Voiceless obstruents and "fortis" nasal consonants may occur before interrupted sequences. Elsewhere, these consonants are limited to word-final syllables. If interrupted vowels are single nuclei, then a strong generalization may be made regarding the distribution of voiceless and fortis consonants; interrupted vowels are limited to final syllables.

(6) Interrupted vowels always possess but a single vowel quality, whereas true sequences may possess two vowel qualities (reported in Longacre 1957, no examples given).

Were all **VʔV** and **VhV** sequences treated as bisyllabic, final lengthening in some forms but not others would not be explained. Furthermore, their asymmetrical elision patterning would not be explained. The fact that these forms, to the exclusion of most others, may be trisyllabic would not be explained. Moreover, the distribution of both tonal contours and fortis consonants would not be explained. Finally, why these forms always possess but a single vowel quality would not be explained.

Let us now summarize the distribution of laryngeal gestures in Trique ultimas. First, laryngeals may stand in onset position (**ʔV:**). Second, laryngeals may interrupt the vowel (**VʔV, VhV**). Finally, laryngeals may close a syllable (**Vʔ, Vh**). Trique is thus perhaps unique in allwing three distinct phasing relations between phonatory gestures, tone, and vowels.

(73) Trique laryngeally complex vowels with laryngeal abductions:

1	phase optimal	recover {vowel, abduction, tone}	economize	overlap
a ☞	**vowel⇳⟨abduction⇳ intercostals⇨tone⟩** vowel: tone: abduction: intercostals: **h** **a^{L}**	vowel tone abduction	*vowel *tone *abduction *intercostals	**
b	**vowel⇳⟨tone⇨ abduction⇳intercostals⇨ tone⟩** vowel: tone: abduction: intercostals: **a^{L} h a^{L}**	vowel tone abduction	*vowel *tone *abduction *intercostals	***
c	**vowel⇳⟨tone⇨ abduction⇳intercostals⟩** vowel: tone: abduction: intercostals: **a^{L} h**	vowel tone *abduction	*vowel *tone *abduction *intercostals	**
d	**vowel⇳tone⇳abduction⇳ intercostals** vowel: tone: abduction: intercostals: **a^{L}**	vowel *tone abduction	*vowel *tone *abduction *intercostals	

-or-

2	phase optimal	recover {vowel, abduction, tone}	overlap	economize
a ☞	**ha^{L}**	▮vowel ▮tone ▮abduction	**	*vowel *tone *abduction *intercostals
b	**a^{L}ha^{L}**	▮vowel ▮tone ▮abduction	***	*vowel *tone *abduction *intercostals
c	**a^{L}h**	▮vowel ▮tone ▤*abduction	**	*vowel *tone *abduction *intercostals
d	**a̤^{L}**	▮vowel ▤*tone ▮abduction		*vowel *<u>tone</u> *<u>abduction</u> *intercostals

-or-

3	phase optimal	economize	recover {vowel, abduction, tone}	overlap
a ☞	**ha^{L}**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	**
b	**a^{L}ha^{L}**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	***
c	**a^{L}h**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▤*abduction	**
d	**a̤^{L}**	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	▮vowel ▤*tone ▮abduction	

Second, as Trique vowels are laryngeally complex, non-modal phonation and tone are sequenced when both occupy nuclear position. More specifically, non-modal phonation interrupts the vowel: **vowel⇧⟨tone⇨abduction⇨tone⟩**.

(74)

1	phase *optimal	recover {vowel, abduction, tone}	economize	overlap
a	**vowel⇧⟨abduction⇧intercostals⇨tone⟩** vowel: ▤▮▮▮▮ tone: ▮▮▮▮ abduction: ▮ intercostals: ▨ **h a^{L}**	▮vowel ▮tone ▮abduction	*vowel *tone *abduction *intercostals	**
b ☞	**vowel⇧⟨tone⇨abduction⇧intercostals⇨tone⟩** vowel: ▮▮▤▮▮ tone: ▮▮ ▮▮ abduction: ▤ intercostals: ▨ **a^{L} h a^{L}**	▮vowel ▮tone ▮abduction	*vowel *tone *abduction *intercostals	***
c	**vowel⇧⟨tone⇨abduction⇧intercostals⟩** vowel: ▮▮▮▮▤ tone: ▮▮▮▮ abduction: ▤ intercostals: ▨ **a^{L} h**	▮vowel ▮tone ▤*abduction	*vowel *tone *abduction *intercostals	**
d	**vowel⇧tone⇧abduction⇧intercostals** vowel: ▮▮▮▮ tone: ▤▤▤▤▤▤▤▤ abduction: ▮▮▮▮ intercostals: ▨▨▨▨ **a̤^{L}**	▮vowel ▤*tone ▮abduction	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	

-or-

2	phase *optimal	economize	recover {vowel, abduction, tone}	overlap
a	**ha**^{L}	*vowel *tone *abduction *intercostals	vowel tone abduction	**
b ☞	**a**^{L}**ha**^{L}	*vowel *tone *abduction *intercostals	vowel tone abduction	***
c	**a**^{L}**h**	*vowel *tone *abduction *intercostals	vowel tone *abduction	**
d	**a̤**^{L}	*vowel *tone *abduction *intercostals	vowel *tone abduction	

-or-

3	phase *optimal	economize	recover {vowel, abduction, tone}	overlap
a	**ha**^{L}	*vowel *tone *abduction *intercostals	vowel tone abduction	**
b ☞	**a**^{L}**ha**^{L}	*vowel *tone *abduction *intercostals	vowel tone abduction	***
c	**a**^{L}**h**	*vowel *tone *abduction *intercostals	vowel tone *abduction	**
d	**a̤**^{L}	*vowel *tone *abduction *intercostals	vowel *tone abduction	

Finally, the toned vowel may be followed by the abduction: **vowel⇧⟨tone⇨abduction⟩**. This phonetically sub-optimal phasing configuration is employed in order to render both tone and phonation salient, while simultaneously expanding the system of phasing contrasts. Moreover, it is likely that post-vocalic aspiration here is implemented with an increase in internal intercostal muscular activity, in order to enhance the likelihood of recoverability here. Consequently, post-vocalic aspiration comes at an articulatory cost, thus violating **economize**. Finally, were non-

modal phonation phased in parallel with tone--**vowel⇧abduction⇧tone**--tone might would be non-recoverable, violating **recover**.

(75)

1	phase **optimal	recover {vowel, abduction, tone}	economize	overlap
a	**vowel⇧⟨abduction⇧intercostals⇨tone⟩** vowel: tone: abduction: intercostals: **h** **a**^{L}	vowel tone abduction	*vowel *tone *abduction *intercostals	**
b	**vowel⇧⟨tone⇨abduction⇧intercostals⇨tone⟩** vowel: tone: abduction: intercostals: **a**^{L} **h** **a**^{L}	vowel tone abduction	*vowel *tone *abduction *intercostals	***
c ☞	**vowel⇧⟨tone⇨abduction⇧intercostals⟩** vowel: tone: abduction: intercostals: **a**^{L} **h**	vowel tone *abduction	*vowel *tone *abduction *intercostals	**
d	**vowel⇧tone⇧abduction⇧intercostals** vowel: tone: abduction: intercostals: **a̤**^{L}	vowel *tone abduction	*vowel *tone *abduction *intercostals	

-or-

2	phase **optimal	economize	recover {vowel, abduction, tone}	overlap
a	**ha**^{L}	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	**
b	**a**^{L}**ha**^{L}	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	***
c ☞	**a**^{L}**h**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▤*abduction	**
d	**a̤**^{L}	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	▮vowel ▤*tone ▮abduction	

-or-

3	phase **optimal	economize	recover {vowel, abduction, tone}	overlap
a	**ha**^{L}	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	**
b	**a**^{L}**ha**^{L}	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	***
c ☞	**a**^{L}**h**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▤*abduction	**
d	**a̤**^{L}	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	▮vowel ▤*tone ▮abduction	

Now consider the phasing of constrictions and tone.

First, toned vowels may be preceded by a laryngeal constriction: **vowel⇧⟨constriction⇨tone⟩**. This phasing pattern partially violates **overlap**, but is optimal.

(76) <u>Trique laryngeally complex vowels with laryngeal constrictions</u>:

1	phase optimal	recover {vowel, constriction, tone}	economize	overlap
a ☞	**vowel⇧⟨constriction⇨tone⟩** vowel: constriction: tone: ʔ **a**^{L}	▮vowel ▮constriction ▮tone	*vowel *constriction *tone	**
b	**vowel⇧⟨tone⇨constriction ⇨tone⟩** vowel: tone: constriction: **a**^{L} ʔ **a**^{L}	▮vowel ▮constriction ▮tone	*vowel *constriction *tone	***
c	**vowel⇧⟨tone⇨constriction⟩** vowel: constriction: tone: **a**^{L} ʔ	▮vowel ▤*constriction ▮tone	*vowel *constriction *tone	**
d	**vowel⇧tone⇧constriction** vowel: constriction: tone: **a̤**^{L}	▮vowel ▮constriction ▤*tone	*vowel *<u>constriction</u> *<u>tone</u>	

Second, the constriction and tone are sequenced when both occupy nuclear position. More specifically, the constriction interrupts the vowel: **vowel⇧⟨tone⇨constriction⇨tone⟩**. This pattern is employed in order to render both tone and phonation salient, while simultaneously expanding the system of phasing contrasts.

(77)

1	phase *optimal	recover {vowel, constriction, tone}	economize	overlap
a	**vowel⇧⟨constriction⇨tone⟩** vowel: constriction: tone: ʔ a^L	vowel constriction tone	*vowel *constriction *tone	**
b ☞	**vowel⇧⟨tone⇨constriction ⇨tone⟩** vowel: tone: constriction: a^L ʔ a^L	vowel constriction tone	*vowel *constriction *tone	***
c	**vowel⇧⟨tone⇨constriction⟩** vowel: constriction: tone: a^L ʔ	vowel *constriction tone	*vowel *constriction *tone	**
d	**vowel⇧tone⇧constriction** vowel: constriction: tone: a^L	vowel constriction *tone	*vowel *constriction *tone	

Also, the toned vowel may be followed by the constriction: **vowel⇧⟨tone⇨ constriction⟩**.

(78)

1	phase **optimal	recover {vowel, constriction, tone}	economize	overlap
a	**vowel⇧⟨constriction⇨tone⟩** vowel: constriction: tone: ʔ a^L	vowel constriction tone	*vowel *constriction *tone	**
b	**vowel⇧⟨tone⇨constriction ⇨tone⟩** vowel: tone: constriction: a^L ʔ a^L	vowel constriction tone	*vowel *constriction *tone	***
c ☞	**vowel⇧⟨tone⇨constriction⟩** vowel: constriction: tone: a^L ʔ	vowel *constriction tone	*vowel *constriction *tone	**
d	**vowel⇧tone⇧constriction** vowel: constriction: tone: a^L	vowel constriction *tone	*vowel *constriction *tone	

Finally, again, were the constriction phased in parallel with tone--**vowel⇧ constriction⇧tone**--tone would be non-recoverable.

In summary, as vowels in Trique possess both tone and phonation contrasts, that is, are laryngeally complex, the non-modal phonatory gesture is phased to interrupt the tonal gesture, so that all contrastive information is recoverable. Three distinct phasing patterns involving tone and non-modal phonation in Trique: laryngeals may precede the vowel, interrupt the vowel, or follow the vowel. Note especially that laryngeal interruption is the maximally distinct phasing pattern from elsewhere-attested pre-vocalic and post-vocalic laryngeals.

5.4 Vowels and Laryngeal Gestures in Comaltepec Chinantec

In this section I examine the phenomenon of lexical and morphemic "ballistic" accent in Chinantec.

Ballistic syllables are reportedly articulated more forcefully than "controlled" (non-ballistic, or plain) syllables, affecting pitch, amplitude and phonation. Ballisticity has traditionally been considered a stress-based property of syllables (Rensch 1978, *inter alia*). (Ballisticity is traditionally indicated by an acute accent over the vowel.)

(79)

ballistic		controlled		
ló^{LH}	lime	**lo:**^{H}	skin	Comaltepec dialect (Anderson 1990)
ʔmá^{H}	food	**na**^{H}	now	Palantla dialect (Merrifield 1963)
tý:^{M}	blind	**ty:**^{M}	Peter	Quiotepec dialect (Robbins 1968)

In section 5.4.2, I argue that ballisticity is laryngeally-based, involving a post-vocalic laryngeal abduction, with concomitant increased intercostal muscular activity employed in order to increase the likelihood of recoverability. I present spectrographic evidence from Comaltepec in support of this characterization, showing that ballistic syllables differ from near-minimally contrasting controlled syllables in possessing significant postvocalic aspiration.

I next discuss the distributional and phonological patterning of ballisticity: the laryngeal abduction follows the modally phonated vowel so that all contrasts achieve acoustic transparency.

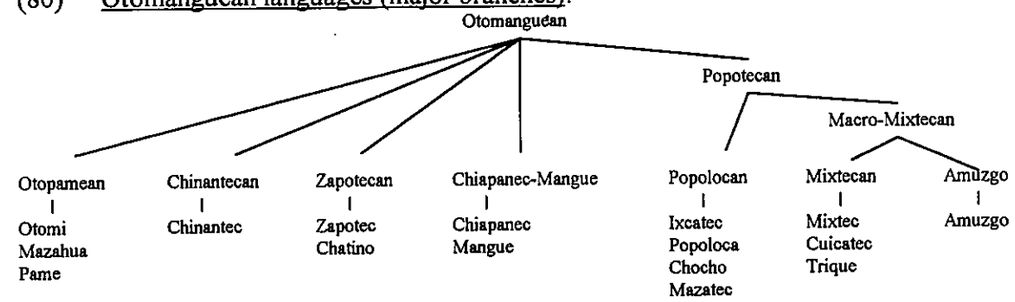
In 5.4.3 I discuss correspondences in other dialects: in Usila and Ojitlán, a pitch fall corresponds to Comaltepec post-vocalic aspiration, while Quiotepec possesses a pitch rise in place of ballisticity.

I begin with a brief overview of Comaltepec Chinantec phonology.

5.4.1 Overview of Comaltepec Chinantec Phonology

The Chinantecan language group is a member of the Otomanguean language family. According to Rensch (1976), Otomanguean consists of the Chinantecan, Otopamaen, Popolocan, Mixtecan, Zapotecan, Chiapanec Mangue, and Amuzgo groups.

(80) Otomanguean languages (major branches):



According to Swadesh (1966), Chinantecan branched from the Otomanguean tree at least sixteen centuries ago. Chinantecan presently consists of at least fourteen mutually unintelligible languages (Eglund 1978).

(81) Chinantec languages:

1. Ojitlán
2. Usila
3. Tlacoatzintepec, Mayultianguis, Quetzalapa
4. Chiltepec
5. Sochiapan
6. Tepetotutla
7. Tlapepusco
8. Palantla
9. Valle Nacional
10. Ozumacín
11. La Alicia, Río Chiquito, Temextitlán, Lalana
12. Lealao
13. Quiotepec, Yolox
14. Comaltepec

Comaltepec Chinantec (hereafter Comaltepec) is spoken by approximately 1400 people in the village of Comaltepec, State of Oaxaca, Mexico (Grimes 1988). An additional community lives in Culver City, California, and environs.

Comaltepec roots and words are usually monosyllabic. The rather rich inflectional system normally involves stem modification of root nuclei, resulting in monosyllabic stems that bear a particularly high informational load. Methods of stem modification involve nasalization, tone, length, consonantism, and phonation contrasts. Additionally, certain irregular patterns are marked by vocalic ablaut. In (82) is a sample partial verb paradigm. Syllable boundaries are indicated by tone marks. Prefixal material (the tense marker) is set off by a space (from Pace 1990:42).

(82)

koːˡhoˡ	I am playing	**koːʔˡ**	you (sg) are playing
niˡ koːˡʰhoʰ	I will play	**niˡ koːʔʰ**	you (sg) will play
kaˡ koᴹhoˡ	I played	**kaˡ koːʔᴹ**	you (sg) played
koːʔᴹ	we are playing	**koːṣˡ**	he/she/they are playing
niˡ koʰhoʔʰ	we will play	**niˡ koṣᴹ**	he/she/they will play
kaˡ koʰhoʔʰ	we played	**kaˡ koːṣˡ**	he/she/they played

Robbins (1968) characterizes the Chinantec morphological system as "vertical," in that morphemes are affixed *on top of* the root itself. This contrasts with "horizontal" systems, in which morphemes are linearly concatenated. In present terms, Chinantec morphology might be considered "parallel" in structure, as opposed to "serial."

In (83) is the segment inventory of Comaltepec.[10]

(83) Comaltepec segment inventory:

p	**t**	**tʃ**		**k**	**i**	**ɨ**	**u**
ᵐb	**ⁿd**	**ⁿdʒ**		**ᵑg**	**e**	**ʌ**	**o**
(f)	**s**	**(ʃ)**	**(ṣ)**	**(x)**	**æ**		**a**
			ʐ				
m	**n**			**ŋ**			
	l						
		j		**w**			

h,ʔ

(Parenthesized forms are restricted in their distribution. These restrictions are discussed momentarily.)

Examples illustrating segmental contrasts are provided in (84).

[10]Anderson, Martinez, and Pace do not include the glides j,w in their consonant inventory, instead considering these nonsyllabic **i,u**, respectively.

(84)

consonants:

pihʔʰ	little (i)	**tʃihʰ**	term of endearment
ᵐbʌʔˡʰ	ball	**ⁿdʒiːˡ**	dog
fiˡ	whistle	**ʃœ̃hˡʰ**	small deer
miːᴹ	plain	**jʌʔᴹ**	above
tiːˡ	thin (i)	**ʐoːˡ**	sweet
ⁿdoːhᴴˡʰ	maguey sap	**kiˡᴹ**	garbage
soːᴹ	ascent	**ᵑguːhᴴˡʰ**	owl
nuːˡ	grass	**xoʔˡ**	rotten
loːˡ	rabbit	**ŋuhˡᴹ**	meat
		wɨᴹ	spider

laryngeals:

hiˡ	book	**ʔoːᴹ**	papaya

vowels:

lihʰ	flower	**ᵐbʌʔˡʰ**	short
heʔˡᴹ	frog	**luˡ**	fly
ⁿdʒæˡ	person	**hoʔˡʰ**	maggot
lihʔʰ	circle	**taˡʰ**	work

The tones listed in (85) are attested in morphologically simplex environments. An example of each tone is presented.

(85)

L	**hiˡ**	book
H	**l̥loʔʰ**	pretty
M	**ⁿdʒœːᴹ**	earthen jar
LM	**ᵑgiŋʔˡᴹ**	swing
LH	**liˡʰ**	tepejilote palm shoot
HLH	**ʔŋiːhᴴˡʰ**	rope

Comaltepec syllables are of the form **ʔ/hCGVːᵀhNʔ** (obligatory elements are underlined). Long, glottally checked syllables are attested only in morphologically complex environments.

I now briefly consider the internal structure of the Comaltepec syllable, examining in turn **(1)** onsets, **(2)** nuclei , and **(3)** codas.

(1) Any consonant, as well as the glides **w**, **j**, and the laryngeals **ʔ**, **h**, may occupy onset position. Examples of each are presented in (80).

The sonorants, as well as the voiced velar stop, may additionally possess a contrastive laryngeal gesture. This laryngeal element is realized with the early portion of its accompanying supralaryngeal constriction. However, according to Anderson, Martinez, and Pace's (1990) analysis, when aspiration co-occurs with the velar stop, they are implemented as a voiceless velar fricative **x**. Examples are in (86).

(86)	**m̥miː**^{L}	water	**ʔmɨ**^{L}	feces
	n̥njœː^{L}	green beans	**ʔniːh**^{HLH}	rope
	ŋŋajŋʔʐ^{LM}	he kills	**ʔŋjoŋʔ**^{LM}	waist
	l̥loʔ^{H}	pretty	**ʔleː**^{L}	dust
	xoʔ^{L}	rotten	**ʔgoː**^{L}	elegant

The glides pattern with the sonorant consonants in allowing laryngeal contrasts (**ʔw**, **w̥w**, **ʔj**, **j̥j**). **w̥w** freely varies with f. Examples of these two patterns are presented in (87).

	with consonants:		with laryngeals:	
(87)	**ⁿdjeh**^{LH}	god	**j̥je**^{HM}	where
	ᵑgjuŋ^{M}	good (a)	**ʔjeː**^{L}	sun
	ᵑgwoː^{L}	hand	**w̥wɨː**^{L}	village (also **fɨː**^{L})
	kweː^{L}	long (i)	**ʔweʔ**^{L}	hard

Any consonant except **ʐ** and the labials may combine with the palatal glide **j**. However, **w** may co-occur only with the velar obstruents. According to Anderson, Martinez, and Pace's analysis, when **j** follows an alveolar consonant and precedes **u** (without a postnuclear nasal), it is realized as palatalization on the alveolar, and fronting and lowering of the vowel.

(88) **ʃœ̃h**^{LH} small deer

However, onset **j** is not contrastive in syllables with nuclear **i**. Similarly, onset **w** is not contrastive in syllables with nuclear **u**.

ja and **jæ** contrast only after laryngeals. After alveolars and labials, **jæ** may occur. After velars, **ja** is attested.

(89)	**hæ**^{LM}	spider	**tæŋ**^{L}	white (a)
	j̥jah^{LM}	cliff	**ʔlæh**^{L}	snare
	ʔæŋ^{LM}	very	**næh**^{LM}	open!
	ʔja^{LM}	griddle	**kjahʔʐ**^{H}	his
	ʔjaŋ^{L}	it sprouts	**ᵑgjaŋ**^{M}	twenty (a)
	ᵐbæ^{LM}	bunch	**ʔjah**^{L}	five (i)
	ʔmæː^{M}	I guard		

(2) Comaltepec possesses contrastive length with all vowel qualities. Some examples are in (90).

	short vowels:		long vowels:	
(90)	**lih**^{H}	flower	**tɨː**^{L}	thin (i)
	heʔ^{LM}	frog	**teː**^{L}	white (i)
	lɨʔ^{H}	circle	**tɨː**^{M}	foot
	ᵐbʌʔ^{LH}	short	**ʐʌː**^{L}	smooth
	lu^{L}	fly	**kuː**^{M}	money
	hoʔ^{LH}	maggot	**ʔoːh**^{H}	rotten
	ⁿdzɑ^{L}	person	**tɑːh**^{LH}	daddy
	ta^{LH}	work	**haŋ**^{L}	one (a)

Any vowel quality except **ʌː** may be contrastively nasal.

(91)	nasal vowels:	
	ʔĩ^{L}	stupid
	ʔẽːʂ^{LH}	his uncle
	hɨ̃ː^{H}	weasel
	hʌ̃ʔʐ^{L}	give
	tũːʔ^{M}	you pour it
	m̥miˡkõʔ^{MH}	you help him
	m̥miˡtõ^{LM}	Macuiltianguis town
	kãː^{M}	I charge (money)

Nuclei may possess post-vocalic aspiration. Syllables with such nuclei are traditionally considered to possess "ballistic stress." Ballistically stressed syllables are considered in detail in section 5.5.

(92) plain vowels: vowels with post-vocalic aspiration:

ⁿgwoːL	good (i)	ⁿgjʌŋ̥M	hand
heʔLM	frog	lihH	flower

Finally, in certain clitic environments, nasals may occupy the nuclear position.

(93) syllabic nasals:

kaLbʌːMn̥n̥L	we hit (yesterday)
niLʔiːHLHn̥n̥H	I will sweat
ŋ̥ŋ̥an̥LʔnLL	I kill

(3) Coda consonants in morphologically simplex environments are limited to ŋ, ʔ, and ŋʔ. Examples are provided in (94).

(94)

huhʔH	pineapple	w̥wiŋLM	many
taʔLM	honey	ⁿgiŋ̥ʔLM	swing
ⁿgjuŋ̥H	good (a)		

In morphologically complex environments, the coda system may be somewhat more complex, allowing **p**, a cliticized form of the copula, **bahʔH**, and **z/ʂ**, a cliticized form of the third person pronoun, **ʔiʂL**. The voiceless alternant is presumably found only in ballistic contexts. Examples are provided in (95).

(95)

hipL	it's a book	ʔjaʂL	her griddle
pihʔpH	it's little	s̃ɨʔzʐH	his clothing

As stated above, Comaltepec possesses roots that are predominantly monosyllabic, while the inflectional system is by and large subsyllabic. A single syllable may thus contain not only the root, drawn from the open class, but also (in the case of verb complexes) active/stative markers, gender markers (two classes), transitivity markers (three classes) aspect (three classes), and possibly subject pronoun clitics (two subsyllabic classes). Thus the Comaltepec syllable bears an unusually high informational load.

Were syllable structure sufficiently complex, subsyllabic morphemic material might at least possess segmental status. In fact, as shown above, the Comaltepec syllable is, segmentally speaking, maximally **CGVNʔ**.

One thus might conjecture that Comaltepec possesses an unusually rich segment inventory. Yet as shown above, under most theories of segmentation, the Comaltepec inventory is comparatively impoverished: the vowel space is occupied by eight qualities,

and the consonant inventory contains up to twenty members, possessing none of the subtle place distinctions found in Dravidian, nor the back articulations of Caucasian.

How then does Comaltepec encode the many contrasts that may be required of a given syllable, without excessive homophony? The answer lies primarily in the extent to which additional contrasts may be superimposed on vowel quality: Comaltepec nuclei possess contrastive tone, and may possess post-vocalic aspiration, contrastive nasalization, and length, thus resulting in extensive parallel production of contrastive values.

In Comaltepec, eight vowel qualities (**i,e,æ,a,o,ʌ,ɨ,u**) may be combined with five tonal qualities (**V**H, **V**M, **V**L, **V**LM, **V**LH), two voice qualities (**V**, **Vh**), a binary nasality contrast (**V**, **Ṽ**), as well as a binary length contrast (**V**, **V**ː). The cross-classification of these five independent systems results in 320 possible nucleus qualities (8 x 5 x 2 x 2 x 2). Thus a single vowel quality may possess up to forty contrastive values. Note that as vowels are more sonorous than consonants, a given vowel quality is better suited to bear the acoustic burden of encoding contrastive information in parallel fashion. Thus a given sonorant onset consonant may only be contrastively aspirated or glottalized, as well as plain. Obstruent onset consonants may only be plain or voiced.

It should not be surprising that these monosyllabic morphological complexes in Comaltepec are obligatorily stressed. While the specific articulatory analogs of stress remain elusive, its function in Comaltepec seems clear: the overall increased amplitude and duration that are usually present under stress results in an acoustic signal which possesses a relatively greater amount of acoustic energy, thus rendering the elements under stress more auditorily prominent. This auditory prominence enhances the many contrasts that a given root syllable potentially bears.

Let us then consider the circumstances under which *unstressed* syllables are found in Comaltepec and other dialects.

Post-tonic and pre-tonic syllables consist of a limited set of clitics, person-of-subject inflectors (in verbs), and possessors (in nouns). Pre-tonic syllables consist of "a handful of verbal prefixes and a few proclitic functors" (Anderson, Martinez, and Pace 1990:4), as well as elements morphologically associated with the tonic (that is, the first syllable of bisyllabic noun or verb roots). Post-tonic syllables possess "a limited number of tone patterns and syllable types" (p.4). These syllables are not a site for inflection, and thus do not possess morphological complexity. Thus, the tonic is the primary domain of inflection.

Foris (1973:232), reporting on the Sochiapan dialect, remarks that unstressed syllables differ from stressed ones in displaying a more limited distribution of phonemes.

Similarly, Merrifield (1963:2) reports that post-tonic syllables in the Palantla dialect consist of a small list of words which do not contrast for tonal features. Pre-tonic syllables, while maintaining tonal contrasts, do not possess post-vocalic elements, except in very careful speech.

Finally, in Quiotepec, Gardner and Merrifield (1990:92) report that "major lexical classes (verbs, nouns, etc) are the source of stressed syllables," and that most pre-tonic

syllables consist of "tense-aspect prefixes, directional prefixes based on motion verbs, and such like. Pre-tonic syllables only occur with single tones." The vocalism of post-tonic syllables is harmonically determined by the stem vowel (Robbins 1961).

It is clear that the Chinantec stressed syllable possesses a rich inventory of both phonological and morphological elements, while unstressed syllables are limited in these respects. Stress may thus be seen as playing the functional role of auditorily enhancing those syllables which bear a higher informational load.

Finally, observe how the phonetic realization of the Chinantec syllable is bound not only to its phonological structure, but to its morphological structure as well. Stressing the root syllable increases the likelihood of recoverability of a large amount of morphological information. Consider the (simplified) verb paradigms in (96) (from Pace 1990). The eleven major paradigms (P1, P2, etc.) are listed according to Class (**A**, **B**, or **C**). Each paradigm consists of a three by four matrix containing aspect (progressive (**P**), intentive (**I**), or completive (**C**)) and person markers (**1s**, **1p**, **2**, **3**). Regarding the second person completive forms, it exhibits the most diversity among verb forms and is consequently chosen by Pace as the citation form; it is not indicated in the matrix.

(96) Simplified verb paradigms, major classes:

Class A										
P1	1s	1p	2	3		P2	1s	1p	2	3
P	H	H	L	LM		P	L:h	H:	L:	L:h
I	MH	Hh	Hh	Mh		I	LH:h	Hh	H:h	Mh
C	Mh	Hh		LM		C	Mh	Hh		L:h
P3	1s	1p	2	3		P4	1s	1p	2	3
P	Mh?	Mh?	Lh?	Lh?		P	Mh?	Mh?	LM?	LM?
I	Hh?	Hh?	H?	Lh?		I	Hh?	Hh?	H?	Mh?
C	Mh?	Hh?		Lh?		C	Mh?	Hh?		LM?

Class B										
P5	1s	1p	2	3		P6	1s	1p	2	3
P	Lh	Lh	Lh	Lh		P	M:h	M:h	M:h	M:h
I	Hh	Hh	Hh	Hh		I	Hh	Hh	Hh	M:h
C	Lh	Hh		Lh		C	Mh:	M:h		M:h
P7	1s	1p	2	3						
P	LMh	LMh	LMh	LMh						
I	LHh	LHh	LHh	LHh						
C	Mh	LH:h		LMh						

Class C										
P8	1s	1p	2	3		P9	1s	1p	2	3
P	H:	H:	H:	L:h		P	LH:h	LH:h	LH:h	HLh
I	H:	H:	H:	Mh		I	LH:h	LH:h	LH:h	Mh
C	H:	H:		L:h		C	LH:h	LH:h		HLh
P10	1s	1p	2	3		P11	1s	1p	2	3
P	LH?	LH?	LH?	LM?		P	LMh?	LMh?	LMh?	LMh?
I	LH?	LH?	LH?	H?		I	LMh?	LMh?	LMh?	LMh?
C	LH?	LH?	LH?	LM?		C	LMh?	LMh?	LMh?	LMh?

Generalizing about verb structure in Comaltepec, onset quality, as well as nuclear and coda supralaryngeal quality, are root-based, while the laryngeal quality of the rime, including tone, phonation, and glottal checking, are inflection-based.[11] If instead glottal checking is considered root-based, the strong generalization may be made that major verb inflection consists exclusively of modification of nuclear laryngeal quality.

(97) syllabic location of Comaltepec verbal morphological components:

	onset:	nucleus:	coda:
supralaryngeal:	root	root	root
laryngeal:	root	inflection	root

Note in particular here that the phonetic realization of Comaltepec laryngeally complex vowels, in which aspiration is phased to follow modal phonation, results in the

[11]One exception to this generalization involves a subset of irregular verbs which possesses palatalizing ablaut in certain aspect/person cells (see Pace 1990:44).

salient encoding of all contrastive information. Moreover, as I show below, this post-vocalic aspiration is implemented with an increase in subglottal pressure. Increased subglottal pressure in this position serves to enhance both the lexical content of the syllable, and its morphological content. As both tone and non-modal phonation sit on a single nucleus, and as both of these gestures are crucial in the determination of the inflectional content of a form, it is most important that both these contrastive laryngeal gestures are recoverable.

Before concluding this section, I would like to consider a peculiarity in the phonotactic patterning of laryngeal gestures with respect to supralaryngeal gestures in the Comaltepec syllable. In his generalizations about glottalic and laryngealized consonants, Maddieson (1984:121) states, "if a language has any laryngealized sonorants, it also has glottalic and laryngealized stops." And while not discussed by Maddieson, the same generalization probably holds for *aspirated* consonants. That is, if a language has aspirated sonorants, it also has aspirated stops.

Comaltepec is in violation of both these cross-linguistic generalizations in that it possesses voiceless and laryngealized sonorants, but it does not possess aspirated or glottalized stops. This is true not only for Comaltepec, but for all the Chinantec languages (see especially Rensch 1976, 1978).

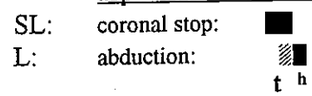
In this final preliminary discussion, I examine this peculiar patterning in the context of Comaltepec (and, by extension, Chinantec) word structure. I show that despite the preference for laryngeals to be phased with stop releases, this optimal site is rendered unavailable due to morphological requirements. Thus morphology can and does influence both the system of contrasts and its realization.

Recall that while onsets, vowel quality, and codas are wholly root-determined, nuclear laryngeal quality varies with inflectional category. Now, as both tone and phonation are crucial in the determination of inflectional category, this contrastive material is not only lexical, but is morphemic as well. In contrast, onset quality and vowel quality vary unpredictably across roots, and thus possess lexical status, but do not, in and of themselves, possess morphemic status.

Now, given the morphemic status of tone and phonation, it is particularly important that this material be saliently encoded in the speech signal. That is, given the high informational load borne by this material, it is especially important that it be recoverable.

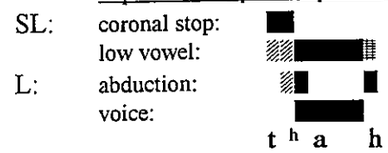
In order to see this, consider a hypothetical situation in which Comaltepec roots possess contrastively aspirated stops. Assuming that these stops are realized in canonical fashion, they would consist of an oral closure followed by a laryngeal abduction, as shown in (98).

(98) aspirated coronal stop:



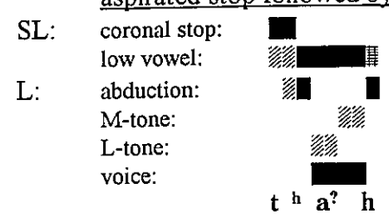
In the context of a post-aspirated vowel, a laryngeal abduction would both precede and follow the vocalic gesture, as shown in (99).

(99) aspirated stop with post-aspirated low vowel (hypothetical):



If aspirated stops were to co-occur with post-vocalic aspiration, a relatively shorter period of the vowel would be realized with modal phonation. Now, as I have discussed in section 5.2, tonal contrasts are optimally realized with modal phonation. As modal phonation would be relatively short if flanked by tautosyllabic laryngeal abductions, tonal material would run the risk of non-recoverability. That is, modal phonation here may not be of sufficient duration to saliently encode the tonal contrast.

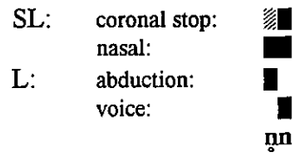
(100) aspirated stop followed by laryngeally complex nucleus (hypothetical):



Were tone unrecoverable, inflectional categories would be lost. Consequently, the absence of aspirated stops in Comaltepec may be viewed as an accommodation of its phonological system to its morphological system, which possesses morpheme-cueing post-vocalic aspiration.

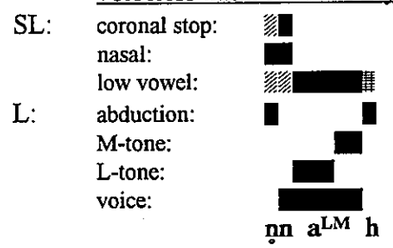
Now recall that laryngeally marked sonorants are perfectly acceptable onsets in Comaltepec inflected verb forms which include post-vocalic aspiration. Why should this be so? These laryngeally contrastive sonorants are realized in canonical fashion: first non-modal phonation, then modal phonation, both occurring with the supralaryngeal consonantal gesture. (101) shows a schematic of a voiceless sonorant.

(101) voiceless coronal nasal:



Given that modal phonation *follows* non-modal phonation here, following vowels possess a relatively longer duration of modal phonation. Consequently, tonal inflectional material is recoverable.

(102) voiceless nasal followed by breathy nucleus:



As laryngeally contrastive sonorants do not render the inflectional material of the rime non-recoverable, they may freely occur with any and all rime qualities, thus expanding the inventory of root contrasts without jeopardizing inflectional contrasts.

The system of morphology thus interacts with phonotactics and phonetics. In Comaltepec, just as in, for example, Chong, this interaction leads to a non-canonical system of contrasts.

5.4.2 The Ballistic Phenomenon

The ballistic phenomenon has been reported in most dialects of Chinantec, as well as in neighboring Amuzgo. It has also been suggested that ballisticity is present in Copala Trique (Hollenbach 1987), and Jalapa Mazatec (Judy Schram and Terry Schram, personal communication, but see Silverman, Blankenship, Kirk, and Ladefoged 1995 for an alternative analysis here involving a length contrast). Bauernschmidt (1965:471) reports the following concerning ballisticity in Amuzgo:

> "Ballistic syllables are characterized by a quick, forceful release and a rapid crescendo to a peak of intensity early in the nucleus, followed by a rapid, uncontrolled decrescendo with fade of voicing. In unchecked syllables there is fortis aspiration, varying to postvelar friction after central and back vowels. In checked syllables the final glottal stop is fortis and often followed by a ballistic release, freely fluctuating from orality to nasality. In

> connected speech the aspiration is much less apparent, if not altogether absent, particularly when the syllable is not stressed."

Ballisticity in Chinantec dialects is described similarly in a number of sources.

Palantla (Merrifield 1963:3):

> "A number of phonetic differences are perceptible between ballistic and controlled syllables. Ballistic syllables are characterized by an initial surge and rapid decay of intensity with a resultant fortis articulation of the consonantal syllable onset and tendency to loss of voicing of post-vocalic elements; controlled syllables exhibit no such initial surge of intensity and display a more evenly controlled decrease of intensity. Ballistic syllables are shorter in duration than controlled syllables."

Tepetotutla (Westley 1971:160):

> "Word stress is either ballistic [...] or controlled [...] Ballistically stressed syllables are of shorter duration than controlled syllables, and show a more rapid variation from high to low in both pitch and intensity."

Sochiapan (Foris 1973:235):

> "Ballistic stressed syllables are characterized by an initial surge and rapid decay of intensity with a resultant fortis articulation of the consonantal syllable onset [...] Ballistic syllables are also shorter in duration than controlled syllables."

Comaltepec (Anderson 1989:3):

> "There are two kinds of syllable stress, ballistic and controlled [...] Ballistic stress is a combination of pitch and stress. It tends to raise high tones and lower low tones."

In most dialects, ballisticity may cross-classify with every other syllable type. Both oral and nasal vowels, both long and short vowels, pre-aspirated and pre-glottalized onsets as well as plain onsets, and open and checked syllables, and nasally closed syllables, may

all possess ballisticity. Note that, at least in Comaltepec, ballisticity may occur with almost any phonological tonal pattern.[12]

Mugele (1982) presents a detailed phonetic description of the interaction of ballisticity and tone in the Lalana dialect. Corroborating certain other reports, Mugele finds ballistic syllables to be shorter in duration than controlled syllables, to possess post-vocalic aspiration, and devoicing of post-nuclear nasals. However, among the characteristic phonetic correlates of ballisticity, Mugele highlights their intensity, or increased amplitude, indicated in spectrograms by a darker spectrographic display.

This increased intensity, argues Mugele, is due to an increase in subglottal pressure. Mugele consequently targets increased subglottal pressure as the defining aerodynamic correlate of ballisticity, phonologizing the phenomenon with the feature [+ballistic syllable].

It should be noted that the feature [ballistic syllable] is not attested outside Chinantec (and neighboring Amuzgo). Furthermore, while enhanced subglottal pressure does appear to be employed in many languages as an indicator of emphasis (that is, "emphatic stress"), it is never reported to possess true phonemic status.[13] Maddieson (1984) makes no mention of subglottal phenomena as possessing minimal contrastive status in any of the languages he investigates.

Additionally, I am aware of no other cases in which stress patterns paradigmatically; it is always a syntagmatic phenomenon. If ballisticity is not a stress-based contrast, it does not constitute a counter-example to this generalization.

Finally, there is no immediate articulatory correlate to subglottal pressure values, unlike every other posited phonological value.

In what follows, I conclude that the ballistic phenomenon is laryngeally-based (specifically, involving a laryngeal abduction) instead of stress-based (involving a contrastive subglottal pressure value). I henceforth refer to my hypothesis as "the abduction hypothesis."

First, I consider how a spread glottis may result in phonetic effects that are similar to those observed in ballistic syllables, expanding on my discussion of enhancing mechanisms presented in section 5.3.

Keating (1990:332), drawing from Ladefoged and Lindau (1986) argues that a given phonological feature may be phonetically implemented in various ways from language to language, or speaker to speaker. She writes:

---

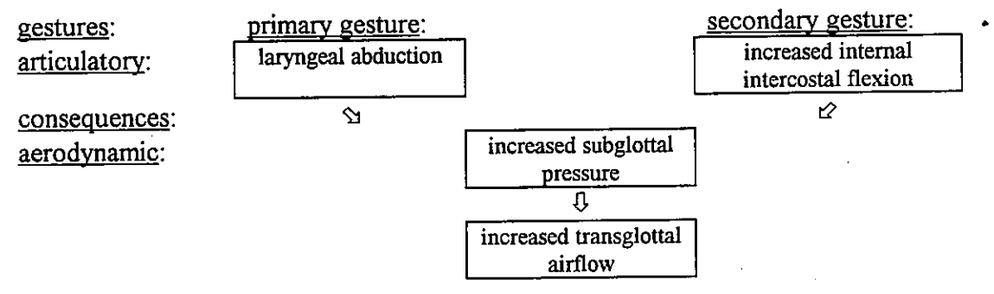
[12]In the Lalana dialect, ballisticity (considered post-vocalic **h** by Rensch and Rensch 1966) does not occur with glottal checking. Also in Lalana, Mugele (1982) reports that only **H**, **L**, and **HL** tones may be present on ballistic syllables, whereas controlled syllables reportedly also possess **MH**, **LH**, and **HLH**.

[13]Mugele describes the articulatory and acoustic properties of Thai "emphatic tone," and their similarity to those of ballisticity.

> "[...A] single feature may have more than one parameter value [...] [L]anguages may differ in how they realize a given value. Such a difference would be related to saliency: the more parameters [that] are used for a given feature, the more robust and salient that feature's value will be."

How may Keating's approach support the abduction hypothesis? Is there evidence that increased subglottal pressure may be a concomitant of aspiration? Indeed, as discussed in Chapter Three, Ladefoged (1958, 1968) reports that in English there are "striking increases in the [respiratory] muscular activity immediately before a word beginning with **h**." (1968:149). Recall that the internal intercostal muscles are involved in the manipulation of subglottal pressure during expiration: all else held constant, increased internal intercostal activity during expiration results in increased subglottal pressure. Increased subglottal pressure, in turn, results in a more rapid expulsion of air from the lungs. It is thus not surprising that increased subglottal pressure is a concomitant of word-initial **h**, for, as Ohala (1990:35) observes, "There are relatively large rapid decreases in lung volume during moments of high oral airflow, e.g., during aspiration, **h**, and fricatives." This increase in airflow is an obvious result of increasing glottal aperture. Thus, when unaided by the presence of a stop release (Kingston 1985, 1990), subglottal pressure may be increased in order to prevent undue weakening of aspiration. While Ohala hypothesizes that these decreases in lung volume "presumably represent a passive collapse of the lungs due to the rapid flow of air out of the lungs and the consequent decrease in lung pressure" (p.35), the findings of Ladefoged (1958, 1968), as well as those presented below, do not corroborate this hypothesis, in that an *active increase* in intercostal flexion may be observed as a concomitant of English word-initial **h**. (99) indicates this hypothesized state of affairs.

(103) laryngeal abduction and subglottal pressure:



There is evidence outside of English supporting Ladefoged's claim. In Fischer-Jørgensen's (1970) analysis of Gujarati breathy vowels, she finds that the intensity of

breathy vowels does not differ significantly from that of modal vowels. However, breathy vowels show increased airflow in comparison to modal vowels, most likely due to greater glottal aperture. Fischer-Jørgensen speculates that an increase in the activity of the expiratory muscles during breathy vowels compensates for the subglottal pressure reduction associated with increased glottal aperture.

(104) plain versus breathy vowels in Gujarati:

		glottal aperture:	intercostal flexion :	intensity:
plain:	higher:			
	lower:	■	■	=
breathy:	higher:	■	■	=
	lower:			

It is thus reasonable to conclude that increased subglottal pressure due to increased internal intercostal activity may be an enhancing concomitant of a laryngeal abduction that is not preceded by a supralaryngeal occlusion.

Is the opposite true? Can a laryngeal abduction serve to *heighten* subglottal pressure? Mugele (pp.96-97) offers the following explanation of ballisticity's concomitant aspiration:

> "The hypothesis that ballistic syllables are produced by an active gesture that raises subglottal air pressure [...] provides an explanation for the increased postvocalic aspiration. Let us assume that, in an open syllable, phonation of the vowel ceases by abducting the vocal folds. In the case of the controlled syllable, phonation ceases by abducting the vocal folds and silence follows. At the time of the abduction of the vocal folds, the flow of air is insufficient to cause any glottal friction (aspiration). In ballistic syllables, however, glottal friction is produced as air under much greater pressure rushes through the vocal folds as they are being abducted. The postvocalic aspiration begins when the vocal folds are abducted to a point where phonation is no longer possible and it continues until glottal opening reaches a point where there is insufficient stricture to maintain the friction. Thus the differences in postvocalic aspiration result from differing amounts of airflow through the glottis as the vocal folds are being abducted in order to terminate the voicing of the vowel".

Thus, according to Mugele, aspiration in [+ballistic syllable] syllables is an aerodynamic consequence of increased subglottal pressure that in fact serves to *reduce* the

degree to which this supposed phonological feature is realized: a spread glottis reduces subglottal pressure here, since lung air volume decreases as glottal aperture increases.

The two theories of ballistic syllables thus provide radically different accounts of the observed occurrence of increased intercostal activity and aspiration. The abduction hypothesis argues that increased subglottal pressure acts to enhance the laryngeal abduction. The [+ballistic syllable] hypothesis cannot account for the occurrence of heightened subglottal pressure and aspiration in terms of phonetic enhancement, as aspiration does not enhance (increase or maintain) subglottal pressure; if anything, it reduces it. In fact, all else held constant, a *constricted* glottis would serve to enhance/maintain subglottal pressure, as it would reduce flow rate, thus slowing the subglottal pressure drop. Instead, [+ballistic syllable] theory relies on hypothesized superficial aerodynamic consequences that increased subglottal pressure may have on glottal aperture.

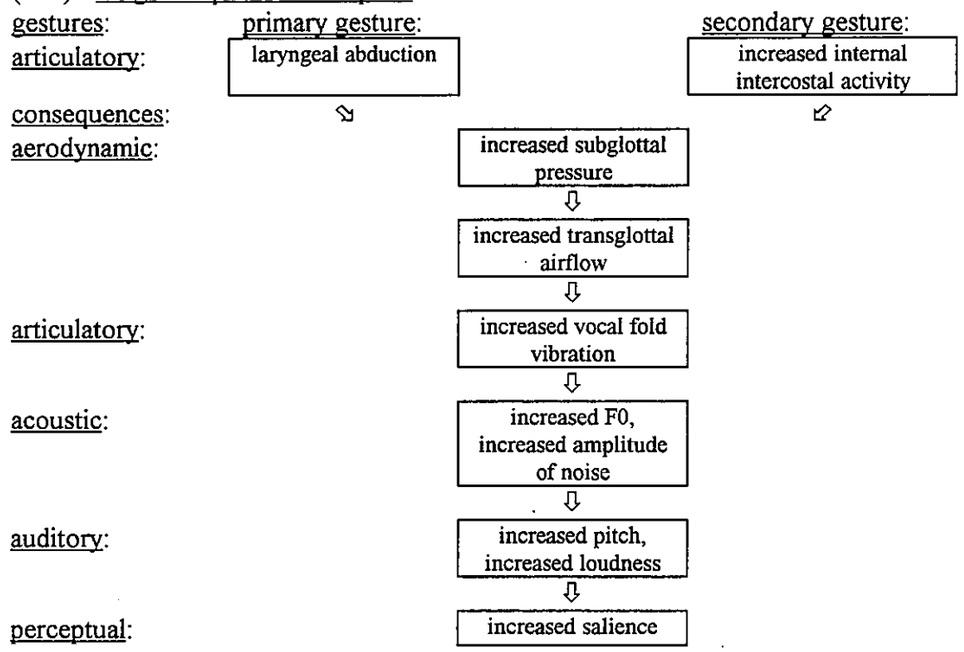
Note additionally that Mugele offers no explanation for observed nasal devoicing in ballistic syllables. Surely, when a nasal follows a vowel, the vocal folds do not naturally abduct; spontaneous voicing continues throughout the supralaryngeal adjustment from vowel to nasal. Yet ballistic syllables are regularly reported to possess devoicing of their post-nuclear nasals. If instead ballisticity involves a primary laryngeal abduction, devoicing is an expected phonetic analog.

Now consider pitch. Anderson (1989:3) reports that in the Comaltepec dialect ballisticity "tends to raise high tones and lower low tones." Anderson Martinez and Pace (1990:8) report that L-tone syllables possess a phonetic downglide in all syllables "with the lowering in pitch being greater in ballistic syllables than in controlled." More significantly, **LH** and **MH** long ballistic syllables possess a non-contrastive initial **H**-tone, and are thus actualized **HLH**, **HMH**. This indicates, *contra* Anderson, that a syllable-initial **L** (or **M**) tone is raised, not lowered. Anderson, Martinez, and Pace report that the initial downglide in such syllables is more salient to non-native ears, but that native speakers "appear to perceive the tone as an upglide" (p.9). This strongly suggests the non-contrastive status of such initial **H** tones, and further, indicates an interaction between length, ballisticity, and tonal contours: an initial **H** emerges upon the occurrence of length and ballisticity in rising tone patterns. Indeed this is exactly the analysis these authors put forth.

The pitch effects of ballisticity may be seen as a consequence of increased glottal aperture with concomitant increased transglottal airflow. While F0 is primarily controlled by the crycothyroid muscle, recall that there is nonetheless evidence suggesting that increased subglottal pressure induces moderate pitch increases (Meuller 1851, Lieberman, Knudson, and Mead, 1969, Hixon, Mead, and Klatt 1971, Titze 1989, Ohala 1990). As pressure increases, flow increases, and as flow increases, rate of vocal fold vibration increases. As the rate of vocal fold vibration is the articulatory correlate of pitch, the relationship between internal intercostal status, glottal aperture, transglottal airflow rate,

subglottal pressure, and pitch, becomes clear. The flowchart in (105) presents these interrelated phenomena.

(105) subglottal pressure and pitch:



Why should these pitch increases affect only long ballistic **LH** and **MH** syllables, and not their short counterparts? Most likely, a noncontrastive syllable-initial **H** in short ballistic syllables would result in the neutralization of lexical contrasts: a short ballistic syllable may lack sufficient duration to accommodate this additional pitch perturbation. The introduction of a phonetic **H** tone in short ballistic syllables could thus very well result in the loss of underlying tonal contrasts. To avoid this, I assume that additional articulatory maneuvers are employed in order to counteract this otherwise automatic pitch rise. In long contours, by contrast, it is less important to curtail this natural initial pitch increase, as no contrast is jeopardized by its presence.

Pitch increases may thus be seen to correlate in part with increases in glottal aperture, which in turn correlate with increased internal intercostal flexion . Note that these correlations do not unequivocally support the abduction hypothesis. Mugele's theory may just as readily account for observed pitch effects in ballistic syllables. However, they are nonetheless consistent with this hypothesis, and in the context of all arguments presented, serve to corroborate the present approach.

Now consider Comaltepec phonology. While most morphologically complex forms in Chinantec are monosyllabic, there is a limited process of syllabic cliticization involving reduced forms of personal pronouns. Anderson, Martinez, and Pace report that in first person cliticization, a copy of the root vowel is suffixed to the base. Open ballistic syllables which undergo this process are characterized by a particularly prominent breathiness in the transition from root to suffix. Thus $\mathbf{ka^{L}\ noh^{M} + R \rightarrow ka^{L}no^{M}ho^{L}}$.[14] The authors' transcription here indicates that aspiration is considered to be in the onset to the following syllable; **h** (transcribed "**O**" in the text) is written after the **M** tone, which indicates its surface syllabification is rightward.

Recall that listeners are especially sensitive to consonant-vowel transitions in the signal, as these components provide the most salient cues. I have conjectured in Chapter Two that this dynamic transition is consequently imparted special significance as a cue to higher level organization, that is, syllabification.

Under Mugele's analysis, no explanation is forthcoming regarding the behavior of aspiration in this context.

Now consider the common historical origins of Chinantec ballisticity, Trique interruption, and Mazatec pre-aspiration/pre-glottalization.

Longacre (1957) reconstructs only a single laryngeal element for Proto-Mixtecan rimes (the language from which Trique has evolved). This element, ***ʔ**, is reconstructed in coda position: ***CVʔ**. It split into **h** and **ʔ** in Trique (though not in its sisters, Mixtec and Cuicatec), and is reflected in modern interrupted forms **VʔV** and **VhV**.

Rensch (1976) departs from Longacre in that he reconstructs two post-vocalic laryngeals for Proto-Mixtecan, ***ʔ** and ***h**. These, in turn are derived from Proto Otomanguean (POM) ****CVʔ** and ****CVh** syllables, which he suggests were phonetically implemented as vocalic interruption (**VʔV**, **VhV**).

Rensch also claims that Popolocan post-laryngealized plosives have their diachronic origins in vocalic interruption, as in Trique, originating from POM ****CVʔ** and ****CVh**.

Rensch (1976:91) states:

> "...the [Chinantec] ballistic syllables correspond with...**CVh** syllables in Mixtecan and Otopamean languages, **ChV** (and **CVhV** and **CVʔV**) syllables in Popolocan languages, and **CVʔV** syllables in the Chatino, Zapotec, and Tlapanec languages."[15]

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[14]"R" stands for "reduplicant," the suffixal morpheme.

[15]Rensch reconstructs Proto-Mixtecan ***CVhV**, which has survived into modern Trique. Rensch derives modern Trique **CVh** (in which **h** is a true coda) as deriving from Proto-

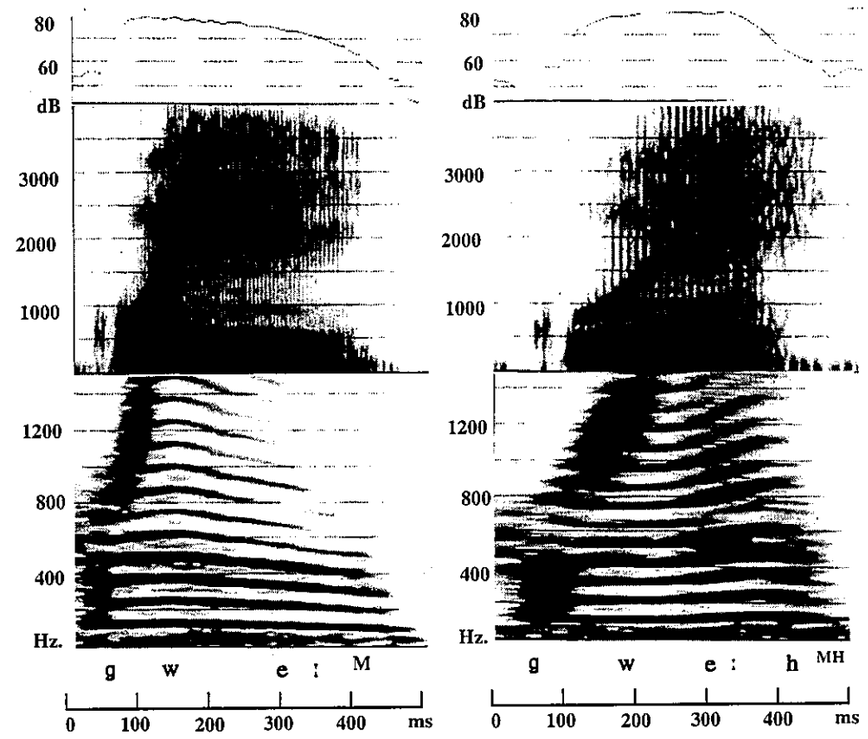
When considering Rensch's claim that Chinantec ballisticity has its historical origins in POM ****CVh** syllables as well, the claimed synchronic phonological link between modern Chinantec ballisticity, modern Trique vocalic **h**-interruption, and modern Mazatec vocalic preaspiration may be traced to their historical origins.

Now consider Comaltepec spectrographic evidence. I present acoustic phonetic evidence which supports the hypothesis that ballistic syllables involve a laryngeal abduction accompanied by an increase in subglottal pressure as a phonetic enhancer.

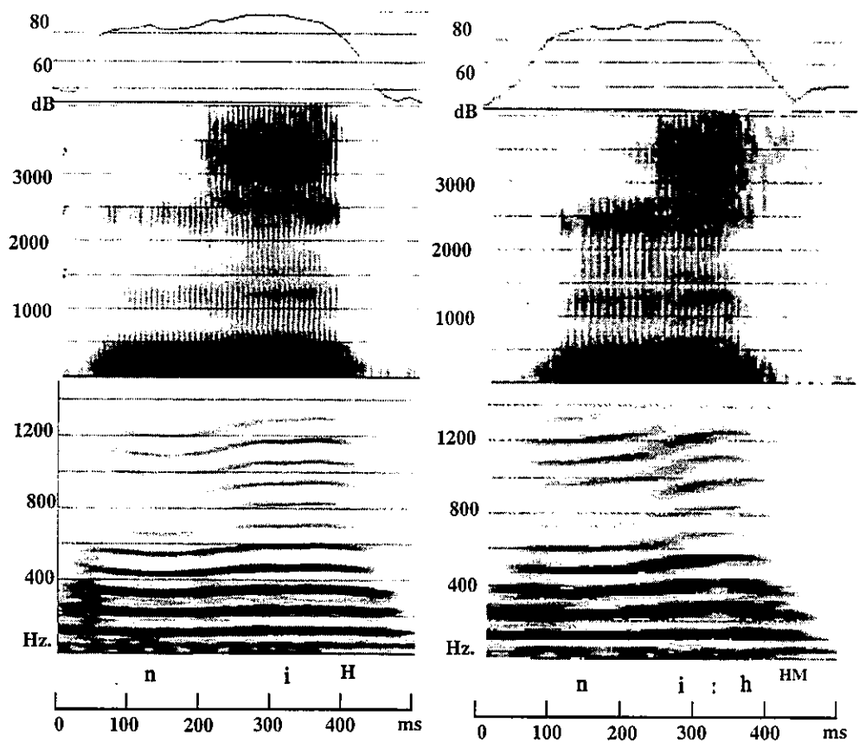
In figures (106) and (107) are energy contours, wideband spectrograms, and narrowband spectrograms, for pairs which minimally or near-minimally contrast in ballisticity. The informant is a forty year old native of Comaltepec.

Mixtecan ***hCV**. The few Trique forms reported by Longacre to consist of glottal interruption and coda **h** (i.e., **CVʔVh**,) Rensch derives from Proto-Mixtecan ***hCVʔ**: **raʔa^{25}h** (to dance).

(106)



(107)



Wideband spectrograms indicate that ballistic syllables differ from controlled syllables in possessing significant postvocalic, aperiodic noise, characteristic of aspiration. This is indicated by the faint markings toward these syllables' right edges, after the cessation of a defined formant structure. Note that this energy is aperiodic, indicated by the lack of vertical striations toward the right edge of the syllable.

In contrast, controlled syllables possess a periodic vibration for the duration of the vowel. This is indicated by the vertical striations, which persist for the duration of the vowel.

Narrowband spectrograms clearly reveal several distinctions between ballistic and controlled syllables.

First, in comparison to controlled syllables, the harmonic structure of ballistic syllables is much less well-defined toward the right edge of the display, in that bandwidths are significantly widened. This loss of definition temporally correlates with the noise present in wideband spectrograms.

Moreover, the harmonic structure of ballistic syllables possesses a slight increase in frequency toward the right edge, where noise is present. This F0 hump is not present in controlled syllables. Instead, harmonic structure here indicates a gradual lowering of fundamental frequency.

Inspection of energy contours indicates a direct correlation between energy levels, F0 levels, and noise levels. Ballistic syllables possess a slight hump, or increase in energy, toward their right edge. The energy contours of controlled syllables correlate with their harmonic contours and noise levels in possessing a gradual decline as the syllable progresses.

The observed pitch increase associated with ballisticity is not limited to Comaltepec. Mugele reports that level **L** and level **H** tones in Lalana possess a slight pitch rise in ballistic syllables, although a slight pitch *fall* is occassionally heard late in the syllable (1982:70). Meanwhile, controlled counterparts involve a gradual pitch fall (p.74), just as is observed in Comaltepec. Below, I report that a similar correspondence between ballisticity and pitch is present in Quiotepec.

Recall the flowchart in (105), which considers a possible interaction between a glottal abduction and a phonetic pitch increase. This chain of reasoning is fully consistent with the Comaltepec evidence. Both wideband and narrowband spectrograms indicate the presence of noise in ballistic syllables. This noise, as noted, is characteristic of aspiration, originating in a laryngeal abduction. Energy contours indicate an increase in overall energy in this position, which presumably has its origins in the contraction of the internal intercostal musculature. This muscular contraction results in an increase in subglottal pressure, thus increasing transglottal airflow. Recall that reading Fischer-Jørgensen (1970) suggests that, all else being equal, a glottal abduction *reduces* overall energy levels. When energy levels during a glottal abduction are equal to or greater than those present during vocal fold approximation, an increase in subglottal pressure due to increased respiratory muscle activity is presumably responsible. Furthermore, narrowband

spectrograms indicate a moderate increase in pitch in this context. Recall that increases in subglottal pressure and airflow result in moderate increases in rate of vocal fold vibration, which correlate with increases in pitch. Therefore, I conclude that the slight increase in F0 in ballistic syllables ultimately derives from an increase in respiratory muscular activity.

Note finally that narrowband spectrograms indicate that the harmonic structure of ballistic syllable vowels is weakened during their aspirated portion due to the noise and bandwidth increases which results from a glottal abduction. Now recall that pitch is determined by harmonic structure. Look in particular at the third through the fifth harmonics, which may be the most important for pitch perception (Plomp 1967, Ritsma 1967, Remez and Rubin 1984, 1993). As harmonic structure is weakened by the presence of aspiration, then aspiration should not be present in environments in which pitch possess linguistic significance. In such laryngeally complex vowels, therefore, tone is realized in modal voice, away from the non-modal phonatory gesture.

A final question remains. Why should the laryngeal abduction which defines the Chinantec ballistic syllable be coordinated with this marked increase in subglottal pressure?

Cross-linguistically, laryngeal abductions are optimally realized at plosive release, word-initially, and stressed-syllable-initially. These are the environments in which aspiration's salience is maximal (Ladefoged 1958, 1968, Kingston 1985, Bladon 1986). Note, for example, that this is exactly the distribution of aspiration in English. Both **h** and the aspirated plosives may be present in these positions. When aspiration would be an onset to an unstressed syllable, it is often lost.

(108) aspiration in English:

	h-aspiration present:		**h**-aspiration absent:
word-initially:	**hə'bɪtʃu̩** habitual	word-medially:	**ˌnanə'bɪtʃu̩** non-habitual
	kɹə'dɛnʃl̩ credential		**'ækɹɪd** acrid
stressed-syllable-initially:	**vi'hɪkjulɪ** vehicular	non-stressed-syllable-initially:	**'vijɪkl̩** vehicle
	ə'tɹ̥ækt attract		**'ætɹəbjuʔ** attribute

Aspiration in ballistic syllables is neither word-initial nor stressed-syllable-initial, nor is it realized at plosive release. Instead, it is post-vocalic. As noted, aspiration in post-vocalic position is in danger of acoustic and auditory weakening. Unlike the realization of aspiration at plosive release, or initially in stressed syllables, post-vocalic aspiration possesses neither a reliable supralaryngeal constriction on which it may anchor,

nor a preceeding increase in subglottal pressure; post-vocalically, no such occlusion or increase in intercostal muscular activity is present. The minimal stricture which is the defining characteristic of a vowel allows air to freely escape the oral cavity. As no build-up of pressure results, post-vocalic aspiration is in danger of being realized in a non-salient fashion. Indeed, recall that Bauernschmidt reports that aspiration in Amuzgo ballistic syllables is much less apparent, if not altogether absent particularly when the syllable is unstressed. Thus internal intercostal flexion should be increased if post-vocalic aspiration is to survive. This may result in a more salient realization of the otherwise weakened aspiration: increased subglottal pressure serves to increase airflow, thus increasing both overall energy and frequency of vocal fold vibration. These features, of course, are exactly those which accompany Comaltepec post-vocalic aspiration.

Moreover, recall the discussion of auditory phonetics in Chapter Two. Bladon (1986) reports that pre-aspirated stops, which may be phonetically characterized as the devoicing of a preceding vowel, are not auditorily salient. This is due both to the weakening of spectral energy in the transition from modal voicing to voicelessness, and to the reliance on the offset of spectral energy.

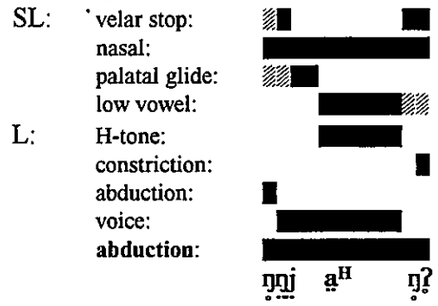
For identical reasons, Bladon argues that post-vocalic aspiration (which can be phonetically identical to the aspiration of an intervocalic pre-aspirated stop) is auditorily non-salient. In order to achieve auditory salience, internal intercostal muscular flexion may be increased, thus increasing the acoustic energy of this auditorily weak gesture.

I conlude that the ballistic phenomenon is best explained by the abduction hypothesis. That is, so-called ballistic accent involves primary post-vocalic aspiration, and secondary increases in subglottal pressure due to internal intercostal muscular flexion .

Now consider in somewhat more detail the phasing of the laryngeal abduction in ballistic syllables. According to Mugele (1982), the feature [+ballistic syllable] is syllabic in its affiliation. I have already shown that the [+ballistic syllable] feature is not a tenable explanation for the phonological and phonetic properties of ballistic syllables, and have instead implicated a laryngeal abduction. I now additionally show that the syllable is not a viable candidate for the abduction's affiliation.

In (109) is a hypothetical maximal syllable expansion in Chinantec, with the abduction associated throughout the syllable: **n̥n̥ja̤ʰŋ̥ʔ**.

(109) syllabic affiliation:



First, a syllabic affiliation of the abduction requires that no subcomponent of the syllable may contrast in aspiration, as the phonological simultaneity of identical gestures results in neutralization. Yet Chinantec freely allows such contrasts (see examples in 5.4.1).

Further, recall that I have claimed (along with Halle and Stevens 1971) that abductions and constrictions may never be phonologically simultaneous. This being the case, the syllabic affiliation of the laryngeal abduction in ballistic syllables becomes an impossibility. Let us consider why.

Syllabic affiliation of the abduction in ballistic syllables predicts that these syllables may not contain any laryngeal constriction, as this would involve the phonological simultaneity of an abduction and a constriction. This impossible configuration renders the structure illicit.

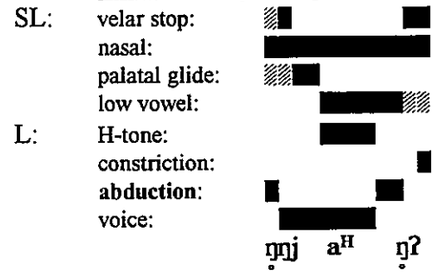
In addition to the predicted unacceptability of ballistic syllables with pre-glottalized onsets, syllabic affiliation also predicts the nonexistence of ballistic checked syllables, as these too involve the phonological simultaneity of an abduction and a constriction. However, glottally checked ballistic syllables freely occur.

(110) **ŋjuhʔ^{L}** you vomit

For these reasons, I reject the possibility that the affilation of the abduction in ballistic syllables is syllabic.

Instead, as the abduction is phased to follow the modally phonated portion of the vowel, this allows for further laryngeal contrasts to both precede and follow the abduction. Thus onsets may be aspirated or laryngealized, and syllables may be checked, both independently of ballisticity. Further, as constrictions are never phased with vowels (i.e., there are no creaky vowels), no impossible gestural configuration is encountered.

(111) post-vocalic phasing of the laryngeal abduction:



I conclude that the abduction in ballistic syllables is nuclear, following the modally phonated portion of the vowel. Due to the requirements of tone perception, the laryngeal abduction is sequenced with respect to tone, and realized post-vocalically, so that all laryngeal contrasts may achieve acoustic transparency.

(112) laryngeally complex vowels in Comaltepec:

1	phase optimal	recover {vowel, abduction, tone}	economize	overlap
a ☞	**vowel⇧⟨abduction⇧intercostals⇨tone⟩** vowel: tone: abduction: intercostals: h aL	 vowel tone abduction	 *vowel *tone *abduction *intercostals	**
b	**vowel⇧⟨tone⇨abduction⇧intercostals⟩** vowel: tone: abduction: intercostals: aL h	 vowel tone *abduction	 *vowel *tone *abduction *intercostals	**
c	**vowel⇧tone⇧abduction⇧intercostals** vowel: tone: abduction: intercostals: aL	 vowel *tone abduction	 *vowel *tone *abduction *intercostals	

-or-

3	phase optimal	economize	recover {vowel, abduction, tone}	overlap
a ☞	**ha^{L}**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	**
b	**a^{L}h**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮▮*abduction	**
c	**a̤^{L}**	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	▮vowel ▮▮*tone ▮abduction	

-or-

4	phase optimal	economize	overlap	recover {vowel, abduction, tone}
a ☞	**ha^{L}**	*vowel *tone *abduction *intercostals	**	▮vowel ▮tone ▮abduction
b	**a^{L}h**	*vowel *tone *abduction *intercostals	**	▮vowel ▮tone ▮▮*abduction
c	**a̤^{L}**	*vowel *<u>tone</u> *<u>abduction</u> *intercostals		▮vowel ▮▮*tone ▮abduction

-and-

1	phase *optimal	recover {vowel, abduction, tone}	economize	overlap
a	**vowel⇧⟨abduction⇧ intercostals⇨tone⟩** vowel: ▮▮▮▮▮▮ tone: ▮▮▮▮▮▮ abduction: ▮ intercostals: ▒ **h a^{L}**	▮vowel ▮tone ▮abduction	*vowel *tone *abduction *intercostals	**
b ☞	**vowel⇧⟨tone⇨ abduction⇧intercostals⟩** vowel: ▮▮▮▮▮▮ tone: ▮▮▮▮▮▮ abduction: ▮▮ intercostals: ▒ **a^{L} h**	▮vowel ▮tone ▮▮*abduction	*vowel *tone *abduction *intercostals	**
c	**vowel⇧tone⇧abduction⇧ intercostals** vowel: ▮▮▮▮▮▮ tone: ▮▮▮▮▮▮▮▮ abduction: ▮▮▮▮▮▮ intercostals: ▒▒▒▒▒▒ **a̤^{L}**	▮vowel ▮▮*tone ▮abduction	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	

-or-

3	phase *optimal	economize	recover {vowel, abduction, tone}	overlap
a	**ha^{L}**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮abduction	**
b ☞	**a^{L}h**	*vowel *tone *abduction *intercostals	▮vowel ▮tone ▮▮*abduction	**
c	**a̤^{L}**	*vowel *<u>tone</u> *<u>abduction</u> *intercostals	▮vowel ▮▮*tone ▮abduction	

-or-

4	phase *optimal	economize	overlap	recover {vowel, abduction, tone}
a	ha^{L}	*vowel *tone *abduction *intercostals	**	vowel tone abduction
b ☞	$a^{L}h$	*vowel *tone *abduction *intercostals	**	vowel tone *abduction
c	$\underline{a}^{L}$	*vowel *tone *abduction *intercostals		vowel *tone abduction

As in Jalapa Mazatec and Trique, Comaltepec vowels possess both tone and phonation contrasts, that is, are laryngeally complex. Therefore, the non-modal phonatory gesture is phased serially with the tonal gesture, so that all contrastive information is recoverable.

The laryngeally complex vowels of Comaltepec pattern as do those of Trique and Jalapa Mazatec.

5.4.3 Ojitlán, Usila, and Quiotepec

In section 5.3 I discussed the diachronic consequences of both increasing and not increasing the intercostal muscular flexion which is implemented along with post-vocalic aspiration: in Jeh, hypothesized historic respiratory muscular activity increases in this context have evolved into a rising tone, while in Huave, hypothesized *lack* of respiratory muscular activity increases here have resulted in a falling tone.

In fact, both these patterns are attested elsewhere in Chinantecan as well. First, Rensch (1976:180) observes a correspondence between the ballistic accent present in most dialects of Chinantec, and a tonal lowering in the Ojitlán and Usila dialects:

> "The Ballistic syllable type of PCn [Proto-Chinantec--D.S.] is continued in C-O [Ojitlán and] C-U [Usila]...largely by tone differences. In C-O the PCn low tone, which yields tone **2** in syllables reflecting PCn controlled syllables, yields tone **3** in syllables reflecting PCn ballistic ones.[16] PCn high-low, likewise, yields tone **4** rather than tone **2**, in forms reflecting PCn ballistic syllables. In C-U the picture is slightly more complex, but a similar lowering of ***L** and ***HL** from tone **3** to tone **4** and the glide **34** takes place in forms reflecting PCn ballistic syllables."

[16]Lower numbers here indicate higher-pitched tones.

Second, the Quiotepec dialect is variously characterized as possessing ballistic accent or *raised* tones in these same contexts (Robbins 1961, 1968, Gardner and Merrifield 1990). Robbins: "I am tempted to guess that the Quiotepec dialect is diachronically in a transition from a three-tone system with accent [ballisticity--D.S.] to a four-tone system" (1968:26). This "accent" is often accompanied by aspiration (p.25), as well as "a slight rise then fall in pitch" (p.24).

These diachronic shifts from phonation to tone are accounted for if language-specific conventions regarding intercostal flexion accompany post-vocalic aspiration. Specifically, decreases (or non-increases) in subglottal pressure during post-vocalic aspiration may lead to a phonemicized pitch fall, as in Ojitlán, Usila, and Huave; increases in subglottal pressure during post-vocalic aspiration may lead to a phonemicized pitch rise, as may be happening in Quiotepec and Jeh.

Thus, when the system of contrasts branches in different directions, culminating in dialectal distinctions--as in Ojitlán and Usila versus Quiotepec--this should not be considered an inexplicable, arbitrary consequence of the abstract nature of phonology. Rather, when phonetic realization is considered in sufficient detail, diverging diachronies may be correctly seen to possess a physical explanation.

5.4.4 Summary

In summary, the Comaltepec ballistic syllable phenomenon involves post-vocalic aspiration. The laryngeal abduction is phased to follow modal phonation, in order to achieve the recoverability of all contrastive laryngeal information, including tone and phonation. In this position, however, aspiration is potentially weakened. Consequently, subglottal pressure is increased by increasing internal intercostal flexion, thus enhancing the salience of the laryngeal abduction.

5.5 Real and Apparent Exceptions

There are, as predicted in the tables in (52) and (53), exceptions to the claim that laryngeally complex languages sequence their tonal and non-modal phonatory gestures. If glottalization or breathiness is sufficiently light, parallel transmission may ensue: the acoustic signal may encode both phonatory and tonal information without resorting to sequencing. Recall, however, that such phasing comes at an auditory price. In this section, I consider real exceptions Mpi and Tamang (5.5.1), and apparent exceptions Yi and Dinka (5.5.2).

5.5.1 Real Exceptions

First consider the real exceptions of Mpi and Tamang.

Case Study: Mpi

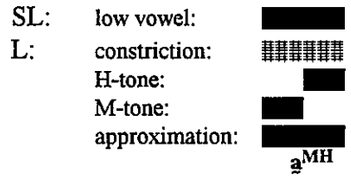
Mpi, a Tibeto-Burman language (Ladefoged and Maddieson 1995) possesses six contrastive tones, in addition to a phonation contrast involving laryngealization. Any tonal pattern may occur with modal phonation or laryngealization, and thus Mpi qualifies as a laryngeally complex language.

(113)

tone:	modal:		laryngealized:	
low rising	si˩˧	to be putrid	s̰i˩˧	to be dried up
low level	si˩	blood	s̰i˩	seven
mid rising	si˧˧	to roll (rope)	s̰i˧˧	to smoke
mid level	si˧	(a color)	s̰i˧	(classifier)
high falling	si˥˩	to die	s̰i˥˩	(name)
high level	si˥	four	s̰i˥	(name)

Moreover, in Mpi, laryngealization persists throughout the duration of the vowel.

(114) Mpi laryngealized vowel:



The Mpi pattern is thus an exception to the claim that non-modal phonation is always truncated in laryngeally complex vowels. How might I account for this patterning, while maintaining my claim?

The answer lies in the degree to which Mpi laryngealized vowels are creaked. Ladefoged and Maddieson (1995) compare laryngealization in Mpi to that in Jalapa

Mazatec. They report that Mpi laryngealized vowels "definitely have a less constricted glottis" (p.16). Recall that Jalapa Mazatec glottalized vowels are laryngeally complex, and indeed limit their non-modal phonation to the vowel's first portion.

With their lesser degree of laryngeal constriction, Mpi vowels may simultaneously implement their tonal and phonatory features, without the risk of non-recoverability. Such a pattern is predicted to exist, although at an auditory cost.

Case Study: Tamang

Consider next Tamang. Tamang is a Tibeto-Burman language spoken by approximately 664,000 people in Nepal and Sikkim, India (Grimes 1988). It is traditionally characterized as possessing a register system of the Mon-Khmer variety, that is, involving pitch and voice quality distinctions.

Weidert (1987) observes that the four registers of Tamang (and related Gurung and Thakali) consist of four pitch patterns and two phonation types. These are presented in (115).

(115) Tamang Registers:

Clear:	Breathy:
High	
Mid-High	
	Mid-Low
	Low

Regarding these four registers, Maddieson (1984) notes that the system may be treated as one in which tone and phonation cross-classify (p.132). A re-organization along these lines is presented in (116) in which phonatory and tonal categories are listed in the external cells, while phonetic realizations are presented in the table interior.

(116) Tamang tone and phonation:

	V:	V̤:
H:	high pitch, modal phonation	mid-low pitch, breathy phonation
L:	mid-high pitch, clear phonation	low pitch, breathy phonation

As tone and phonation may be characterized as cross-classifying here, Tamang is a laryngeally complex language. Yet Weidert says nothing of a part-modal/part-non-modal realization of the breathy registers. Given his silence on the subject, I assume that non-modal phonation probably persists for the duration of its associated vowel. Thus Tamang is probably an exception to my claims regarding the phonetic patterning of laryngeally complex vowels.

It is possible that Tamang is like Mpi, in that breathiness is comparatively light. But as no phonetic descriptions of Tamang register detail such information, and as no

instrumental analyses of these vowels is available, I simply do not know the degree of breathiness here.

Another possibility centers on the relative simplicity of the Tamang laryngeal system. With only two tones and one contrastive voice quality, Tamang is quite distinct from Otomanguean languages, such as Trique, which may possess up to five contrastive pitch levels, many pitch contours, and up to three phonation types (see especially Longacre 1952, 1959).

Given this simplicity, pitch targets may be sufficiently distant from one another to yet emerge distinct, even when breathiness is fully superimposed. Indeed, according to Weidert's impressionistic description (116), phonetic pitch contrasts between breathy and clear tones suggests that little effort is required to maintain lexical contrasts.

As it stands for now however, the status of Tamang remains an open question.

In laryngeally complex languages, there is a trade-off between the strength of non-modal phonation and its tendency to be sequenced. If weakly implemented, non-modal phonation may persist throughout the duration of the vowel without rendering opaque concomitant tone. Mpi and Tamang, for example, possess tone and phonation contrasts which cross-classify. However, the relatively light implementaion of non-modal phonation--at least in Mpi--does not render contrastive pitch opaque. Consequently, contrastive phonatory and tonal gestures here may be implemented simultaneously. Stated another way, ease of articulation here--lightly implementing non-modal phonation--allows for the parallel production of laryngeal abduction and tone. Of course, however, articulatory ease comes at an auditory price, as these contrastive gestures are less saliently encoded than if serially produced.

Tone and *strongly* implemented non-modal phonation are sequenced so that all contrasts are recoverable. Here, **economize** is ranked higher than **overlap**. This is what is found in Otomanguean.

These two strategies are summarized in (117).

(117) trade-off relations in laryngeally complex vowels:

economize⟩⟩overlap	**strong non-modal phonation**	**vowel⇧⟨tone⇨abduction⟩, etc.** (e.g. Otomanguean)
overlap⟩⟩economize	**weak non-modal phonation**	**vowel⇧tone⇧abduction, etc.** (e.g. Mpi, Tamang)

In summary, when laryngeally complex languages make their non-modal phonatory gesture acoustically prominent, they must resort to sequencing so that tone may be reliably encoded as well. When somewhat less acoustically prominent, non-modal phonation may occur with contrastive pitch.

Also, perhaps, when the system of laryngeal contrasts is sufficiently simple, the window for a given pitch target is larger, and therefore there is less risk of encountering acoustic opacity; all contrasts are recoverable.

5.5.2 Apparent Exceptions

In this section I consider apparent exceptions to my claims regarding laryngeally complex vowels. The languages in question--Yi and Dinka--are shown to be laryngeally *simplex*, not complex, involving tone and *pharyngeal* contrasts, not tone and laryngeal contrasts.

Case Study: Yi

Yi, a Tibeto-Burman language of southwestern China (Nishida 1979, Danstuji 1982, Maddieson and Hess 1987), has traditionally been regarded as a language which possesses both tonal contrasts and a phonation contrast involving glottalization. As the tonal system fully cross-classifies with glottalization, Yi is, at first glance, a laryngeally complex language. The Xide dialect possesses high, mid, and low-falling tones. The vowel inventory is in (118).

(118) plain:

i u

ɛ o

ɒ

glottalized:

ḛ ṵ

ɛ̰ o̰

a̰

Glottalization pervades the vowel in Yi; there is no sequencing of the non-modal phonatory gesture with respect to tone. Yet I now claim that Yi does not constitute a true counterexample to the claims presented herein regarding laryngeally complex languages, as so-called glottalization is in fact pharyngealization.

Dantsuji (1982) reports that non-glottalized vowels in Xide Yi regularly possess a lower F1 than their glottalized counterparts. His mean F1 values within vowel quality and across speakers is presented in (119) (p.3).

(119)

non-glottalized: vowel:	F1, mean Hz:	glottalized: vowel:	F1, mean Hz:
i	311.3	ḛ	666.7
ɒ	490.0	a̰	1024.7
o	340.0	o̰	737.1
u	326.7	ṵ	635.7
ɛ	353.3	ɛ̰	620.0

As F1 inversely correlates with tongue height, Danstuji speculates that glottalized vowels are implemented with a lower tongue position than are plain vowels. Nishida (1979) draws a similar conclusion regarding this relationship in Lolo.

Now, why should there be a correlation between tongue height and glottal constriction? One possibility, discussed in Gregerson (1976) in the context of Mon-Khmer register, is that so-called glottalized vowels in Yi do not in fact possess a contrastive glottal constriction, but instead possess a contrastive *pharyngeal* constriction. There are four lines of evidence to support this hypothesis.

(1) Consider tongue height. A pharyngeal constriction involves the movement of the tongue root toward the back of the pharyngeal wall. Now, as the mass of the tongue is a constant, expansion in one area forces contraction in another area. Specifically, tongue root expansion results in tongue body lowering. Tongue body lowering, of course inversely correlates with F1, which is raised in glottalized vowels. If glottalized vowels are instead pharyngealized vowels, this F1 distinction is straightforwardly accounted for.

(2) Maddieson and Hess (1987) report that glottalized vowels in Liangshan Yi do not possess the characteristic spectral tilt of glottalized vowels. While glottalized vowels typically possess an enhancement of H2 with respect to H1 (see, for example, Ladefoged, Maddieson, and Jackson 1988, Cao and Maddieson 1992, Kirk, Ladefoged, and Ladefoged 1993, Silverman, Blankenship, Kirk, and Ladefoged 1995), Maddieson and Hess' acoustic analysis does not yield this canonical result. The authors speculate that glottalized vowels here in fact involve a supraglottal mechanism, perhaps a constriction in the epiglottal region.

(3) A pharyngeal constriction may in fact raise F1 in and of itself--apart from any tongue body lowering--in essence shortening the resonant cavity at its closed end. Lindau (1975) reports that tounge root advancement in Akan is often accompanied by elevation of the larynx, resulting in a smaller pharyngeal cavity. This larynx raising, of course, raises F1.

(4) Ladefoged reports (1975:149) that a slight tensing of the laryngeal musculature is perhaps an inevitable concomitant of a marked pharyngeal constriction (see also Ladefoged . This slight laryngealization may thus explain the perceptual properties that pharyngealization and laryngealization share.

These characteristics (F1 values, spectral tilt, and moderate laryngealization) may be accounted for if Yi glottalized vowels are in fact pharyngealized, not laryngealized.

But note that in at least one study, (Kirk, Ladefoged, and Ladefoged 1993) a correlation is found between true laryngealization and F1 values: in Jalapa Mazatec form pairs which minimally contrast for creakiness, these researchers find slightly higher F1 in creaky vowels compared to their modal counterparts. As discussed in section 5.3, the authors hypothesize that the slight F1 increase found in creaky vowels may be the result of moderate larynx raising here, which shortens the oral cavity, consequently raising F1.

So if both a raised F1 and a potentially unstable F0 are present in Yi creaky vowels as well as in Jalapa Mazatec creaky vowels, how can it be concluded that it is a

pharyngeal constriction is the primary gesture in Yi, while a *laryngeal* constriction is the primary gesture in Jalapa Mazatec? The answer lies in the *degree* of F1 difference and *degree* of quasi-periodicity between the two voice qualities. For example, five speakers of Jalapa Mazatec are investigated by Kirk, Ladefoged, and Ladefoged (1993). In form pairs which minimally contrast for creakiness, these researchers find only slight differences in F1 values. These F1 differences are reportedly insufficient to reliably quantify the difference in the two phonation types (p.441). Instead, creaky vowels in Jalapa involve the characteristic spectral tilt of laryngealized vowels, in which H2 is markedly more prominent than H1. Now recall that I have already discussed the marked degree of glottal wave non-periodicity which accompanies creakiness here. These two facts taken together strongly suggest that the laryngeal constriction is primary

The *slight* F1 difference in the Jalapa Mazatec contrast should be compared to that present in Yi. Here, F1 values for creaky vowels are roughly *twice* those found in modal vowels (see (119)). Moreover, and this is most important, there is no report of pronounced non-periodicity of the glottal wave in Yi. Without this aperiodicity, the perception of pitch should not be significantly disrupted.

It is apparent that the F1 distinctions in Yi versus those of Jalapa Mazatec are a consequence of their distinct articulatory origins. Jalapa Mazatec creaky vowels are the result of laryngeal constrictions. Here, concomitant larynx raising results in a slight truncation of the oral cavity, thus serving to slightly raise F1. The so-called "creaky" vowels in Yi, however, involve a primary pharyngeal constriction, which greatly alters the oral cavity configuration. This articulatory reconfiguration serves to raise F1 to a far greater extent than does simple larynx raising.

The table in (120) presents a summary of the discussion up to this point.

(120) pharyngealization versus laryngealization:

	pharyngealization:	laryngealization:
primary gesture:	-pharyngeal constriction	-laryngeal constriction
automatic articulatory concomitants:	-tongue body raising -larynx constriction -larynx raising	-larynx raising
acoustic consequences:	-primary F1 raising -secondary quasi-periodicity	-primary quasi-periodicity, and H2 prominence -secondary F1 raising

Let us reconsider the Yi vowel system in light of this reasoning. In (121a) I have superimposed the plain and "creaky" systems (re-transcribed as pharyngeally constricted) repeated here as (121b).

(121) a. <u>full inventory</u>:

i u
e̤ ṳ
ɛ o
ɛ̤ ɒ ɔ̤
a̤

b. <u>plain</u>:

i u
ɛ o
ɒ

<u>pharyngealized</u>:

e̤ ṳ
ɛ̤ ɔ̤
a̤

In conclusion, if Yi glottalized vowels actually involve a pharyngeal constriction, they do not constitute a counterexample to the claim that laryngeally complex vowels sequence their non-modal phonatory gestures. Instead, these vowels are best characterized as possessing both tonal and *pharyngeal* gestures. Consequently, the acoustic and articulatory complications which arise in laryngeally complex languages are largely irrelevant here, as pharyngeal aperture interacts only minimally with laryngeal musculature.

Case Study: Dinka

Dinka, a Western Nilotic language spoken in Sudan, has been described as possessing creaky and breathy vowels, as well as contrastive tone (see, for example, Andersen 1993). In this section, I argue that Dinka is in fact like Yi, in that it possesses a *pharyngeal* contrast that gives rise to a percept that is not dissimilar to that of a *laryngeal* contrast. Dinka is thus shown not to counterexemplify my claims regarding laryngeally complex languages.

Andersen (1993:1) reports on the superficial patterning of morphological material in Dinka. Observe the striking similarity between Dinka and Otomanguean gross morphological patterning.

> "Dinka [...] is to a large extent a monosyllabic language. Nevertheless, it has a complex morphology. Thus a significant part of its morphology is non-affixal being manifested by way of morphophonological alternations in the root. Such alternations involve one or more of the following parameters: vowel quality, vowel length, voice quality, tone, and final consonant."

Now, in no description of Dinka is it reported that breathiness or creakiness persists for only part of the vowel (see, for example, Jacobson 1980, Andersen 1987, 1993, Denning 1987, Malou 1988). Rather, spectrograms from Malou suggest that voice quality persists for the duration of the vowel. The examples in (122) are from Andersen 1993.

(122) à-wè̤c you are kicking it
à-wè̤ec he is kicking it hither
à-tɛ̤̂ɛ̤ŋ he is dusting
à-tɛ̤̂ɛ̤ŋ I am dusting for him

The terms "creaky" and "breathy" are, according to Andersen (1987), "...mere impressionistic labels carrying no implications as to the articulatory basis of the distinction" (fn.4, p.26). Indeed, Jacobson, in his x-ray analysis of Western Nilotic vowels, plainly states that "it would be confusing to suggest a feature such as Creaky/Breathy [to characterize the contrast in question--D.S.]--these can be mixed up with phonation types. As yet, there is no instrumental evidence that a different mode of vocal cord vibration is taking place" (pp.196-197).

So-called breathy vowels in Dinka regularly possess a markedly *lower* F1 than their non-breathy counterparts. Malou's data are shown in (123).

(123)

<u>non-breathy</u>:		<u>"breathy"</u>:	
<u>vowel</u>:	<u>F1, mean Hz</u>:	<u>vowel</u>:	<u>F1, mean Hz</u>:
i	185	i̤	125
e	310	e̤	250
ɛ	375	ɛ̤	310
a	500	a̤	400
ɔ	375	ɔ̤	310
o	250	o̤	240
u	210		

Recall that Fischer-Jorgensen (1970) finds no significant formant distinctions between breathy and non-breathy vowels in Gujarati. If anything, breathy vowels in Gujarati possess a marginally higher F1 within the class of mid vowels. Thus true breathy vowels, at least in Gujarati, have little effect on tongue height. The Gujarati findings thus lend support to the hypothesis that the Dinka contrast under investigation is not laryngeal in nature.

Malou concludes that Dinka breathy vowels are characterized by a pharyngeal expansion. He additionally reports, however, that the larynx is somewhat lowered. This corroborates Lindau's findings in Akan, who, recall, points out that tongue root

advancement is often accompanied by a lowering of the larynx. It is not yet clear whether this accompanying larynx lowering is a mere physiological concomitant of pharyngeal expansion, or is instead some sort of enhancing mechanism. Indeed, larynx lowering here serves to reduce F1, just as tongue body raising does. Consequently, F1 contrasts between plain vowels and pharyngeally expanded vowels are enhanced.

Finally, and, again, most importantly, there is no report of a disruption of pitch perception in Dinka "breathy" vowels. If Dinka possesses a pharyngeal contrast, and not a laryngeal contrast, no disruption of pitch perception is predicted.

I conclude that voice quality in Dinka does not constitute a counterexample to my claims regarding the patterning of laryngeally complex vowels. As Dinka voice quality is pharyngeally-based, not laryngeally-based, it is not a laryngeally complex language, and is consequently not subject to the hypothesized constraints influencing the realization of laryngeally complex vowels.

5.5.3 Chong and Sedang Again

Before concluding, consider one more question: might **(1)** Chong and/or **(2)** Sedang be examples of Gregerson's (1976) interpretation of Mon-Khmer register, in that they possess a *pharyngeal* contrast, not a *laryngeal* contrast?

(1) Thonkum (1987, n.d.) shows that there are no co-occurrence restrictions involving vowel quality and register. That is, vowel quality and register fully cross-classify. Examples, taken from Thonkum's Appendix II (n.d.), are presented in (124).

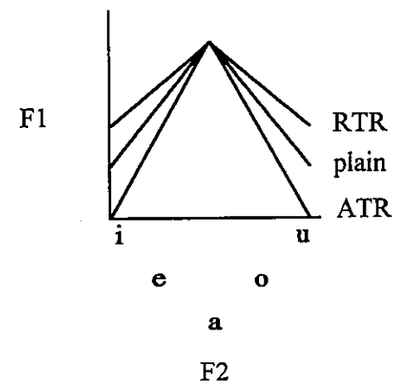
(124) vowel quality and phonation in Chong:

	R1	R2	R3	R4
i	**kriː** to cut open	**kəkrii̤t** cricket	**ci̤t** to wipe	**ki̤i̤t** to pour
e	**ceɾt** to whittle	**ceẹt** sambhar deer	**pẹɾt** plague	**pẹːẹt** hips
ɛ	**kənɛŋ** kind of climber	**kəmɛɛ̰ŋ** soot	**mɛ̰ŋ** mustache	**kəmɛ̰ŋ** jaws
ɯ	**kəlɯŋ** older sibling	**kənɯ̰ŋ** gum	**lɯ̰ŋ** (to lie) with one's face up	**lɯ̰ŋ** deep
ɤ	**kɛphlɤŋ** gun	**kətɤ̰ŋ** palate	**jɤ̰ɤ̰ŋ** high	**kəmɤ̰ŋ** chin
a	**kədaːj** plank	**kəjaːj̰** wind	**kəlaa̰j** a bunch of coconuts	**kəlaːj̰** loose
ɔ	**kəlɔŋ** to cross	**kəlɔ̰ŋ** bridge	**kəlɔ̰ŋ** husband, male	**kɛɲɔ̰ŋ** kind of Job's tears
o	**loːj** to swim	**kəkloːj̰** snake-headed fish	**ro̰ːj** to sprinkle (e.g. salt)	**ro̰ːj̰** alive
u	**puɾt** kind of tufted fern	**puɾ̰t** rotten	**pṵt** to speak	**lṵːt̰** soft

As all vowels freely combine with breathy and/or creaky registers, this suggests that manipulation of the pharyngeal cavity is not markedly involved in the Chong register system. Whence this implication?

Low vowels involve a redundant pharyngeal constriction. Because the mass of the tongue is a constant, squeezing down the tongue body inevitably involves a bulging of the tongue root. Consequently, in languages which possess a contrast between plain and pharyngeally constricted vowels, or plain and pharyngeally expanded vowels, it is far less likely that the low vowels participate in this particular contrast. It is consequently expected that such systems display the F1 characteristics schematized in (125), plotted against F2.

(125)



Here, pharyngealized non-low vowels possess a higher F1 than their plain counterparts. This is due to the inevitable tongue body lowering that accompanies tongue root retraction. Similarly, expanded-pharynx non-low vowels possess a lower F1 than their plain counterparts, due to tongue body raising. The low vowel itself, however, does not participate in either opposition, due to its required pharyngeal constriction. For example, Gregerson (1976) analyzes Miller's (1967) presentation of the vowels in Brou, a Mon-Khmer language of Vietnam, Laos, and Thailand, as possessing a pharyngeal contrast in all long non-low vowels. Similarly, in many of the ATR harmony languages of West Africa, low vowels do not contrast for tongue root advancement; they are redundantly non-advanced (see Gregerson 1976 for further discussion on the parallels between Mon-Khmer register and West African ATR systems).

Now note that this asymmetrical distribution should not hold for laryngealization. That is, if a system possesses contrastive creakiness, then any and all vowel qualities may be involved in the opposition. Since tongue configuration is largely independent of laryngeal configuration, It is predicted that creakiness does not distribute asymmetrically across vowel qualities. This symmetrical patterning should also hold of breathy phonation superimposed on vowel quality. Indeed, this is exactly what is found. Systems with

contrastive laryngealization or contrastive breathiness allow the full cross-classification of vowel quality and phonation. Maddieson (1984): "In the languages with laryngealized, voiceless, or breathy vowels, the vowels in these sets have the same qualities as vowels which are found in the plain voiced vowel set" (p.132). Additionally, Fischer-Jørgensen (1970) reports that only small and inconsistent differences in vowel quality are found between breathy vowels and modal vowels in Gujarati.

However, Thonkum's investigation of F1 values shows that breathy registers possess a lower F1 than their creaky counterparts. If breathy registers in fact involve a pharyngeal expansion, this lower F1 is an expected acoustic consequence, as tongue root advancement results in tongue body raising, and consequent F1 lowering. Thonkum notes this possibility, but correctly cautions that breathy registers may involve a slight degree of larynx lowering, which also may account for their somewhat lower F1 values. Moreover, the enlarged glottal opening that characterizes breathiness may serve to increase the length of the resonant chamber, in essence elongating the tube beyond the glottis itself. This too may result in a lower F1.

But note especially that the F1 contrasts in Chong breathy versus creaky registers are not nearly as marked as those found in Yi. Thonkum's (n.d.) vowel formant plots indicates a contrast no greater than 100 Hz. between all four registers. This suggests that Chong is like Jalapa Mazatec in that slight F1 differences are a consequence of larynx height and glottal opening: breathy registers possess a slightly lowered larynx and a more open glottis, thus slightly lowering F1, while creaky registers possess a slightly raised larynx, and a more closed glottis, thus slightly raising F1.

Finally, let us consider spectral tilt. Recall that creaky vowels have been found to possess a characteristic spectral tilt involving a more prominent H2 relative to the fundamental (Ladefoged, Maddieson, and Jackson 1988, Cao and Maddieson 1992, Kirk, Ladefoged, and Ladefoged 1993, Silverman, Blankenship, Kirk, and Ladefoged 1995). In fact, Thonkum's (1987) spectral investigation does not display this characteristic tilt. However, Thonkum compares *F*1 with H0, not *H*1 with H0. As different components of the spectrum are compared, no reliable conclusions may be drawn here.

I conclude that there is no evidence which supports the hypothesis that a pharyngeal contrast is present in Chong. Instead, root-final laryngealization is implemented as a creak on its tautosyllabic vowel.

(2) Let us finally consider the possibility that Sedang actually displays a pharyngeal contrast, as opposed to a laryngeal contrast in light of the following: systems involving pharyngealization or tongue root advancement often display asymmetries across vowel qualities: low vowels often do not participate in this contrast. Why should this be so?

Now, as I am unaware of any instrumental studies of Sedang, my only recourse is to exploit the predictions of the present approach to laryngealization and pharyngealization.

Smith (1968) reports that any single vowel quality (seven in all) or diphthong (nine in all) may be laryngealized. This includes the vowels that Smith reports are or may be phonetically low. The table in (126) is excerpted directly from Smith (his Chart IV, p.57).

(126) vowel quality and phonation in Sedang:

	unmodified:	laryngealized:
simple:	7	7
central glide:	4	4
back glide:	3	3
front glide:	2	2

Based on this free distribution of creakiness with respect to vowel quality, it may tentatively be concluded that Sedang possesses a laryngeal contrast, not a pharyngeal contrast.

If Sedang indeed possess laryngealization where certain other Mon-Khmer languages possess pharyngealization (for example, Brou), this suggests that these two articulatorily distinct though acoustically similar gestures may bear an intimate diachronic relationship to one another. That is, pharyngealization may, over time be reinterpreted as laryngealization, or, vice versa. Similarly, pharyngeal expansion may diachronically vary with breathiness. Of course, as I have just shown, the acoustic similarities here originate from their articulatory similarities (see Denning 1987 for a full discussion here).

This suggests the extreme rarity of languages which possess both a vocalic laryngeal contrast and a vocalic pharyngeal constrasts, as such a contrast is non-salient. To the best of my knowledge, the only language which cross-classifies phonation and pharynx aperture in this fashion is !Xóõ (Traill 1986). Significantly, laryngealization and pharyngealization here display rather different phasing patterns with respect to vocalism, thus serving to enhance the otherwise difficult contrast (see Traill 1986 for details).

In summary, I have considered apparent exceptions to my claim regarding the phonetic realization of laryngeally complex vowels. These apparent exceptions--Yi and Dinka--are not in fact laryngeally complex languages. In Yi, so-called creaky vowels involve a primary pharyngeal constriction, not a laryngeal constriction. Similarly, in Dinka, so-called breathy vowels involve a pharyngeal expansion, not a laryngeal expansion.

5.6 Conclusion

In this chapter I have investigated the optimal phasing relationships between vowels and laryngeal gestures. In laryngeally complex languages, the sequencing of contrastive laryngeal configurations may be observed, so that all contrastive information is

recoverable. Alternatively, the vowel, non-modal phonation, and tone, may be produced in parallel.

Chapter Six
Conclusion

In this dissertation I have investigated the phasing patterns between laryngeal and supralaryngeal gestures. I have motivated this patterning by appealing to the complex interaction of articulatory, aerodynamic, acoustic, and auditory phonetics.

I conclude that phasing patterns between particular gestural combinations are employed to maximize the auditory recoverability of linguistically significant material, and that these gestural configurations are means to achieve auditory ends. These patterns are explainable in terms of the forces at work in phonological systems, that is, that phonologies evolve to best fulfill their function; to keep meaningful elements distinct without excessive effort. Indeed, in this sense every phonological system is optimal.

Moreover, I have established a functional link between auditory salience and markedness: the more salient, the less marked, and the less salient, the more marked.

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