For my teacher, Donca Steriade

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ABSTRACT

This phonological study investigates the articulatory timing ("phasing") relationships that render acoustic cues optimally recoverable by the listener, and the strong tendency for languages to allow sub-optimal timing patterns only if they allow optimal ones. The primary area of focus is the Otomanguean language group of Oaxaca, Mexico and neighboring states, which possesses "laryngeally complex" vowels, a typologically unusual pattern in which tone and non-modal phonatory settings (breathiness, creakiness) cross-classify. The laryngeally complex vowels of Jalapa Mazatec, Comaltepec Chinantec, and Copala Trique are studied in depth. Also explored are the phasing relations between obstruents and laryngeals, and sonorants and laryngeals, including phonological analyses from such diverse groups as Mon-Khmer, Tibeto-Burman, and Nilotic, among others.

Throughout the investigation, findings from a number of disciplines—aerodynamics, acoustics, audition—are applied to the sound patterns in an effort not only to describe them in phonetic detail, but also to explain their phonological and typological behavior.

ACKNOWLEDGMENTS

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 study 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 was always 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.

Bruce Hayes’ unparalleled intelligence, his oftentimes startling enthusiasm, his always having my best interests in mind, and his faith in my ability, are gratefully acknowledged.

Pat Keating and Peter Ladefoged, in two quite distinct but equally important ways, have proven more and more invaluable (semantic anomaly intended) as my graduate career progressed from insular formalist to enlightened functionalist. I have also benefited greatly from many meetings, both arranged and impromptu, with Ian Maddieson.

Sincere thanks also go to Jody Kreiman, Bruce Gerratt, and Norma Antoñanzas-Barroso at the UCLA voice lab, for their support these last two years, and for their patience with my technical inexpertise. Thanks also to Judi Lynn Anderson of the SIL, Oaxaca branch, for her assistance and for her years of Chinantec fieldwork, and to Paul Kirk for his generous help with the Mazatec.

Thanks to Stefan Frisch, Sean Fulop, Chip Gerfen, Matt Gordon, Chai-Shune Hsu, Peggy MacEachern, Brian Potter, and Richard Wright.

Thanks to the UCLA Department of Linguistics, the Graduate Division, and the President's office, for six years of books, music, and beer. And thanks to the NIH for Training Grant T32 DC 00008 for two more years of the same!

Thanks, as always, to my family, Ethan, Jerry, Shaheen, Arif, Nadim, my mother Phyllis, my departed father, Bob, and, forever, Zhang Jie.

1

INTRODUCTION

1.0 INTRODUCTORY REMARKS

Linguistic sound systems necessarily possess contrastive values that are sufficiently distinct from one another such that their individual characters may be learned by the listener. In this way, any given value in any given sound system fulfills its functional role of rendering forms distinct which differ in meaning.

This study is an investigation into the gestural timing (or *phasing*) patterns that render acoustic cues optimally recoverable. Results show that sound systems typically maximize the perceptual distinctness among their contrastive phasing patterns. Moreover, sound systems tend to allow sub-optimal phasing patterns only if they allow optimal ones.

1.1 AUDITORY SALIENCE

Both source cues (the broadband noise associated with vocal fold spreading, the silence or creak which accompanies glottal constriction, and pitch cues) as well as filter cues (those accompanying a supralaryngeal constriction at a particular place, and of a particular degree, with or without velic lowering) are potentially subject to perceptual obscuring. Now, laryngeal gestures and supralaryngeal gestures are articulatorily independent of each other, and therefore may, in theory, be implemented simultaneously. Thus, for example, a voiceless aspirated stop consists of an oral occlusion as well as an articulatorily independent laryngeal abduction. However, were the realization of these two gestures strictly simultaneous, the laryngeal abduction would not be cued to 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 cue this laryngeal posture. Stated simply, the full oral closure here reduces the acoustic output to zero. With zero acoustic energy, no laryngeally-based information other than voicelessness is perceivable. A listener can tell that there is 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:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L (laryngeal):	abduction:	ÛÛ
		↑silence
		↑burst, offset transitions
		↑formants
	percept:	p a

Throughout this study, a variant of Browman and Goldstein's "gestural score" model (1986) is employed, in which the implementation of a given gesture is displayed in its temporal relation to other implemented gestures. The location of relevant acoustic/auditory cues is indicated beneath the display, followed by IPA (International Phonetic Alphabet) transcription.

Now, before going on, I am aware that "perceptual salience," and "optimal and sub-optimal timing" are not necessarily quantifiable measures. In this study 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 the associated cues for a given gesture is argued to correlate with the degree of auditory nerve response. In short, the greater the firing rate of the auditory nerve at the relevant characteristic frequencies, the more salient I assume the percept to be, and, consequently, the closer to "optimal" a given pattern is. This idea is considered in greater detail in Chapter Two.[1]

Optimizing auditory salience contributes to the fulfillment of the phonological system's primary function. In the case at hand, due to the temporal sequencing (or staggering) of the two gestures, the otherwise obscured cues are 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 transmit the relevant information. The resulting phonetic string consists of two perceptually salient elements ordered in time:

(2)
Optimal realization of an aspirated "p"

```
SL:   labial stop:        ÛÛ
      low vowel:          ÛÛÛÛÛÛÛÛ
L:    maximal abduction:  ÛÛ
                          ↑silence
                           ↑burst, offset transitions
                             ↑broadband noise
                                ↑formants
      percept:             p  h   a
```

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 convey 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 broadband noise is not as clearly transmitted when it precedes a stop closure, pre-aspirated stops constitute a sub-optimal realization:

(3)

Phonetically sub-optimal realization of an aspirated "p"

SL:	labial stop:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	maximal abduction:	ÛÛ
		↑reduced broadband noise
		↑silence
		↑burst, offset transitions
		↑formants
	percept:	h p a

It should also be noted that laryngeal abductions are common concomitants of phonologically *plain* stops as well. Here, the abduction is indeed phased more or less simultaneously with the oral occlusion. 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 broadband 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.

When the system of phasing contrasts exhausts the set of phonetically optimal phasing relations for a given set of gestures, or when more stringent morphological and/or phonotactic constraints are enforced, phonetically sub-optimal phasing patterns may be employed. An important observation here is that these system-internal contrastive and/or allophonic phasing patterns are normally *maximally distinct* from each other in terms of their phasing. Some of these sub-optimal realizations are discussed in subsequent chapters of this study.

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 transmitting 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 cue 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 aspiration 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 study I establish implicational hierarchies based on auditory optimality: the presence of a sub-optimal pattern usually implies the presence of an optimal pattern.

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 requisite recoverability of acoustic cues. I continue with a brief discussion of parallel production and serial production (1.5), and notation (1.6).

1.2 GESTURAL SEQUENCING

As discussed in 1.1, the optimal realization of aspirated stops involves temporally staggering the maximal laryngeal gesture 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 (1993a,b) 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, shown in 4.

(4)

a. *Unattested realization of a labio-velar stop*

SL: labial stop: ÛÛ
velar stop: ÛÛ
low vowel: ÛÛÛÛÛÛÛÛ
↑silence
↑labial burst, offset transitions
↑formants
percept: p a

b. *Optimal realization of a labio-velar stop*

SL: labial stop: ÛÛ
velar stop: ÛÛ
low vowel: ÛÛÛÛÛÛÛÛ
↑velar onset transitions
↑silence
↑labial burst, offset transitions
↑formants
percept: k͡p a

A third case of temporal sequencing that is especially relevant for the present investigation involves solely laryngeal gestures. Vowels, with maximum sonority, possess sufficient acoustic energy so that a contrastive laryngeal gesture may be phonetically simultaneous with the supralaryngeal configuration. 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). In 5 are timing schematics of prototypical breathy and creaky vowels.

(5)
Phonetic realizations of contrastively phonated vowels

SL:	low vowel:	ÛÛÛÛÛÛ
L:	abduction:	ÛÛÛÛÛÛ
	approximation:	ÛÛÛÛÛÛ
		↑formants, broadband noise, voicing
	percept:	a̤
SL:	low vowel:	ÛÛÛÛÛÛ
L:	constriction:	ÛÛÛÛÛÛ
	approximation:	ÛÛÛÛÛÛ
		↑formants, creak, voicing
	percept:	a̰

However, in certain languages contrastive phonation gestures in vowels are phased such that the vowels 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, pitch 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 cues are effectively transmitted to the listener. 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 in these contexts. I especially concentrate on the Comaltepec dialect of Chinantec. Chinantec possesses a lexical and morphemic contrast traditionally referred to as “ballistic accent” (the term in this context is 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 6 are some examples from three dialects.

(6)

Ballistic		*Controlled*		
lo:h˩˥	lime	lo: ˥	skin	Comaltepec (Anderson 1990)
mah˥	food	na˥	now	Palantla (Merrifield 1963)
ty:h˧	blind	ty: ˧	Peter	Quiotepec (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 6 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 phonemic 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 in modal voice. I provide supporting evidence for this approach to laryngeally complex vowels from the related Otomanguean languages of Mazatec and Trique. While Comaltepec Chinantec possesses both prevocalic and postvocalic phonation contrasts (ʔV˥ / hV˥, Vʔ˥ / Vh˥), related Jalapa Mazatec possesses only prevocalic laryngeals, while related Copala Trique possesses both these patterns, and in addition possesses laryngeally “interrupted” vowels, in which the laryngeal intrudes upon the vowel (VhV˥ / VʔV˥). Note in particular two things. First, if a language has only one phasing pattern among the involved gestures, it possesses pre-vocalic non-modal phonation. This phasing pattern is later argued to be the auditorily optimal pattern. Second, when a language has more than one phasing pattern here, the additional patterns are normally maximally distinct from the optimal pattern in terms of phasing. Thus post-vocalic aspiration is maximally distinct from pre-vocalic aspiration, and interruption, being equidistant from both extremes, is maximally distinct once again.

I have thus far considered some examples of gestural sequencing. Now consider gestural *re*-sequencing, or metathesis, exemplified by the so-called hitpaʔel pattern in Hebrew. Here, a prefix-final coronal stop metathesizes with a root-initial consonant, but only if this root consonant is a sibilant. 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 noise, and only secondarily are cued by the onset and offset transitions. 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 (t+s) would neutralize with affricate onsets (ts). Upon re-sequencing, all contrasts are maintained and enhanced (st). This is shown in 7.

(7)

a. *Input*

SL: coronal stop: ÛÛ
coronal fricative: ÛÛ
low vowel: ÛÛÛÛÛÛÛÛ
↑silence
↑burst, poor offset transitions
(indistinct from ts)
↑high frequency noise
↑formants
percept: t s a

b. *Output*

SL: coronal stop: ÛÛ
coronal fricative: ÛÛ
low vowel: ÛÛÛÛÛÛÛÛ
↑high frequency noise
↑silence
↑burst, good offset transitions
↑formants
percept: s t a

See Sherman 1994 for a more 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 the salience of their cues: increasing temporal exposure to cues may result in a more salient percept (Kaun 1995, Flemming 1995). Most importantly, expanding gestures across intervening consonantal constrictions results in more formant transitions and/or more distinctive discontinuities in the speech signal, serving to better transmit the relevant acoustic cues. 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 values. 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. 8 provides a schematic.

(8)

Front rounded vowels

SL:	high vowel:	ÛÛÛÛÛÛ	ÛÛÛÛÛÛ	ÛÛÛÛÛÛ	
	front vowel:	ÛÛÛÛÛÛ		ÛÛÛÛÛÛ	
	round vowel:		ÛÛÛÛÛÛ	ÛÛÛÛÛÛ	
	back vowel:		ÛÛÛÛÛÛ		
		↑higher F2	↑lower F2	↑indistinct	F2
	percept:	i	u	y	

How might languages overcome this potential non-recoverability? One method of achieving salience here, discussed at length in Kaun 1995, involves realizing the potentially non-salient contrastive cues 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. 9 provides a schematic.

(9)

Round harmony

a. Sub-optimal:

SL: coronal stop: ÛÛ
high vowel: ÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
front vowel: ÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
round vowel: ÛÛÛÛÛÛÛ
↑indistinct F2
↑onset transitions
↑silence
↑offset transitions
↑formants
percept: y t i

b. Possible optimal:

SL: coronal stop: ÛÛ
high vowel: ÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
front vowel: ÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
round vowel: ÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
↑indistinct F2
↑onset transitions
↑silence
↑burst, offset transitions
↑more distinct F2
percept: y t y

Kaun notes that in non-high front rounded vowels, lip protrusion is often less pronounced than in their high counterparts. As the degree of lip protrusion correlates with the degree of F2 lowering, the corresponding cues may be less robustly transmitted than their high vowel counterparts. 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.

A second method of increasing the likelihood of recoverability in this type of vowel involves the temporal sequencing of their constituent components; the tongue-fronting gesture and the lip-rounding gesture. As these gestures are no longer simultaneous upon sequencing, the mismatch between F2 quality and articulatory positioning is not encountered. 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:). The diachronic output is schematized in 10.

(10)
Possible optimal

SL:	high vowel:	ÛÛÛÛÛÛ
	front vowel:	ÛÛÛ
	round vowel:	ÛÛÛ
	back vowel:	ÛÛÛ
		↑distinct F2
		↑distinct F2
	percept:	i u

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 from other values. 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 1997).

While linguistically significant higher pitch is surely auditorily distinct from linguistically significant lower pitch, spreading occurs in this environment. Why should this be so? Sundberg (1973, 1979) provides instrumental evidence showing that pitch rises take much longer to initiate than do pitch falls of the same distance.[2] Therefore, in a syllable with a LH tone pattern, the H tone might be implemented only at the very end of the vowel. In 11 I show this pattern with a voiced coronal stop and a low vowel followed by a low-toned vowel.

(11)

Unattested realization of Comaltepec Chinantec LH pattern

SL:	coronal stop:	ÛÛ ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
L:	H-tone:	ÛÛÛ
	L-tone:	ÛÛÛ ÛÛÛÛÛÛ
	approximation:	ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
		↑low energy
		↑burst, offset transitions
		↑formants, low pitch
		↑toward higher pitch
		↑onset transitions
		↑low energy
		↑burst, offset transitions
		↑formants, low pitch
	percept:	d a ˩ ˩˥ d a ˩

In 11 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. This impedance potentially disrupts both the frequency and the amplitude of the H tone. But in fact, the H component of a Comaltepec Chinantec LH contour tone regularly spreads from its syllable of origin on to a following vowel. 12 shows this configuration.

(12)
Optimal realization of Comaltepec Chinantec LH pattern

SL:	coronal stop:	ÛÛ ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
L:	H-tone:	ÛÛÛÛÛÛ
	L-tone:	ÛÛÛ ÛÛÛ
	approximation:	ÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛÛ
		↑low energy
		↑burst, offset transitions
		↑formants, low pitch
		↑toward higher pitch
		↑onset transitions
		↑low energy
		↑burst, offset transitions
		↑formants, high pitch
		↑formants, low pitch
	percept:	d a ˩ ˩˥d a ˥ ˩

As its duration is increased upon spreading to overlap with a following vowel, this higher pitch becomes more salient. Its cues are reliably present in the speech signal, thus ensuring 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 cues for 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. This is represented in 13.

(13)
Unattested realization of a coronal nasal with a contrastive laryngeal abduction

SL:	coronal stop:	ÛÛ
	nasal:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	ÛÛ
		↑nasally channeled noise
		↑obscured offset transitions
		↑formants
	percept:	N̥ a

Therefore, the temporal duration of the contrastive laryngeal gesture is truncated with respect to the accompanying supralaryngeal gestures, sequenced to precede voicing.[3] A portion of the supralaryngeal gesture is thus realized with modal voice, rendering its formant structure recoverable. Usually, voicelessness is realized during the first portion of the nasal, as in 14.

(14)

Optimal realization of a coronal nasal with a contrastive laryngeal abduction

SL:	coronal stop:	ÛÛ
	nasal:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	Û
	approximation:	ÛÛÛÛÛÛÛ
		↑nasally channeled noise
		↑nasal murmur
		↑clear offset transitions
		↑formants
	percept:	N̥n a

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, as indicated in 15.

(15)

Alternative realization of a coronal nasal with a contrastive laryngeal abduction

SL:	coronal stop:	ÛÛ
	nasal:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	ÛÛ
	approximation:	ÛÛÛÛÛÛÛÛ
		↑nasal murmur
		↑breathy nasal murmur
		↑breathy offset transitions
		↑formants
	percept:	nn̤a̤ a

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

When gestural overlap would result in a diminished contrast, *serial production* is sometimes implemented in order to avoid neutralization. In this study, 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, broadband noise would not be present 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 cues the laryngeal abduction, and formant transitions cue 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 TABULAR DISPLAYS

In order to make more explicit the involved phasing relationships and their relative recoverability, I present in tabular form a succinct distillation of the relevant facts and arguments. First, recall that the phasing pattern which most effectively conveys acoustic information regarding implemented gestures is the optimal pattern. Second, recall that increasingly sub-optimal patterns are normally *maximally distinct* from optimal in their phasing relationships, provided all contrastive information is still recoverable. 16 portrays this information in schematic tabular form.

(16)
Schematic of tabular displays

optimal	auditorily optimal phasing pattern
sub-optimal	maximally distinct phasing pattern
increasingly sub-optimal	again maximally distinct phasing pattern

For example, aspiration and stops may be implemented in two distinct ways. The sub-optimal pattern, pre-aspiration, implies the presence of the optimal pattern, post-aspiration. This is shown in 17, where t is a cover term for any stop. Thus, for example, Huautla Mazatec possesses optimal t^h, but also possesses sub-optimal ${}^h t$. In such cases, all contrastive gestures are recoverable, but auditory response is not always optimal (as in the case of ${}^h t$).

(17)
Stops and aspiration

optimal	t^h
sub-optimal	${}^h t$

Given limitations on both articulatory control on the part of the speaker, and auditory resolution on the part of the listener, contrastive phasing patterns are exceedingly limited in number. In Chapter Five I present data from Copala Trique, which possesses three contrastive phasing patterns among a given set of gestures, which is the maximal number I have encountered. Not surprisingly, these phasing contrasts involve vocalism; given their increased duration and increased energy in comparison to other supralaryngeal configurations, it is not surprising that the maximal number of contrastive phasing patterns is found in this class.

The various phasing patterns are relations between the gestures themselves. These are indicated throughout with the shorthand symbols listed in 18.

(18)

Schematic of possible phasing patterns

Phasing patterns:	Schematic examples:		Gloss:
parallel (⇳)	a⇳b	a: ÛÛÛÛÛ Û b: ÛÛÛÛÛ Û $\overset{\frown}{ab}$	phase a and b strictly simultaneously
sequence (⇨)	a⇨b	a: ÛÛÛ b: ÛÛÛ a b	phase a to precede b
expand (⇧)	*a*⇧*b*⇨*c*	a: ÛÛÛÛÛ Û b: ÛÛ c: ÛÛ a $\overset{\frown}{ab}$ $\overset{\frown}{ac}$	phase a to precede b, but also in parallel with ordered b and c
truncate (⇩)	a⇩b	a: ÛÛÛ b: ÛÛÛÛÛ Û $\overset{\frown}{ab}$ 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 bi-directional 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 19, abstracting away from place of articulation.

(19)
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: stagger the maximal abduction to around stop release.

1.7 CONCLUSION, AND OUTLINE OF THE STUDY

The primary function of a phonological system is to keep meaningful elements distinct. Realizing this function involves optimizing the salience among contrastive values. Phasing relationships among gestures are organized to maximize recoverability. These relationships involve temporal sequencing, temporal expansion, temporal truncation, and parallel production. The achievement or non-achievement of auditory salience involves the complex interdependence among 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 structure 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, Zsiga 1993, Byrd 1994, Jun 1995, and Lindblom (et.al.) 1969, 1971, 1972, 1983, 1984. Chapter Three discusses the interaction of obstruents and laryngeal gestures. Chapter Four investigates the interaction of sonorant consonants and laryngeal gestures. Chapter Five discusses the interaction of vowels and laryngeal gestures.

NOTES

1. See also Wright 1996 for auditory influences on phonological patterning.

2. 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).

3. I could just as readily consider this strategy an *expansion* of the supralaryngeal value. However, in this study, the term *gestural expansion* refers to values which come to flank other values. For this reason, I refer to the process presently under discussion as *gestural truncation* of one gesture relative to another. Moreover, I am not suggesting that truncation here is in any way a synchronically active process, merely, that one gesture is limited in its realization to overlap with only a portion of another gesture.

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2

PREVIOUS WORK

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 principles of auditory phonetics (1986), and Mattingly's discussion of parallel transmission (1981). It is additionally inspired 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. Finally, the present approach to phonological investigations is inspired by the work of Lindblom and associates (1969, 1971, 1972, 1983, 1984), who numerically model phonological systems according to principles of both least effort, and, especially relevant here, maximization of perceptual distinctness.

In this chapter I present and critique the foundations of these areas of research.

2.1 BROWMAN AND GOLDSTEIN (1986, 1989, 1990, 1991, 1992)

This study 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, "...[T]he gestures for a given utterance, together with their temporal patterning, perform a dual function. They characterize 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 ... [T]here 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, see also Huffman 1990).

Byrd (1994) argues against a strict interpretation of Browman and Goldstein's 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 well motivated reasons why these three landmarks should be exploited. 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, particular gestural phasing patterns are employed to achieve particular auditory 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 in Chapter One, I add the relevant acoustic/auditory information below the gestural score itself.

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). See 1.

(1)
Tiers in Articulatory Phonology

```
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, as schematized in 2.

(2)
Functional independence of articulatory subsystems

Supralaryngeal:	Oral:	Û	etc.
	Nasal:	Û	etc.
Laryngeal:		Û	etc.
		↑auditory/acoustic cues	

It should nonetheless be noted that this presentation represents the *articulatory* independence of these subsystems, and not their phonological independence. That is, the laryngeal system and the supralaryngeal system may 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 effective communication of contrastive information. 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 by hypothesis invariant across contexts. In the present approach however, only relative gestural target durations are modeled. 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 cues. The resulting temporal stability of oral closure-then-laryngeal abduction is, by hypothesis, a consequence of this optimal coordination of gestures.

Extending this notion to its logical extreme, the segment and the syllable, which have remained unquestioned building blocks of many phonological theories, are here regarded as potentially epiphenomenonal. That is, speaker (and linguist) intuitions about segmentation and syllabification may be a mere consequence of the location and temporal stability of particular auditory cues, and may not in and of themselves necessarily possess any linguistic significance. Thus, characterizing laryngeal gestures as being, for example, phonologically consonantal or vocalic in affiliation is herein for expository expedience only.

To summarize, in this study I employ a variant 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 relevant auditory/acoustic cues. 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 are thus realized at this site so that they may achieve maximal acoustic salience.

The present approach broadens Kingston's conclusions by placing them in the context of the more general patterns 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 gestural sequencing, temporal truncation, temporal expansion, and or parallel realization.

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 that is unaccompanied by vocal fold approximation (a prerequisite for 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 accommodate laryngeal information.

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 may actually increase 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 realized with a salient burst upon closure release. 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 broadband noise is saliently cued to the listener.

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, ongoing transglottal flow does not serve to increase intraoral pressure. Instead, additional gestures obligatorily accompany the glottal constriction which serve to raise oral pressure.

In ejective stops, the glottis shuts, the larynx raises, the pharyngeal cavity may be constricted, and the pharyngeal walls may be stiffened, thus reducing the size of the supraglottal cavity, consequently raising intraoral pressure (Kingston 1985, MacEachern, 1997). Now, at stop release, the compressed air rushes through the mouth. The accompanying laryngeal constriction is saliently cued 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 these types of oral constriction: laryngeal gestures are less likely to be realized around a nasal or continuant release.

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 however, that Dixit and

Brown (1978) find that in phonologically plain plosives in Hindi, peak intraoral pressure is equivalent to that found in voiceless aspirated stops; even in plain stops, the vocal folds are somewhat abducted during the oral closure, in part to avoid voicing, and thus the intraoral cavity fills 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 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 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 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 among 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 syllable-final stops), these laryngeal gestures are not implemented in order to produce aspiration in the relevant environment. However, when broadband noise or loud popping 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 post-aspirated counterparts. 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), subsequent 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 accommodate temporal precedence relations between laryngeal and supralaryngeal features: while Closure accommodates supralaryngeal features, Release usually accommodates laryngeal articulations. 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 4.

(4)

Pre-aspirated stops	*Pre-glottalized stops*
ht hk hts htʃ hʈʂ	
hm hn hɲ	ʔm ʔn ʔɲ
hnt hnk hnts hntʃ hnʈʂ	ʔnt ʔnk ʔnts ʔntʃ ʔnt
Post-aspirated stops	*Post-glottalized stops*
th kh tsh tʃh ʈʂh	tʔ kʔ tsʔ tʃʔ ʈʂʔ
nth nkh ntsh ntʃh nʈʂh	ntʔ nkʔ ntsʔ ntʃʔ nʈʂʔ
mh nh	mʔ nʔ ɲʔ
Post-aspirated continuants	*Post-glottalized continuants*
vh sh ʂh	vʔ yʔ sʔ ʂʔ lʔ

Regarding the patterning of aspiration and glottalization, Steriade observes that with certain systematic though presently irrelevant exceptions, nasals, plosives, and nasal-plosive clusters may be pre-aspirated, nasals and nasal-plosive clusters may be pre-glottalized, provided no ʔ follows, and also, plosives, nasals, and continuants may be post-aspirated/-glottalized.

Thus, Steriade observes, most stops (oral or nasal) may contrast pre-and post-aspiration/-glottalization. However, continuants may only be post-aspirated/-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 stops 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, as shown in 5.

(5)

Pre-aspirated stop		*Pre-glottalized stop*	
place		place	
|		|	
A_0	A_{max}	A_0	A_{max}
|		|	
[spread]		[constricted]	

(where A_0 = closure, A_{max} = (approximant) release)

Post-aspirated/post-glottalized plosives and nasals, however, are represented with [spread] or [constricted] associated to stop Release, as in 6.

(6)

<table>
<tr><td colspan="2">Post-aspirated stop</td><td colspan="2">Post-glottalized stop</td></tr>
<tr><td>place</td><td></td><td>place</td><td></td></tr>
<tr><td>|</td><td></td><td>|</td><td></td></tr>
<tr><td>A_0</td><td>A_{max}</td><td>A_0</td><td>A_{max}</td></tr>
<tr><td></td><td>|</td><td></td><td>|</td></tr>
<tr><td></td><td>[spread]</td><td></td><td>[constricted]</td></tr>
</table>

Finally, a plain stop possesses no contrastive laryngeal feature, as in 7.

(7)

<table>
<tr><td colspan="2">Plain stop</td></tr>
<tr><td>place</td><td></td></tr>
<tr><td>|</td><td></td></tr>
<tr><td>A_0</td><td>A_{max}</td></tr>
</table>

Given their monopositional status, continuants either possess or lack a [spread]/[constricted] feature associated to their single A-position, as in 8.

(8)

<table>
<tr><td>Plain continuant</td><td>Aspirated continuant</td><td>Glottalized continuant</td></tr>
<tr><td>place</td><td>place</td><td>place</td></tr>
<tr><td>|</td><td>|</td><td>|</td></tr>
<tr><td>A_f</td><td>A_f</td><td>A_f</td></tr>
<tr><td></td><td>|</td><td>|</td></tr>
<tr><td></td><td>[spread]</td><td>[constricted]</td></tr>
</table>

(where A_f = fricative)

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 discontinuities in the signal. For this reason, nasals may fall in line after stops as being the most likely class to accommodate laryngeal contrasts at both onset and offset.[2]

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 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)

In addition to aerodynamic considerations, there are interacting auditory reasons why aspiration is preferably realized on a stop release, as opposed to a stop onset.

Based on the findings of Tyler, Summerfield, Wood, and Fernandes (1982), Delgutte (1982), and others, 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 (9) (1986:5).

(9)

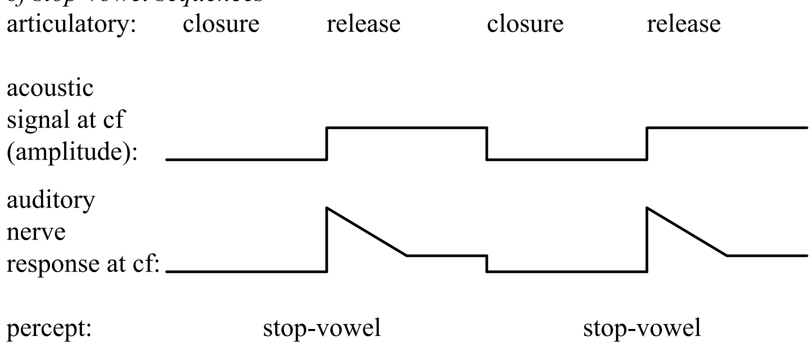
Relevant principles of auditory phonetics

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 at a given characteristic frequency ("cf") does not seem to respond exclusively to absolute levels of acoustic energy. Instead, it responds in part to local changes, especially increases in acoustic energy. Consequently, the same acoustic signal may evoke a greater response, that is, be more salient, when in one 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 so prevalent.

The schematic in 10 displays in gross terms the transforming effect that the auditory nerve imparts on the incoming acoustic signal in this context.

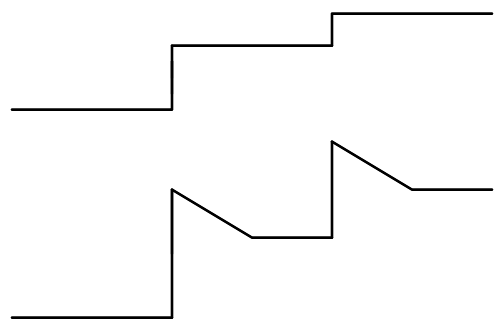
(10)
Gross schematic of articulatory, acoustic, and auditory characteristics of stop-vowel sequences



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 is auditorily salient, as schematized in 11.

(11)
Gross schematic of articulatory, acoustic, and auditory characteristics of post-aspirated stop

articulatory:
supralaryngeal: stop release vowel
laryngeal: abduction



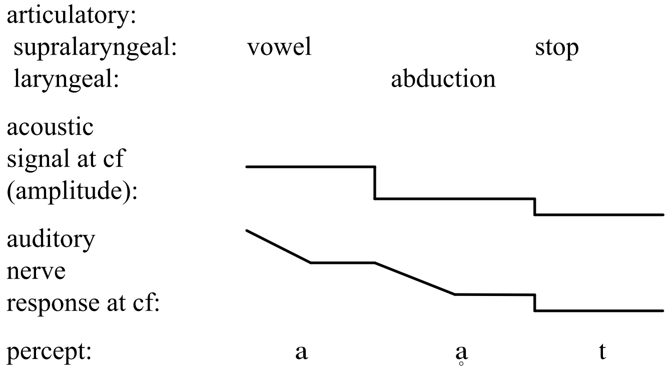
acoustic signal at cf (amplitude):

auditory nerve response at cf:

percept: t ^{h} a

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. Since auditory response is much greater for the onset of spectral activity as opposed to its offset (Principle 3), the likelihood of recovery here is lowered. See 12.

(12)
Gross schematic of articulatory, acoustic, and auditory characteristics of pre-aspirated stop



As Bladon concludes, "...[G]iven 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.

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 seem to be most successful in transmitting information. Rather, transitions from periods of greater stricture (Cs) to periods of lesser stricture (Vs) 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 increase in amplitude result in maximal auditory nerve response. Moreover, amplitude plateaus result in the rapid decay of auditory nerve response. Consequently, phasing patterns are auditorily better to the extent that amplitude increases abruptly and frequently.

2.5 ZSIGA (1993), BYRD (1994), AND JUN (1995)

Zsiga (1993) addresses the observation that lexical phonological processes are typically categorical 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 categorically. 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. Now, as stated in section 2.1, in this study I describe sound patterns in terms of articulatory gestures. Nonetheless, Zsiga's model—in which hypothesized phonological simultaneity is modeled in a(n auto-) segmental framework, while phasing detail is expressed in gestural terms—captures one aspect of the distinction between parallel transmission 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 would involve 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 (but cf. Steriade 1992). That is, the features which combine to produce an aspirated stop are represented in parallel. See 13.

(13)
Unordered autosegmental model of an aspirated "p" (abbreviated)

```
              root
           /          \
[alveolar stop]     [spread glottis]
```

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 some hypothesized 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, as exemplified in 14.

(14)
Gestural model of aspirated "t"

```
SL:   alveolar stop:      ÛÛ
L:       abduction:        ÛÛ
                          ↑burst, transitions
                            ↑broadband noise
                            t h
```

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 hypothesized 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 fall victim to such criticism. Specifically, only when phasing patterns are sufficiently auditorily distinct from each other may they play their fundamental role in the system of contrasts.

Now 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 according to Jun’s findings. This reduction in acoustic payoff may, in time, lead to the eventual deletion of A. This diachronic tendency is schematized in (15).

(15)
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 study 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.

2.6 LINDBLOM (ET.AL.) (1969, 1971, 1972, 1983, 1984)

While a strict quantitative model of contrastive timing configurations is not formulated herein, the work of Lindblom and Sundberg (1969, 1971) and Liljencrants and Lindblom (1972) may be viewed as a blueprint from which a reliable model might ultimately be built. Liljencrants and Lindblom actually expand upon the so-called LS (Lindblom and Sundberg) Model presented in the two earlier papers. The perceptual space—in their case, the vowel space—is the product of particular articulatory—tongue, lip, jaw, and larynx—postures, whose coordination is constrained by natural limitations on vocal tract configuration. From these modeled positions, a set of corresponding acoustic values may be derived. For vowels, this set includes the first three formants, which are most important in determining a given vowel quality. Formant values are plotted in a three-dimensional acoustic space, with each dimension corresponding to one of the three formant values. Now, with a sufficiently rich data set fed into a computer program written to maximize the linear distance between the points on the three dimensional scale (eventually converted from Hertz, an acoustic scale, to Mels, an auditory scale), maximally distinct vowel qualities may be calculated. As the number of points increases, naturally, linear distances between points are diminished. Liljencrants and Lindblom report that “The formant patterns which [the LS Model] can generate are in close agreement with those of basic vowel qualities,” (p.855) and that sufficient variation in the search procedure exists to model the system-to-system variation found in actual inventories.[3]

Although the LS Model, which has been employed to quantify paradigmatic distinctness, is not employed herein, it should nonetheless be kept in mind as the overriding inspiration for the present approach to the contrasts under discussion. However, it should be noted that the nature of the present data differ from that investigated by Lindblom et.al. The present data set, of course, does not involve the shades and colors of acoustic/auditory quality (timbre) which correlate with largely static formant values. Rather, we are here dealing with more grossly defined spectral characteristics which correlate with dynamic spectral changes over time. The inventory of potential contrasts we are dealing with, then, is syntagmatic rather than paradigmatic. Given this intrinsic dynamism, a proper model here requires overt reference to the temporal coordination—sequencing, expansion, truncation, and/or overlap—of the involved articulatory gestures. We thus require, in addition to acoustic and auditory scales, a time scale, expressed in milliseconds, to properly model contrasts that are primarily temporal in nature.

2.7 Conclusion

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

NOTES

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.

2. 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—neither of which was present 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 does not follow this trend, as sonorants possess contrastive phasing relationships involving laryngeals, while stops do not.

3. Actually, Bladon (1986) points out that certain incorrect predictions of the model, specifically, the overgeneration of high central vowels, might be a consequence of the abundance of auditory boundary markers in this region of the vowel space.

Page 50

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3

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 once again that contrastive aspiration and glottal closures 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 survive. 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 reference to Korean, Sanskrit, and Icelandic as well. I conclude that the optimal realization of such stops involves a laryngeal abduction or constriction 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

stop⇨laryngeal	phase maximal laryngeal gesture around stop release interval
laryngeal⇨stop	phase maximal laryngeal gesture to precede stop closure

3.1.1 Stops and Laryngeal Abductions

Given the nature of a full supralaryngeal closure, a laryngeal abduction must be staggered with respect to the occlusion in order for broadband noise to be recovered by the listener.

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 aerodynamic properties of their release, as well as their effect on the auditory nerve, which presumably serves to increase perceptual salience of the characteristic broadband noise. 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 aerodynamically sub-optimal, since, unlike stop onsets it does 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 the reliable transmission of their cues. 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 cues.

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 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 further 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 sub-optimal phasing relationships in order to cue all the contrasts required of fully inflected stems: the Huautla dialect maintains contrasts involving aspiration both preceding 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*	
ʰti˧	fish	tʰa˧	light in weight
ʰtse˩˨	a sore	tsʰe˥˧	clean
ʰtʃi˧	small	tʃʰa˧	brother-in-law
ʰka˦˥	stubble	kʰã˨	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, Silverman 1996 for additional discussion of the

Jalapa dialect). This peculiar phonation change—heavy breathy phonation followed by light breathy phonation—renders pitch cues recoverable. 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 articulatory, timing and aerodynamic distinction between these two gestural configurations, and, relatedly, the difficulty in discerning such a distinction on the part of the listener. See 3.

(3)

Unattested contrast involving an oral closure-laryngeal abduction-vowel sequence

Aspirated stop:

SL:	coronal stop:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	ÛÛ
	L-tone:	ÛÛÛÛÛ
		↑silence
		↑burst, transitions
		↑broadband noise
		↑formants, pitch
	percept:	t ^{h} a˩

Stop with breathy vowel:

SL:	coronal stop:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	ÛÛÛ
	approximation:	ÛÛÛÛÛÛ
	L-tone:	ÛÛÛÛ
		↑silence
		↑burst, transitions
		↑breathiness

↑clear voice, formants, pitch

percept: t a̤ a˩

3 schematically models the distinction between an aspirated stop (t^ha˩), and a plain stop followed by a breathy-then-modal vowel (ta̤a˩). 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 display this pattern, and avoid a combination of gestures involving a plain stop followed by a breathy release (for example, most Mazatec dialects, and Oriya (Dhall 1966)), even when breathy vowels are elsewhere attested, i.e. after non-plosives.

As breathy phonation may precede modally phonated vowels here, Huautla expands its system of phasing contrasts in stops by implementing a phasing pattern which maximizes perceptual distinctness (pre-aspiration versus post-aspiration).

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 may come at an articulatory cost. With several counts against them (auditory, articulatory, and aerodynamic deficits), it is hardly surprising that pre-aspirates are comparatively rare, and that their presence implies the presence of optimal post-aspirates. In 4 are schematics of the Huautla contrast.

(4)
Aspiration contrasts in Huautla de Jimenez Mazatec stops
Post-aspirated stop:

SL:	coronal stop:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	ÛÛ
	L-tone:	ÛÛÛÛÛ
		↑silence
		↑burst, transitions
		↑broadband noise
		↑formants, pitch
	percept:	t ʰ a˩

Pre-aspirated stop:

SL:	coronal stop:	ÛÛ
	low vowel:	ÛÛÛÛÛÛÛÛ
L:	abduction:	ÛÛ
	L-tone:	ÛÛÛÛÛÛ
	intercostals:	ÛÛ
		↑broadband noise
		↑silence
		↑burst, transitions
		↑formants, pitch
	percept:	ʰ t a˩

In Huautla then, pre-aspirated plosives do indeed render all contrasts auditorily recoverable, although perhaps at an articulatory cost. Two phasing relationships between stops and laryngeal abductions are in 5.

(5)

Supralaryngeal closures and/or laryngeal abductions in Huautla

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

Before concluding this case study of Huautla, observe an additional asymmetry in the patterning of laryngeal gestures with respect to supralaryngeal gestures here: while plosives may be either post-aspirated or pre-aspirated, they may only be post-glottalized, and never pre-glottalized. 6 repeats the relevant patterns from Chapter 2.

(6)

Pre-aspirated stops	*Pre-glottalized stops*
ht hk hts htʃ hʈʂ	
hm hn hɲ	ʔm ʔn ʔɲ
hnt hnk hnts hntʃ hnʈʂ	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 consider this pattern here. Given the acoustic quality of aspiration (random noise across a large portion of the frequency range), its cues are recoverable even when preceding a voiceless stop, especially if the necessary gesture is 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, pre-glottalized voiceless plosives are unattested.

In summary, the optimal realization of 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, this additional value is implemented as a laryngeal abduction—possibly with extra internal intercostal flexion—followed by a supralaryngeal closure, e.g. ^ht. While sub-optimal, this phasing pattern is nonetheless maximally distinct from optimal post-aspirates.

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, MacEachern 1997). 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 transmission of the contrastive laryngeal constriction. Were the larynx not raised and the pharynx not constricted, the air in the sealed oral cavity might not be compressed, and thus would lack a 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 cued, 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. This is schematized in the display in 7.

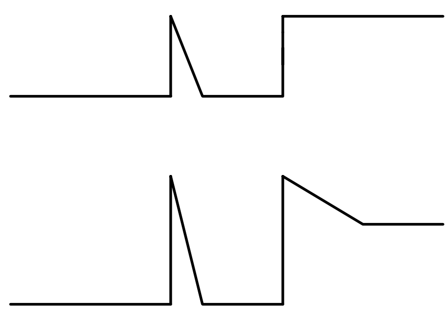
(7)

Gross schematic of articulatory, acoustic, and auditory characteristics of ejective stop

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

acoustic signal at cf (amplitude):

auditory nerve response at cf:



percept: t ’ a

Now compare post-glottalized stops with pre-glottalized stops. Since supraglottal wall hardening, pharyngeal constriction, and larynx raising would offer negligible acoustic payoff in this context, glottalization here is realized as a mere creaking of the latter portion of the previous vowel. (Recall that without a preceding sonorant, pre-glottalized voiceless stops are probably unattested.) 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, as schematized in 8.

(8)

Gross schematic of articulatory, acoustic, and auditory characteristics of pre-glottalized stop

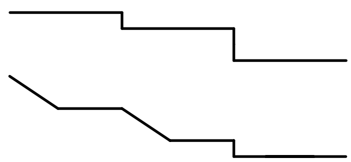
articulatory:

supralaryngeal: vowel stop

laryngeal: approx. approx. constriction

acoustic signal at cf (amplitude):

auditory nerve response at cf:



percept: a a̰ t

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. 9 summarizes in tabular form the results of the present discussion.

(9)

Stops and contrastive laryngeal constrictions (ejectives, creaks)

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

There are indeed cases in which laryngealization is realized preceding the oral occlusion, overlapping with a preceding vocalic gesture, to the exclusion of optimal ejectives. This phasing pattern is sub-optimal, as auditory nerve response is not maximal. See 10.

(10)

Sub-optimal realization of laryngealized stops

SL:	coronal stop:	ÛÛ
	low vowel:	ÛÛÛÛÛÛ
L:	constriction:	ÛÛÛ
		↑formants
		↑creak
		↑transitions
	percept:	a a̰ t

This non-canonical realization may sometimes be explained when considering both phonotactic and morphological influences on phasing relationships, as I now show by investigating the laryngeals of Chong, Korean, Sanskrit, and Icelandic.

CASE STUDIES: CHONG, KOREAN, SANSKRIT, AND ICELANDIC

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, Sanskrit and Icelandic implement three variations of this general pattern. I conclude that morphological patterning can and does exert an influence on the phasing of gestures.

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. 11 shows the Krathing Chong segment inventory.

(11)
Chong segment inventory

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

Thonkum reports that Chong contains four contrastive “registers,” listed in 12.

(12)
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-occurring phonetic properties. 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 13.[1]

(13)

Examples of Chong registers

R1:	c^{h}ih^{1}	c^{h}ih	to dry in the sun
	puk^{1}	puk	rotten smell
	sii^{1}	siː	head louse
	p^{h}oʔ^{2}	p^{h}oʔ	to dream
R2:	kəsut^{2}	kəsuṵt	to come off
	t^{h}am^{2}	t^{h}aa̰m̰	crab
	kəp^{h}aŋ^{2}	kəp^{h}aa̰ŋ	scraps, chips
	kəpɯt^{2}	kəpɯɯ̰̃t	to wear (skirt, trousers)
R3:	puut^{3}	pṳːt	to speak
	kəlaa^{3}	kəla̤ː	ear
	pɔh^{3}	pɔ̤h	ashes
	kəcaai^{3}	kəca̤ːj	nine
R4:	luuc^{4}	lṳːṵc	soft
	kəlaai^{4}	kəla̤ːa̰j	loose
	cam^{4}	ca̤a̰m̰̃	bruised
	krɤt^{4}	krɤ̤ɤ̰t	to leak

Possible codas are presented in 14, along with an example of each.

(14)
Chong codas

Stops:	p	kəkɛɛp^{1}	kəkɛːp	to cut (with scissors)
	t	peet^{3}	pe̤ːt	plague
	c	kənooc^{2}	kənoːo̰c	nipple
	k	lɛɛk^{1}	lɛːk	chicken
Nasals:	m	cum^{4}	cṳṵm̰	vine, climber
	n	k^{h}iin^{2}	k^{h}iːḭn̰	guard
	ɲ	(no examples given)		
	ŋ	kəlɛɛŋ^{2}	kəlɛːɛ̰ŋ	floor
glides:	j	luj^{4}	lṳṵj	earthworm
	w	ŋew^{2}	ŋɛɛ̰w̰	curved
laryngeals:	ʔ	rəkoʔ^{1}	rəkoʔ	tips (of climbers and creepers)
	h	pah^{3}	pa̤h	dry

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

R3 (breathy) vowels are free to occur with any syllable type. However, one notable exception to this otherwise free distribution involves the set of pre-vocalic 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 contrastively co-occur.

The distribution of creaky registers is far more limited, however: creaky registers are contrastive only when a coda is present. Moreover this coda consonant must be supralaryngeally articulated. As creaky registers (in which creakiness is present only on the latter portion of the vowel) and plain glottal stop codas are so similar in their articulatory and acoustic characteristics, the two cannot contrast. Indeed, post-vocalic glottal checking may actually induce creak on latter portion of the vowel, thus potentially thwarting any possibility of a contrast between the two. Thus, plain root-final glottal stop may be viewed as the realization of creaky register in otherwise open roots. Post-vocalic h and creaky register cannot co-occur either, as such configurations would require simultaneous vocal fold abduction and constriction. However, a laryngeal abduction timed fully simultaneously with the vowel may freely occur with either post-vocalic h or ʔ. Such forms involve either a plain or a breathy vowel, followed by a laryngeal abduction or laryngeal constriction. Thus, post-vocalic ʔ and h never occur with creaky registers, though are free to occur with so-called breathy registers, as shown in 15.

(15)
h and ʔ codas

SL:	low vowel:	ÛÛÛÛÛÛÛ	low vowel:	ÛÛÛÛÛÛÛ
L:	abduction:	Û	abduction:	ÛÛÛÛÛÛÛ
	approximation:	ÛÛÛÛÛÛ	approximation:	ÛÛÛÛÛÛ
		↑formants		↑formants, breathiness
		↑broadband noise		↑broadband noise
	percept:	a h		ạ h

Examples:	kəpɔh^{1}	kəpɔh	thread
	ʔih^{1}	ʔih	not
	pɔh^{3}	pɔ̤h	ashes
	kɔh^{3}	kɔ̤h	to knock

SL:	low vowel:	ÛÛÛÛÛÛÛ	low vowel:	ÛÛÛÛÛÛÛ
L:	abduction:		abduction:	ÛÛÛÛÛÛ
	constriction:	Û	constriction:	Û
	approximation:	ÛÛÛÛÛÛ	approximation:	ÛÛÛÛÛÛ
		↑formants		↑formants, breathiness
		↑silence		↑silence
	percept:	a ʔ		a̤ ʔ

Examples:	kəloʔ^{1}	kəloʔ	skin
	leʔ^{1}	leʔ	kind of hat
	klɔʔ^{3}	klɔ̤ʔ	to vomit
	peʔ^{3}	pe̤ʔ	delicious

However, laryngealization may be phased with the latter portion of the vowel and into sonorant codas. These supralaryngeal gestures possess sufficient acoustic energy to convey 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 cue the contrast. Indeed, as discussed in Chapter 4, this partially modal realization of creaked nasals better cues place of articulation, and is, not surprisingly, the cross-linguistic norm. See 16.

(16)

Laryngealization with sonorant codas

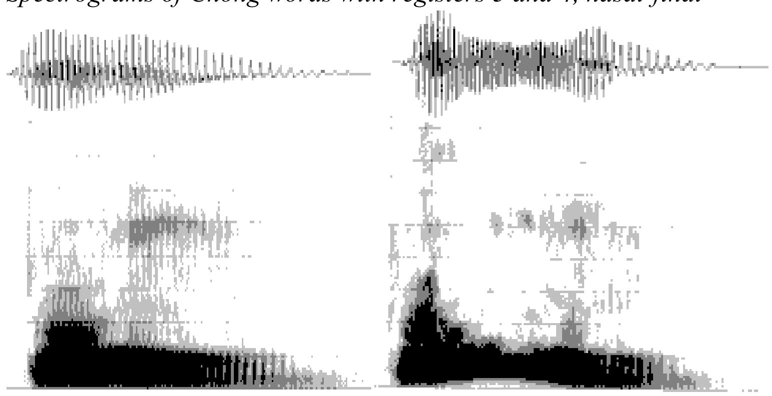
SL:	low vowel:	ÛÛÛÛÛÛÛÛ	low vowel:	ÛÛÛÛÛÛÛÛ
	coronal stop:	ÛÛ	coronal stop:	ÛÛ
	nasal:	ÛÛ	nasal:	ÛÛ
L:			abduction:	ÛÛÛÛ
	constriction:	ÛÛÛ	constriction:	ÛÛÛ
	approximation:	ÛÛÛÛÛÛÛÛ	approximation:	ÛÛÛÛÛÛÛÛ
		↑formants		↑formants
				breathiness
		↑creak		↑creak
		↑nasality		↑nasality
		↑voice		↑voice
	percept:	a a̰ n̰n		a̤ a̰ n̰n

Examples:	ɲɯɯj^2	ɲɯːɯ̰j	kind of mushroom
	cum^4	cṳṵm̰̃	vine, climber

In 17 are waveforms and wideband spectrograms of a breathy form, and a breathy-creaky form, both of which are closed by nasals. These spectrograms were made from Therapan Thonkum’s original recordings, in file in the UCLA Phonetics Laboratroy archive. Observe in particular the change in periodicity toward the end of the creaked form, accompanied by a lowering of the fundamental frequency.

(17)

Spectrograms of Chong words with registers 3 and 4, nasal-final



pṳːŋ	pṳṵŋ
the entrails of animals	watermelon

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, as in 18.

(18)

Laryngealization with stop codas

SL: low vowel: ÛÛÛÛÛÛÛÛ low vowel: ÛÛÛÛ
ÛÛÛÛ

coronal stop: ÛÛ coronal stop: ÛÛ

L: abduction: ÛÛÛÛ

constriction: ÛÛÛ constriction: ÛÛÛ

approximation: ÛÛÛÛÛÛ approximation: ÛÛÛÛÛÛ

↑formants ↑formants

breathiness

↑creak ↑creak

↑transitions ↑transitions

↑silence ↑silence

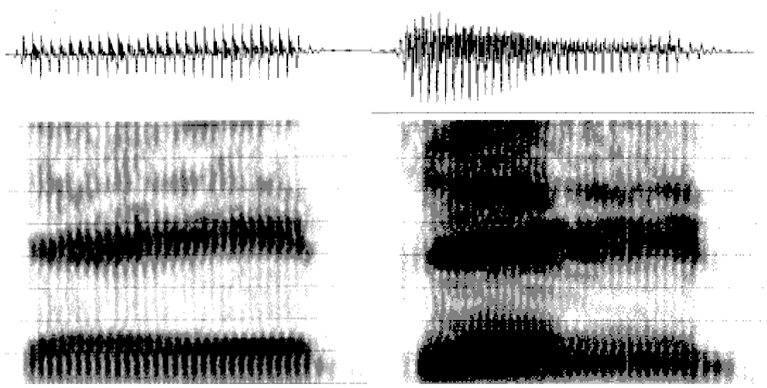
a a̰ t a̤ a̰ t

Examples:	kɤɤt[2]	kɤːɤ̰t	shallow
	lɔɔp[4]	lɔ̤ːɔ̰p	gadfly

In 19 are waveforms and wideband spectrograms of plain and creaked stop-final words in Chong. Observe the diminution of energy on the right portion of the creaked form.

(19)

Spectrograms of Chong words with registers 1 and 2, stop-final



ceet	ceḛt
to whittle	sambhar deer

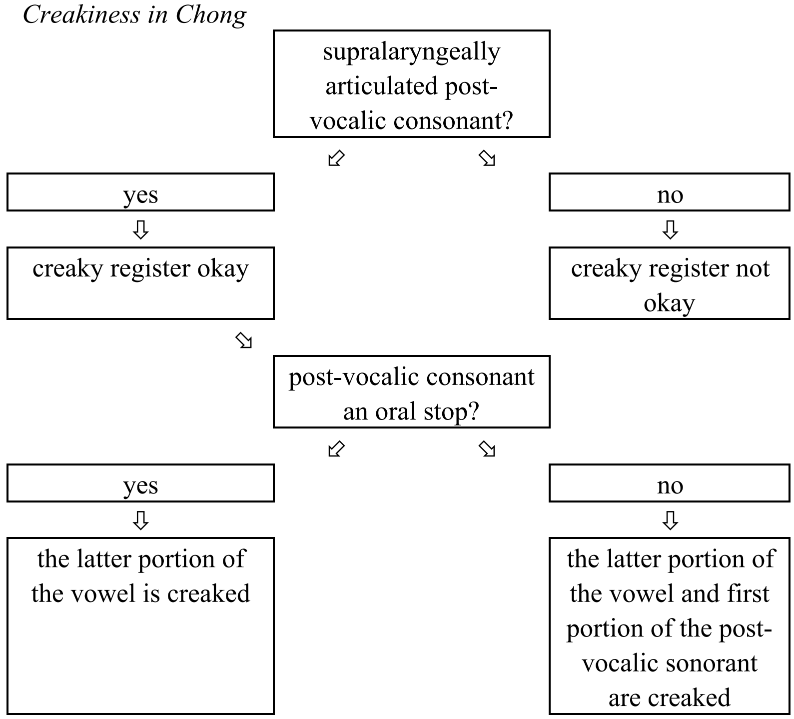
Recall that voiceless oral occlusions possess no acoustic energy. Consequently, unlike vowels and sonorants, they cannot accommodate cues for this contrastive laryngeal constriction. Therefore, the laryngeal gesture is phased to precede the stop closure, so that the cues to the laryngeal configuration are 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 20 summarizes the distribution of creakiness in Chong.

(20)

Creakiness in Chong



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. First, 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 (cf.19). Second, 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, tautomorphemic 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 cues 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 accommodate laryngeal contrasts.

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, and thus auditory recoverability is achieved. Independent morphological and phonological constraints 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. Three languages which display variants of this pattern are Korean, Sanskrit and Icelandic.

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, t^{h}, t’, tʃ, tʃ^{h}, tʃ’, as well as s, and s’) require release in order to cue their contrastive laryngeal 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. Examples are in 21.

(21)

Korean root-final laryngeals

k’otʃ^{h} + i	→	k’otʃ^{h}i / k’oʃi[2]	flower (nom.)
k’ot˥			flower
sup^{h} + i	→	sup^{h}i	wood (nom.)
sup˥			wood
pakɢ + ɨɾo	→	pak’ɨɾo	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.

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 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 stop 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. 22 provides some examples from Whitney 1889.

(22)

Sanskrit root-final laryngeals

√dag^{ɦ}	reach to	dag^{ɦ}iṣjanti	(Fut.)
√bud^{ɦ}	know, wake	bod^{ɦ}i	(Aor.)
√dab^{ɦ}	harm	dab^{ɦ}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. Examples are in 23.

(23)

Sanskrit unsuffixed roots

√dag^{ɦ}	reach to	d^{ɦ}ak	(root noun, nom. sing.)
√bud^{ɦ}	know, wake	b^{ɦ}ut	(root noun, nom. sing.)
√dab^{ɦ}	harm	d^{ɦ}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 sizable array of non-neutralized allomorphs, may thus be seen as a consequence of unrelease. That is, the generalization seems to hold that release was necessary for the realization of aspiration.[3]

Finally, consider phenomenon of pre-aspiration in Icelandic. Pre-aspiration here requires an expansion of the ideas discussed up to this point, for Icelandic possesses both non-alternating and alternating pre-aspiration. Intervocalically, pre-aspiration here is contrastive with post-aspirated stops, plain singleton stops, and plain geminates (24a).[4] Also, pre- and post-aspiration bear an allophonic relationship in certain contexts (24b). Pre-aspiration never follows a long vowel, and never precedes a long stop (24c).

(24)
Contrasts and alternants involving pre-aspiration in Icelandic

a.	VhtV	contrasts with
	V:tʰV	contrasts with
	V:tV	contrasts with
	Vt:V	
b.	VhtV	alternates with
	V:tʰV	(in certain contexts)
c.	*V:htV	
	*Vht:V	

Non-alternating pre-aspirates are contrastive in morphologically simple contexts where the involved stop closure immediately precedes an unstressed vowel; the pre-aspiration closes the preceding stressed syllable. In (25) are some examples (all examples are from Thráinsson 1978; transcriptions are IPA).

(25)
Non-alternating pre-aspirates

ˈkʰahpi	hero
ˈθahka	thank
ˈhahtyr	hat

Also, pre-aspiration is non- alternating where the involved stop closure precedes l or n, which in turn precedes an unstressed vowel. This pattern is exemplified in 26.

(26)

Pre-aspirated stops before sonorants

ˈɛhplɪ	apple	ˈɔhpna	open
ˈaj̥tla	intend	ˈvɛhtnɪ	hydrogen
ˈɛhkla	lack	ˈvahkna	wake up

Pre-aspirated alternants arise when a morpheme-final aspirate is followed by a homorganic aspirate. Homorganicity here may be lexical or derived through syncope and/or assimilation. Moreover, the homorganic cluster is not geminated, but instead is realized as a singleton stop closure. Post-aspiration does not appear here, as indicated in 27.

(27)

Pre-aspirated alternants before aspirate-initial suffixes

	$majt^h$+a	→	ˈmajːt^{h}a	meet (inf.)
but	$majt^h$+t^h+ɪ	→	ˈmaj̥tɪ	meet (past)
	$vejt^h$+a	→	ˈvejːt^{h}a	grant (inf.)
but	$vejt^h$+t^h+i	→	ˈvej̥ti	grant (past)
	nit^h+a →		ˈniːt^h+a	utilize (inf.)
but	nit^h+t^h+a	→	ˈnihta	utilize (past)

Additionally, pre-aspirated alternants appear upon attaching an l- or n-initial suffix to an aspirate-final root, as exemplified in 28.

(28)

Pre-aspirated alternants before l- or n-initial suffixes

pʰipʰ+a	→	ˈpʰiːpʰa	pipe (nom. sg.)
pʰipʰ+na	→	ˈpʰihpna	pipe (gen. pl.)
katʰ+a	→	ˈkaːtʰa	street (nom. sg.)
katʰ+na	→	ˈkahtna	street (gen. pl.)
kʰakʰ+a	→	ˈkʰaːkʰa	cake (nom. sg.)
kʰakʰ+na	→	ˈkʰahka	cake (gen. pl.)

Finally, sonorants may optionally vary with their devoiced counterparts. When devoiced, a plain stop follows; when not devoiced, an aspirate follows, as exemplified in 29.

(29)

Free variants

ul̥pa	~	ulpʰa	coat
hejm̥ta	~	hejmtʰa	demand
van̥ta	~	vantʰa	lack
viŋ̊ka	~	viŋkʰa	wave

Generalizing about pre-aspirated alternants, as well as lexical pre-aspirates which precede a coronal sonorant, two crucial observations must be made. First, pre-aspirates arise only when the stop is not followed by a morphologically ordered vowel. This should not be at all surprising. Second, pre-aspiration gravitates toward stress. In all cases of pre-aspiration as an alternant, its realization is coordinated with a stressed syllable, and away from unstressed syllables. As stress plays the functional role of increasing acoustic energy through increased aerodynamic force, as well as overall lengthening and sometimes hyperarticulation (de Jong 1991), aspiration quite naturally is optimally implemented in stressed domains. When aspiration would not be realized under stress, it may not be present, as in English, or it may migrate to a stressed position, as in Icelandic. Note additionally that coordinating the laryngeal abduction with the stressed syllable accounts for its tightest temporal coordination with the preceding vowel as opposed to the following stop, as shown instrumentally by Kingston (1990). Kingston finds that pre-aspiration bears the most stable temporal relationship with the preceding vowel, and a marginally less stable temporal relationship with the following stop closure. This becomes intuitive when considering that the primary auditory cues for (post-vocalic) pre-aspiration are encoded around the onset of aspiration, while offset cues are relatively diminished: as auditory nerve response is poor upon the termination of acoustic energy, the diminution of energy involved at the onset of aspiration results in a better cue than the onset of silence. In the present approach, recall, intuitions about segmentation and syllabification may be a consequence of the location and consequent temporal stability of the most salient cues.

To summarize this section, in Chong neither root-final release nor suffixation is ever available. 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. In Korean, appropriate suffixation provides the proper environment for the optimal realization of otherwise neutralized aspiration and glottalization. Sanskrit too had the proper system of suffixation to allow for optimal post-aspirates. In contrast to Korean, however, upon unrelease, aspiration may migrate to root-initial stop release. Finally, Icelandic displays elements of both the Chong and the Korean patterns. When suffixation is unavailable for the optimal realization of root-final aspiration, sub-optimal pre-aspiration is employed.

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 the marginal case of 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), as schematized in 30.

(30)

a. *Unattested realization of contrastively aspirated fricative*

SL: coronal fricative: ÛÛ
L:abduction: ÛÛ
↑high frequency noise
percept: s

b. *Optimal realization of contrastively aspirated fricative*

SL: coronal fricative: ÛÛ
L:abduction: ÛÛÛÛ
↑high frequency noise
↑broadband noise
percept: 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 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, Chong, and Icelandic show that morphological and/or phonotactic constraints may prohibit access to this optimal phasing location. In such cases, laryngeal gestures may be phased sub-optimally, preceding the supralaryngeal closure.

NOTES

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} krɤ̤ɤ̰t (to leak), luuc^{4} lṳːṵc (soft), tʰam^{2} tʰa̤a̰m̰ (crab); laryngeal contours on post-vocalic sonorants are not indicated.

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

3. See Lombardi (1994) for a formal characterization of the Sanskrit pattern.

4. Both Thráinsson and Kingston assume that non-alternating pre-aspirates are derived from underlying geminates. As there is no immediate evidence for this abstract representation which never surfaces, I do not make this same assumption. Rather, I assume that non-alternating pre-aspirates are indeed lexical pre-aspirates, thus adopting Thráinsson's “weak-h” hypothesis.

4

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: non-modal phonation is followed by modal phonation. In this fashion, cues are optimally transmitted to the listener.

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 transmit formant transition information 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 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. As just noted, the optimal site of the truncated laryngeal gesture is the first portion of the nasal. In this fashion, nasal place of articulation information is fully recoverable by the listener.

4.1.1 MODALLY PHONATED NASALS

Modally phonated nasals convey place of articulation information in two major ways. First, and most importantly, modal phonation at nasal onset, and especially nasal offset, result in salient formant transitions between the nasal and neighboring vowels (Fant 1960, Fujimura 1962, Recasens 1983, Bhaskararao and Ladefoged 1991). Fujimura (p.1875) writes "[T]here is no doubt that the formant transitions of the adjacent vowels often play a ... dominant role in the recognition of ... individual nasals." 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 present during the nasal murmur itself (Fant 1960, Dantsuji 1984,86,87, Kurowski and Blumstein 1984).[1] Fant (147-148), 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.

Nasal murmur formants thus potentially contribute place of articulation information as well. Here, the steady state portion of the nasal contains place cues primarily in the form of a nasal zero, or anti-resonance; a frequency range of dampened energy. The farther back in the oral cavity the constriction, the higher in frequency is this reduction in energy. Moreover, nasality as a class may be cued by both a low frequency formant, as well as a mid-range energy plateau. Given the location of cues for nasal consonants, intervocalic nasals, for example ama ana aŋa, enjoy an abundance of cues, and, not coincidentally, are never subject to neutralization.

Recasens (1983) summarizes the distinct roles 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 (p.1347):

- -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

To summarize, the primary cues for nasal place of articulation are present at the dynamic formant transitions into and especially out of the nasal. Additional cues are sometimes present in the steady-state nasal murmur.

4.1.2 NASALS AND LARYNGEAL ABDUCTIONS

A laryngeal abduction occurring with a nasal stop involves a dramatic decrease in acoustic energy in comparison with its voiced counterpart. Ladefoged and Maddieson (1996) 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 cueing nasal place of articulation. Therefore, a voiced transition between a phonologically voiceless nasal and a neighboring (modal) vowel serves to better cue 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 1996). Again, without a salient formant structure, nasal place-of-articulation information may not be present 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 salient in the signal. Therefore, if a nasal stop is voiceless throughout, it is unlikely that oral place-of-articulation will be cued to the listener.

Consequently, in order to saliently convey 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.[3] Alternatively, breathy phonation may be implemented on the latter portion of the nasal. Here, voicing necessarily accompanies the laryngeal abduction, so that sufficient energy is present to transmit formant transition information from speaker to listener. These patterns are schematized in 1.

(1)

Nasals and laryngeal abductions

nasal⇳⟨abduction⇳intercostals⇨ approximation⟩	phase voicelessness to first portion of nasal
⟨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. Here, recoverability is optimal: acoustic energy increases incrementally. Alternatively, breathy phonation may be implemented at the latter portion of the nasal: nn̤.

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). Some examples are in 2.

(2)

Voiced nasals		*Voiceless nasals*	
mâ̰	lift up	N̥mâ̰	from
na	pain	N̥na	nose
ɲa	right	N̥ɲa	considerate
ŋâ	fish	N̥ŋâ	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, as schematized in 3.

(3)
Burmese voiceless nasals

SL:	labial stop:	ÛÛ	alveolar stop:	ÛÛ
	nasal:	ÛÛ	nasal:	ÛÛ
L:	abduction:	Û	abduction:	Û
	intercostals:	Û	intercostals:	Û
	approximation:	Û	approximation:	Û
		↑voiceless nasality		↑voiceless nasality
		↑nasal murmur		↑nasal murmur
		↑offset transitions		↑offset transitions
	percept:	N̥m		N̥n

SL:	palatal stop:	ÛÛ	velar stop:	ÛÛ
	nasal:	ÛÛ	nasal:	ÛÛ
L:	abduction:	Û	abduction:	Û
	intercostals:	Û	intercostals:	Û
	approximation:	Û	approximation:	Û
		↑voiceless nasality		↑voiceless nasality
		↑nasal murmur		↑nasal murmur
		↑offset transitions		↑offset transitions
	percept:	N̥ɲ		N̥ŋ

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, as schematized in 4.

(4)

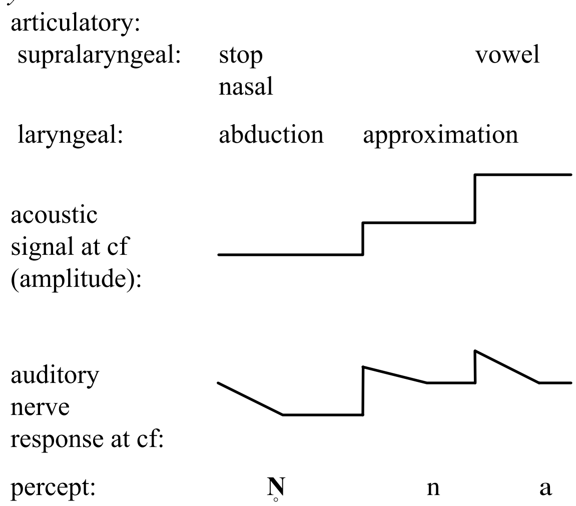
Voiceless portion of Burmese voiceless nasals

SL:	labial stop:	Û	alveolar stop:	Û
	nasal:	Û	nasal:	Û
L:	abduction:	Û	abduction:	Û
	intercostals:	Û	intercostals:	Û
		↑voiceless nasality		↑voiceless nasality
	percept:	N̥		N̥

SL:	palatal stop:	Û	velar stop:	Û
	nasal:	Û	nasal:	Û
L:	abduction:	Û	abduction:	Û
	intercostals:	Û	intercostals:	Û
		↑voiceless nasality		↑voiceless nasality
	percept:	N̥		N̥

Early phasing of the laryngeal abduction guarantees that the modal nasal murmur abuts a following vowel, hence optimizing the salience of offset transitions. This constitutes the canonical realization of a voiceless nasal. Additionally, 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 auditory response to the signal is optimal, as spectral energy increases incrementally from voiceless nasality, to nasal murmur, to orality. In 5 is a schematic.

(5)
Gross schematic of articulatory, acoustic, and auditory characteristics of early voicelessness in nasals



Indeed, early aspiration in voiceless nasals is far more prevalent than late breathiness (Henderson 1985).

Note that the canonical realization of voiceless nasals is distinct from the canonical realization of aspirated stops. While aspirated stops normally involve the late staggering 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 morpho-phonemic alternations exist between voiced and voiceless nasals in Burmese. Prefixing aspiration to certain verbs results in a transitive or causative reading. These are termed h/non-h pairs in Okell 1969. When the root is obstruent-initial, the obstruent is post-aspirated. This is the optimal realization of an aspirated obstruent. However, when plain nasals undergo causativization, voiceless nasality precedes nasal modal voice. In 6 are some examples (data from Okell 1969).

(6)

Obstruent-initial

pi	be pressed	p^{h}i	press, compress
pe	break off, be chipped	p^{h}e	break off (a piece)
po	appear	p^{h}o	reveal
ceʔ	be cooked	c^{h}eʔ	cook
puʔ	fall, be situated	c^{h}aʔ	drop, throw, put
sowʔ	be torn, shabby	s^{h}owʔ	tear
suʔ	be damp	s^{h}uʔ	moisten, make damp
kwe	be split, separated	k^{h}we	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, morphemic aspiration is always realized optimally.

CASE STUDY: SUKUMA

Despite the cross-linguistic prevalence of early voicelessness 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 transmitting formant nasal structure, as such nasals may be post-consonantal or post-pausal. Consequently, as mentioned earlier, non-modal phonation here involves breathiness, 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 salient in the speech signal. Additionally, spectral energy decreases in the transition from nasal murmur to breathiness, thus reducing auditory nerve response at the point of spectral change. This may account for the fact that this phasing pattern is far less prevalent than the Burmese-type pattern. In 7 is a schematic.

(7)

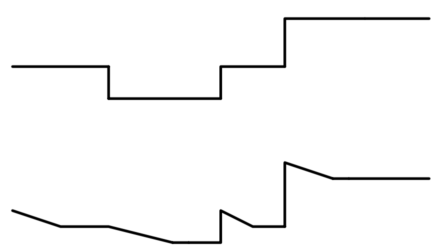
Gross schematic of articulatory, acoustic, and auditory characteristics of late breathiness in nasals

articulatory:
supralaryngeal: stop nasal — vowel

laryngeal: abduction approximation — approximation:

acoustic signal at cf (amplitude):

auditory nerve response at cf:



percept: n n̤ a̤ a

Maddieson (1991) reports that the production of "aspirated nasals" in Sukuma usually involves the sequence of events listed in 8.

(8)

Sukuma aspirated nasals

1. Voicing, oral closure, and velic lowering. This results in a plain nasal stop: n.
2. Intraoral pressure and nasal airflow increase, along with continued voicing. This indicates that a glottal abduction has been added to the configuration: nn̤.
3. oral closure is released, while nasality and breathy phonation persist into the following vowel: nn̤a̤͡a.

In 9 are some examples. These nasals are represented orthographically by a digraph nasal+"h".

(9)

Sukuma breathy nasals

ndɪɪnhɔɔ	ndɪɪn͡n̤ɔ̤͡ɔ	ladle
mhala	m͡m̤a̤͡ala	gazelle
mhala nhaale	m͡m̤a̤͡ala n͡n̤a̤͡ale	small gazelle
mhayɔ	m͡m̤a̤͡ajɔ	word

In summary, there is a trade-off in the realization of contrastively phonated nasals. Specifically, voiceless phonation requires early realization, 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 laryngeal abduction is implemented with voicing, as simultaneous voicing during the supralaryngeal transition increases the likelihood of conveying 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.

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 Comaltepec Chinantec are modally phonated. Some examples are provided in 10.

(10)

Voiceless nasals in Comaltepec Chinantec

m̥mɨː˩	water
ɲ̥ɲœː˩	green beans
ŋ̥ŋajɲʔ˩˨	he kills

However, in post-vocalic position, a different phasing pattern is present. Consider the post-vocalic nasal, and its interaction with post-vocalic aspiration. When such syllables possess a post-vocalic nasal, several authors, discussing a variety of dialects, report that this nasal is normally devoiced. Merrifield (1963:3) reports that such 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 aspiration is implemented co-extensively with the post-vocalic nasal, as schematized in 11.

(11)

Post-vocalic aspiration with post- vocalic nasal

SL:	low vowel:	ÛÛÛÛÛÛÛÛ
	velar stop:	ÛÛ
	nasal:	ÛÛ
L:	abduction:	ÛÛ
	voice:	ÛÛÛÛÛÛ
		↑formants
		↑voiceless nasality
	percept:	a N̥

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?

Anderson, Martinez, and Pace (1990:7) discuss the phonetic realization of the Comaltepec post-vocalic nasal in a variety of environments. In 12 I quote directly from these authors, although notation has been changed into IPA.

(12)
Comaltepec Chinantec post-vocalic nasals

a. The postnuclear nasal is alveolar preceding n within the word, or preceding any alveolar consonant across a word boundary.

ka˩ w̥wen̥ʔ˩˨ neʔ˩	the animal was frightened
j̥ju:n̥˩˥ la˥˩	this child
j̥ju:n̥˩˥ zeʔ˦	sick child

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

pimʔ˥	(<..Nʔ + p)	he is tiny
j̥ju:m̥˩˥ piŋʔ˥		small child

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

j̥ju:ŋ̥˩˥ kʌŋʔ˦	big children
w̰wiŋʔ˥	black child
j̥ju:ŋ̥̊˩˥ haŋʔ˦	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˩ l̥lejɲ̥˧	(<..N̥ + ʐ)	he will tremble
ʔʌjɲ̥˩˨	(<..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 present in the speech signal. Therefore, aspiration may be implemented co-extensively with the nasal. In this way, all contrastive information is recoverable.

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

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. In 13 are these two phasing patterns.

(13)
Nasals and laryngeal constrictions

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

Why should this be the case? A heavy glottal constriction may result in sufficient aperiodicity, or jitter, to disrupt transmission of a salient nasal formant structure. Given the brevity of the formant transitions 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, formant transitions may be rendered unrecoverable. This is indicated in 14.

(14)

Heavily constricted nasals

SL:	labial stop:	ÛÛ	alveolar stop:	ÛÛ	velar stop:	ÛÛ
	nasal:	ÛÛ	nasal:	ÛÛ	nasal:	ÛÛ
L:	constriction:	ÛÛ	constriction:	ÛÛ	constriction:	ÛÛ
	approximation:	ÛÛ	approximation:	ÛÛ	approximation:	ÛÛ
		↑creak		↑creak		↑creak
	percept:	N̰		N̰		N̰

In the limiting case, a full glottal closure reduces airflow to zero. With zero airflow, of course, no acoustic energy is present to convey a downstream constriction or velic lowering, as schematized in 15.

(15)

Nasals with glottal closure

SL:	labial stop:	ÛÛ	alveolar stop:	ÛÛ	velar stop:	ÛÛ
	nasal:	ÛÛ	nasal:	ÛÛ	nasal:	ÛÛ
L:	constriction:	ÛÛ	constriction:	ÛÛ	constriction:	ÛÛ
		↑silence		↑silence		↑silence
		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, as in 16.

(16)

Optimal realizations of laryngealized nasal

SL:	coronal stop:	ÛÛ	coronal stop:	ÛÛ
	nasal:	ÛÛ	nasal:	ÛÛ
L:	constriction:	Û	constriction:	Û
	approximation:	Û	approximation:	ÛÛ
		↑silence		↑creak
		↑nasal murmur		↑nasal murmur
		↑offset transitions		↑offset transitions
		ʔn		n̰n

4.2 Liquids and Laryngeal Gestures

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: the abduction may be implemented strictly simultaneously with a constricted lateral gesture, actually resulting in a lateral fricative (e.g. Zulu ɬ) (Ladefoged 1975), or the abduction is truncated with respect to the lateral gesture (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: first, 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 second, 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.

First, unlike, say, nasals or stops, laterals are almost exclusively coronal articulations, for only 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 1996)). 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 contrastive values 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).

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 not so much for plain laterals (which may be confused with alveolar nasals), but does hold for voiceless laterals.[4] 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.

First, the lateral gesture may be sufficiently constricted, so that oral frication results, culminating in a voiceless lateral fricative ɬ, as in Zulu. Here, it is perhaps the added frication due to increased constriction which helps cue the configuration. This is schematized in 18.

(18)
Zulu laryngeally abducted lateral
SL: lateral fricative: ÛÛ
L: abduction: ÛÛ
↑voiceless lateral frication
percept: ɬ

Alternatively, the laryngeal gesture may be truncated relative to the oral gesture, l̥l. The non-modal laterals of Otomanguean are implemented in this second fashion. See 17.

(17)
Otomanguean laryngeally abducted lateral
SL: lateral approximant:ÛÛ
L: abduction: Û
approximation: Û
↑broadband noise
↑laterality
↑offset transitions
percept: l̥ l

Otomanguean laryngeally constricted lateral

SL: lateral approximant:ÛÛ
L: constriction: Û
approximation: Û
↑creak
↑laterality
↑offset transitions
percept: l̰ l

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,ŋ̊,ŋ̰). As I discuss in section 4.1, fully voiceless nasals run a 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 possesses oral contrasts, and since, regardless of their implementation, laryngeally contrastive laterals are acoustically distinct from other classes, the oral constriction here may enjoy a relative freedom of aperture and timing with respect to the laryngeal abduction, and the attested variation results. The two attested phasing patterns are shown in 19.

(19)
Laterals and laryngeal gestures

lateral fricative⇕abduction	phase the abduction and a lateral fricative in parallel
⟨abduction⇨approximation⟩⇕ lateral approximant	phase the abduction during the first portion of a lateral approximant

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 contrast is Diegueño, which possesses both voiced and voiceless laterals at both the dental and alveolar places of articulation (l̪,l,ɬ̪,ɬ). Tellingly, according to Langdon (1970:31), the acoustic distinction between the apical and laminal lateral fricatives is, "even after long exposure ... still very hard for [her] to differentiate."[5]

4.3 GLIDES AND LARYNGEAL GESTURES

Like nasals, non-modal 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 cue 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 the durational difference between glides and vowels, and the energy difference between glides and vowels. I consider each in turn.

First, as glides are by definition non-syllabic, they are of a shorter temporal duration than their vocalic counterparts. This makes it difficult to saliently cue both oral and laryngeal contrasts simultaneously here. Second, 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 transmit oral and laryngeal cues in glides.

With their shorter duration and reduced energy in comparison to vowels, it is less likely that all the contrastive information in non-modally phonated glides is reliably recoverable if produced in parallel. Therefore, in such contexts, 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 non-modal 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 (20) are examples of labial and palatal glides with an abduction and a constriction.

(20)

Glides and laryngeals

	optimal realization:		sub-optimal realization:	
SL:	palatal glide:	ÛÛ	palatal glide:	ÛÛ
L:	abduction:	Û	abduction:	Û
	intercostals:	Û	intercostals:	Û
	approximation:	Û	approximation:	ÛÛ
		↑broadband noise		↑broadband noise
		↑formants		↑formants
		↑offset transitions		↑offset transitions
	percept:	j̥ j		j j̤

SL:	labial glide:	ÛÛ	labial glide:	ÛÛ
L:	abduction:	Û	abduction:	Û
	intercostals:	Û	intercostals:	Û
	approximation:	Û	approximation:	ÛÛ
		↑broadband noise		↑broadband noise
		↑formants		↑formants
		↑offset transitions		↑offset transitions
	percept:	w̥w		ww̤

SL:	palatal glide:	ÛÛ	palatal glide:	ÛÛ
L:	constriction:	Û	constriction:	ÛÛ
	approximation:	Û	approximation:	Û
		↑silence		↑silence
		↑formants		↑formants
		↑offset transitions		↑offset transitions
	percept:	ʔ j		j j

SL:	labial glide:	ÛÛ	labial glide:	ÛÛ
L:	constriction:	Û	constriction:	ÛÛ
	approximation:	Û	approximation:	Û
		↑silence		↑silence
		↑formants		↑formants
		↑offset transitions		↑offset transitions
	percept:	ʔw		ww̰

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 voicelessness in glides (in those dialects in which possess a voiced-voiceless glide contrast). In 21 are some examples of each.

(21)

English palatal voiceless glide		*English labial voiceless glide*	
ˈj̥jumən	human	ˈw̥wɪtʃ	which
ˈj̥juːtʃ	huge	ˈw̥wɛn	when

4.4 CONCLUSION

To optimize recoverability, non-modally phonated sonorant consonants are realized with laryngeal gestures phased to the early portion of the supralaryngeal configuration. When phased to the latter portion of the sonorant, voicing is added to the configuration in order to mitigate the potential non-salience of formant transition cues into a following vowel.

NOTES

1. The reader is cautioned that the term "murmur," when employed in the context of 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 possess any characteristic burst frequencies, nor are they well-suited to accommodate aspiration simultaneously with formant transitions.

3. Again, this is not to imply that an active process of truncation is involved here, but rather, merely, that the laryngeal gesture persists for only a portion of the supralaryngeal gesture.

4. For example, in certain central Chinese dialects (e.g., Shashi), I have observed that laterals and alveolar nasals are in free variation.

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

5

VOWELS AND LARYNGEAL GESTURES

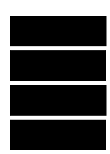
5.0 INTRODUCTION

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, as schematized in 1.

(1)

Breathy low vowel

SL:	low vowel:	
L:	abduction:	
	intercostals	
	approximation:	



↑formants, broadband noise

percept: a̤

creaky low vowel

SL: low vowel:

L: constriction:

approximation:

↑formants, creak

percept: a̰

Also, obviously, vowels are ideally suited to accommodate contrastive pitch, or tone. Sonorant consonants may also be pitch-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 1915)). However, obstruents may not bear linguistically significant pitch values. The pronounced oral constriction which defines an obstruent makes it difficult to reliably produce contrastive pitch 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 pitch 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. Pre-vocalic laryngeals in Jalapa Mazatec, pre-and post-vocalic laryngeals in Chinantec, and pre-, post-, and laryngeally "interrupted" vowels in Trique are all shown to support the hypothesis that tone and non-modal phonation are sequenced in laryngeally complex class languages so that all laryngeal values achieve salience. In section 5.4 I consider both real and apparent exceptions to my claims regarding laryngeally complex vowels.

5.1 BREATHY VOWELS

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.

Phasing patterns between vowels and laryngeal abductions include pre-aspiration (ha), post-aspiration (ah), and breathiness (a̤). So consider these three possible phasing patterns with respect to auditory nerve response.

For ha energy increases at the onset of voicing, triggering a sudden excitation of the auditory nerve, as shown in 2.

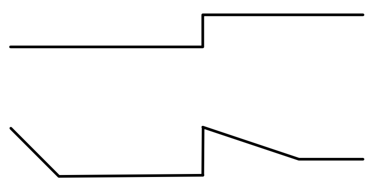
(2)

Gross schematic of articulatory, acoustic, and auditory characteristics of h-V sequences

articulatory:		
supralaryngeal:	vowel	
laryngeal:	abduction	approximation

acoustic
signal at cf
(amplitude):

auditory
nerve
response at cf:



percept:	h	a

And while both a̤ and ah suffer a loss of cues, neither risks non-recoverability. For a̤, energy is constant throughout; auditory nerve response diminishes and stabilizes, as in 3.

(3)
Gross schematic of articulatory, acoustic, and auditory characteristics of V̤

articulatory:
 supralaryngeal: vowel approximation
 laryngeal: abduction

acoustic signal at cf (amplitude):

auditory nerve response at cf:

percept: a̤

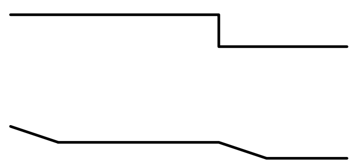
Finally, for ah, auditory nerve response diminishes at the transition from voicing to voicelessness, as in 4.

(4)

Gross schematic of articulatory, acoustic, and auditory characteristics of V-h sequences

articulatory:
 supralaryngeal: vowel
 laryngeal: approximation abduction

acoustic
signal at cf
(amplitude):



auditory
nerve
response cf:

percept: a h

Thus hV sequences are always preferred to V̤. 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 Kur, 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. These three phasing patterns are restated in 5, in order of preference.

(5)
Phasing patterns between vowels and laryngeal abductions

⟨abduction⇳intercostals⇨ approximation⟩⇳vowel	phase voicelessness to the first portion of the vowel
vowel⇳abduction⇳intercostals⇳ approximation	phase the vowel, the laryngeal abduction, and voicing in parallel
⟨approximation⇨abduction⇳inter costals⟩⇳vowel	phase voicelessness to the latter portion of the vowel

Normally only when a language employs the optimal phasing relationship between two gestures, may it resort to a *sub*-optimal phasing relationship if it is to further exploit the involved gestures.[1] Consequently, after a language allows ha sequences, it might then possess sub-optimal a̤ or ah.

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 6 is the Gujarati segment inventory (from Taylor 1985).

(6)

Gujarati segment inventory

p	t	tʃ	ʈ	k	i				u
p^{h}	t^{h}	tʃ^{h}	ʈ^{h}	k^{h}		e		o	
b	d	dʒ	ɖ	ɡ			a		
b^{h}	d^{h}	dʒ^{h}	ɖ^{h}	ɡ^{h}					
v	s	ʃ	ʂ		i̤				ṳ
m	n	ɲ	ɳ	ŋ		e̤		o̤	
	r,l		ɭ				a̤		
	j								
h									

Vowels in Gujarati may be plain or breathy. In 7 are some examples of breathy vowels (from Fischer-Jørgensen 1970; no glosses provided in original).

(7)

Gujarati breathy vowels

tʃi̤r	mo̤r	dṳd
bi̤	do̤ɽ	pe̤lo
se̤dʒ	ko̤ɽ	ta̤ro
me̤k	ko̤	wa̤li
ba̤r	po̤r	kə̤ɽi

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, any consonant may precede a breathy vowel except those listed in 8.

(8)

Onsets disallowed with breathy vowels

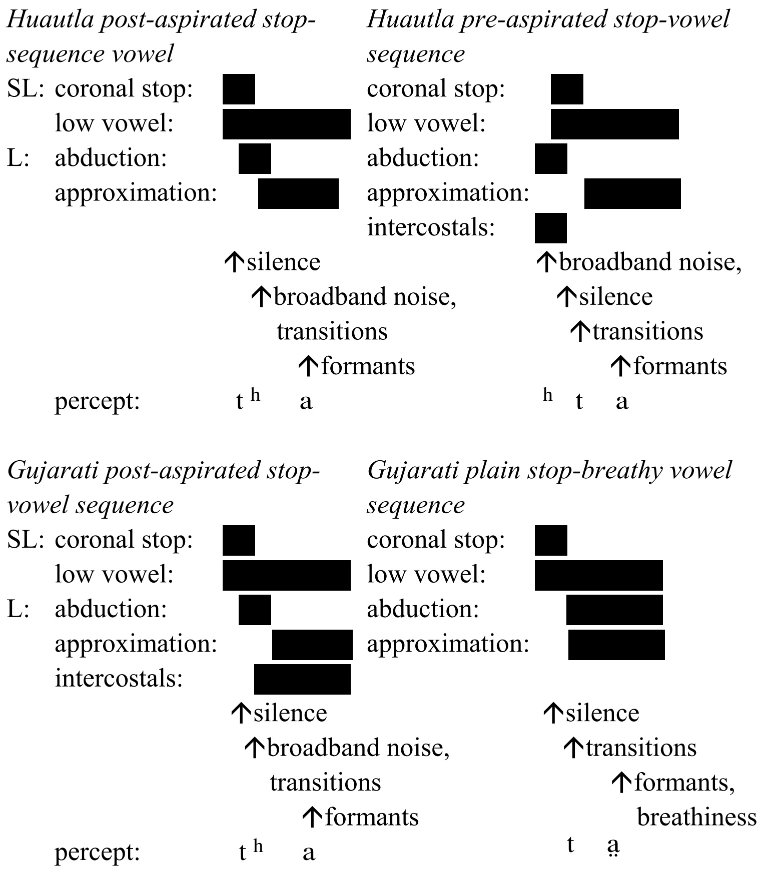
p^h	t^h	tʃ^h	ʈ^h	k^h
b^h	d^h	dʒ^h	ɖ^h	ɡ^h
	ɲ	ɳ		
		ɭ		
h				

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

Now consider a further observation: despite the existence of hV-V̤ contrasts, it is particularly rare for languages to possess aspirated plosive-plain vowel sequences that contrast with plain plosive-breathy vowel sequences. For example, t^{h}a rarely contrasts with ta̤. Gujarati (Patel and Mody 1960) and Chong (F.E. 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 ^{h}ta in addition to t^{h}a, while Gujarati expands its inventory of contrasts by allowing ta̤ in addition to t^{h}a? The patterns are schematized in 9.

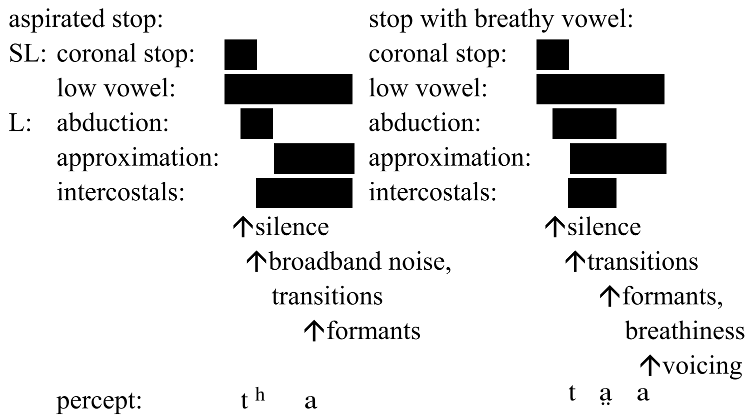
(9)



The answer is found by analyzing contrastiveness within the context of the systems as wholes. I consider Mazatec, then Gujarati.

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 realized on the vowel's latter portion. Consequently, in a language like Jalapa Mazatec, the phasing distinction between an aspirated stop (t^ha) 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. This is shown in 10.

(10)
Unattested contrast involving an oral closure-laryngeal abduction-vowel sequence (repeated from section 3.1)



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.

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 (t^ha), and plain stop-breathy vowel sequences (tạ̤) 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 air 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 in Gujarati. 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 ~ n̺a̤, la̤ ~ l̺a̤). 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 probable 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 distinguishable are more readily contrastive, while those patterns that are less readily distinguishable are less readily contrastive.

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

5.2 CREAKY VOWELS

Like the phasing relations between voicelessness and vowels, the optimal pattern of creakiness/silence 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 transmit the gesture's cues. 11 shows the three patterns in apparent order of prevalence.

(11)
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

Thus, usually, ʔa is allowed first, followed by aʔ, and finally a̰.

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 vocalic in its affiliation. 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 12 is the Sedang segment inventory (all data from Smith 1968, 1979).[2]

(12)
Sedang segment inventory

p	t	tʃ	k	i				u
^{m}b	^{n}d	^{n}dʒ	^{ŋ}g	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 13.

(13)
Sedang codas
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 14 I present the distribution of laryngeal gestures in Sedang onsets.

(14)

Laryngeals in Sedang onsets

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 outʔlo	there also	
mot	to enter	ʔmot	to hunt with a dog
^{m}bo	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	k^{h}i	wind

d. Laryngeals may stand alone.

ho.v̰vã̰	right (hand)
ʔi.j̰ja	little

Regarding 14a, glottalized sonorants are implemented as pre-glottals. This, recall, is the optimal realization of laryngeally modified sonorants.

Now consider laryngeal abductions in onsets 14b,c. The laryngeal abductions in voiceless sonorants 14b 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 14c represent the canonical realization of aspirated stops, in that the laryngeal abduction is manifested at the release of the supralaryngeal occlusion. 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 15.

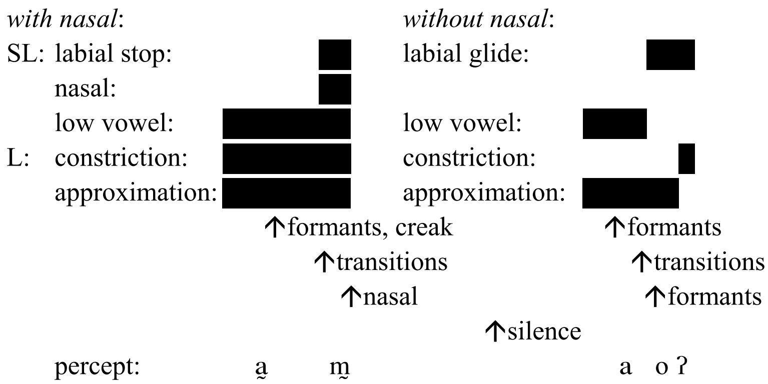
(15)

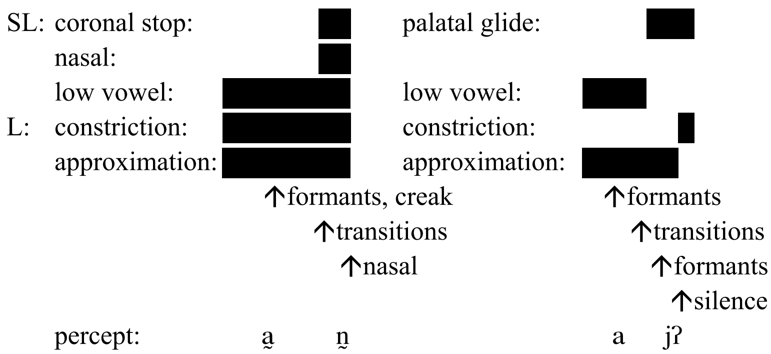
"Delaryngealization"

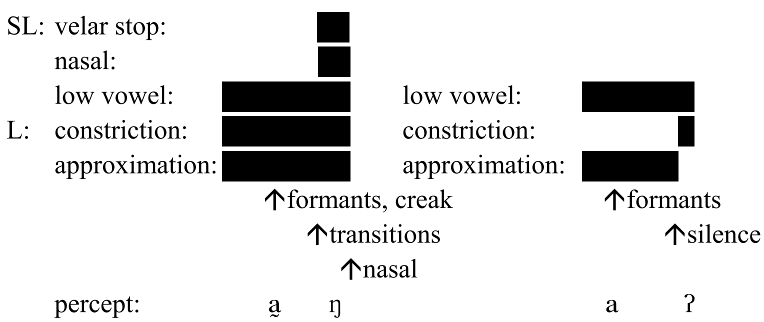
	tṵm̰	~	twoʔ	all
	reḛn̰	~	rejʔ	to bite
	ʃa̰ŋ̰	~	ʃaʔ	bitter
	tʃa̰ŋ̰	~	tʃaʔ	fish fin
	r̥rḭŋ̰	~	r̥rjɔʔ	hundred
but	mḭm̰			plump baby
	prw̰a̰ŋ̰			a name

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. These patterns are schematized in 16.

(16)
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. 17 provides examples of varying and non-varying forms.

(17)
Varying and non-varying forms

tʃa̰ŋ	~	tʃaʔ	fish fin
tʃaʔ̃			sword
ra̰ŋ	~	raʔ	arrow
raʔ̃			dried (wood)

Now consider the following distributional pattern: creaky vowels may be present in either open syllables, or syllables closed by sonorants, and, most significantly, "final glottal stop contrasts with [vowel—D.S.] laryngealization in open syllables" (p.60). 18 shows two sets of minimal triplets involving plain, creaked, and checked vowels.

(18)
Minimal triplets

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

Now, were creaky vowels only present in closed syllables, it might be concluded that Sedang is like Chong, in that phonetically creaked vowels are dependent upon the presence of a supralaryngeally articulated coda consonant. 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. Also, if phased to precede the vowel, it is again implemented as a glottal stop. Smith reports that "[I]nitial consonants have no restrictive effect on [vowel—D.S.] laryngealization" (p.60). 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 19 is a summary of the distribution of laryngeal gestures within the Sedang syllable.

(19)

Syllable position	*Example*	
Onset:		
- plain	kja	grave
- abduction	ho.v̰vã̰	right (hand)
	k^{h}ja	wind (n)
	r̥re	small animal in sewage
- constriction	ʔi.j̰ja	little
	l̰lõ	there also
Nucleus:		
- plain	kwa	pipe
- constriction	c^{h}a̰	wild cat
Coda:		
- plain	po.lwam	spider
- abduction	(no examples given)	
- constriction	lḛm̰	good
	ho.raʔ	to stay awake

19 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.

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. Sedang thus displays all three phasing patterns between laryngeal constrictions and vocalism: the optimal pattern (ʔa), the maximally distinct pattern (aʔ), and an again maximally distinct pattern (a̰).

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 contrastive on a single vowel. This is the laryngeally complex class. 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), and Remez and Rubin (1984, 1993). 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. may be 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 schematically in 20, employing an F0 of 125 Hz., in which the shaded bar indicates this region.

(20)
Optimal pitch source during modal phonation

Formant:	*Harmonic*:	*Frequency*:
	...	...
	H9	1125
	H8	1000
F1	H7	875
	H6	750
	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. This language possesses H, M, L, LM, and LH tones. Comaltepec Chinantec also possesses a phonation contrast involving aspiration. Cross-classifying tone and phonation, the possible vocalic laryngeal contrasts in 21 emerge.

(21)

Predicted laryngeal contrasts in Comaltepec Chinantec

tone→ *phonation↓*	H	M	L	LM	LH
V	V˥	V˧	V˩	V˩˧	V˩˥
V̤	V̤˥	V̤˧	V̤˩	V̤˩˧	V̤˩˥

At least nuclear laryngeal contrasts thus might be predicted to exist in Comaltepec Chinantec. However, tone and the laryngeal abduction are sequenced in laryngeally complex vowels in more than one way. In Comaltepec Chinantec, the abduction is sequenced to either precede or follow the tone, resulting in a modally phonated toned vowel preceded or followed by voicelessness, as shown in 22.

(22)

Laryngeal contrasts in Comaltepec Chinantec

tone→ *phonation↓*	H	M	L	LM	LH
V	V˥	V˧	V˩	V˩˧	V˩˥
hV	hV˥	hV˧	hV˩	hV˩˧	hV˩˥
Vh	Vh˥	Vh˧	Vh˩	Vh˩˧	Vh˩˥

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 cross-linguistic patterning of laryngeally complex languages, considering in turn Jalapa Mazatec, Comaltepec Chinantec, and Copala Trique.

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 Hmong (Lyman 1974, Smalley 1976, M.K. 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.[3] The table in 23 (adapted from Huffman) exemplifies these tonal contrasts.

(23)

White Hmong "tones"

High	tau˥	pumpkin
Rising	tau˧˥	to dam up (water)
Low	tau˩	axe
Mid (normal)	tau˧	to be able
Falling (normal)	tau˥˧	sp. of grass
Creaky	tau˧˩	bean
Breathy	tau˥˧	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˧˩. For female speakers, the breathy tone is implemented as a high, whispered fall: V̤˥˧. Ratliff (p.12): "...[M]y perception of the difference 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." That is, the relative pitch of the breathy tone is not crucial to the 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 1994) 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, exemplified in 24.

(24)

Mandarin tones

high level	tʰan˥	greedy
mid rising	tʰan˧˥	deep
dipping	tʰan ˨˩˦	perturbed
high falling	tʰan˥˩	spy
toneless	lə	(aspect)

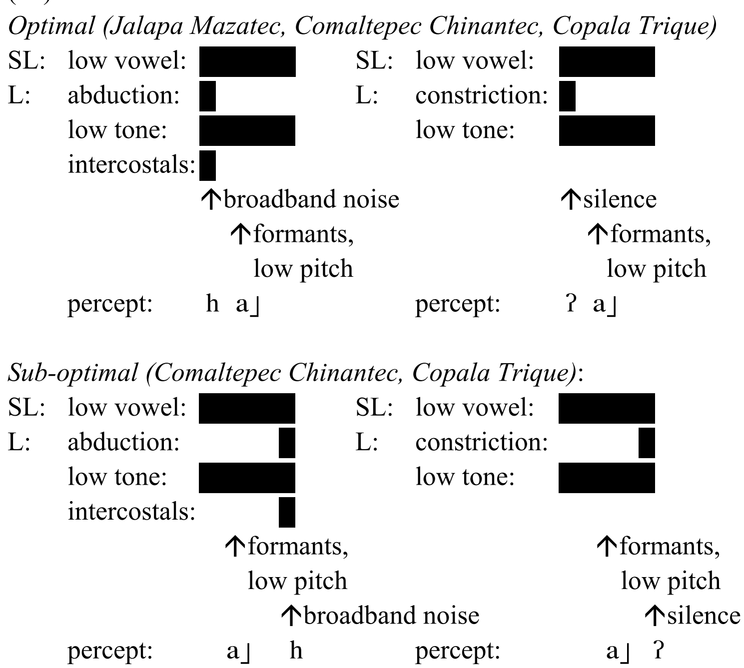
The dipping tone is in fact a level low tone in most contexts (L). Phrase-finally, it may be realized MLH, and before another dipping tone, it is realized as a high rising tone (MH). For all these realizations—except MH—a laryngeal creak may optionally accompany the tone pattern. Thus L freely varies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

5.3.2 LARYNGEALLY COMPLEX LANGUAGES

In laryngeally complex languages non-modal phonation cross-classifies with tone. The Otomanguean languages, which are laryngeally complex, employ three distinct phasing patterns involving tone and phonation: early sequencing of non-modal phonation (hV˥, ʔV˥, exemplified by Mazatec, Chinantec, and Trique), late sequencing of non-modal phonation (Vh˥, Vʔ˥, exemplified by Chinantec and Trique), and vocalic "interruption," in which the vowel is intruded upon by its non-modal component (VhV˥, VʔV˥, exemplified by Trique). In all these cases, tone is realized on the modal portion of the vowel. Moreover, as we have seen in earlier discussion, the presence of a sub-optimal phasing pattern usually implies the presence of a better pattern. And as more phasing patterns are allowed, they are maximally distinct from less marked patterns. Here, prevocalic non-modal phonation is argued to be optimal, while post-vocalic non-modal phonation is maximally distinct from this optimal pattern. Vocalic interruption, in which the non-modal phonatory gesture is equidistant from these two extremes, is maximally distinct once again. 25 portrays the patterning in schematized form.

(25)



Again sub-optimal *(Copala Trique)*

SL:	low vowel:		SL:	low vowel:
L:	abduction:		L:	constriction:
	low tone:			low tone:
	intercostals:			
		↑formants, low pitch		↑formants, low pitch
		↑broadband noise		↑silence
		↑formants, low pitch		↑formants, low pitch
	percept:	a˩ h a˩	percept:	a˩ ʔ a˩

Before investigating the language data, I discuss in detail the motivation for sequencing tone and non-modal phonatory gestures in laryngeally complex languages, considering, in turn, sufficient acoustic discriminability, and sufficient articulatory compatibility.

SUFFICIENT ACOUSTIC DISCRIMINABILTY

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. As it turns out however, a reliable and stable pitch percept which derives from glottal vibration may be disrupted during non-modal phonation. While, creaky phonation may result in glottal wave quasi- or a-periodicity, breathy phonation may also disrupt the transmission of a periodic glottal vibration. In this subsection I consider each of these types of non-modal phonation. Anticipating my conclusion, when a periodic glottal wave is either obscured or not present, a salient pitch value may not be perceived by the listener.

Acoustic analyses of breathy vowels indicate that the fundamental frequency is enhanced relative to the lower harmonics (Bickley 1982, M.K. 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 harmonics, as well as the pitch period. During breathy phonation the harmonic structure possesses increased bandwidths, as well as an overall increase in noise, which in some cases has been shown to largely obscure the harmonic structure (Silverman 1994a, 1996b, 1997a, Silverman, Blankenship, Kirk, and Ladefoged 1995). This is schematically portrayed in 26 (where "⇳" indicates bandwidth increases).

(26)
Schematic of weakened harmonic structure characteristic of breathy vowels

Formant:	*Harmonic*:	*Frequency*:
	...	...
	H9	1125⇳
	H8	1000⇳
F1	H7	875⇳
	H6	750⇳
	H5	625⇳
	H4	500⇳
	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, pitch may not be reliably cued when implemented with breathy voice. Indeed, in

Silverman 1996b I provide preliminary experimental evidence that indicates listeners are less adept at discriminating pitch values during Jalapa Mazatec breathy phonation than during Jalapa Mazatec modal phonation. And although it is only in an experimental setting, as opposed to a natural linguistic setting, that listeners might be called upon to determine just- and near-just-noticeable differences in pitch, it is not at all unlikely that languages should evolve to avoid less-good contrasts in favor of better contrasts, even if their less-good status only emerge in experimental contexts. For example, subjects are able to discriminate minor differences in voice onset time (VOT) that are never employed in language. Instead, languages typically employ VOT differences that are far less effortfully noticeable; positive VOT (aspirated), zero VOT (plain), and negative VOT (voiced). Thus, given that pitch differences seem to be better-noticeable during modal phonation than during breathy phonation, languages which possess tonal and breathy phonation contrasts on a given vowel may avoid their simultaneous implementation, so that tone is more likely recoverable.

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 1996). 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). Now note that Rosenberg (1966), and Ritsma (1967) find that when a pulse period varies, or jitters, by more than 10%, an otherwise just-noticeable pitch difference within the 300-1000 Hz. range is rendered indiscriminible. A schematic is presented in 27 (where “↑↓↑↓” indicates jitter).

(27)
Schematic of jittered pitch source characteristic of creaky vowels

Formant:	*Harmonic*:	*Frequency*:
	...	...
	H9	1125↑↓↑↓
	H8	1000↑↓↑↓
F1	H7	875↑↓↑↓
	H6	750↑↓↑↓
	H5	625↑↓↑↓
	H4	500↑↓↑↓
	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 tone is recoverable. Below, I show that this prediction is correct.

SUFFICIENT ARTICULATORY COMPATIBILITY

Lindblom (1983) investigates the principle of least effort in biological motor systems such as speech production, and its relevance to the study of linguistic sound patterns. Very briefly, a particular motor goal, or combination of motor goals in sequence or in simultaneity, seems to abide by a "sufficient compatibility" condition: antagonistic articulatory postures tend to be avoided. Thus, for example, vowel – tongue-tip consonant – vowel coarticulation is, in the main, allowed up to the point just before a contrast would be neutralized: "There is an overriding constraint on the place of the tongue tip closure that remains constant [in order to maintain the contrast-D.S.] but there is no invariance of underlying tongue-body shape [to allow for maximum coarticulation-D.S.]. It reaches a state of 'sufficient compatibility' and then begins to anticipate the final vowel" (p.225). Extreme displacements, either from a neutral position (quantified in Lindblom's model), or from a neighboring target posture, tend to be avoided.

While this avoidance of articulatory antagonism, again, may involve gestures in sequence or in simultaneity, Lindblom's illustrative examples—coarticulation, vowel reduction, and aspects of syllable structure—all involve sequential articulatory targets. The present data, although presented as incompatible if implemented simultaneously—those needed to achieve the broadband noise which characterizes aspiration or those needed to implemented creak, and those needed to reach a particular pitch target—are nonetheless subject to this Lindblomian interpretation. Indeed, it is, by hypothesis, these gestures' very incompatibility that may be contributing to their *de facto* sequencing. In this subsection then, I turn my attention to these articulatory considerations in the context of Lindblom's "sufficient compatibility" condition. I consider, in turn, pitch production with modal phonation, and pitch production with non-modal phonation. Anticipating my rather uncontroversial conclusion, the inability to achieve a particular articulatory configuration may result in the non-achievement of the intended acoustic goal.

Ohala (1978) summarizes the interacting muscular, articulatory, and aerodynamic factors involved in pitch production. Briefly, pitch 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 vocal fold 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. Implementing a high tone primarily involves tensing the vocal folds. Secondarily, glottal aperture may be increased. Subglottal pressure, of course, should remain high throughout. Finally, the larynx may be raised. A low tone primarily involves laxing the vocal folds. Lowness may be enhanced if glottal aperture is decreased; subglottal pressure might be reduced. Finally, the larynx is lowered. These configurations are presented in tabular form in 28.

(28)
Tone (with modal phonation)

primary gesture		V˥	V˩
vocal fold tension:	higher:	✓	
	lower:		✓
enhancing gestures			
glottal aperture:	higher:	✓	
	lower:		✓
intercostal flexion:	higher:	✓	
	lower:		✓
larynx height:	higher:	✓	
	lower:		✓

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 and tone, as in 29. Breathy voice is implemented primarily through abducting the vocal folds, while maintaining a glottal pulse. 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 1991). The source of this larynx lowering is not fully clear; it may simply be an automatic muscular by-product of glottal abduction.

(29)
Breathy phonation

primary gesture	V̤
glottal aperture:	higher: ✓
	lower:
enhancing gestures	
vocal fold tension:	higher:
	lower: ✓
intercostal flexion:	higher: ✓
	lower:
larynx height:	higher:
	lower: ✓

Now consider what would happen if a speaker were to simultaneously implement contrastive breathiness and 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 may be accompanied by larynx lowering.

Now consider lower pitch and breathiness. Both are implemented with lax vocal folds, and larynx lowering. However, while lowness is enhanced by reducing subglottal pressure, breathiness is enhanced by increasing subglottal pressure. Moreover, lowness is enhanced by reducing glottal aperture, while breathiness involves increases in glottal aperture. In 30 potential conflicts are shaded.

(30)

Tone with breathy phonation

	V̤˥	V̤˩
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 neighboring 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. Moreover, a laryngeal abduction here may reduce pitch, as the vocal folds are necessarily slackened, and the larynx is perhaps somewhat lowered. Thus, if a preceding supraglottal closure is unavailable, aspiration should be implemented with an increase in subglottal pressure, in order to facilitate the cueing of aspiration in this otherwise weak position. Indeed, this is exactly what spectrographic evidence from Comaltepec Chinantec suggests.

EXCURSUS: JEH, HUAVE, AND ARAWAKAN

I briefly digress and consider three possible realizations of postvocalic aspiration: First, post-vocalic aspiration may be accompanied by an increase in internal intercostal flexion, giving rise to a pitch increase as well. Second, postvocalic aspiration may not be accompanied by an increase in intercostal flexion, thus giving rise to a pitch fall. Finally, postvocalic aspiration may not be accompanied by an increase in intercostal flexion, thus eventually neutralizing the aspiration contrast. Jeh, Huave, and Arawakan exemplify these three patterns. I briefly consider each in turn.

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. Some correspondences are shown in 31.

(31)

Dak Wak	*Other northern dialects*	
tɛː˩˥	tɛh	to scythe
daj˩˥	daj̥	loud

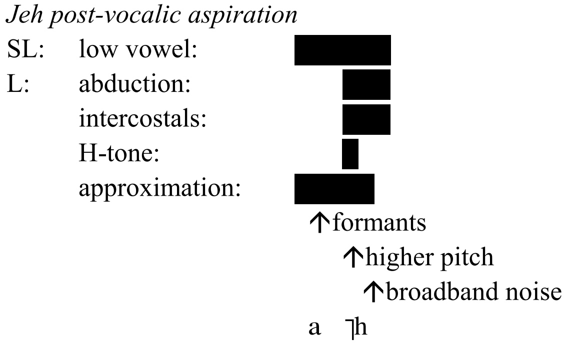
In still other northern dialects syllable final h reportedly freely varies with a rising tone (p.45).

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.

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 latter portion of modally phonated vowel. 32 portrays this effect.

(32)

Jeh post-vocalic aspiration



And so in time, the system of contrasts may evolve such that the pitch rise, rather than the post-vocalic aspiration, cues the contrast. Ultimately, aspiration may be lost altogether, and the pitch rise is the sole cue to the contrast, as in Dak Wak. This is portrayed in 33.

(33)
Jeh vowel-final H tone

SL:	low vowel:	
L:	H-tone:	
	approximation:	

↑formants
↑higher pitch
a a˥

Now, 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.[4] Huave is a tonal language of indeterminate affiliation, spoken by approximately 13,000 people in Oaxaca, Mexico (Grimes 1989). Noyer (1991) reports that long vowels in Huave alternate with Vh sequences, as shown in 34. Geminate vowels alternate with Vh (underlined), conditioned by stress. Closed final syllables are stressed.

(34)
Huave alternations

a.	…à ˈp*éè*d	he cuts
b.	…àp*èh* ˈtíʌw	they cut

Stress-shift off the derived penult in 34b results in surface Vh. "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.

(35)
[Noyer's #38 -D.S.]   -VVCV(V)C#

In such an environment the sequence Vh is abundantly represented" (p.10). Examples are in 36.

(36)
Vh sequences

wahtat	sawfish
ʃehken	dull
tehpɛaj	washtub

Now, some dialects possess geminate vowels where others possess Vh sequences. Moreover, in emphatic speech, long vowels Vː may be realized with h-interruption (VhV). Most significantly, these alternating long vowels are always realized with falling tones.

How might the Huave facts be interpreted in accordance with the present approach to phasing and recoverability? I claim that long, falling-toned vowels have their historic origins in vowels followed by aspiration. 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 post-vocalic aspiration unaccompanied by subglottal pressure and flow increases: the vocal folds are slackened, and the larynx is lowered. In time, this may evolve into a long vowel with a falling pitch; exactly what is found in most environments in Huave today, as portrayed in 37.

(37)

Huave historic post-vocalic aspiration

SL: low vowel:

L:abduction:

L-tone:

approximation:

↑formants

↑lower pitch

↑broadband noise

a ˩ h

Given its weak position, this aspiration would seem a prime candidate for deterioration and ultimate loss, were subglottal pressure and flow not sufficiently increased. See 38.

(38)

Huave vowel-final low tone

SL: low vowel:

L: L-tone:

approximation:

↑formants

↑ lower pitch

a a˩

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 or not a length distinction or tonal distinction ultimately evolves into the sole contrastive value remains to be seen.

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, 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 merge with its absence. Payne (1991), and Parker (1994) report this diachronic process in certain Arawakan languages.

In summary, these case studies suggest that language-specific conventions concerning whether a particular contrastive gestural configuration is enhanced or not may, in time, lead to divergent systems of contrasts.

SUFFICIENT ARTICULATORY COMPATIBILITY (CONTINUED)

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 serve 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). See 39.

(39)
Creaky phonation

primary gesture	V̰
glottal aperture:	higher:
	lower: ✓
enhancing gestures	
vocal fold tension:	higher: ✓
	lower:
intercostal flexion:	higher: ✓
	lower:
larynx height:	higher: ✓
	lower:

Creakiness is largely articulatorily 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. 40 provides a tabular summary, and again, potential conflicts are shaded.

(40)
Tone with creaky phonation

	V̰˥	V̰˩
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 (Thonkum 1987) and Mandarin (Hombert 1978)). 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 an utterance 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 pronounced 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 overly difficult to implement a given gestural configuration involving tone and phonation, it may be difficult to implement many distinct configurations in sequence. Certainly, it is at least more difficult to achieve such sequences of pitch targets during non-modal phonation than it is during modal phonation. 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.

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 may be sequenced in laryngeally complex vowels of this type. As I now show, non-modal phonatory gestures are phased early in the toned vowel in Jalapa Mazatec, Comaltepec Chinantec, and Copala Trique. In Comaltepec Chinantec and Copala Trique, they may also be phased late in the vowel, and in Copala Trique only, they may interrupt the toned vowel.

5.3.3 Vowels and Laryngeal Gestures in Jalapa Mazatec

Jalapa Mazatec (Pike and Pike 1947, Kirk 1966, 1969, Bull 1983, Steriade 1992, 1994, Kirk, Ladefoged, and Ladefoged 1991, 1993, Silverman 1994a, 1997b, 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 the Otomanguean language family. Jalapa Mazatec contains the segment inventory shown in 41 (from Silverman, Blankenship, Kirk, and Ladefoged 1995).

(41)
Jalapa Mazatec segment inventory

p	t	ts	tʃ	k	i	u
p^{h}	t^{h}	ts^{h}	tʃ^{h}	k^{h}		o
^{m}b	^{n}d	^{n}dz	^{n}dʒ	^{ŋ}g	æ	a
	s		ʃ			
m	n		ɲ	ŋ		
	l					
w		j				
h,ʔ						

(labial obstruents and the lateral are limited to loanwords)

Tone, nasality, and length contrasts greatly expand the vowel inventory. Jalapa Mazatec posseses three level tones (˩, ˧, ˥), as well as a series of tonal contours (Kirk 1966).

Laryngeals may stand alone prevocalically, as exemplifed in 42.

(42)
Prevocalic laryngeals:

ʔa˧	why	he˧	finish
ʔã˧	I	ha˥	men

The sonorants of Mazatec are unusual in that laryngeal contrasts may either precede or follow modal phonation. When the laryngeal contrast precedes the modally phonated sonorant, the transition from syllable onset to syllable nucleus is modally phonated. Some examples are shown in 43 (from Kirk 1966, and Silverman, Blankenship, Kirk, and Ladefoged 1995).

(43)

Aspirated nasals and glides		*Laryngealized nasals and glides*	
m̥ma˧	black	ti˥ʔmæ˧	he is sick
n̥næ˧	he falls	ʔna˧	shiny
ɲ̊ɲa˧	growth, bush	ʔɲa˩	chills
j̊ju˧	peace	ʔja˩	ants
w̥wæ˧	use up	ʔwi˧	drinks

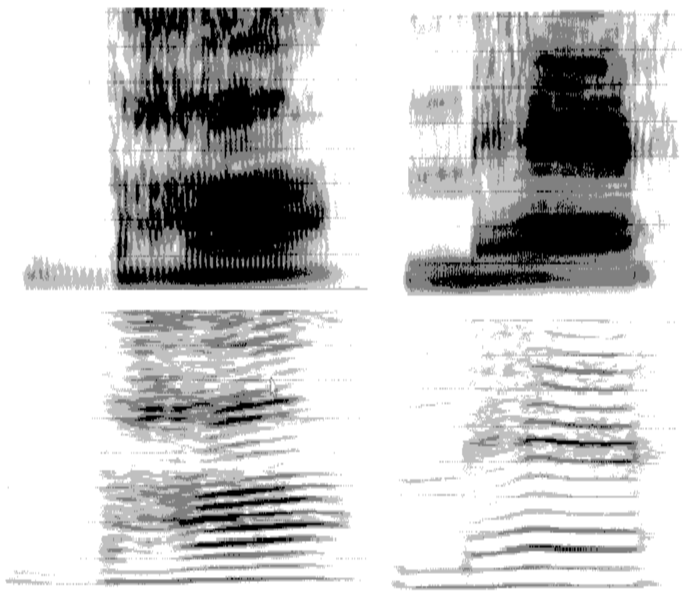
In addition, breathiness or creakiness may accompany Jalapa Mazatec vowels. In either case, non-modal phonation is realized primarily on the first portion of the vowel, actually beginning toward the end of any prevocalic sonorant. The second portion of the vowel usually possesses severely weakened breathiness or creakiness, verging on modal phonation. Some examples are in 44 (from Kirk, 1966, Silverman, Blankenship, Kirk, and Ladefoged 1995).

(44)

Breathy vowel		*Creaky vowel*	
mm̤æ̤͡æː˦˥	wants	mm̰o̰͡o˧se̤͡e˧	eviction
nn̤a̤͡a˦˥	my tongue	nn̰æ̰͡æ˧	he says
ɲɲ̤a̤͡a˧	nine	ɲɲ̰V̰͡V	(unattested)
jj̤æ̤͡æ˩	boil	ww̰a̰͡aj˧tsẽːj˧	he remembers
ww̤o̤͡o˧	hungry	ti˥ww̰ḛ͡e˧	hits, gives birth to

In 45 are wideband and narrowband spectrograms of two prototypical Jalapa Mazatec breathy vowels produced by two native speakers. Note in particular the absence of a clear harmonic structure during the initial portion of vocalism, where breathy phonation resides.

(45)
Spectrograms of laryngeally complex vowels in Jalapa Mazatec



mm̤æ̤͡æ˦	^{n}da̤͡a˦
hard	he wants

Observe additionally that Jalapa Mazatec is analyzed as possessing a series of aspirated voiceless plosives. 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 (46).

(46)

Aspirated stops with creaky vowels in Jalapa Mazatec

tʰo̰͡õ˧	fifteen
fi˧|kʰa̰͡a˥	get (carry)
tʃʰa̰͡a˩	spoon

This unusual distribution is possible (though certainly not probable) 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 clear. Given the necessary phonetic co-occurence of voicing and breathiness here, a laryngeal abduction in this context does not provide as pronounced a discontinuity in 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 tʰa does not provide a salient contrast with tʰa̤a, but is sufficiently contrastive with tʰa̰a Indeed, I am aware of no language which contrasts breathy phonation in the context of a preceding aspirated stop.[5] In 47 is a tabular summary of the relevant facts from Jalapa Mazatec.

(47)

Phasing and recoverability in Jalapa Mazatec laryngeally complex vowels

vowel⇳⟨abduction⇳intercostals⇨ tone⟩	phase voicelessness to the first portion of the toned vowel
vowel⇳⟨constriction⇨tone⟩	phase creakiness to the first portion of the toned vowel

Non-modal phonation may be prevocalic in Jalapa Mazatec. In the context of a preceding voiceless stop, or in isolation, aspiration is voiceless; elsewhere, aspiration is implemented simultaneously with voicing, that is, as breathy phonation.

5.3.4 VOWELS AND LARYNGEAL GESTURES IN COMALTEPEC CHINANTEC

In this section I examine the phenomenon of lexical and morphemic “ballistic accent” in Chinantec, and its relation to phasing and recoverability in laryngeally complex vowels.

So-called 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, as in 48.)

(48)

Ballistic		*Controlled*		
ló˩˥	lime	loː˥	skin	Comaltepec dialect (Anderson 1990)
ʔmá˥	food	na˥	now	Palantla dialect (Merrifield 1963)
tý́ː˧	blind	tyː˧	Peter	Quiotepec dialect (Robbins 1968)

Instead, 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 the Comaltepec dialect in support of this characterization, showing that ballistic syllables differ from near-minimally contrasting controlled syllables in possessing significant postvocalic aspiration. Additionally, I discuss correspondences in other dialects of Chinantec: 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.

Chinantec, like Mazatec, is a member of the Otomanguean language family. 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).

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.

Comaltepec roots and words are usually monosyllabic. As in all Otomanguean languages, 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 here involve nasalization, tone, length, consonantism, and phonation contrasts. Additionally, certain irregular patterns are marked by vocalic ablaut. In 49 is a sample partial verb paradigm. Syllable boundaries are indicated by tone marks. Prefixal material (the tense marker) is set off by a space (all Comaltepec data are from Anderson 1989, Anderson, Martinez and Pace 1990, and Pace 1990).

(49)

Sample partial verb paradigm

koː˩ ho˩	I am playing	koːʔ˩	you (sg) are playing
ni˩ koː˩˥ho˥	I will play	ni˩ koːʔ˥	you (sg) will play
ka˩ ko˧ho˩	I played	ka˩ koːʔ˧	you (sg) played
koːʔ˧	we are playing	koːʂ˩	he/she/they are playing
ni˩ ko˥hoʔ˥	we will play	ni˩ koʂ˧	he/she/they will play
ka˩ ko˥hoʔ˥	we played	ka˩ koːʂ˩	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 50 is the segment inventory of Comaltepec.[6]

(50)

Comaltepec segment inventory

p	t	tʃ		k	i	ɨ	u
ᵐb	ⁿd	ⁿdʒ		ᵑg	e	ʌ	o
(f)	s	(ʃ)	(ʂ)	(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 51.

(51)

Consonants

pihʔ˥	little (i)	ⁿdʒiː˩	dog
ᵐbʌʔ˩˥	ball	ʃœ̃h˩˥	small deer
fi˩	whistle	jʌʔ˧	above
miː˧	plain	z̨oː˩	sweet
tiː˩	thin (i)	ki˩˧	garbage
ⁿdoːh˩˥	maguey sap	ᵑguːh˩˥	owl
soː˧	ascent	xoʔ˩	rotten
nuː˩	grass	ŋuh˩˧	meat
loː˩	rabbit	j̥jah˩˧	cliff
tʃih˥	term of endearment	wɨ˧	spider

Laryngeals

hi˩	book	ʔoː˧	papaya

Vowels

lih˥	flower	ᵐbʌʔ˩˥	short
heʔ˩˧	frog	lu˩	fly
ⁿdʒæ˩	person	hoʔ˩˥	maggot
lɨhʔ˥	circle	ta˩˥	work

The tones listed in 52 are attested in morphologically simplex environments. An example of each tone is presented.

(52)

Tones

L	hi˩	book
H	l̥loʔ˥	pretty
M	^{n}dʒœː˧	earthen jar
LM	ᵑgiŋʔ˩˧	swing
LH	li˩˥	tepejilote palm shoot

Comaltepec syllables are of the form ʔ/h*C*G*V*ː^{T}hNʔ (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, onsets, nuclei , and codas.

Any consonant, as well as the glides w, j, and the laryngeals ʔ, h, may occupy onset position. Examples of each are presented in 51.

The sonorants, as well as the voiced velar stop, may additionally possess a contrastive laryngeal value. This laryngeal 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 53.

(53)

Sonorants and laryngeals

m̥mɨː˩	water	ʔmɨ˩	feces
n̥njœː˩	green beans	ʔniːh˩˥	rope
ŋ̊ŋajŋʔʐ˩˧	he kills	ʔŋjoŋʔ˩˧	waist
l̥loʔ˥	pretty	ʔleː˩	dust
xoʔ˩	rotten	ʔgoː˩	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 54.

(54)

With consonants		*With laryngeals*		
^{n}djeh˩˥	god	jje˥˧		where
$^{\text{ŋ}}$gjuŋ˧	good (a)	ʔ̊jeː˩		sun
$^{\text{ŋ}}$gwo̊ː˩	hand	w̥wɨː˩	(also fɨː˩)	village
kweː˩	long (i)	ʔweʔ˩		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, as in 55.

(55)
Hypothesized /sju /
ʃœ̃h˩˥ small deer

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. 56 provides examples.

(56)

ja and jæ

hæ˩˨	spider	tæːŋ˩	white (a)
jjah˩˨	cliff	ʔlæh˩	snare
ʔ̊æŋ˩˨	very	næh˩˨	open!
ʔjå˩˨	griddle	kjahʔʐ˥	his
ʔjaːŋ˩	it sprouts	^{ŋ}gjaːŋ˧	twenty (a)
^{m}bæ̊˩˨	bunch	ʔjah˩	five (i)
ʔmæː˧	I guard		

Regarding nuclei, Comaltepec possesses contrastive length with all vowel qualities. Some examples are in 57.

(57)

Short vowels		*Long vowels*	
lih˥	flower	tiː˩	thin (i)
heʔ˩˨	frog	teː˩	white (i)
lɨʔ˥	circle	tɨː˧	foot
^{m}bʌʔ˩˥	short	ʐʌː˩	smooth
lu˩	fly	kuː˧	money
hoʔ˩˥	maggot	ʔoːh˥	rotten
^{n}dʒæ˩	person	tæːh˩˥	daddy
ta˩˥	work	haːŋ˩	one (a)

Any vowel quality except ʌː may be contrastively nasalized. Examples are in 58.

(58)

Nasalized vowels

ʔĩ˩	stupid
ʔẽːʂ˩˥	his uncle
hɨ̃ː˥	weasel
hʌ̃ʔz̨˩	give
tũːʔ˧	you pour it
m̥mɨ˩ kõʔ˧˥	you help him
m̥mi˩ tæ̃˨˩	Macuiltianguis town
kãː˧	I charge (money)

Nuclei may possess post-vocalic aspiration. As already noted, syllables with such nuclei are traditionally considered to possess "ballistic stress." Some examples are in 59.

(59)

Plain vowels		*Vowels with post-vocalic aspiration*	
ᵑgwoː˩	good (i)	ᵑgjʌŋ̊˧	hand
heʔ˨˩	frog	lih˥	flower

Finally, in certain clitic environments, nasals may occupy the nuclear position. In 60 are some examples.

(60)

Syllabic nasals

ka˩ bʌː˧ n̥n̩˩	we hit (yesterday)
ni˩ ʔɨː˩˥ n̥n̩˥	I will sweat
ŋ̊ŋan̥˩ ʔn̩˩	I kill

Coda consonants in morphologically simplex environments are limited to ŋ, ʔ, and ŋʔ. Examples are provided in 61.

(61)

Simplex codas

huhʔ˥	pineapple	w̥wɨŋ˩˥	many
taʔ˩˥	honey	ᵑgiŋ̥ʔ˩˥	swing
ᵑgjuŋ̥˥	good (a)		

In morphologically complex environments, the coda system may be somewhat more complex, allowing p, a cliticized form of the copula, bahʔ˥ , and ʐ/ʂ, a cliticized form of the third person pronoun, ʔiʂ˩ . The voiceless alternant here is found only in ballistic contexts. Examples are provided in 62.

(62)

Complex codas

hip˩	it's a book	ʔjaʂ˩	her griddle
pihʔp˥	it's little	sɨ̃ʔʐ˥	his clothing

As stated above, Comaltepec roots 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 discussed 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.

In Comaltepec, eight vowel qualities (i,e,æ,a,o,ʌ,ɨ,u) may be combined with five tonal qualities (V˥ , V˧ , V˩ , V˩˥ , V˥˩), two voice qualities (V, Vh), a binary nasality contrast (V, Ṽ), as well as a binary length contrast (V, Vː). The cross-classification of these five independent systems results in 320 possible nucleus qualities (8 x 5 x 2 x 2 x 2). A single vowel quality may thus 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 possessing contrastive information in parallel. Thus a given sonorant onset consonant in Comaltepec may only be contrastively aspirated or glottalized, as well as plain. Obstruent onset consonants may only be plain or voiced. Again, we see how more contrastive values are possible under better acoustic conditions.

It should not be surprising that these monosyllabic morphological complexes in Comaltepec are obligatorily stressed. 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). 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. 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 rare bisyllabic noun or verb roots). Thus, the tonic is the primary domain of inflection.

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. 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.[7] This is schematized in 63.

(63)
Syllabic location of Comaltepec verbal morphological components

	onset:	*nucleus*:	*coda*:
supralaryngeal:	root	root	root
laryngeal:	root	inflection	root

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 phonemic and morphemic 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.

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.[8] 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.

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.[9] 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.

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). However, increases in subglottal pressure are argued to enhance the salience of the primary laryngeal gesture. I henceforth refer to this hypothesis as the “aspiration hypothesis."

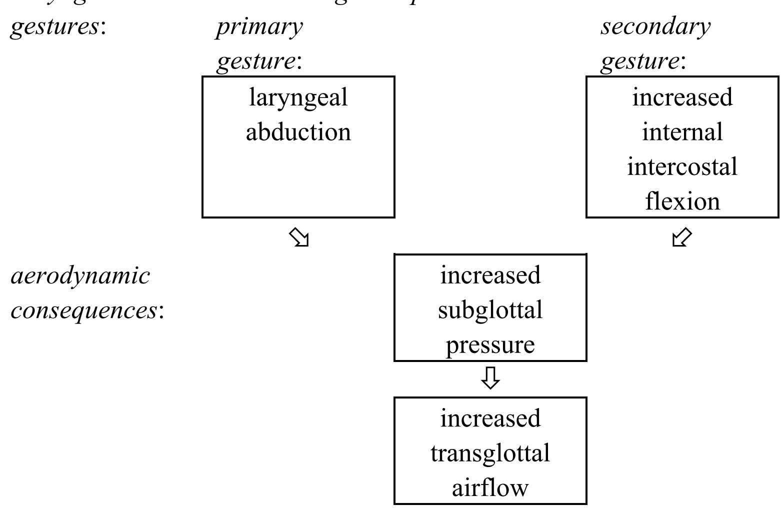
First, I consider how a spread glottis may result in phonetic effects that are similar to those observed in ballistic syllables, expanding on my earlier discussion of enhancing mechanisms.

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 from speaker to speaker. She writes:

> ... [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 are used for a given feature, the more robust and salient that feature's value will be."

How may Keating's approach support the aspiration 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. The flowchart in 64 indicates this hypothesized state of affairs.

(64)
Laryngeal abductions 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.

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 aspiration hypothesis argues that increased subglottal pressure acts to enhance the cues of 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 speculative superficial aerodynamic consequences that increased subglottal pressure may have on glottal aperture.

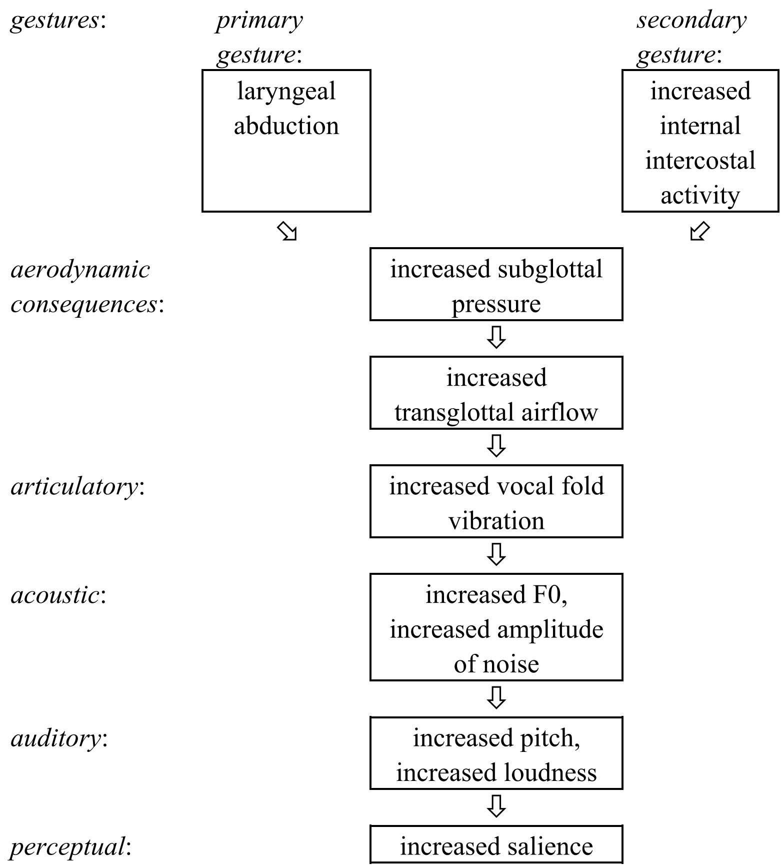
Note additionally that Mugele offers no explanation for observed nasal devoicing in ballistic syllables. Surely, when a nasal follows a vowel, the vocal folds do not naturally abduct; spontaneous voicing continues throughout the supralaryngeal adjustment from vowel to nasal. Yet ballistic syllables are 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 (as discussed in 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 65 presents these interrelated phenomena.

(65)

Subglottal pressure and pitch



(The reported pitch increase associated with ballisticity is not limited to Comaltepec. Mugele reports that level L and level H tones in the Lalana dialect 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.)

Then, upon the implementation of the glottal abduction, after airflow increases, subglottal pressure naturally falls off, consequently *reducing* transglottal flow and pitch. This is exactly what reportedly occurs at the far end of ballistic syllables.

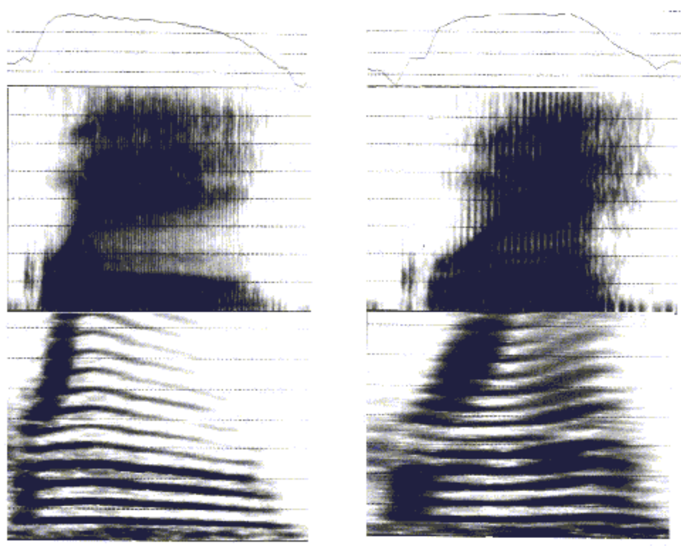
Why should these pitch increases affect only long ballistic LH and MH syllables, and not their short counterparts? Most likely, a noncontrastive syllable-initial H in short ballistic syllables would result in the neutralization of lexical contrasts: a short ballistic syllable may lack sufficient duration to accommodate this additional pitch perturbation. The introduction of a H tone in short ballistic syllables could thus very well result in the loss of 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 aspiration 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.

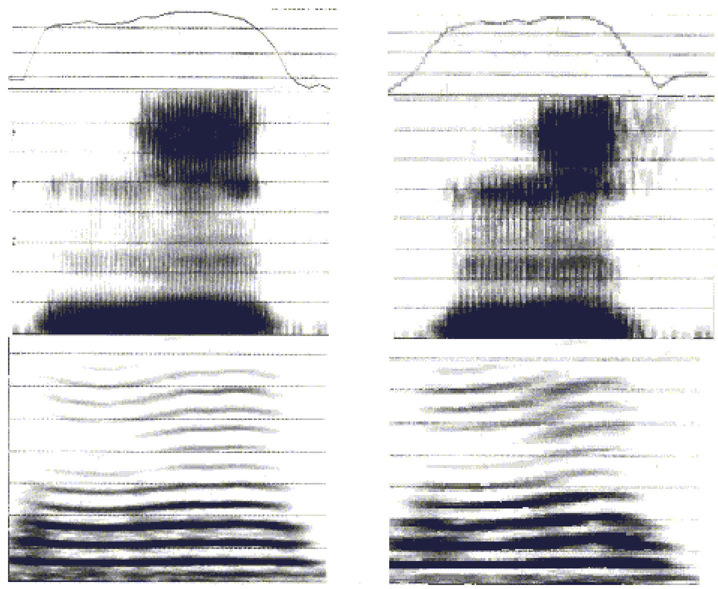
Now consider Comaltepec phonology. While most morphologically complex forms in Chinantec are monosyllabic, there is a limited process of syllabic encliticization involving reduced forms of personal pronouns. Anderson, Martinez, and Pace report that in first person cliticization, a copy of the root vowel 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 ka˩ noh˧ + R → ka˩ no˧ ho˩ .[10] Under Mugele's analysis, no explanation is forthcoming regarding the behavior of aspiration in this context.

Finally, consider Comaltepec spectrographic evidence. In 66 are energy contours, wideband and narrowband spectrograms, for pairs which minimally or near-minimally contrast in ballisticity. The speaker is a forty year old native of Comaltepec.

(66)
Spectrograms of controlled and ballistic syllables in Comaltepec Chinantec



kweː˧	(mɨ˧)	kweːh
long	arm	



ni˥ face

ni:h˦ sit!

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.

Inspection of energy contours indicates a direct correlation between energy 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.

Recall the flowchart in 65, which considers the consequences of increasing sublglottal pressure. 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 upon reading Fischer-Jørgensen (1970) one assumes 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, there often is 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 often reported in ballistic syllables ultimately derives from an increase in respiratory muscular activity.

Finally, 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 the pulse period and the 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.

Allow me to summarize the results of this section. 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.[11] When aspiration would be an onset to an unstressed syllable, it is often lost. Examples are in 67.

(67)
Aspiration in English

	h-aspiration present:		*h-aspiration absent*:
word-initially:	həˈbɪtʃuɫ̩ habitual	*word-medially*:	ˌnanəˈbɪtʃuɫ̩ non-habitual
	kɹ̥əˈdɛnʃɫ̩ credential		ˈækɹɪd acrid
stressed-syllable-initially:	viˈhɪkjulɹ̩ vehicular	*non-stressed-syllable-initially*:	ˈvijɪkɫ̩ vehicle
	əˈtɹ̥ækt attract		ˈætɹəbjuʔ 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.

Thus, 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.

I conclude that the ballistic phenomenon is best explained by the aspiration hypothesis. That is, so-called ballistic accent involves primary post-vocalic aspiration, and secondary increases in subglottal pressure due to internal intercostal muscular flexion.

As Comaltepec also allows the optimally phasing pattern among vowels, non-modal phonation, and tone (that is, pre-vocalic non-modal phonation), the sound patten here falls in line after Jalapa Mazatec: after optimal phasing patterns, maximally distinct patterns may then be contrastive, as outlined in 68.

(68)
Phasing and recoverability in Comaltepec Chinantec laryngeally complex vowels

vowel⇳〈abduction⇳intercostals⇨tone〉	phase voicelessness to the first portion of the toned vowel
vowel⇳〈tone⇨abduction⇳intercostals〉	phase voicelessness to the latter portion of the toned vowel

vowel⇳〈constriction⇨tone〉	phase creakiness to the first portion of the toned vowel
vowel⇳〈tone⇨constrictions〉	phase creakiness to the latter portion of the toned vowel

CASE STUDIES: OJITLÁN, USILA, AND QUIOTEPEC

Earlier in this section 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.[12] 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.

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.

5.3.5 Copala Trique

The Mixtecan language of Copala Trique implements a third realization of laryngeally complex vowels. In addition to pre-vocalic and post-vocalic laryngeals, Copala Trique also possesses laryngeally "interrupted" vowels, in which the laryngeal gesture intrudes upon the central portion of the otherwise modal vowel.

Copala Trique is spoken by approximately 8000 people in San Juan Copala, Oaxaca, Mexico (Grimes 1988). The word in Copala Trique normally consists of a bisyllabic root and sub-syllabic inflectional material (consisting of tone, length, ablaut, and/or consonantism) residing on the final syllable. Copala Trique possesses the segment inventory listed in 69 (from Hollenbach 1977).

(69)
San Juan Copala Trique segment inventory

p	t				k	i		ɨ	u
b	d				ɡ		e		o
		tʃ	cç	ʈʂ				a	
	s	ʃ		ʂ					
	z	ʒ							
	ɾ								
m	n								
	l								
			j		w				

ʔ, h

(labial obstruents occur only in loans)

Copala Trique also possesses eight contrastive tonal patterns, shown in 70.

(70)
Copala Trique tones

˧˥ ˦ ˧ ˧ ˧˩ ˨ ˩ ˩˧

Copala Trique words are stress-final. Open final syllables are usually long, and there is a freer distribution of consonants in finals than in (unstressed) initial syllables. Only the laryngeals (ʔ and h) may close syllables, and only final syllables may be closed. Examples of lengthened open finals are presented in 71, from the various dialects discussed by Longacre (1952, 1957) and Ruiz de Bravo Ahuja (1975).[13]

(71)

Lengthened open finals

ma˨ɾeː˧	red
gu˧naː-▌	to remain
ɾa˧ʔaː˧	hand
ɾi˧oː-▌	trough, manger

Laryngeals may be pre-vocalic. Interestingly, in the native vocabulary, h has been lost in pre-vocalic position, evolving into a tonal upglide (Longacre 1957). This, of course, is a highly uncommon distribution. It is very rarely the case that a language allows post-vocalic aspiration to the exclusion of pre-vocalic aspiration. This pattern, then, counter-exemplifies my claims regarding phasing and recoverability. However, pre-vocalic h is attested in Spanish loans, as exemplified in 72.

(72)

Pre-vocalic h in Spanish loans

ʔɨ̃ː˨	nine	liha-▌	sandpaper
ʔu˩ʔuː˩	five	hu˧ljaː˧	Julia
ʔweʔe˩	ice, frost	gaw̥weː-▌	coffee
ʔnɨh˩	inside of		

Examples of post-vocalic laryngeals are presented in 73.

(73)

Post-vocalic ʔ		*Post-vocalic h*	
waʔ˩	the right	ʒu˦kwah˥	to be twisted
jaʔ-▌	teeth	jah˧	ashes
ni˩kaʔ˩	short	ɾah˦	to grind

Vowel interruption is exemplified in 74.

(74)

Interrupted vowels

ɡa˧tuʔu˦	incense-burner	ɾi˧uhu˩	hollow reed
		na˧ʔaha˦	conversation

Longacre (1952:75;fn2) presents six reasons to interpret interrupted vowels as laryngeal gestures timed to interrupt a single vocalic gesture, rather than a bisyllabic sequence involving two distinct vowel gestures.

First, interrupted vowels are distinguished from true sequences of vowel-laryngeal-vowel, in that interrupted forms do not undergo final lengthening. Thus weʔe˧ (house) is monosyllabic, while we˧ʔeː˥ (beautiful) is bisyllabic. Longacre hypothesizes that since interrupted vowels manifest their vocalism on either side of the laryngeal, each half is a single mora in length. Therefore, length under stress is redundant.

Second, Longacre shows that interrupted forms lose their second vocalic component in phrasal contexts 75.

(75)

Interrupted forms in phrasal contexts

jaha˧	but	jah˧ zi˧ŋa˥	nasturtiums
joʔo˧	but	joʔ˧ ɡa˧ci˦	the past year
nakihi˦	but	nakih˩ ɾu˩ne˦	bean-atole

This elision is not reported for true V-ʔ-V sequences, although syllable-final h elides within the phrase.

Third, interrupted vowels often appear in otherwise canonical bisyllabic words, whereas true trisyllabic words are quite rare 76.

(76)

Bisyllabic words

na˩kihi˧	atole	ɡa˧uʔu˦	incense burner
ɡi˧ʔjaha˦	holy day, festival	ɾe˧kaʔa˦	stick

na˦nɨhɨ˩˧	open	ɾe˧˦keʔe˧	splinter
da˧˦kuhu˩˧	ascent		

Fourth, tonal sequences occurring on interrupted forms are limited to those which occur on single vowels.[14]

Fifth, 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, that is, they are limited to final syllables.

Finally, interrupted vowels always possess but a single vowel quality, whereas true vowel-laryngeal-vowel 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. I thus concur with Longacre that interrupted syllables indeed consist of a single vocalic gesture interrupted by a non-modal phonatory gesture.

Let us now summarize the distribution of laryngeal gestures in Copala Trique final syllables. First, laryngeals may stand in onset position (hV˥ [loans only], ʔV˥). Second, laryngeals may be post-vocalic (Vh˥, Vʔ˥). Finally, laryngeals may interrupt the vowel (VhV˥, VʔV˥). Trique is thus perhaps unique in allowing three distinct timing relations among phonatory gestures, tone, and vowels.

In summary, Copala Trique possesses three phasing patterns in its class of laryngeally complex vowels: optimal pre-vocalic laryngeals, maximally distinct post-vocalic laryngeals, and again maximally distinct laryngeal interruption.

5.3.6 SUMMARY

77 summarizes in tabular form the patterns presented in this section.

(77)

Summary of the patterns

Jalapa Mazatec	hV˥, ʔV˥		
Comaltepec Chinantec	hV˥, ʔV˥	Vh˥, Vʔ˥	
Copala Trique	hV˥ (loans only), ʔV˥	Vh˥, Vʔ˥	VhV˥, ʔV˥

Again, the presence of sub-optimal phasing patterns normally implies the presence of optimal phasing patterns, where optimality correlates with degree of auditory nerve response at the relevant charactersitic frequency, and where increasingly sub-optimal patterns are maximally distinct from better phasing patterns.

5.4 REAL AND APPARENT EXCEPTIONS

There are exceptions to the claim that laryngeally complex vowels sequence their tonal and non-modal phonatory gestures. If glottalization or breathiness is sufficiently light, parallel transmission may ensue: the acoustic signal may possess both phonatory and tonal information without resorting to sequencing. In this section, I consider real exceptions Mpi and Tamang (5.5.1), and apparent exceptions Yi and Dinka (5.5.2).

5.4.1 REAL EXCEPTIONS

If Lindblom's notion of sufficient articulatory compatability is indeed an independent force acting to constrain the patterning of linguistic sound systems, then certain predictions might be made about alternative realizations of laryngeally complex vowels. Recall that I have argued that insufficient articulatory compatability may be a factor in accounting for the observed sequencing between modal and non-modal phonation in Otomanguean laryngeally complex vowels. However, if sufficient articulatory compatability is somehow achieved among the various potentially conflicting gestures, then we might yet observe the full parallel production of tone and non-modal phonation. This may result in a certain loss of acoustic and auditory salience of the involved cues, thus moderately affecting acoustic discriminability. Consider the real exceptions of Mpi and Tamang in this light.

CASE STUDY: MPI

Mpi, a Tibeto-Burman language (Ladefoged and Maddieson 1996) 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. In 78 are some examples from Mpi.

(78)

Tone	*Modal*		*Laryngealized*	
low rising	si˩˨	to be putrid	sḭ˩˨	to be dried up
low level	si˩	blood	sḭ˩	seven
mid rising	si˧˦	to roll (rope)	sḭ˧˦	to smoke
mid level	si˧	(a color)	sḭ˧	(classifier)
high falling	si˥˩	to die	sḭ˥˩	(name)
high level	si˥	four	sḭ˥	(name)

Moreover, in Mpi, laryngealization persists throughout the duration of the vowel, as portrayed in 79.

(79)
Mpi laryngealized vowel

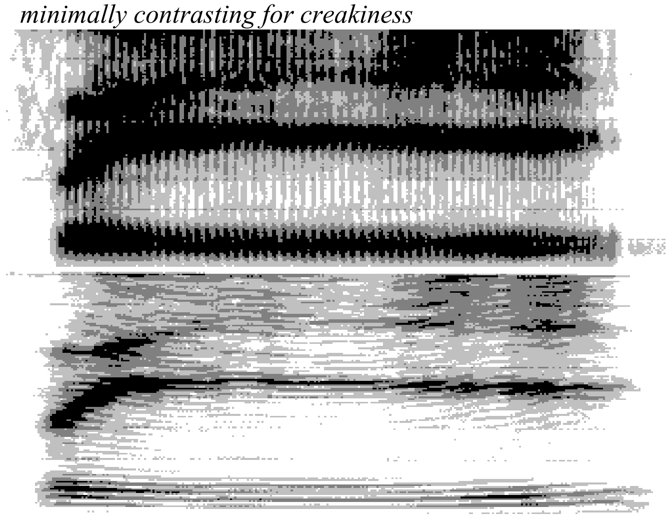
SL: low vowel:
L: constriction:
H-tone:
M-tone:
approximation:

↑formants, creak
↑mid
↑high

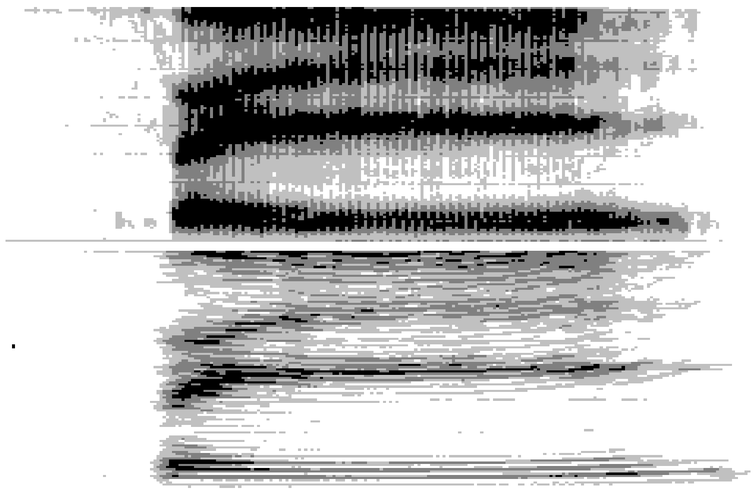
percept: a̰˧˥

The Mpi pattern is thus an exception to the claim that non-modal phonation and tone are always sequenced in laryngeally complex vowels. How might I account for this patterning? The answer lies in the degree to which Mpi laryngealized vowels are creaked. Ladefoged and Maddieson (1996) 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 as well, and indeed limit their non-modal phonation to the vowel's first portion. In 80 are wideband and narrowband spectrograms of a pair of words which minimally contrast for creakiness, taken from the archives of the UCLA phonetics laboratory (orginally recorded by Jimmy Harris in April, 1966). Observe in particular the fairly steady glottal pulse pattern of the creaked form (in the wideband spectrogram), as well as its by and large clear and steady harmonic structure (in the narrowband spectrogram).

(80) *Wideband and narrowband spectrograms for Mpi forms minimally contrasting for creakiness*



si˩
to be putrid



sḭ ˩˨
to be dried up

But with their lesser degree of laryngeal constriction, Mpi vowels may simultaneously implement their tonal and phonatory features, without the risk of non-recoverability. Thus parallel transmission ensues, do to the fact that the weakening of non-modal phonation. That is, sufficient articulatory compatability is achieved at the partial expense of sufficient acoustic discriminabilty. The quantification of this reduction in acoustic discriminability remains an unresolved issue, although a promising method would involve calculating the degree of speech jitter, and the consequent loss of pitch discriminability.

CASE STUDY: 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.

The four registers of Tamang consist of four pitch patterns and two phonation types. These are presented in 81, from Mazaudon 1973.

(81)
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 82 in which phonatory and tonal categories are listed in the external cells, while phonetic realizations are presented in the table interior.

(82)
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 may be considered a laryngeally complex language. Yet researchers say nothing of a part-modal/part-non-modal realization of the breathy registers. Given their 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 one tonal and phonation contrast, 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, 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 apparently 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 unrecoverable concomitant tone; sufficient articulatory compatibility is achieved. Mpi and Tamang, for example, possess tone and phonation contrasts which cross-classify. However, the relatively light implementation of non-modal phonation—at least in Mpi—does not render contrastive pitch unrecoverable. Consequently, contrastive phonatory and tonal gestures here may be implemented simultaneously. Tone and *strongly* implemented non-modal phonation are sequenced so that all contrasts are recoverable.

5.4.2 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, Dantsuji 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 seems, at first glance, a laryngeally complex language. The Xide dialect possesses high, mid, and low-falling tones. The vowel inventory is in (83).

(83)

plain			*glottalized*		
i		u			
			ḛ		ṵ
ɛ		o			
	ɒ		ɛ̰		ɔ̰
				a̰	

Glottalization pervades the vowel in Yi; there is no sequencing of the non-modal phonatory gesture with respect to tone. Yet I claim that Yi isnot a true laryngeally complex language, 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 84.

(84)

non-glottalized		*glottalized*	
vowel	*F1, mean Hz.*	*vowel*	*F1, mean Hz.*
i	311.3	ḛ	666.7
ɒ	490.0	a̰	1024.7
o	340.0	ɔ̰	737.1
u	326.7	ṵ	635.7
ɛ	353.3	ɛ̰	620.0

As F1 inversely correlates with tongue height, Dantsuji 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 F1, 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.

First, pharyngeal constrictions raise F1 by shrinking the pharyngeal cavity and raising the larynx. Lindau (1975) reports that tounge root advancement in Akan is often accompanied by elevation of the larynx, resulting in a smaller pharyngeal cavity. Pharynx size, of course, inversely correlates with F1 value.

Second, 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.

Third, 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 retraction may result in tongue body lowering. This sort of 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.

Finally, Ladefoged reports (1975:149) that a slight tensing of the laryngeal musculature is perhaps an inevitable concomitant of a marked pharyngeal constriction. This slight laryngealization may thus partially explain the perceptual properties that pharyngealization and laryngealization share.

These acoustic 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 pharyngeal 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 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. Moreover, and this is most important, there is no report of pronounced non-periodicity of the glottal wave in Yi. Without this non-periodicity, the perception of pitch should not be significantly disrupted.

It seems 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 pharyngeal cavity, thus serving to slightly raise F1. The so-called "creaky" vowels in Yi, however, involve a primary pharyngeal constriction, which greatly alters the pharyngeal cavity configuration. This articulatory reconfiguration serves to raise F1 to a far greater extent than does simple larynx raising.

The table in 85 presents a summary of the discussion up to this point.

(85)

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 (86a) I have superimposed the plain and “creaky” systems (re-transcribed as pharyngeally constricted) repeated here as (86b).

(86)

a. *full inventory*

i u
e̙ u̙
ɛ o
ɛ̙ ɒ ɔ̙
a̙

b.

plain	*pharyngealized*
i u	
	e̙ u̙
ɛ o	
ɒ	ɛ̙ ɔ̙
	a̙

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 not a 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 87 are from Andersen 1993.

(87)

à̰-wḛ̀c	you are kicking it
à̰-wḛ̀ḛc	he is kicking it hither
à̰-tɛ̰̂ɛ̰ŋ	he is dusting
à̰-tɛ̤̂ɛ̤ŋ	I am dusting for him

The terms "creaky" and "breathy" are, according to Andersen (1987:fn.4,p.26), "...mere impressionistic labels carrying no implications as to the articulatory basis of the distinction." Indeed, Jacobson (1980:196-197), 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."

So-called breathy vowels in Dinka regularly possess a markedly *lower* F1 than their non-breathy counterparts. Malou's data are shown in 88.

(88)

non-"breathy"		*"breathy"*	
vowel	*F1, mean Hz.*	*vowel*	*F1, mean Hz.*
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-Jørgensen (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 and/or pharyngeal cavity size. The Gujarati findings thus lend indirect 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. She 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 lower F1, just as root advancement does. Consequently, F1 distinctions between plain vowels and pharyngeally expanded vowels are enhanced.

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 probably 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.

5.4.3 Chong and Sedang again

Before concluding, consider one more question: might Chong and/or Sedang be examples of Gregerson's (1976) interpretation of Mon-Khmer register, in that they possess pharyngeal contrasts, not laryngeal contrasts?

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 89.

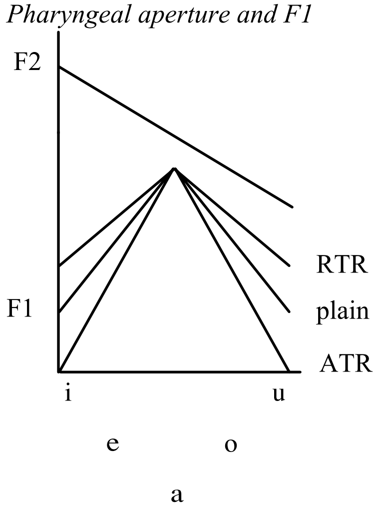
(89)

Vowel quality and phonation in Chong

	R1	R2	R3	R4
i	kriː to cut open	kəkriḭt cricket	ci̤ːt to wipe	ki̤ːḭt to pour
e	ceːt to whittle	ceḛt sambhar deer	pe̤ːt plague	pe̤ːḛt hips
ɛ	kənɛːŋ kind of climber	kəmɛːɛ̰ŋ soot	mɛ̤ːŋ mustache	kəmɛ̤ːŋ jaws
ɯ	kəlɯŋ older sibling	kənɯɯ̰ŋ gum	lɯ̤ŋ (to lie) with one's face up	lɯ̤ɯ̰ŋ deep
ɤ	kɛphlɤːŋ gun	kətɤːɤ̰ŋ palate	jɤ̤ɤ̤ŋ high	kəmɤ̤ːɤ̰ŋ chin
a	kədaːj plank	kəjaːa̰j wind	kəla̤a̤j a bunch of coconuts	kəla̤ːa̰j loose
ɔ	kəlɔːŋ to cross	kəlɔːɔ̰ŋ bridge	kəlɔ̤ːŋ husband, male	keɲɔ̤ːɔ̰ŋ kind of Job's tears
o	loːj to swim	kəkloːo̰j snake-headed fish	ro̤ːj to sprinkle (e.g. salt)	ro̤ːo̰j alive
u	puːt kind of tufted fern	puːṵt rotten	pṳːt to speak	lṳːṵt 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. Low vowels involve a redundant pharyngeal constriction. Again, because the mass of the tongue is a constant, squeezing down the tongue body may involve 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 90, plotted with F2.

(90)
Pharyngeal aperture and F1



Here, pharyngealized non-low vowels possess a higher F1 than their plain counterparts. Similarly, expanded-pharynx non-low vowels possess a lower F1 than their plain counterparts. 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 (1984:132): "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." 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, as concluded in Chapter 3, root-final laryngealization is implemented as a creak on its tautomorphemic vowel.

Let us additionally consider the possibility that Sedang actually displays a pharyngeal contrast, as opposed to a laryngeal contrast, considering that systems involving pharyngealization or tongue root advancement often display asymmetries across vowel qualities.

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 91 is excerpted directly from Smith (his Chart IV, p.57).

(91)
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 configurations 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 (see Denning 1987 for a full discussion here).

This suggests the extreme rarity of languages which possess both vocalic laryngeal contrasts and vocalic pharyngeal constrasts, as such contrasts are 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 inital claims 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.

5.5 CONCLUSION

In this chapter I have investigated the optimal phasing relationships between vowels and laryngeal gestures. In particular, in laryngeally complex languages the sequencing of phonation and tone may be observed, so that all contrastive information is recoverable. Also, the presence of less optimal patterns usually implies the presence of optimal ones, where optimal and increasingly sub-optimal patterns are maximally distinct from each in terms of phasing.

However, laryngeally complex vowels may yet be implemented in full parallel, with a potnetial moderate loss of acoustic detail. Here, sufficient articulatory compatability is achieved among the various gestures.

NOTES

1. Chamicuro is one language that actually allows post-vocalic laryngeals to the exclusion of pre-vocalic laryngeals (Parker 1994).

2. w is v in onset position.

3. Lyman (1974) considers “creaky-toned” vowels creaked. However, Smalley (1976) and M. K. Huffman (1989) describe them as glottally checked. Ratliff (1992) reports that David Strecker and others observe free variation between checking and creakiness.

4. Thanks to Rolf Noyer for suggestng I investigate his Huave data.

5. F.E. Huffman (1985) reports a single possible exception in the Ban Thung Saphan dialect of Chong—c^{h}a̤ːk, 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.

6. Anderson, Martinez, and Pace do not include the glides j,w in their consonant inventory, instead considering these i,u, respectively.

7. One exception to this generalization involves a subset of irregular verbs which possss palatalizing ablaut in certain aspect/person cells (see Pace 1994:44).

8. In the Lalana dialect, ballisticity (considered post-vocalic h in 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 also possess MH, LH, and HLH.

9. Mugele describes the articulatory and acoustic properties of Thai “emphatic tone,” and their similarity to those of ballisticity.

10. “R” stands for “reduplicant,” the suffixal morpheme.

11. Word-initial aspiration in English may be governed by somewhat different forces. Here, the implementation of aspiration maintains a salient distinction between so-called “voiceless” and “voiced” stops: in word-initial position, voicing in plosives is difficult

to implement (Westbury and Keating 1986) and would run the risk of neutralizing with “voiceless” stops, were these not aspirated.

12. Lower numbers here indicate higher-pitched tones.

13. 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).

14. 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˧˥ = tu˩ʔu˧.

6

CONCLUDING REMARKS

In this study 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, in necessary combination with the principles of contrast maintenance and sufficient articualtory compatability. I have argued that sound systems typically maximize the perceptual distinctness among their contrastive phasing patterns. Moreover, sound systems tend to allow sub-optimal phasing patterns only if they allow optimal ones.

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