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Phonation types: a cross-linguistic overview

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Differences in phonation type signal important linguistic information in many languages, including contrasts between otherwise identical lexical items and boundaries of prosodic constituents. Phonation differences can be classified along a continuum ranging from voiceless, through breathy voiced, to regular, modal voicing, and then on through creaky voice to glottal closure. Cross-linguistic investigation suggests that this phonation continuum can be defined in terms of a recurring set of articulatory, acoustic, and timing properties. Nevertheless, there exist several languages whose phonation contrasts do not neatly fall within the phonation categories defined by other languages.

1. Introduction

Cross-linguistic phonetic studies have yielded several insights into the possible states of the glottis. People can control the glottis so that they produce speech sounds with not only regular voicing vibrations at a range of different pitches, but also harsh, soft, creaky, breathy and a variety of other phonation types. These are controllable variations in the actions of the glottis, not just personal idiosyncratic possibilities or involuntary pathological actions. What appears to be an uncontrollable pathological voice quality for one person might be a necessary part of the set of phonological contrasts for someone else. For example, some American English speakers may have a very breathy voice that is considered to be pathological, while Gujarati speakers need a similar voice quality to distinguish the word /ba̤r/ meaning “outside” from the word /bar/ meaning “twelve” (Pandit, 1957; Ladefoged, 1971). Likewise, an American English speaker may have a very creaky voice quality similar to the one employed by speakers of Jalapa Mazatec to distinguish the word /já̰/ meaning “he wears” from the word /já/ meaning “tree” (Kirk, Ladefoged & Ladefoged, 1993). As was noted some time ago, one person’s voice disorder might be another person’s phoneme (Ladefoged, 1983).

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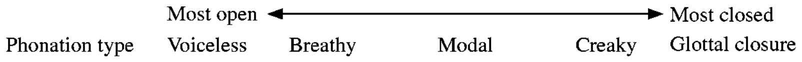


Figure 1. Continuum of phonation types (after Ladefoged, 1971).

2. The cross-linguistic distribution of phonation contrasts

Ladefoged (1971) suggested that there might be a continuum of phonation types, defined in terms of the aperture between the arytenoid cartilages, ranging from voiceless (furthest apart), through breathy voiced, to regular, modal voicing, and then on through creaky voice to glottal closure (closest together). This continuum is depicted schematically in Fig. 1.

Although this is somewhat of an oversimplification, there nevertheless appears to be a linguistic continuum that can be characterized using these terms as an ordered set. Sections 2.1–2.4 explore some of the ways in which languages exploit this phonation continuum. Throughout the discussion, a number of languages with different types of phonation contrasts will be mentioned. The names of all of these languages are summarized in Appendix A, along with some additional basic information about each language: genetic affiliation, where spoken, references, and type of phonations contrasted.

2.1. *Voiced vs. voiceless contrasts*

The majority of languages employ two points along the phonation continuum in making contrasts: voiced and voiceless sounds. This contrast is particularly common among stop consonants and is exploited in a number of widely-spoken languages, such as English, Japanese, Arabic and Russian. The minimal pair *wrangle* with a voiced /g/ *vs. rankle* with a voiceless /k/ illustrates the contrast between voiced and voiceless stops in English. In a smaller set of languages, the voiced *vs.* voiceless contrast is found in sonorants. For example, Burmese, Hmong, Klamath, and Angami have a voiced *vs.* voiceless contrast among the nasals. Sample words illustrating this contrast in Burmese are given in Table I.

No language appears to make a clear voicing distinction in vowels, though it is common, as in Japanese, for phonologically voiced vowels to devoice in certain contexts such as in final position and when adjacent to voiceless consonants (see Gordon (1998) for a cross-linguistic survey of vowel devoicing).

TABLE I. Voiced and voiceless nasals in Burmese (from Ladefoged & Maddieson, 1996, 111)

	Voiced		Voiceless	
Bilabial	mă	"hard"	m̥ă	"notice"
Alveolar	nă	"pain"	n̥ă	"nose"
Palatal	ɲă	"right"	ɲ̊ă	"considerate"
Velar	ŋă	"fish"	ŋ̊ă	"borrow"
Labialized alveolar	nʷă	"cow"	n̥ʷă	"peel"

2.2. *Breathy voice*

Another point on the phonation continuum exploited by certain languages (far fewer in number than languages which have voiceless sounds) is breathy voice. Breathy phonation is characterized by vocal cords that are fairly abducted (relative to modal and creaky voice) and have little longitudinal tension (see Ladefoged (1971), Laver (1980), and Ní Chasaide & Gobl (1995) for discussion of the articulatory settings characteristic of breathy phonation); this results in some turbulent airflow through the glottis and the auditory impression of "voice mixed in with breath" (Catford, 1977, 99). Certain languages contrast breathy voiced and regular modal voiced sounds. Some of these languages, e.g., Hindi, Newar, Tsonga, make this contrast among their nasals. Words illustrating the breathy *vs.* modal voiced contrast in Newar appear in Table II.

Waveforms and spectrograms illustrating the breathy *vs.* modal voiced contrast for two of these Newar words (uttered in isolation) appear in Fig. 2, with the modal voiced nasal on the left and the breathy voiced one on the right. The waveforms are excerpted sections from the modal voiced and breathy voiced nasals, respectively, with the time of the excerpt labeled on the *x*-axis of the waveforms.

TABLE II. Modal voiced and breathy voiced nasals in Newar

Modal voiced		Breathy voiced	
maː	"garland"	m̤aː	"be unwilling"
naː	"it melts"	n̤aː	"knead"

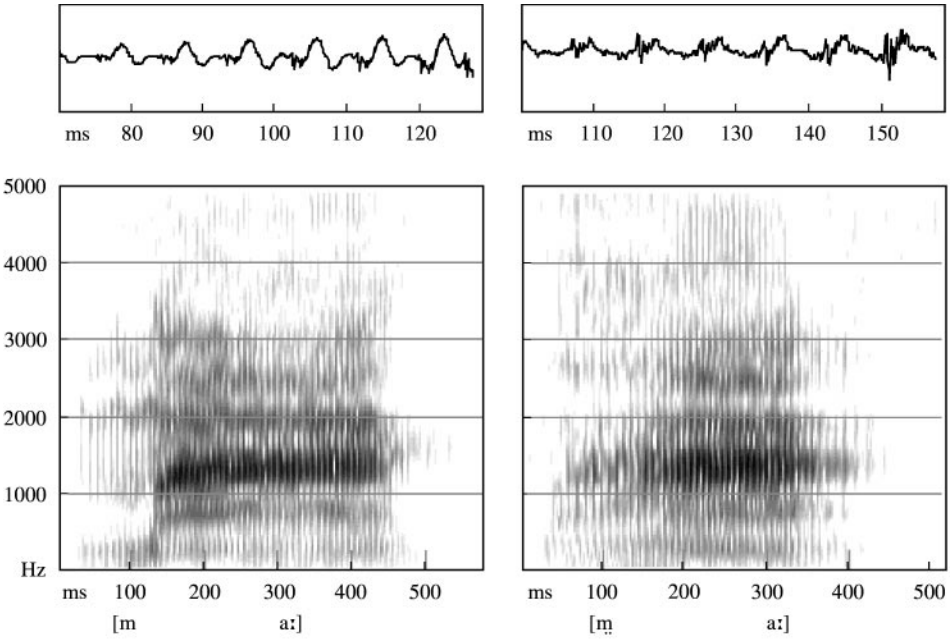


Figure 2. Spectrograms and waveform excerpts of modal and breathy voiced nasals in the Newar words /maː/ "garland" and /m̤aː/ "be unwilling" (male speaker).

Table III. Modal and breathy voiced vowels in Gujarati

Modal voiced		Breathy voiced	
bar	"twelve"	ba̤r	"outside"
pɔr	"last year"	pɔ̤r	"dawn"
kan	"ear"	ka̤n	"Krishna"
mɛl	"dirt"	mɛ̤l	"palace"

The waveform for the breathy voiced nasal is characterized by a fair amount of noisy energy which contributes a relatively jagged appearance to the waveform and diminishes the clarity of individual pitch pulses. In comparison, the modal voiced nasal is not marked by this turbulence and has relatively well-defined pitch pulses. One of the more salient features differentiating modal and breathy voiced nasals in the spectrograms is the visually well-defined nasal-to-vowel transition characteristic of the modal voiced nasal (at about 130 ms) but not the breathy voiced nasal (at about 150 ms). In fact, breathiness persists throughout the vowel following the breathy voiced nasal, resulting in increased formant bandwidths relative to the modal voiced vowel in the spectrogram on the left. In addition, the breathy voiced nasal has some high-frequency noise not present in the modal voiced nasal. The aperiodic energy characteristic of breathy nasals in Newar, as seen in the waveform and, to a lesser extent, in the spectrogram, in Fig. 2, is a general feature of breathiness in other languages discussed below (see also the discussion of the acoustic correlates of breathiness in Section 5).

As it turns out, Newar also makes a breathy *vs.* modal voiced contrast in their stops. Languages with contrastively breathy voiced obstruents are relatively rare cross-linguistically, although they are common in Indo-Aryan and other languages spoken in Asia, e.g., Hindi, Maithili, Telugu, in addition to Newar (see Ladefoged & Maddieson (1996) for further examples).

Some languages contrast breathy and modal voicing in their vowels rather than consonants. Gujarati, which was mentioned earlier in the introduction, is one such language. Representative pairs illustrating this contrast appear in Table III. (We present waveforms and spectrograms illustrating breathy voiced vowels in the discussion of Jalapa Mazatec and San Lucas Quiaviní Zapotec in Section 2.3.)

2.3. *Creaky voice*

Another type of phonation along the continuum in Fig. 1 is creaky voice, which contrasts with modal voice in many languages and with both modal voice and breathy voice in other languages. Creaky phonation (also termed vocal fry) is typically associated with vocal folds that are tightly adducted but open enough along a portion of their length to allow for voicing (Ladefoged, 1971; Laver, 1980; Ní Chasaide & Gobl, 1995). The acoustic result of this laryngeal setting is a series of irregularly spaced vocal pulses that give the auditory impression of a "rapid series of taps, like a stick being run along a railing" (Catford, 1964, 32). Like the contrast between breathy and modal voiced among obstruents, contrasts between creaky and modal voice are also relatively rare in obstruents, though Hausa and certain other Chadic languages make such a contrast for stops. The creaky stops in these languages are implosives and involve larynx lowering as well as a creaky voice quality (see Ladefoged & Maddieson (1996) for discussion).

TABLE IV. Modal and creaky nasals in Kwakw"ala

Modal voiced		Creaky voiced	
nəm	"one"	n̰an̰əm̰a	"nine"
naka	"drinking"	n̰ala	"day"

Some languages contrast creaky and modal voicing among their sonorants. This type of contrast is particularly common in Northwest American Indian languages, e.g., Kwakw'ala, Montana Salish, Hupa, and Kashaya Pomo, among many others. Representative words illustrating the creaky *vs.* modal voiced contrast among nasals in Kwakw'ala (Boas, 1947) appear in Table IV.

Fig. 3 contains (in the top figure) a waveform and spectrogram for a word (uttered in isolation) with three creaky voiced nasals in Kwakw'ala: one occurs word-initially and the others after vowels. The waveform is excerpted from the transition from the vowel preceding the creaky /m̰/ into the nasal itself. The waveform and spectrogram on the bottom illustrate for comparative purposes modal voiced nasals occurring in the same language; the waveform is from the modal voiced /m/. Differences in phonation type are indicated in the phonetic transcription below the spectrograms in Fig. 3 (and in subsequent spectrograms throughout the paper).

Looking at the waveforms, the creaky phonation is characterized by irregularly spaced pitch periods and decreased acoustic intensity relative to modal phonation. Furthermore, there are fewer pitch periods per second in the creaky token than in the modal one (particularly at the beginning of the waveform up to 660 ms when creak is strongest), indicating a lowered fundamental frequency for the creaky nasal. These properties differentiating creaky and modal voice are discussed further in Section 5. The spectrogram on the left indicates that creak is realized primarily at the beginning of the creaky voiced nasals, visually reflected in the increased distance between the vertical striations reflecting pitch pulses, before modal voicing commences in the latter portion of the nasals (indicated by modal voiced nasals in the transcription below the spectrogram). The localization of creak to the beginning of sonorants is a common timing pattern in languages with creaky voiced sonorants (see Section 4.2 for further discussion of the timing issues involved in the realization of creaky voicing associated with sonorants.) Of particular interest in Fig. 3 are the creaky voiced pitch periods at the beginning of the word-initial nasal in the spectrogram on the left, as word-initial creaky nasals are comparatively rare in languages of the world (see Section 4.2 for discussion).

Creaky voicing is also found among vowels in certain languages, including some languages which also use breathy voice to create a three-way phonation contrast. Table V contains words illustrating the three-way contrast between modal voiced, breathy voiced, and creaky voiced vowels in Jalapa Mazatec. Spectrograms illustrating each of the three vowel types in Jalapa Mazatec (from words uttered in isolation) appear in Fig. 4.

Both the breathy voiced and the creaky voiced vowel are characterized by decreased intensity in the waveform, as well as a lowered fundamental frequency relative to the modal voiced vowel. In addition, the breathy voiced vowel is marked by substantial turbulent energy which makes it difficult to discern individual pitch pulses. As Silverman (1997) points out, creakiness and breathiness tend not to be coextensive with entire

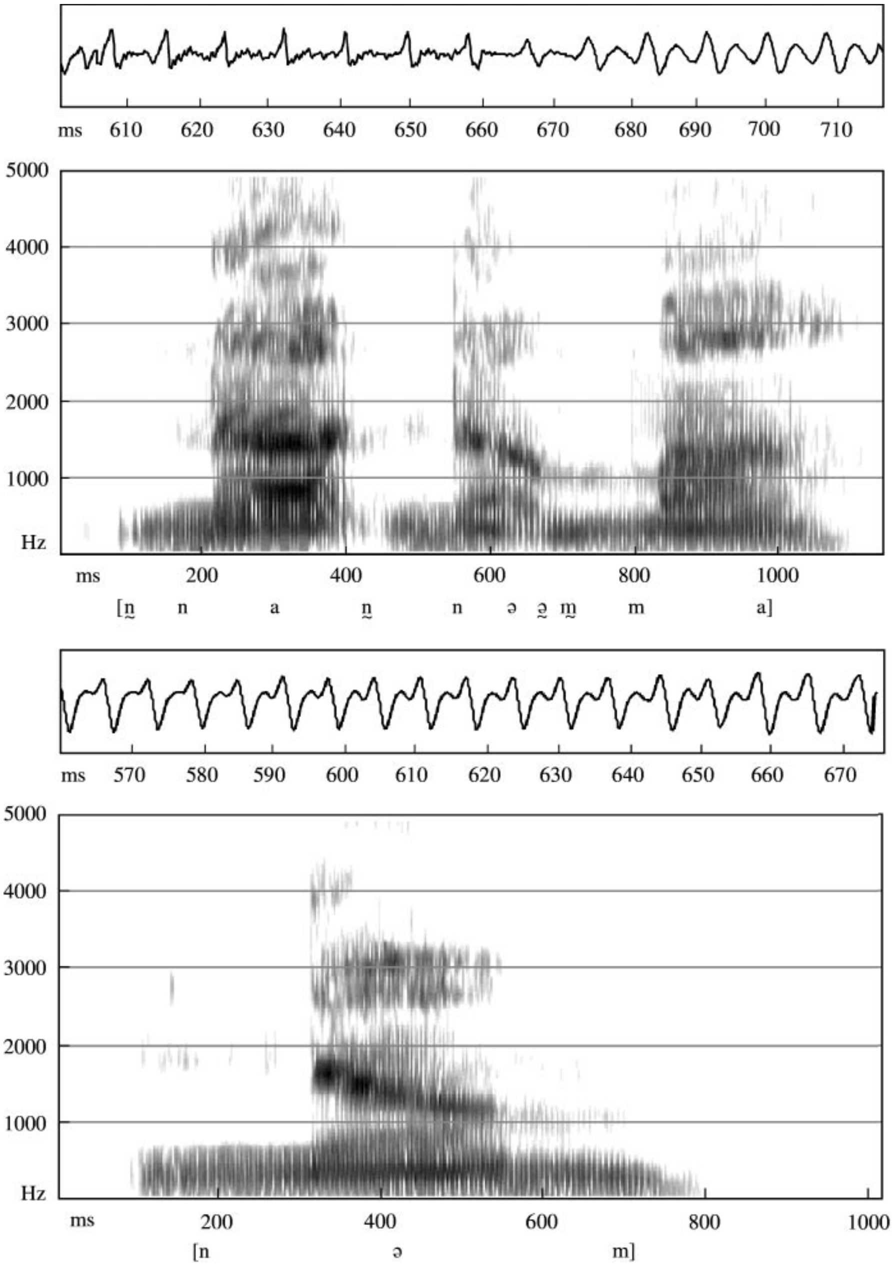


Figure 3. Spectrograms of creaky and modal voiced nasals in the Kwakw'ala words /n̰an̰əm̰a/ "nine" and /nəm/ "one" (female speaker).

vowels in Jalapa Mazatec. It is thus apparent from the spectrograms that the breathy phase of the breathy vowel is largely localized to the first portion of the vowel. In the breathy token in Fig. 4, there is even a short portion of the vowel during which phonation temporarily ceases as the larynx opens too wide for vocal fold vibration to

TABLE V. Modal, breathy, and creaky voiced vowels in Jalapa Mazatec (from Ladefoged & Maddieson, 1996, 317)

Modal voiced		Breathy voiced		Creaky voiced	
já	“tree”	já̤	“he wears”	já̰	“he carries”
nt^{h}ǽ	“seed”	ndǽ̤	“horse”	ndǽ̰	“buttocks”

continue. In the creaky voiced vowel, creakiness is most pronounced during the middle of the vowel, as reflected in the widely spaced vertical striations reflecting lowered fundamental frequency (210–260 ms). It is also interesting to note that both the breathy and creaky vowels have greater overall duration than their modal voiced counterparts. This additional length associated with nonmodal vowels in Jalapa Mazatec is shared with other languages (see Section 5 for discussion).

A similar three-way contrast between modal, breathy voiced, and creaky voiced vowels is also found in San Lucas Quiaviní Zapotec (Munro & Lopez, 1999). Words (uttered in isolation) illustrating the modal *vs.* breathy *vs.* creaky contrast in this language appear in Table VI.

Representative waveforms and spectrograms of some of these words as uttered by a female speaker appear in Fig. 5. The waveform for breathy voice shows the same noisiness and reduced intensity characteristic of breathy voice in Newar (Fig. 2) and Jalapa Mazatec (Fig. 4). Creakiness is associated with less frequent pitch periods which are very irregular in their duration. From the spectrogram it is clear that the breathy exemplar becomes progressively more breathy and thus noisier throughout the vowel culminating in a completely voiceless offset. Note that the modal vowel also ends somewhat breathy, most likely because the words were said in isolation where the vowel is in utterance-final position, a common environment for allophonic breathiness (see Section 3). Like the breathy vowel, the creaky vowel starts off fairly modal before nonmodal phonation commences. In the spectrogram for the creaky vowel, the irregular pitch periods indicative of creak are particularly noticeable at the end of the vowel, which culminates in a glottal stop. It is interesting to note that another speaker of San Lucas Quiaviní Zapotec from whom data have been collected, a male, sustains creaky phonation throughout the entire duration of the phonemically creaky vowel, rather than localizing the creakiness to the latter portion of the vowel. Conversely, the female speaker whose spectrograms appear in Fig. 5 tends to have noticeably breathier vowels than the male speaker. Gender-dependent differences of this sort, particularly increased breathiness for female speakers, have also been observed in languages with allophonic rather than contrastive nonmodal phonation, including English (e.g., Henton & Bladon, 1985; Klatt & Klatt, 1990; Hanson & Chuang, 1999).

TABLE VI. Modal, breathy, and creaky vowels in San Lucas Quiaviní Zapotec

Modal voiced		Breathy voiced		Creaky voiced	
laː	“is named”	na̤ː	“hard, strong”	mna̰ːʔ	“woman”
daː	“Soledad”	kilda̤	“forehead”	ɾda̰ːʔ	“lets go of”
ndiː	“right”	bi̤ː	“air”	bdḭːʔ	“gate”
ʒiː	“tomorrow”	nʒi̤ː	“salty”	ɾʒḭːʔ	“gets milked”

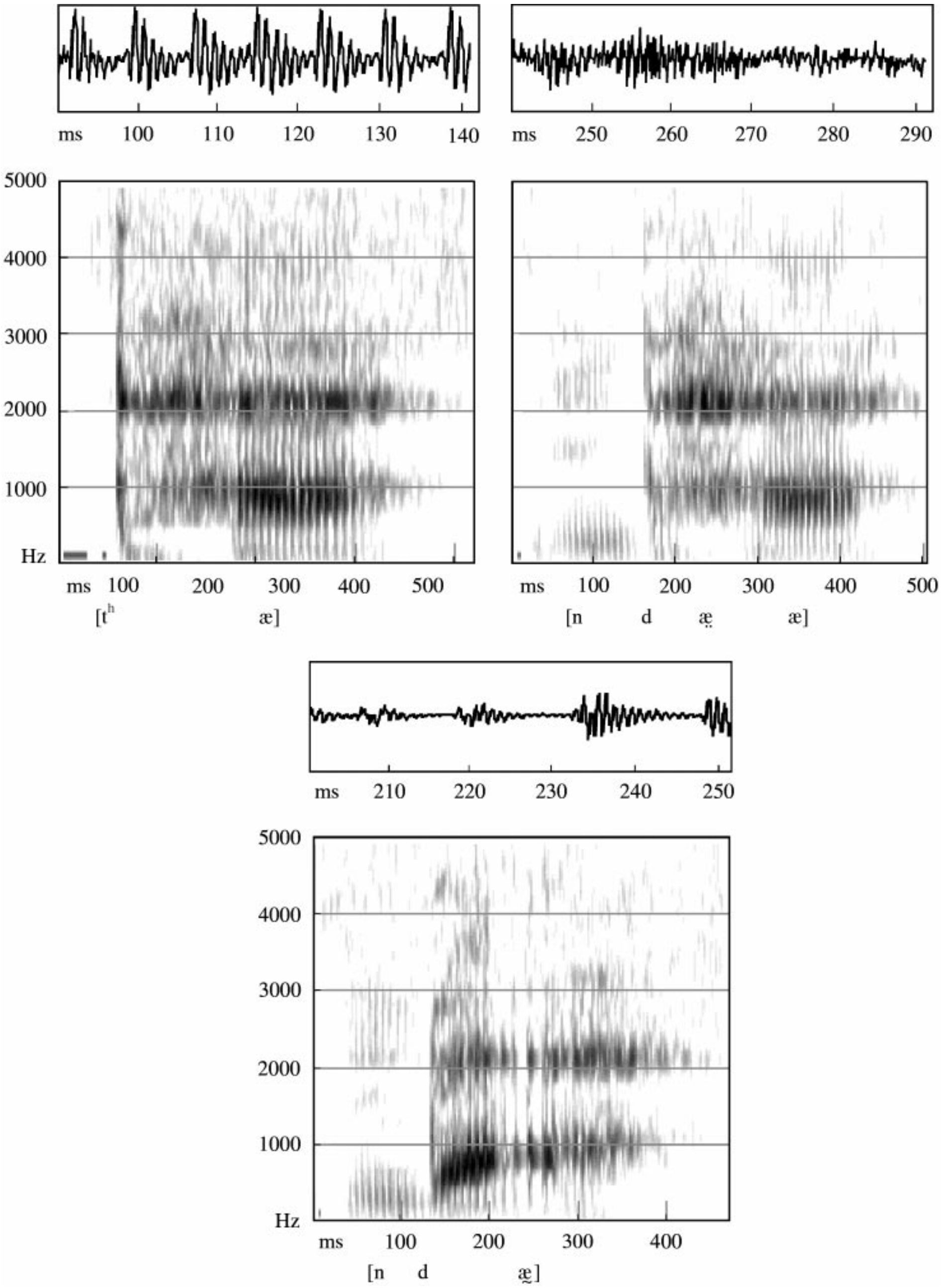


Figure 4. Spectrograms and waveform excerpts of modal, breathy, and creaky voiced vowels in the Jalapa Mazatec words /ntʰǽ / "seed", /ndǽ̤/ "horse", and /ndǽ̰/ "buttocks" (female speaker).

Certain languages employ voice qualities which resemble creaky voice in involving increased constriction in the laryngeal area, but which do not neatly fall under the rubric of creaky voice. For example, Mpi has a tense phonation type which clearly differs from creaky phonation in other languages, though it shares certain properties with creaky voice (such as increased spectral tilt; see Section 5 for discussion of phonetic correlates of phonation differences). Furthermore, Bruu has contrasts that might be described as involving stiff *vs.* slack vocal folds. But the stiffness is not the same as that in creaky voice of the kind used in Jalapa Mazatec, nor does the slackness sound like breathy voice in Gujarati. The stiffness seems to include not only some compression of the glottis, but also increased tension of the pharyngeal walls. This could be classified as a creaky voice, with a "helping feature" (Stevens, Keyser & Kawasaki, 1986). In addition, certain vowels in !Xóõ employ a voice quality which is typically referred to as "strident" in the literature (Ladefoged & Maddieson, 1996). Traill (1985) has given a good description of this voice quality, including X-ray pictures of his own pronunciation of the sound. (His language consultants attest to the high quality of his pronunciation.) It has a narrowing above the glottis that involves the aryeppiglottic fold that affects the vibration of the true vocal folds. Strident vowels are associated with irregular noisy vibrations and higher first and second formant values due to the pharyngeal constrictions associated with the movement of the aryeppiglottic fold and backing of the epiglottis (Ladefoged & Maddieson, 1996).

2.4. *Glottal stop*

Before concluding the discussion of the nature of linguistic phonation contrasts, a few words about the fifth step along Ladefoged's continuum of phonation types are in order. This fifth step, complete glottal closure, entails an absence of vocal fold vibration, as that occurring in the middle of the English interjection *uh-oh.* Glottal stops like the one occurring in this English example are quite common in languages of the world often contrasting with oral stops, unlike in English where glottal stop is noncontrastive. Often, phonemic glottal stops are realized as creaky phonation on neighboring sounds rather than with complete glottal closure (Ladefoged & Maddieson, 1996, 75).

3. Allophonic nonmodal phonation

Thus far, we have only considered languages in which phonation differences are used contrastively. Nonmodal phonation types also commonly arise as allophonic variants of modal phonation in certain contexts. Segmentally conditioned allophonic nonmodal phonation on vowels is extremely common in the vicinity of consonants that are not produced with modal phonation. For example, allophonic breathiness is characteristically found on vowels adjacent to /h/ and allophonic creak is often associated with vowels adjacent to glottal stop, with languages differing in the duration of this allophonic nonmodal phonation (see Blankenship, 1997). Final voiceless stops in certain varieties of English also trigger a short creaky phase on the end of the immediately preceding vowel. In many languages, particularly those of the Pacific Northwest, e.g., Hupa, Quileute, Yana, Takelma (Sapir, 1912), allophonic nonmodal phonation occurs on vowels preceding stops (subject to certain prosodic restrictions in some languages; see Section 4.1), breathiness before voiceless stops and creak before ejectives. In Chitimacha (Swadesh, 1934), underlying glottalized stops are realized as preglottalized stops in syllable-final position.

Nonmodal phonation, especially creaky voice, is commonly used cross-linguistically as a marker of prosodic boundaries, either initially and/or finally, as, for example, in

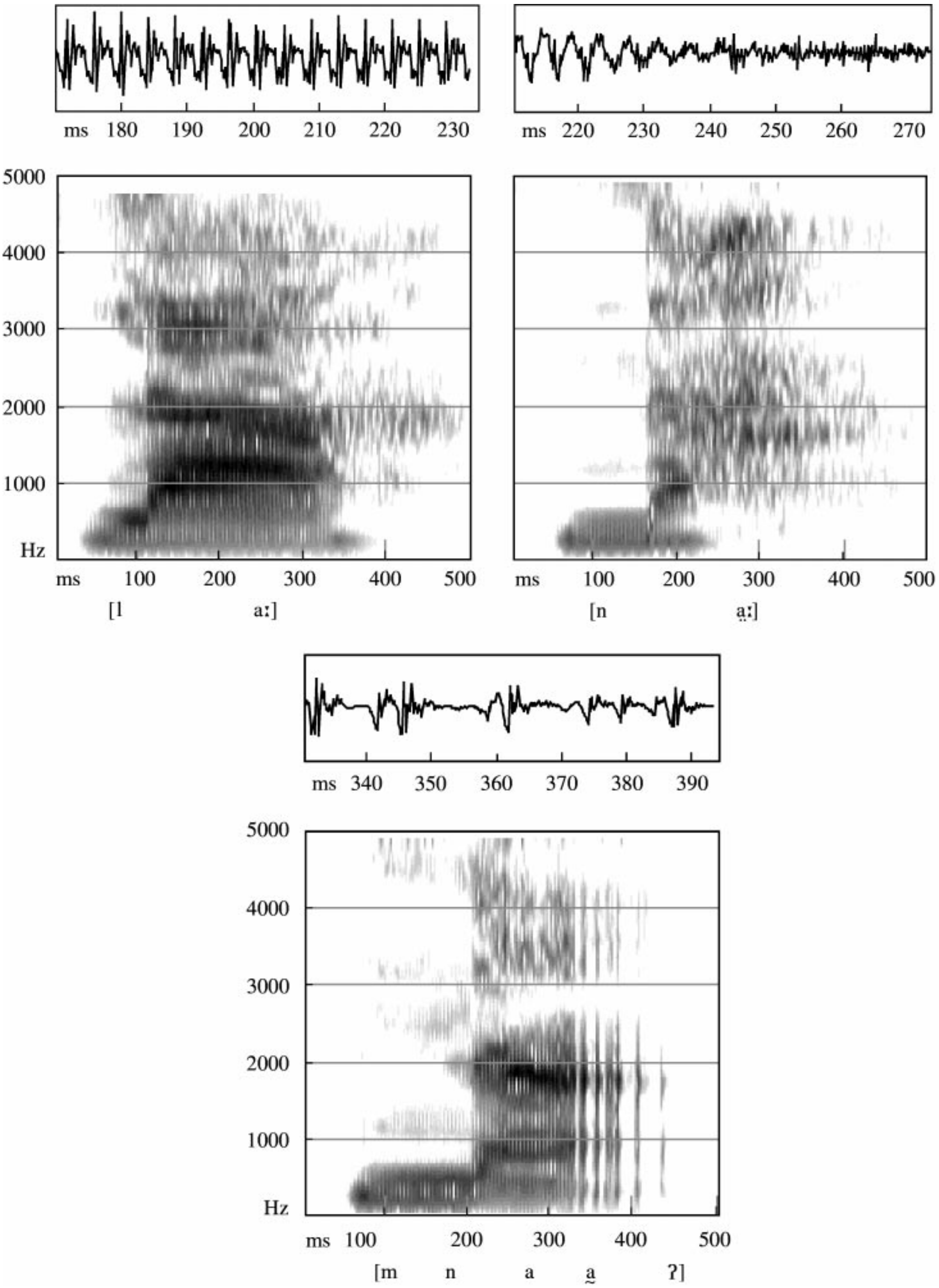


Figure 5. Spectrograms and waveform excerpts of modal, breathy, and creaky voiced vowels in the San Lucas Quiaviní Zapotec words /laː/ "is named", /na̤ː/ "hard, strong", and /mna̰ːʔ/ "woman" (female speaker).

Swedish (Fant & Kruckenberg, 1989), English (Lehiste, 1979; Kreiman, 1982; Dilley, Shattuck-Hufnagel & Ostendort, 1996), Finnish (Lehiste, 1965), Czech (Lehiste, 1965), and Serbo-Croatian (Lehiste, 1965). Vowel-initial words frequently have a creaky onset in many languages, where creakiness is more common at the beginning of larger prosodic units than smaller ones (Pierrehumbert & Talkin, 1992; Dilley *et al*., 1996) and more frequent in accented than unaccented syllables (Pierrehumbert, 1995; Dilley *et al*., 1996). There are numerous other factors in addition to accent and constituency, e.g., grammatical category, frequency of occurrence, segmental context, etc., which influence the likelihood of nonmodal phonation occurring (see Dilley *et al*., (1996) for an overview of some of the relevant literature on prosodically conditioned glottalization).

4. Issues in the timing of nonmodal phonation

Thus far in our discussion of segmental phonation contrasts, we have not talked about the timing of phonation events. In many cases, sounds which are described as being realized with nonmodal phonation do not extend their nonmodal phonation over an entire segment. Rather, nonmodal phonation is often confined to a portion of the sound and/or spills over onto an adjacent sound. An especially common timing feature of nonmodal phonation is its confinement to contexts in which its potentially detrimental effects on other perceptually important properties are minimized.

4.1. *Timing of nonmodal phonation in vowels*

Among contrastively nonmodal voiced vowels, creakiness and breathiness are localized to a portion of the vowel in Jalapa Mazatec (see spectrograms in Fig. 4; also, Silverman, Blankenship, Kirk & Ladefoged, 1995; Blankenship 1997). Silverman (1995, 1997) suggests a link between the confinement of nonmodal phonation to a portion of vowels and the use of contrastive tone in Jalapa Mazatec. He hypothesizes, and then corroborates for breathy phonation in later experimental work (Silverman, to appear) that, because nonmodal phonation influences fundamental frequency (see discussion in Section 5), it adversely affects the ability of vowels to support tonal contrasts. By preserving modal phonation on a portion of the vowel, there is sufficient space remaining on which to realize tonal contrasts effectively, particularly since the overall duration of non-modal vowels is substantially longer than that of modal vowels. Thus, preservation of nonmodal phonation on a portion of the vowel does not come at the expense of rendering information about toneless salient.

Confinement of nonmodal phonation to portions of vowels is not only a feature of languages that use tone contrastively. In Hupa (Golla, 1970, 1977; Gordon, 1998), which does not have contrastive tone, creaky voice and breathy voice spread from syllable-final ejectives and voiceless obstruents, respectively, onto only the latter half of a preceding long vowel and not onto short vowels at all. By asymmetrically spreading nonmodal phonation in this way, there is always a portion of the vowel which is characterized by modal phonation, the entire vowel in the case of short vowels and the first half of long vowels. A similar spreading asymmetry conditioned by vowel length is found in Quileute (Powell & Woodruff, 1976), with the added restriction that nonmodal phonation does not spread onto unstressed long vowels. It is thus only those vowels that are presumably longest, namely the stressed long vowels, that support nonmodal phonation in Quileute and only for a portion of their duration. One might hypothesize that the Hupa and Quileute patterns stem from a detrimental effect of nonmodal phonation on not only the ability to realize tonal information, as shown by Silverman (to appear), but also on the ability to realize place information in vowels. In support of this hypothesis, nonmodal phonation types often alter formant structure (see Section 5). The additional length associated with breathy vowels in languages like Kedang (Samely, 1991) could also reflect an attempt to enhance the overall salience of place information in the face of the reduced salience at any one point in time due to nonmodal phonation.

4.2. *Timing of nonmodal phonation in consonants*

Nonmodal phonation realized on consonants displays interesting timing patterns. Here, we discuss some of the timing properties characteristic of the most common type of nonmodally voiced consonants: creaky voiced sonorants. Creaky voiced sonorants, also termed "glottalized" sonorants, show an overwhelming cross-linguistic tendency to realize their creak early in the sonorant, often sharing it with the immediately preceding vowel, an as yet poorly understood timing preference presumably driven by auditory considerations (see Kingston, 1985; Silverman, 1995; Steriade, 1999). These "precreaked" sonorants are reported in a number of North American Indian languages, including Montana Salish (Flemming, Ladefoged & Thomason, 1994), Klamath (Barker, 1964; Blevins, 1993), Yokuts (Newman, 1944), Coast Tsimshian (Dunn, 1979), Nuuchahnulth (Shank & Wilson, 2000), Nez Perce (Aoki, 1970*a*), Kalispel (Vogt, 1940), Heiltsuk (Rath, 1981), Ineseño Chumash (Applegate, 1972), Squamish (Kuipers, 1967). In Fig. 3, we saw examples of precreaked sonorants in Kwakw'ala.

In a number of other languages, the location of the creak is dependent on the context in which the creaky voiced sonorant occurs. In the most typical case, glottalized sonorants realize their creak primarily at the beginning (often shared with the preceding vowel) in prevocalic position, but shift their creak towards the end when they do not precede a vowel. This timing asymmetry is found, for example, in Caddo (Chafe, 1976), Shuswap (Kuipers, 1974), Chitimacha (Swadesh, 1934), Bella Coola (Nater, 1984). In Kashaya Pomo (Buckley, 1990, 1992), glottalized sonorants are restricted to preconsonantal and final (i.e., coda), positions, where their creak is realized near the end. This timing pattern is consistent with the tendency for glottalized sonorants in many languages to realize their creak at the beginning in positions that are not prevocalic. Typically, context-dependent timing differences of the type just discussed are implicitly described in primary sources with reference to isolated words; it is conceivable that an investigation of words in phrasal contexts could reveal further interesting timing properties.

Hupa (Golla, 1970, 1977; Gordon, 1996) has turned what once was a predictable timing asymmetry between preglottalized nasals in prevocalic position and postglottalized nasals in preconsonantal and final position into a morphologically contrastive timing difference due to a chronologically later apocope process (loss of word-final vowels) affecting final short vowels. Thus, preglottalized sonorants appear in root-final position of stems which historically ended in a short vowel (which still surfaces before consonant-initial clitics), while postglottalized nasals occur in consonant-final stems. Due to final vowel loss, we thus find pairs of words differing in whether they end in a pre- or postglottalized nasal. In practice, this contrast typically does not rely solely on the timing of glottalization, since nasals originally occurring before a vowel are alveolar whereas those not followed by a vowel are velar. However, place assimilation affecting final nasals can turn a velar nasal to an alveolar one, thereby eliminating the place difference between pre and postglottalized nasals. Fig. 6 contains spectrograms (from words uttered in isolation) illustrating pre (on the left) and post (on the right) glottalized nasals in Hupa (with an accompanying place difference).

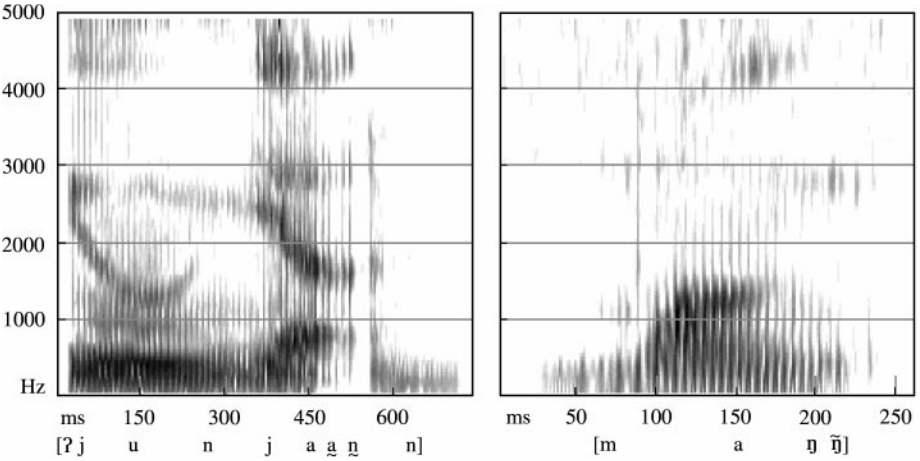


Figure 6. Spectrograms of a pre- and postglottalized sonorants in the Hupa words /kʲʼunjaːn̰/ (in this token, phonetically [ʔjunjaːn̰]) "acorn" and /maŋ̰/ "fly" (female speaker).

In the case of the preglottalized nasal on the left, creak is realized primarily on the end of the preceding vowel (450–550 ms). In the postglottalized nasal at the end of the word on the right, creak is realized at the end of the velar nasal (210–230 ms).

4.3. *Auditory motivations for timing of nonmodal phonation*

A unifying feature of languages which asymmetrically realize creak at the beginning of prevocalic sonorants and at the end of sonorants in other positions is their avoidance of creaky voice on transitions from the sonorant into the following vowel. Shifting nonmodal phonation away from the CV transition is plausibly driven by considerations similar to those hypothesized above to account for the dispreference for nonmodal phonation to be coextensive with entire vowels. Transitions from consonants into an adjacent vowel, particularly those into a following vowel, provide important information about place and manner of the consonant (see experimental data in Malécot (1956, 1958), Recasens (1983), Kurowski & Blumstein (1984), Manuel (1991), *inter alia*, and its implications for phonological neutralization patterns in Jun (1995, 1996)). By realizing nonmodal phonation at the beginning of a prevocalic sonorant, the transitions into a following vowel, which are perceptually most valuable, remain modal voiced and thus clearer from an auditory standpoint. In positions that are not prevocalic, i.e., in final or preconsonantal position, sonorants are adjacent to a vowel on only one side, the left side. By shifting the glottalization to the end of the sonorant in these contexts, the sole consonant–vowel transition is realized with modal voicing and thus retains maximal perceptual salience.

Other languages display asymmetries in the timing of glottalized sonorants based on vowel length and stress in ways that fit in with the hypothesis that nonmodal phonation adversely affects the perception of place information. In Saanich (Montler, 1986), creaky voiced sonorants share their creak with a preceding vowel if it is stressed, otherwise with the following vowel. In Cowichan (Bianco, 1999), glottalized sonorants in intervocalic position realize their glottalization at the beginning if the preceding vowel is full, i.e., long, otherwise at the end. (In preconsonantal and final position, glottalization is consistently realized at the end of the sonorant, a pattern similar to the one reported above for Caddo, Shuswap, Chitimacha, Bella Coola, Hupa, and Kashaya Pomo.) Similarly, creak migrates onto stressed vowels in Shuswap (Kuipers, 1974). These timing patterns are amenable to the same explanation claimed earlier to drive the timing patterns seen in nonmodal vowels: nonmodal phonation is realized in environments where its effect on other perceptually significant properties is minimized.

Clearly, however, it is not only the realization of information about place and manner which is relevant in accounting for timing patterns associated with nonmodal phonation. In many languages, e.g., Nez Perce (Aoki, 1970*b*), Hupa (Golla, 1970), Thompson Salish (Thompson & Thompson 1992), Yokuts (Newman, 1944), glottalized sonorants either do not occur or are rare in word-initial position or after another consonant. As Steriade (1999) suggests, this phonological restriction likely results from the rigid language-specific phonetic preference for realizing creaky voice at the beginning of sonorants, combined with a requirement that creak be realized at least partially on an adjacent vowel, thereby enhancing the salience of the creaky phonation. Since sonorant in word-initial or postconsonantal position has no preceding vowel on which to realize its creak, creaky sonorants are banned in these positions in many languages.

In contrast to languages that restrict glottalized sonorants in word-initial and post-consonantal position, Nuuchahnulth (Shank & Wilson, 2000) restricts word-final and preconsonantal glottalized sonorants. This phonological restriction is presumably also driven from a combination of auditorily-driven requirements on timing, albeit a slightly different combination than is responsible for the restriction against word-final and postconsonantal sonorants seen in other languages. In Nuuchahnulth, glottalized sonorants must realize their creak at the beginning, while simultaneously preserving modal voiced transitions into at least one adjacent vowel. In final and preconsonantal positions, both requirements cannot be satisfied; the result is a phonological ban on glottalized sonorants in these positions.

As this section's preliminary hypotheses suggest, cross-linguistic exploration of phonation timing patterns is in its relative infancy. As a greater amount of phonetic and phonological data on the distribution and realization of phonation contrasts comes to light, we will be in a better position to describe and explain the rich set of timing patterns observed in languages of the world.

5. Phonetic properties associated with phonation types

Ladefoged & Traill (1980) and Ladefoged (1983), following suggestions from Ken Stevens (pers. comm.), showed that phonation differences can be quantified through a number of phonetic measurements, even if certain physiological or auditory properties defining these phonation types are harder to define. Much work on linguistic voice quality (e.g., Fischer-Jørgensen, 1967; Bickley, 1982; Maddieson & Ladefoged, 1985; Huffman, 1987; Traill & Jackson, 1988; Ladefoged, Maddieson & Jackson, 1988; Thongkum, 1988; Kirk *et al.*, 1993; Blankenship, 1997, etc.) has focused on discovering these phonetic dimensions along which contrasts in phonation type are realized. This body of work has revealed a number of cross-linguistic similarities in the realization of phonation differences, but has also indicated some differences. Some of the properties used to describe phonation differences have been discussed in the context of the examples in Section 2.

Here, we summarize some of these results, focusing on differences between modal voice and the two most common nonmodal phonation types, breathy voice and creaky voice.

There are a number of acoustic, articulatory, and aerodynamic properties that potentially distinguish creaky and breathy phonation (as well as other nonmodal phonation types) from each other and from modal phonation. Languages differ in the precise set of properties used to distinguish these phonation types, though there is generally some agreement between languages in how phonation contrasts are signaled. Here, we focus on some acoustic and aerodynamic characteristics defining phonation differences in naturally occurring nonpathologic speech (see Gerratt & Kreiman this volume for discussion of phonation differences in vocal pathologies). These include periodicity (Section 5.1), intensity (Section 5.2), spectral tilt (Section 5.3), fundamental frequency (Section 5.4), formant frequencies (Section 5.5), duration (Section 5.6), and airflow (Section 5.7). Further discussion of the physiological characteristics of various laryngeal settings can be found in Catford (1964), Ladefoged (1971), Laver (1980), Hirose (1995), and Ní Chasaide & Gobl (1995).

5.1. *Periodicity*

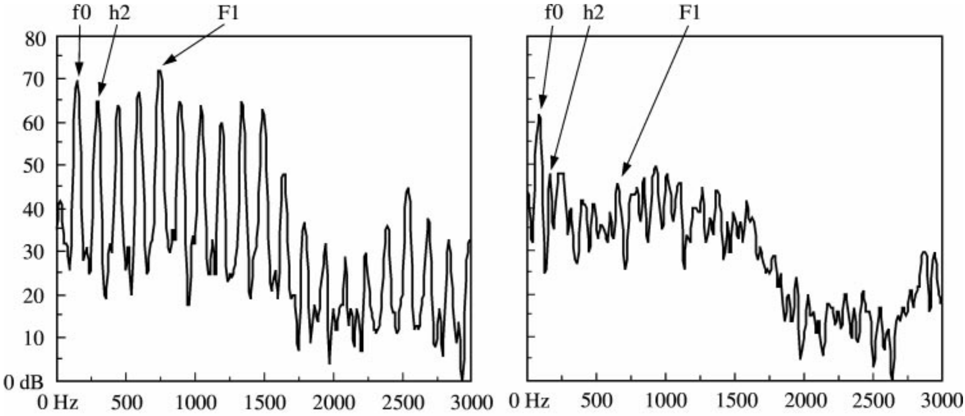
Creaky phonation is characteristically associated with aperiodic glottal pulses. This feature of creak was evident in the waveforms and spectrograms of creak in figures in Section 2. The degree of aperiodicity in the glottal source can be quantified by measuring the "jitter", the variation in the duration of successive fundamental frequency cycles. Jitter values are higher during creaky phonation than other phonation types, as found for Burmese by Javkin & Maddieson (1985) and Jalapa Mazatec (Kirk *et al.*, 1993). Breathiness is characterized by increased spectral noise, particularly at higher frequencies, as we saw earlier in waveforms and spectrograms of breathy sounds in Newar, Jalapa Mazatec, and San Lucas Quiaviní Zapotec. This noise reflects the presence of substantial random noise during breathy vowels (particularly at high frequencies) due to the persistent leakage of air through the glottis (see Ladefoged *et al.* (1988) for !Xóõ and Blankenship (1997) for Jalapa Mazatec and Chong).

5.2. *Acoustic intensity*

Breathy phonation is associated with a decrease in overall acoustic intensity in many languages, e.g., Gujarati (Fischer-Jørgensen 1967), Kui and Chong (Thongkum, 1988), Tsonga (Traill & Jackson, 1988), Hupa (Gordon, 1998). Creakiness also triggers a reduction in intensity (relative to modal phonation) in certain languages, e.g., Chong (Thongkum, 1988) and Hupa (Gordon, 1998). The reduction in intensity characteristic of both creaky and breathy vowels relative to modal ones was evident in the waveforms and spectrograms in Section 2.

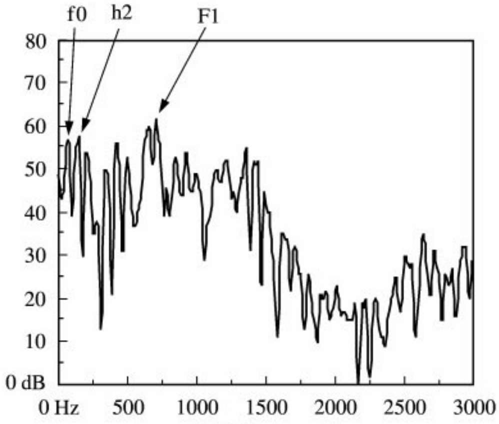
5.3. *Spectral tilt*

One of the major acoustic parameters that reliably differentiates phonation types in many languages is spectral tilt, i.e., the degree to which intensity drops off as frequency increases. Spectral tilt can be quantified by comparing the amplitude of the fundamental to that of higher frequency harmonics, e.g., the second harmonic, the harmonic closest to the first formant, or the harmonic closest to the second formant. Spectral tilt is



/daː/ 'soledad'

/kilda̤/ 'forehead'



/ɾda̰ːʔ/ 'lets go of'

Figure 7. FFT spectra of modal, breathy, and creaky /a/ in the San Lucas Quiaviní Zapotec words /daː/ “Soledad”, /kilda̤/ “forehead”, and /ɾda̰ːʔ/ “lets go of” (male speaker).

characteristically most steeply positive for creaky vowels and most steeply negative for breathy vowels. In other words, the fall off in energy at higher frequencies is least for creaky voice and most for breathy voice. Subtraction of the amplitude of the fundamental from the amplitude of higher harmonics thus yields the greatest values for creaky vowels and the smallest values for breathy vowels, with intermediate values for modal vowels. Spectral tilt reliably differentiates phonation types in a number of languages, including Jalapa Mazatec (Kirk *et al.*, 1993; Silverman *et al.*, 1995), which contrasts creaky, breathy, and modal vowels, !Xóõ (Bickley, 1982; Ladefoged, 1983; Ladefoged *et al.*, 1988), which distinguishes between breathy and modal vowels (as well as a third type of phonation, strident, discussed in Section 2.3), Gujarati (Fischer-Jørgensen, 1967), which contrasts breathy and modal vowels, Kedang (Samely, 1991), which contrasts modal and breathy vowels, Hmong (Huffman, 1987), which distinguishes breathy and modal vowels, Tsonga (Traill & Jackson, 1988), which contrasts breathy and modal nasals, some minority languages of China (Jingpho, Haoni, Wa, Yi) examined by Maddieson & Ladefoged (1985), which contrast a “tense” phonation somewhat different from creaky phonation with a more modal phonation type, and, finally, Mpi, which also contrasts tense and nontense (or "lax") phonation.

Different measures of spectral tilt do not always behave uniformly in differentiating phonation types in a single language. In Mpi, which uses tone contrastively, Blankenship (1997) found interactions between tone level and measurements of spectral tilt. The amplitude difference between the fundamental and the second harmonic was a more reliable indicator of phonation type for high tone than for either mid or low tone, whereas the amplitude difference between the fundamental and the harmonic closest to the second formant was more useful for differentiating phonation contrasts in mid and low tone vowels than in high tone vowels.

Differences in spectral tilt between creaky, breathy, and modal vowels in San Lucas Quiaviní Zapotec are illustrated in Fig. 7 by means of FFT spectra from a male speaker.

In the creaky vowel, the amplitude of the second harmonic is slightly greater than that of the fundamental. At the other extreme, in the breathy vowel, the amplitude of the second harmonic is considerably less than that of the fundamental. The modal vowel occupies the middle ground between the creaky and breathy vowels: its second harmonic has slightly less amplitude than the fundamental. Similar differences between phonation types can be seen by comparing the amplitude of the harmonic closest to the first formant relative to that of the fundamental. In the breathy vowel, the harmonic closest to the first formant has much lower amplitude than the fundamental. In the creaky vowel, on the other hand, the harmonic closest to the first formant has much greater amplitude than the fundamental. The modal vowel is intermediate, characterized by very similar amplitude values for the fundamental and the first formant. Spectral tilt values, as defined by two measurements, h2-f0 and F1-f0, thus form a continuum differentiating the three phonation types of San Lucas Quiaviní Zapotec: breathy vowels have the greatest drop off (or smallest increase depending on the particular measure) in energy as frequency increases, while creaky vowels display the largest boost in energy as frequency is increased.

Spectral tilt has been associated with various physiological characteristics. Holmberg, Hillman, Perkell, Guiod & Goldman (1995) found that intensity differences between the fundamental and the second harmonic correlate with the percentage of the glottal cycle during which the glottis is open (the open quotient): the less the amplitude of the second harmonic relative to that of the fundamental, the greater is the open quotient. Stevens (1977) has suggested that a general measure of spectral slope, quantified in terms of amplitude differences between the fundamental and higher harmonics, correlates with the abruptness (or gradualness) of vocal fold closure: the less the amplitude of higher harmonics relative to that of the fundamental, the less abrupt is the glottal closing gesture. Both an increased open quotient and a less abrupt glottal closing gesture are physiological correlates of breathiness (see Huffman (1987) on breathiness in Hmong). Conversely, a decreased open quotient and a more precipitous closing gesture are potentially associated with creakiness (see Javkin & Maddieson (1985) on creak in Burmese). Consequently, it is not surprising that both measures of spectral tilt (h2-f0 and F1-f0) often pattern together in languages.

5.4. *Fundamental frequency*

Nonmodal phonation types are commonly associated with the lowering of fundamental frequency, a tendency which was evident in earlier waveforms in Section 2 and in the spectra in Fig. 7. Creaky voice is associated with lowered fundamental frequency values (relative to modal phonation) in many languages, synchronically or diachronically, e.g., Mam (England, 1983), Northern Iroquoian languages such as Mohawk, Cayuga, and Oneida (Chafe, 1977; Michelson, 1988; Doherty, 1993). It should, however, be noted that this lowering effect is not universal, as certain languages have developed high tone as a reflex of glottal constriction (see Hombert, Ohala & Ewan (1979) for discussion). The historical development of Athabaskan languages from proto-Athabaskan provides a nice example of how glottalization can be associated with high tone in some languages but with low tone in closely related languages (Leer, 1979). Breathy phonation appears to be more consistently associated with lowered tone in the majority of languages (see Hombert *et al.* (1979) for an overview).

5.5. *Formant frequencies*

Formant frequencies may also vary as a function of phonation type. For example, Kirk *et al.* (1993) observe that frequency values for the first formant are higher during creaky phonation than either breathy or modal phonation in Jalapa Mazatec, which they speculate is due to a raising of the larynx and concomitant shortening of the vocal tract during creaky voice. Maddieson & Ladefoged (1985) also report raised first formant values for tense vowels in Haoni. Conversely, Thongkum (1988) reports that breathiness is associated with a lowering of the first formant in Chong, though she does not observe this difference in the related languages Nyah Kur and Kui. Based on observations of other scholars (Henderson, 1952; Gregerson, 1976), Thongkum suggests that the lowering of the first formant during breathy phonation in Chong might be attributed to larynx lowering; this explanation would fit in with the suggestion of Kirk *et al.* (1993) that the opposite effect, the raising of the first formant during creaky phonation, is an acoustic correlate of larynx raising. Samely (1991) also found that breathy vowels have lower first and second formant values than modal vowels in Kedang, though it should be pointed out that breathy vowels in this language are associated with increased pharyngeal width which could contribute to the observed formant differences.

5.6. *Duration*

Nonmodal phonation types are in some languages, though not all, associated with increased duration. This is not true of Hmong (Huffman, 1987) and is not true of the San Lucas Quiaviní Zapotec data in Fig. 5. Breathy vowels are substantially longer than modal vowels, however, in Kedang (Samely, 1991) and Jalapa Mazatec (Kirk *et al.*, 1993; Silverman *et al.*, 1995), and creaky vowels are longer than modal vowels in Jalapa Mazatec (Kirk *et al.*, 1993; Silverman *et al.*, 1995). A related observation in keeping with the greater duration characteristic of nonmodal phonation types is that nonmodal phonation may occur on phonemic long vowels but not on phonemic short vowels in Hupa (Golla, 1970, 1977; Gordon, 1998). Quileute (Powell & Woodruff, 1976) displays a similar restriction, with the added proviso that the long vowels must be stressed to support nonmodal phonation (see Section 4 for further discussion of duration and timing issues relevant for nonmodal phonation).

5.7. *Aerodynamic properties*

Phonation contrasts also appear to be associated with aerodynamic differences, at least as far as the limited amount of relevant data show. Maddieson & Ladefoged's (1985) study of four minority languages of China (Jingpho, Wa, Yi, Haoni) shows that the tense vowels in the four languages are generally associated with less airflow for a given subglottal pressure than the lax vowels, suggesting that the tense vowels are associated with a more constricted glottis that allows less air flow.

6. Conclusions

In summary, the investigation of phonation differences is an important area of research, as many languages employ distinctions which rely solely on differences in voice quality. As we have seen, these distinctions may involve two or more different phonation types and may affect consonants, vowels, or both consonants and vowels. In addition, many other languages regularly use nonmodal phonation types as variants of modal voice in certain prosodic contexts. Languages also differ in their timing of nonmodal phonation relative to other articulatory events in interesting ways, although there are certain recurrent timing patterns and distributional restrictions which warrant explanation.

Differences in phonation type can be signaled by a large number of quantifiable phonetic properties in the acoustic, aerodynamic, and articulatory domains, the last of which has been relatively unstudied due to the invasive measurement techniques required. It is unlikely, however, that future research will yield many truly universal observations about the range and realization of phonation types in languages of the world. We can never know whether some language in the past had or in the future will have a novel method of using the vocal folds to make a linguistic contrast. The occurrence of phonetic rarities such as the strident voice quality that occurs in !Xóõ (Section 2.3) and a few neighboring languages shows that we can use the glottis in totally unexpected ways. If the Xóõ did not exist, and someone had suggested that a sound of this kind could be used in a language, scholars would probably have said that this was a ridiculous notion. !Xóõ is an endangered language, and we are lucky to have been able to hear these sounds. But who knows what other phonation types could occur in a language?

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References

Aoki, H. (1970*a*). A note on glottalized consonants, *Phonetica*, **21,** 65–75.
Aoki, H. (1970*b*). *Nez Perce grammar*. Berkeley: University of California Press.
Applegate, R. (1972). *Ineseño Chumash grammar*. Ph.D dissertation, University of California, Berkeley.

Barker, M. (1964). *Klamath grammar*. Berkeley: University of California Press.

Benguerel, A. & Bhatia, T. K. (1980). Hindi stop consonants: an acoustic and fiberscopic study. *Phonetica*, **37,** 134–148.

Bianco, V. (1999). *Weight-by-sonority in Cowichan*. Ms. University of California, Santa Barbara.

Bickley, C. (1982). Acoustic analysis and perception of breathy vowels. In *Speech communication group working papers*, pp. 71–82. Cambridge: Massachusetts Institute of Technology.

Blankenship, B. (1997). *The time course of breathiness and laryngealization in vowels*. PhD dissertation, University of California, Los Angeles.

Blevins, J. (1993). Klamath laryngeal phonology, *International Journal of American Linguistics*, **59,** 237–280.

Boas, F. (1947). *Kwakiutl grammar with a glossary of the suffixes*. (Helene Boas Yampolsky & Zelig Harris, editors). *Transactions of the American Philosophical Society*, **37**(3), 201–377.

Buckley, E. (1990). Glottalized and aspirated sonorants in Kashaya. In *Papers from the 1990 Hokan-Penutian Workshop* (M. Langdon, editor), pp. 75–91. Carbondale, IL: Southern Illinois University.

Buckley, E. (1992). *Theoretical aspects of Kashaya phonology and morphology*. PhD dissertation, University of California, Berkeley [Published by CSLI 1994].

Catford, J. (1964). Phonation types: the classification of some laryngeal components of speech production. In *In honour of Daniel Jones*, D. Abercrombie, D. B. Fry, P. A. D. MacCarthy, N. C. Scott & J. L. M. Trim, editors), pp. 26–37. London: Longmans.

Catford, J. (1977). *Fundamental problems in phonetics*. Edinburgh: Edinburgh University Press.

Chafe, W. (1976). *The Caddoan, Iroquoian, and Siouan languages* [*Trends in Linguistics, State of the Art Reports* 3]. The Hague: Paris.

Chafe, W. (1977). Accent and related phenomena in the Five Nations Iroqouis languages. In *Studies in stress and accent* [*Southern California Occasional Papers in Linguistics* 4], (L. Hyman, editor), pp. 169–8. Los Angeles: University of Southern California.

Dilley, L., Shattuck-Hufnagel, S., & Ostendorf, M. (1996). Glottalization of word-initial vowels as a function of prosodic structure, *Journal of Phonetics*, **24,** 423–444.

Dixit, R. P. (1989). Glottal gestures in Hindi plosives, *Journal of Phonetics*, **17,** 213–237.

Doherty, B. (1993). *The acoustic-phonetic correlates of Cayuga word-stress*. PhD dissertation, Harvard University.

Dunn, J. (1979). *A reference grammar for the Coast Tsimshian language*. Ottawa: National Museums of Canada.

England, N. (1983). A grammar of Mam, a Mayan language. Austin: University of Texas Press.

Fant, G. & Kruckenberg, A. (1989). Preliminaries to the study of Swedish prose reading and reading style, *Speech Transmission Laboratory—Quarterly Progress and Status Report* 2, pp. 1–83. Stockholm: Royal Institute of Technology.

Fischer-Jorgensen, E. (1967). Phonetic analysis of breathy (murmured) vowels in Gujarati, *Indian Linguistics*, **28,** 71–139.

Flemming, E., Ladefoged, P. & Thomason, S. (1994). Phonetic structures of Montana Salish, *UCLA Working Papers in Phonetics*, **87,** 1–33.

Golla, V. (1970). *Hupa grammar*. PhD dissertation, University of California, Berkeley.

Golla, V. (1977). A note on Hupa verb stems, *International Journal of American Linguistics*, **43**(4), 355–358.

Gordon, M. (1996). The phonetic structures of Hupa, *UCLA Working Papers in Phonetics*, **93,** 164–187.

Gordon, M. (1998). The phonetics and phonology of nonmodal vowels: a cross-linguistic perspective, *Berkeley Linguistics Society*, **24,** 93–105.

Gregerson, K. (1976). Tongue-root and register in Mon-Khmer. In *Austroasiatic Studies I* (P. Jenner, editor), pp. 323–366. Honolulu: University of Hawai'i.

Hanson, H. & Chuang, E. (1999). Glottal characteristics of male speakers: acoustic correlates and comparison with female data, *Journal of the Acoustical Society of America*, **106,** 1064–1077.

Henderson, E. (1952). The main features of Cambodian pronunciation, *Bulletin of the School of Oriental and African Studies*, **14,** 149–174.

Henton, C. G. & Bladon, R. A. W. (1985). Breathiness in normal female speech: inefficiency versus desirability, *Language and Communication*, **5,** 221–227.

Hirose, H. (1995). Investigating the physiology of laryngeal structures. In *The handbook of phonetic sciences*, (W. Hardcastle & J. Laver, editors), pp. 116–136. Cambridge, MA: Blackwells.

Holmberg, E., Hillman, R., Perkell, J., Guiod, P. & Goldman, S. (1995). Comparisons among aerodynamic, electroglottographic, and acoustic spectral measures of female voice, *Journal of Speech and Hearing Research*, **38,** 1212–1223.

Hombert, J.-M., Ohala, J. & Ewan, W. (1979). Phonetic explanations for the development of tones, *Language*, **55**(1), 37–58.

Huffman, M. K. (1987). Measures of phonation type in Hmong, *Journal of the Acoustical Society of America*, **81,** 495–504.

Javkin, H. & Maddieson, I. (1985). An inverse filtering study of creaky voice, *UCLA Working Papers in Phonetics*, **57,** 115–125.

Jun, J. (1995). *Perceptual and articulatory factors in place assimilation: an optimality-theoretic approach.* PhD dissertation, UCLA.

Jun, J. (1996). Place assimilation as the result of conflicting perceptual and articulatory constraints, *West Coast Conference on Formal Linguistics*, **14,** 221–238.

Kagaya, R. & Hirose, H. (1975). Fiberoptic, electromyographic and acoustic analyses of Hindi stop consonants, *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics*, **9,** 27–46.

Kingston, J. (1985). *The phonetics and phonology of the timing of oral and glottal events.* PhD dissertation, University of California, Berkeley.

Kirk, P. L., Ladefoged, J. & Ladefoged, P. (1993). Quantifying acoustic properties of modal, breathy and creaky vowels in Jalapa Mazatec. In *American Indian linguistics and ethnography in honor of Laurence C. Thompson* (A. Mattina & T. Montler, editors), Missoula, MT: University of Montana Press.

Klatt, D. & Klatt, L. (1990). Analysis, synthesis, and perception of voice quality variations among female and male talkers, *Journal of Acoustical Society of America*, **87,** 820–857.

Kreiman, J. (1982). Perception of sentence and paragraph boundaries in natural conversation, *Journal of Phonetics*, **10,** 163–175.

Kuipers, A. (1967). *The Squamish language: grammar, texts, dictionary.* The Hague: Mouton.

Kuipers, A. (1974). *The Shuswap language.* The Hague: Mouton.

Kurowski, K. & Blumstein, S. (1984). Perceptual integration of the murmur and formant transitions for place of articulation in nasal consonants, *Journal of the Acoustical Society of America*, **76,** 383–390.

Ladefoged, P. & Maddieson, I. (1996). *The sounds of the world's languages.* Cambridge, MA: Blackwells.

Ladefoged, P. (1971) *Preliminaries to linguistic phonetics.* Chicago: University of Chicago.

Ladefoged, P. (1983). The linguistic use of different phonation types. In *Vocal fold physiology: Contemporary research and clinical issues* (D. Bless & J. Abbs, editors), pp. 351–360. San Diego: College Hill Press.

Ladefoged, P. & Antoñanzas-Barroso, N. (1985). Computer measures of breathy phonation, *UCLA Working Papers in Phonetics*, **61,** 79–86.

Ladefoged, P., Maddieson, I. & Jackson, M. (1988). Investigating phonation types in different languages. In *Vocal fold physiology: voice production, mechanisms and functions* (O. Fujimura, editor), pp. 297–317. New York: Raven Press.

Ladefoged, P. & Traill, A. (1980). Phonological features and phonetic details of Khoisan languages. In *Bushman and Hottentot Linguistic Studies 1979* (J. W. Snyman, editors), Pretoria: University of South Africa.

Laver, J. (1980). *The phonetic description of voice quality.* Cambridge: Cambridge University Press.

Leer, J. (1979). *Proto-Athabaskan verb stem variation, part one: phonology.* Fairbanks: Alaska [Native Language Center Research Papers 1].

Lehiste, I. (1965). Juncture. *Proceedings of the 5th International Congress of Phonetic Sciences, Münster 1964*, pp. 172–200. New York: S. Karger.

Lehiste, I. (1979). Sentence boundaries and paragraph boundaries—perceptual evidence. *In The Elements: a Parasession on Linguistic Units and Levels, Chicago Linguistics Society*, Vol. 15, pp. 99–109.

Maddieson, I. & Ladefoged, P. (1985). "Tense" and "lax" in four minority languages of China, *Journal of Phonetics*, **13,** 433–454.

Malécot, A. (1956). Acoustic cues for nasal consonants: an experimental study involving tape-splicing technique, *Language* **32,** 274–284.

Malécot, A. (1958). The role of releases in the identification of released final stops, *Language*, **34,** 370–380.

Manuel, S. (1991). Some phonetic bases for the relative malleability of syllable-final versus syllable-initial consonants. *Actes du XIIème Congres International des Sciences Phonetiques*, August 1991, pp. 118–121.

Michelson, K. (1988). *A comparative study of Lake-Iroquoian accent.* Dordrecht: Kluwer.

Montler, T. (1986). *An outline of the morphology and phonology of Saanich, North Straits Salish.* Missoula, MT: University of Montana.

Munro, P. & Lopez, F. (1999). *Di'csyonaary X:tèe'n Dìi'zh Sah Sann Lu'uc.* Los Angeles: UCLA Chicano Studies Research Center.

Nater, H. F. (1984). *The Bella Coola language.* Ottawa: National Museums of Canada.

Newman, S. (1944). *Yokuts language of California.* New York: Viking Fund Publications in Anthropology.

Ní Chasaide, A. & Gobl, C. (1995). Voice source variation. In *The handbook of phonetic sciences*, (W. Hardcastle & J. Laver, editors), pp. 427–461. Cambridge, MA: Blackwells.

Pandit, P. (1957) Nasalization, aspiration and murmur in Gujarati, *Indian Linguistics*, **17,** 165–172.

Pierrehumbert, J. (1995). Prosodic effects on glottal allophones. In *Vocal Fold Physiology: Voice Quality Control* (O. Fujimura & M. Hirano, editors), pp. 39–60. San Diego: Singular Publishing Group.

Pierrehumbert, J. & Talkin, D. (1992). Lenition of /h/ and glottal stop. In *Papers in Laboratory Phonology II: Gesture, Segment, Prosody* (G. Docherty & D. R. Ladd, editors), pp. 90–127. Cambridge: Cambridge University Press.

Powell, J. & Woodruff, F. (1976). *Quileute dictionary.* Moscow, Idaho: University of Idaho.

Rath, J. (1981). *A practical Heiltsuk-English dictionary, with a grammatical introduction.* Ottawa: National Museums of Canada.

Recasens, D. (1983). Place cues for nasal consonants with special reference to Catalan, *Journal of the Acoustical Society of America*, **73,** 1346–1353.

Samely, U. (1991). *Kedang (Eastern Indonesia), some aspects of its grammar*. Hamburg: Helmut Buske Verlag.

Sapir, E. (1912). *The Takelma language of southwestern Oregon*. Republished in V. Golla (1990), *The collected works of Edward Sapir* VIII, New York: Mouton de Gruyter.

Shank, S. & Wilson, I. (2000). Acoustic evidence for as a glottalized pharyngeal glide in Nuu- chah-nulth. In *Proceedings of the 35th International Conference on Salish and Neighboring Languages* (S. Gessner & S. Oh, editors), pp. 185–197. Vancouver: University of British Columbia, Department of Linguistics.

Silverman, D. (1995). *Phasing and recoverability*. PhD dissertation, University of California, Los Angeles [Published by Garland 1997].

Silverman, D. (1997). Laryngeal complexity in Otomanguean vowels, *Phonology*, **14,** 235–262.

Silverman, D. (to appear). Pitch discrimination during breathy versus modal phonation, *Papers in Laboratory Phonology VI*. Cambridge: Cambridge University Press.

Silverman, D., Blankenship, B., Kirk, P. & Ladefoged, P. (1995). Phonetic structures in Jalapa Mazatec, *Anthropological Linguistics*, **37,** 70–88.

Steriade, D. (1999). Phonetics in phonology: the case of laryngeal neutralization, *UCLA Working Papers in Phonology*, **3,** 25–146.

Stevens, K. (1977). Physics of laryngeal behavior and larynx modes, *Phonetica*, **34,** 264–279.

Stevens, K. N., Keyser, S. J. & Kawasaki, H. (1986). Toward a phonetic and phonological theory of redundant features. In *Invariance and variability in speech processes* (J. Perkell & D. Klatt, editors), pp. 426–449. Hillsdale, NJ: Lawrence Erlbaum Associates.

Swadesh, M. (1934). A phonetic study of Chitimacha, *Language*, **10,** 345–362.

Thompson, L. & Thompson, M. T. (1992). *The Thompson language*. Missoula, MT: University of Montana.

Thongkum, T. (1988). Phonation types in Mon-Khmer languages. In *Vocal fold physiology: voice production, mechanisms and functions* (O. Fujimura, editor), pp. 319–334. New York: Raven Press.

Traill, A. & Jackson, M. (1988). Speaker variation and phonation type in Tsonga nasals, *Journal of Phonetics*, **16,** 385–400.

Traill, A. (1985). *Phonetic and phonological studies of !Xóõ Bushman*. Hamburg: Helmut Buske Verlag.

Vogt, H. (1940). *The Kalispel language, an outline of the grammar with text, translations and dictionary*. Oslo: J. Dybwad.

Yadav, R. (1984). Voicing and aspiration in Maithili: a fiberoptic and acoustic study, *Indian Linguistics*, **45,** 27–35.

Appendix A

The names of languages with different types of phonation contrasts are summarized in Table AI, along with some additional basic information about each language.

TABLE I. Languages discussed in the text with phonation contrasts

Language	Nonmodal phonation	Genetic affiliation*	Area	References
!Xóõ	Strident	Khoisan	Botswana	Traill (1985), Ladefoged & Antoñanzas-Barroso (1985), Ladefoged *et al.* (1988)
Bella Coola	Creaky	Salishan	British Columbia, Canada	Nater (1984)
Bruu	Stiff	Austro-Asiatic	Thailand, Laos	Ladefoged (fieldwork)
Burmese	Breathy, creaky	Sino-Tibetan	Myanmar	Javkin & Maddieson (1985)
Caddo	Creaky	Caddoan	Oklahoma, U.S.A.	Chafe (1976)
Chitimacha	Creaky	Gulf	Louisiana, U.S.A.	Swadesh (1934)
Chong	Breathy, creaky	Austro-Asiatic	Thailand	Thongkum (1988)

Appendix A. Continued

Language	Nonmodal phonation	Genetic affiliation*	Area	References
Coast Tsimshian	Creaky	Penutian	British Columbia, Canada	Dunn (1979)
Cowichan	Creaky	Salishan	British Columbia, Canada	Bianco (1999)
Gujarati	Breathy	Indo-European	India	Pandit (1957), Fischer-Jørgensen (1967)
Haoni	Tense	Sino-Tibetan	China	Maddieson & Ladefoged (1985)
Hausa	Creaky	Afro-Asiatic	Nigeria	Ladefoged & Maddieson (1996)
Heiltsuk	Creaky	Wakashan	British Columbia, Canada	Rath (1981)
Hindi	Breathy	Indo-European	India	Kagaya & Hirose (1975), Benguerel & Bhatia (1980), Dixit (1989)
Hmong	Breathy	Hmong-Mien	Laos	Huffman (1987)
Hupa	Creaky	Na Dene	California, U.S.A.	Gordon (1996)
Ineseño Chumash	Creaky	Chumash	California, U.S.A.	Applegate (1972)
Jalapa Mazatec	Breathy, creaky	Otomanguean	Mexico	Kirk *et al.* (1993), Silverman *et al.* (1995), Silverman (1997)
Jingpho	Tense	Sino-Tibetan	China	Maddieson & Ladefoged (1985)
Kalispel	Creaky	Salishan	Washington, Montana, U.S.A.	Vogt (1940)
Kashaya Pomo	Creaky	Hokan	California, U.S.A.	Buckley (1990, 1992)
Kedang	Breathy	Austronesian	Indonesia	Samely (1991)
Klamath	Creaky	Penutian	Oregon, U.S.A.	Barker (1964), Blevins (1993)
Kui	Breathy	Dravidian	Thailand	Thongkum (1988)
Kwakw’ala	Creaky	Wakashan	British Columbia, Canada	Boas (1947)
Maithili	Breathy	Indo-European	India	Yadav (1984)
Montana Salish	Creaky	Salishan	Washington, Montana, U.S.A.	Flemming *et al.* (1994)
Mpi	Tense	Sino-Tibetan	Thailand	Blankenship (1997)
Newar	Breathy	Sino-Tibetan	Nepal	Ladefoged (1983)
Nez Perce	Creaky	Penutian	Idaho, U.S.A.	Aoki (1970*a*, *b*)
Nuuchahnulth	Creaky	Wakashan	British Columbia, Canada	Shank & Wilson (2000)

Appendix A. Continued

Language	Nonmodal phonation	Genetic affiliation*	Area	References
Nyah Kur	Breathy	Austro-Asiatic	Thailand	Thongkum (1988)
Quileute	Creaky	Chimakuan	Washington, U.S.A.	Powell & Woodruff (1976)
Saanich	Creaky	Salishan	British Columbia, Canada	Montler (1986)
San Lucas Quiaviní Zapotec	Breathy, creaky	Oto-Manguean	Mexico	Munro & Lopez (1999)
Shuswap	Creaky	Salishan	British Columbia, Canada	Kuipers (1974)
Squamish	Creaky	Salishan	British Columbia, Canada	Kuipers (1967)
Takelma	Creaky	Penutian	Oregon, U.S.A.	Sapir (1912)
Telugu	Breathy	Dravidian	India	Ladefoged & Maddieson (1996)
Thompson Salish	Creaky	Salishan	British Columbia, Canada	Thompson & Thompson (1992)
Tsonga	Breathy	Niger-Congo	Mozambique	Traill & Jackson (1988)
Wa	Tense	Austro-Asiatic	China	Maddieson & Ladefoged (1985)
Yana	Creaky	Hokan	California, U.S.A.	Sapir & Swadesh (1960)
Yi	Tense	Sino-Tibetan	China	Maddieson & Ladefoged (1985)
Yokuts	Creaky	Penutian	California, U.S.A.	Newman (1944)

*Genetic affiliations are according to the 14th edition of the SIL Ethnologue (CD-ROM version, 2000, edited by Barbara Grimes).