ARTICLE

The cross-linguistic patterns of phonation types

Christina M. Esposito[1] | **Sameer ud Dowla Khan**[2] **Department of Linguistics Reed**
Portland Oregon USA

Correspondence
Christina M. Esposito, Macalester College, St Paul, MN.
Email: esposito@macalester.edu

Abstract

We provide an update on the state of research on phonation (the production of sound by the vocal folds) since Gordon and Ladefoged's, Journal of Phonetics, 2001 29, 383–406 overview, focusing on the acoustics ofsi363

vocal fold vibration impossible, and on the other end we have complete glottal closure ([ʔ]). The three intermediate points—breathy, modal, and creaky—are all produced with vibrating vocal folds, and are arranged in order from largest to smallest vocal fold aperture.

The majority of the world's languages (see Table 3, cell 1) distinguish between one (or both) of the extremes on this continuum (i.e., voiceless sounds) and one center point (i.e., voiced sounds). For such languages, there is only modal voicing, cross-linguistically the most common voiced phonation type. In addition to modal phonation, countless languages also make distinctions within the voiced range of this continuum (e.g., breathy, creaky).

As just one example of how these phonation types might be produced, Figure 2 shows spectrograms of breathy, modal, and creaky voicing in White Hmong. In the spectrogram of the breathy example, , [pɔ̤˥˨] “paternal grandmother,” we see noise distributed throughout the vowel (visualized as a kind of fuzziness), particularly in the mid and higher frequencies. In the spectrogram of the creaky example , [pɔ̰˧˩] “to see,” we see wider, more irregular intervals between vocal pulses (visualized as vertical striations), particularly at the end of the vowel. The spectrogram of the modal example , [pɔ˥˨] “female” has neither of these characteristics.

Phonation types have been studied by a wide range of disciplines over a long history, leading to the use of competing terminology for very similar phenomena. Some terms are simply conventions within particular languages or regions. For example, early studies on breathy voice used the term “murmur” (e.g., Fischer-Jørgensen, 1967; Ladefoged, 1971), especially for South Asian languages. Similarly, “clear” is used in opposition to “breathy” for Austroasiatic languages (e.g., Watkins, 2002), referring roughly to modal voice or something slightly further towards the closed end of the continuum. “Muddy” is traditionally used in the context of Sinitic languages for breathier phonations in historical analyses of Middle Chinese as well as synchronic analysis of modern Wu varieties (Gao & Hallé, 2017). Across studies, one finds “lax,” “slack,” “muddy,” “murmured,” and “whispery” on the breathier (more open) half of Ladefoged's continuum, and “tense,” “stiff,” “laryngealized,” and “glottalized”

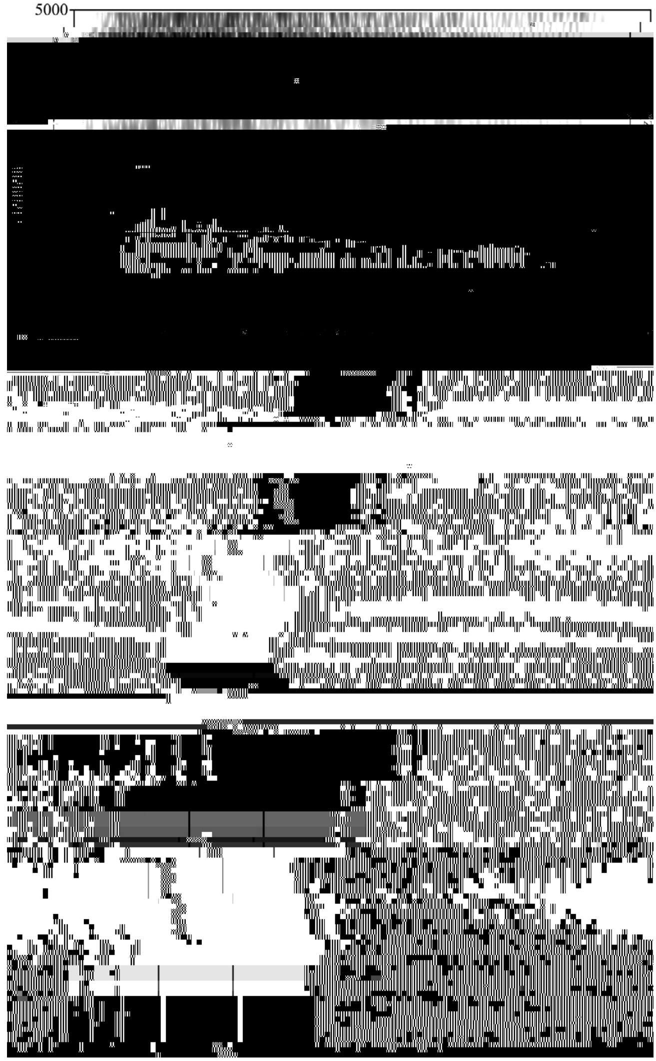

FIGURE 2 Spectrograms of the White Hmong words , [pɔ̤˦˨] "paternal grandmother" (breathy, top), , [pɔ˥˨] "female" (modal, middle), and , [pɔ̰˨˩] "to see" (creaky, bottom)

FIGURE 3 Phonation types on a continuum of glottal width from Ladefoged (1971), updated to include a selection of additional labels reflecting conventional usage. Note that their placement is somewhat arbitrary due to vague and overlapping definitions

Esling & Harris, 2005; Edmondson & Esling, 2006; Moisik, 2013 for greater details on valvular models of phonation). Nevertheless, while phonation almost certainly involves many intersecting dimensions in both articulation and acoustics (see Section 2.3 for a multidimensional approach to acoustic cues of phonation), most authors (ourselves included) approach phonation using Ladefoged's unidimensional model as a convenient starting point, especially when focusing on the cross-linguistically most common contrastive voice qualities: breathy, modal, and creaky.

1.1 | Goals of paper

The goals of the current paper are (a) to provide an update on the state of research since Gordon and Ladefoged's (2001) overview, maintaining their original focus on the acoustics of phonation as it is used for contrastive and allophonic purposes, and (b) to also expand further into studies of the perception of phonation, reflecting the considerable recent growth in that field. In the interest of space and in keeping with Gordon and Ladefoged's (2001) approach, we do not attempt to provide an extensive overview of the articulatory mechanisms involved in phonation (see Garellek, 2019a, 2019b; Kreiman & Sidtis, 2011; Laver, 1981), nor do we cover the

and Bengali (Khan, 2010; Mikuteit & Reetz, 2007), and to a lesser extent in other South Asian languages, for example, Malayalam (Namboodiripad & Garellek, 2016). Breathy obstruents are also found in the Owerri variety of Igbo (Ladefoged, 1964). A contrast between lax/slack and tense/stiff stops is described in Javanese (Brunelle, 2010; Thurgood, 2004). Notably, because obstruents allow for a negligible degree of airflow during the consonant articulation itself, any associated phonation on the breathier half of the continuum will be primarily realized on the adjacent vowels. This means that the phonation will be understood as phonetically vocalic but phonologically consonantal; see Section 2.4 for further discussion of this issue.

Non-modal sonorants include breathy nasals (e.g., [m̤] or [mʱ]) in Marathi (Berkson, 2019) and Tsonga (Traill & Jackson, 1988) and creaky approximants [j̰] in Chadic languages (Ladefoged, 1964) including Hausa (Lindau, 1984; Lindsey, Hayward, & Haruna, 1992), Bura, and Margi. Note that while the articulatory complications of producing breathier phonations during an obstruent are not present in sonorants (due to their continuous airflow through either the oral or nasal passages), non-modal sonorants appear to be less common than their obstruent counterparts (Berkson, 2019), though this may be due to simply being underreported in many phonetic and phonological studies.

Of note, very few languages (cell 4) contrast phonation types on both consonants and vowels; in fact, this seems to be limited to five languages !Xóõ (Traill, 1985), Ju|'hoansi (Miller, 2007), Wa (Watkins, 2002), White Hmong (Esposito & Khan, 2012), and Gujarati (Esposito & Khan, 2012)—all of which contrast breathy-voiced aspirated obstruents in addition to breathy vowels (often alongside other non-modal phonations).

Some languages are ambiguous or at least complex in the association of non-modal phonation. Tense and lax phonations in Yi languages, for example, are measurable on both sonorant onsets and vowel nuclei: one interpretation is that the phonation is associated to the vowel but allophonically spreads to the consonant, while another interpretation views phonation as associated to the entire syllable (Garellek, Ritchart, & Kuang, 2016). In Wu Chinese varieties, the presence of non-modal phonation on vowels (and occasionally on onset consonants) is generally considered a property of the tone class: higher-register *ī* tones are associated with generto its associated segment (Section 2.4), followed by a focus on how phonation can be expressed partially through duration (Section 2.5).

2.1 | Acoustic measurements

Researchers have relied mainly on spectral balance and spectral tilt measures to quantify the acoustic signal. The most common spectral balance measure—the difference between the amplitude of the first and second harmonics (H1–H2)—reflects the open quotient, that is, the proportion of the glottal cycle during which the glottis is open (Holmberg, Hillman, Perkell, Guiod, & Goldman, 1995). H1–H2 has been used to successfully measure phonation types in a wide variety of languages such as !Xóõ (Bickley, 1982; Garellek, 2019a, 2019b), Coatzospan Mixtec (Gerfen & Baker, 2005), Jalapa Mazatec (Blankenship, 2002; Garellek & Keating, 2011; Kirk et al., 1993), Chanthaburi Khmer (Wayland & Jongman, 2003), Phnom Penh Khmer (Kirby, 2014), Green Mong (Andruski & Ratliff, 2000), White Hmong (Esposito, 2012), Marathi (Berkson, 2019), Gujarati (Khan, 2012), Mon (Abramson et al., 2015), Takhian Thong Chong (DiCanio, 2009), SAV Zapotec (Esposito, 2010b), Sgaw Karen (Brunelle & Finkeldey, 2011), Yi (Kuang, 2011), Trique (DiCanio, 2012, 2014), and so forth. Other studies have relied on spectral tilt measures, quantifying the amplitude between the first harmonic (H1) and the harmonics exciting higher formants (e.g., H1–A1, H1–A2, H1–A3); these are reported to correlate with the abruptness of vocal fold closure (Stevens, 1977). Spectral tilt measures have been used success-

(DiCanio, 2009), Gujarati (Esposito & Khan, 2012; Khan, 2012), White Hmong (Esposito, 2012; Esposito & Khan, 2012), Yi (Kuang & Cui, 2018; Kuang & Keating, 2014), and Bo, Gujarati, Luchan Hani, White Hmong, Mandarin, Black Miao, Southern Yi, Santiago Matatlán Zapotec and San Juan Guelavía Zapotec (Keating, Kuang, Esposito, Garellek, & Khan, 2011, 2012).

The most common measure derived from an EGG signal is one of vocal fold contact during a vibratory cycle, variably referred to as contact quotient, closed quotient, or closing quotient, but generally abbreviated CQ (Baken & Orlikoff, 2000; Rothenberg & Mahshie, 1988). CQ is a ratio of the duration of the vocal fold contact phase to the total duration for a complete vibratory cycle. Phonation types produced with wider vocal fold aperture (e.g., breathy, lax) have lower CQ values compared to phonations types produced with greater vocal fold contact (e.g., creaky, tense), with modal voicing in between. Studies comparing acoustic and EGG measures (DiCanio, 2009; Esposito, 2012) found that CQ was inversely correlated with H1−H2, indicating that both reflect glottal aperture.

Other EGG measures assess the speed of vocal fold activity. One common measure, Derivative-EGG Closure Peak Amplitude (DECPA), corresponds to the amplitude of the positive peak in the derivative of the EGG signal, which is the highest rate of increase of vocal fold contact. Phonations produced with faster glottal closure have greater DECPA values than phonations produced with slower glottal closure. And, while breathy phonation is produced with vocal folds that have less abrupt closure compared to other phonation types (Childers & Lee, 1991; Klatt & Klatt, 1990), one unusual finding is that DECPA values are higher for breathy phonation than for creaky and/or modal phonation in White Hmong (Esposito, 2012) and Yi (Kuang & Keating, 2014), as well as for breathy-aspirated stops in Gujarati (Esposito & Khan, 2012). Furthermore, DECPA is only weakly correlated with both spectral slope and balance measures (Esposito, 2012), or not correlated at all (Keating et al., 2010). One suggestion for the unexpected DECPA values is that the vocal folds are further apart in breathy phonation than in other phonation types, and therefore must move more quickly to return to their initial position (Esposito, 2012; Keating et al., 2010).

2.3 | Variation in production

As with many phonological features, phonation types are variable, both within and across languages. We see evidence for variation as a function of (a) phrasal position, as in SAV Zapotec (Esposito, 2010a, 2010b) and Burmese (Gruber, 2011), (b) gender, as women are breathier than men in both Jalapa Mazatec (Blankenship, 2002) and Chanthaburi Khmer (Wayland & Jongman, 2003), or (c) speaker: in Coatzospan Mixtec, creaky/laryngealized vowels manifest as audible creak, subtle laryngealization, or without any audible creakiness (Gerfen & Baker, 2005).

Furthermore, across languages, there is variation in what is labeled "breathy" or "creaky" voice. Keating, Garellek, and Kreiman (2015) investigated the wide range of phonation types that fall under the category of "creak," such as vocal fry, multiply pulsed voice, aperiodic voice, non-constricted creak, and tense/pressed voice. These differed from prototypical creak along the following parameters: low f0, irregular f0, glottal constriction, damped pulses, and/or multiple subharmonics.

Similarly, in their studies on breathiness, Tian, Zhou, and Kuang (2019) and Tian and Kuang (2019) find support for three types of "breathier" voice qualities: slack/lax voice, dominated by changes in spectral cues (as in Southern Yi), whispery voice, produced with noise as the dominant acoustic feature (as in Shanghainese Wu), and [true] breathy voice, produced with both (as in Gujarati and White Hmong); as the authors note, these should be interpreted as overlapping regions in a continuous phonetic space and not distinct divisions.

A cross-linguistic acoustic study (Keating et al., 2010) of multiple phonation types in four languages—Gujarati, Jalapa Mazatec, White Hmong, and Yi breathiness, while breathy vowels showed stable (Gujarati) or increasing (White Hmong) breathiness throughout the vowel (Esposito & Khan, 2012). In the spectrograms of Gujarati shown in Figure 5, the breathy voice "fuzziness" obscuring the otherwise-clear striations of modal voicing is visible across the entire breathy vowel in the word [ba̤ɾ] "outside" (middle panel), while it is restricted to the onset of the modal vowel following the breathy consonant in the word [bʱa

2.5 | Duration of non-modal phonation

Duration of non-modal phonation varies with language, with almost every possible pattern being attested. Non-modal vowels are longer than their modal counterparts in Kedang (Samely, 1991), Jalapa Mazatec (Kirk et al., 1993), Chanthaburi Khmer (Wayland & Jongman, 2003), Khmu' Rawk (Abramson, Nye, & (Luang-)Thongkum, 2007), and Gujarati (Fischer-Jørgensen, 1967), while in other languages, non-modal vowels are shorter than their modal counterparts, for example, the creaky vowels in Hmong (Andruski & Ratliff, 2000; Esposito, 2012) and Coatzospan Mixtec (Gerfen & Baker, 2005) and the two phonation clusters involving tense voice in Chong (DiCanio, 2009). And in languages like Yalálag Zapotec (Avelino, 2010) and Suai (Abramson et al., 2004), there is no difference in duration between non-modal and modal vowels.

3 | RELATIONSHIP TO OTHER PHONOLOGICAL CATEGORIES

In many languages, phonation contrasts interact with contrasts in other phonological dimensions, such as airstream mechanism (Section 3.1), tone (Section 3.2), and vowel quality (Section 3.3). Non-modal phonation can also arise as a result of coarticulation (Section 3.4). As we explain below, when phonation categories are hard to separate from tone and/or vowel quality categories, the term “register” (Henderson, 1952) is often used to label this multi-dimensional feature.

3.1 | Relationship to airstream mechanism

Two classes of non-pulmonic consonants involve a narrowing and downward or upward movement of the glottis: glottalic ingressive (i.e., implosive) and glottalic egressive (i.e., ejective) consonants, respectively. Due to the glottal constriction required for these non-pulmonic sounds, they are often associated with creakier phonations in many languages, and by extension, pulmonic sounds can be associated with breathier phonations to help enhance their contrast with glottalic sounds.

As an example of the former case, creaky obstruents (e.g., [b̰]) are documented as an optional realization of implosives (e.g., [ɓ]) in West African languages such as Bura, Hausa, Margi, Kalabari, and Igbo (Ladefoged, 1964) and Mayan languages such as K'iche', Kaqchikel, Q'eqchi', Tz'utujil, and Poqomchi' (Pinkerton, 1986). And as an example of the latter case, slack voice is described in the Nguni languages of southern Africa (Rycroft, 1980), for example, Xhosa displayed in Table 4, with the contrastive role of f0 shown in rows and the contrastive role of vowel phonation shown in columns.

Ignoring cell 1, for which there is neither a tone/pitch accent nor phonation contrast on vowels, we can focus on languages that have at least one of these kinds of lexical contrasts. In cell 4a, both tone and vowel phonation are independently contrastive, and thus different combinations of tone and vowel phonation are attested; for example, in Jalapa Mazatec, the three tones (low, mid, high) cross with the three phonations (modal, breathy, creaky/laryngealized) to give nine attested combinations of these two suprasegmental dimensions (Garellek & Keating, 2011; Kirk et al., 1993; Silverman et al., 1995). Dinka (Andersen, 1993; Denning, 1989; Edmondson & Esling, 2006; Remijsen & Manyang, 2009), Mpi (Blankenship, 2002), Yalálag Zapotec (Lancia, Avelino, & Voigt, 2013), Yi languages (Kuang & Keating, 2014), and !Xóõ (Garellek, 2019a, 2019b; Traill, 1985) also allow for tone and phonation to be (nearly) fully cross-classified, demonstrating the orthogonality of the two dimensions in these languages.

Arguably more interesting, however, are the two ways in which the line between the tone and phonation can be blurred. Languages in cells 2a and 2b are described as having contrastive phonation on vowels, but no contrast in tone, even though the contrastive phonations in 2b include f0 specifications as part of their realization. Languages in cells 3a and 3b are described as having contrastive tone, but no contrast in phonation, and yet the contrastive tones in 3b are described as having voice qualities allophonically associated with them. In cells 4a and 4b, tone and phonation interact in all words, but while languages in cell 4a suggest two orthogonal

languages in which vowel phonation plays a systematic role in lexical contrasts (cells 2a, 2b, 3b, 4a, 4b), we note that f0 also plays a major role in virtually every example; the only exceptions we are aware of (cell 2a) are Danish, for which Grønnum (2014) demonstrates that f0 perturbations are not a reliable cue for laryngealization (ʕ), and Gujarati, for which Khan (2012) argues f0 plays no systematic role in enhancing breathy phonation. It is noteworthy though, that even for this latter language, older studies in the form of impressionistic description (Pandit, 1957) and instrumental work (Dave, 1967; Fischer-Jørgensen, 1967) report a small and statistically inconsistent relation between f0 and breathy phonation, suggesting at least a subtle and complex interplay between the two. We return to this curiosity in Section 4.1.

3.3 | Relationship to vowel quality

Formant frequency may differ based on phonation type, but this is language-specific. Compared to their modal counterparts, a lower first formant frequency (F1) is found for: (a) breathy vowels in Kedang (Samely, 1991), Nilotic languages (Denning, 1989), various Mainland Southeast Asian languages (Bradley, 1982; Hombert, 1978), and Xhosa (Jessen & Roux, 2002), (b) breathy and breathy-creaky vowels in Krathing Chong ((Luang)-Thongkum, 1987), and (c) lax phonation in Yi (Kuang, 2011), meaning that these breathier phonations may be associated to higher vowel quality. Similarly, higher F1 (i.e., lower vowel quality) is reported for creaky/tense phonation in Hani (Maddieson & Ladefoged, 1985) and Mpi (Blankenship, 2002). However, in languages such as Mon ((Luang)-Thongkum, 1987), Nyah Kur ((Luang)-Thongkum, 1986), Suai ((Luang)-Thongkum, 1986), Khmu' Rawk (Abramson et al., 2007), Gujarati (Khan, 2012), Jalapa Mazatec (Garellek & Keating, 2011), F1 frequencies are largely unaffected by phonation type. While the results are mixed when we compare across languages, a study on the relationship between voice quality and vowel quality in eight languages—!Xóõ, Burmese, Gujarati, Jalapa Mazatec, Mon, White Hmong, Yi, and Zapotec—did show a cross-linguistic pattern in the relationship between vowel quality and voice quality; when using H1–H2 as the measure of voice quality, vowels with higher F1 and F2 (i.e., lower, fronter vowels) tend to be produced with creakier phonation, with voice quality contrasts more robustly distinguished, while vowels with lower F1 and F2 (i.e., higher, backer vowels) tend to be breathier, with voice quality contrasts less dispersed (Esposito, Sleeper, & Schafer, 2019 to appear). At the greatest extreme, Luanyjang Dinka has a breathy versus modal (“brassy”)” distinction across six5(e)-33b.9

(Esposito, 2012) and Gujarati (Khan, 2012), there is no significant difference between phonation types across different vowel qualities.

3.4 | Coarticulation

Non-modal phonation can arise due to the effect of glottal consonants adjacent to vowels, for example, creaky vowels [V̰] resulting from the coalescence of /VʔV/ in K'iche' (Baird, 2011) or

Khan (2010) showed that Gujarati listeners were more sensitive to H1–H2 differences, even small ones, than listeners of English or Thai. Likewise, Mandarin listeners were more sensitive to changes in H1–H2 than English listeners (Kreiman & Gerratt, 2010). Taken together, these studies show that listeners are sensitive to H1–H2 regardless of language background, but that the degree of sensitivity is language-dependent.

Another main area of focus is the role of phonation in the perception of contrastive tone. In Cantonese Yue (Yu & Lam, 2014), Mandarin (Yang, 2011), and Green Mong (Andruski, 2006), non-modal phonation associated with certain tones increases the accuracy of tone identification; in the case of Mandarin it also increases the speed of identification (Belotel-Grenié & Grenié, 1994, 2004). And, in Coatzospan Mixtec, listeners are able to utilize small pitch and amplitude perturbations timed in the middle of the vowel (in the absence of spectral cues) to determine the difference between creaky/laryngealized versus modal vowels (Gerfen & Baker, 2005).

However, not all tonal contrasts are cued by phonation differences. Garellek et al. (2013)

distinguished primarily by phonation to one in which pitch is dominant, as in Suai (Abramson et al., 2004), Kammu (Svantesson & House, 2006), or Vietnamese (Thurgood, 2002), or to one in which vowel quality is dominant, as in Southern Yi (Kuang & Cui, 2018) and Standard Khmer (Wayland & Jongman, 2002). In a slightly different situation, Phnom Penh Khmer has lost consonant+rhotic clusters but developed a tone distinction in which breathiness plays a perceptual role (Kirby, 2014). Indeed, many Austroasiatic languages in particular are described as having undergone or as currently undergoing some form of evolution to generate a phonation contrast, which in many cases has further morphed into a tonal contrast (Sidwell & Rau, 2015). The reverse, in which a phonation contrast arises out of what was historically a tonal contrast, is also argued for in Quiaviní Zapotec (Uchihara, 2016).

The results of perception studies on phonation have offered insight into the distribution of non-modal phonation. Breathy sonorants, in particular breathy nasals, are rare, both within and across languages when compared to their obstruent counterparts (Berkson, 2019). There may be a perceptual explanation for this: a study on Marathi revealed that listeners identified breathiness in obstruents with significantly greater accuracy than in sonorants (Berkson, 2016). And, another study on the typologically rare contrast—breathy-voiced consonants versus breathy vowels—found that acoustic differences between these two types of segments were not robust enough to be perceptually salient for listeners of Gujarati (Esposito, Khan, Berkson, & Nelson, 2019). While it had been hypothesized that differences in timing and magnitude of phonation could play a role in distinguishing these phonation types (Esposito & Khan, 2012), but Esposito, Khan, et al. (2019) demonstrate that this may not be the case. Listeners' inability to reliably distinguish between these types of consonants might explain why these contrasts are so rare.

5 | CONCLUSION

In the nearly two decades since Gordon and Ladefoged's (2001) review of cross-linguistic phonation types, there has been a surge of high-quality research on the topic. Acoustic, articulatory, and perceptual evidence has emerged to support the idea that while phonation contrasts do exist in a continuous space (as laid out by Ladefoged 30 years prior), that space is more accurately conceived of as multidimensional rather than as a single continuum of glottal width. This complex of phonetic realizations-585.6(tntinn3]TJ0-1.29830)4(5354ately)-263[(come-349.7nto,)-362hs-585 marker of lexical tone, as researchers find faster, more accurate lexical identification when non-modal voice qualities are predictably realized with tone.

Lastly, perceptual experiments have also shed light on the looming question of why it is so rare to find contrasts in the association of non-modal phonation, that is, a contrast between non-modal vowels versus non-modal consonants, within the same language. Only five languages (to our knowledge) are documented to have this contrast in association. Results from perception work suggest that, while non-modal phonation is fairly common across many different languages and language families, distinguishing non-modal phonations associated to different segments is highly error-ful and subject to reduction to a two-way modal versus non-modal

Berkson, K. H. (2019). Acoustic correlates of breathy sonorants in Marathi. [illegible], *73*, 70–90.

Bickley, C. (1982). Acoustic analysis and perception of breathy vowels. (Speech Communication Group Working Papers), Research Lab of Electronics, MIT, 73–93.

Bishop, J., & Keating, P. (2012). Perception of pitch location within a speaker's range: Fundamental frequency, voice quality and speaker sex. [illegible], *132*, 1100–1112.

Blankenship, B. (2002). The timing of non-modal phonation in vowels. [illegible], *30*, 163–191.

Bradley, D. (1982). Register in Burmese. In D. Bradley (Ed.), [illegible] (Pacific Linguistics Series A-62) (pp. 117–132). Canberra, Australia: Australian National University.

Brunelle, M. (2010). The role of larynx height in the Javanese tense–lax stop contrast. In R. Mercado, E. Potsdam, & L. D. Travis (Eds.), [illegible] (pp. 7–24). Amsterdam, the Netherlands: John Benjamins.

Brunelle, M., & Finkeldey, J. (2011). Tone perception in Sgaw Karen. Paper presented at: Proceedings of the 17th Inted9stop.17th361.8(the)-2ics

Esposito, C. M. (2010b). Variation in contrastive phonation in Santa Ana del Valle Zapotec. [illegible], *40*, 181–198.

Esposito, C. M. (2012). An acoustic and electroglottographic study of white Hmong tone and phonation. [illegible], *40*, 466–476.

Esposito, C. M., & Khan, S. D. (2012). Contrastive breathiness across consonants and vowels: A comparative study of Gujarati and white Hmong. [illegible], *42*, 123–143.

Esposito, C. M., Khan, S. D., Berkson, K. H., & Nelson, M. (2019). Distinguishing breathy consonants and vowels in Gujarati. [illegible], *6*, 214–243.

Jessen, M., & Roux, J. (2002). Voice quality differences associated with stops and clicks in Xhosa. *30*, 1–52.

Kaun, A. R. (2004). The typology of rounding harmony. In B. Hayes, R. Kirchner, & D. Steriade (Eds.), , Cambridge: Cambridge University Press.

Keating, P., Esposito, C. M., Garellek, M., Khan, S. D., & Kuang, J. (2010). Phonation contrasts across languages. *108*, 188–202.

Keating, P., Esposito, C. M., Garellek, M., Khan, S. D., & Kuang, J. (2011). Phonation contrasts across languages. Paper presented at: Proceedings of the International Congress of Phonetic Sciences, Hong Kong. 1046–9.

Keating, P., Garellek, M., & Kreiman, J. (2015). Acoustic properties of different kinds of creaky voice. Paper presented at: Proceedings of the 18th International Congress of Phonetic Sciences, Glasgow. 0821.1–0821.5.

Keating, P., Kuang, J., Esposito, C. M., Garellek, M. & Khan, S. D. (2012). Multi-dimensional phonetic space for phonation contrasts. Poster presented at: LabPhon13 in Stuttgart, Germany.

Keating, P., Mikoś, M. J., & Ganong, W. F. (1981). A cross-language study of range of voice onset time in the perception of initial stop voicing. *70*, 1251–1271.

Khan, S. D. (2010). Bengali (Bangladeshi standard). *40*, 221–225.

Khan, S. D. (2012). The phonetics of contrastive phonation in Gujarati. *40*, 780–795.

Kingston, J., & Diehl, R. (1994). Phonetic knowledge. *70*, 419–454.

Kirby, J. P. (2014). Incipient tonogenesis in Phnom Penh Khmer: Acoustic and perceptual studies. *43*, 69–85.

Kirk, P. L., Ladefoged, J., & Ladefoged, P. (1993). Quantifying acoustic properties of modal, breathy and creaky vowels in Jalapa Mazatec. In A. Mattina & T. Montler (Eds.), . Missoula, MT: University of Montana Press.

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

Kreiman, J., & Gerratt, B. R. (1996). The perceptual structure of pathologic voice quality. *100*(3), 1787–1795.

Kreiman, J., & Gerratt, B. R. (2005). Perception of aperiodicity in pathological voice. *117*, 2201–2211.

Kreiman, J., & Gerratt, B. R. (2010). Perceptual sensitivity to first harmonic amplitude in the voice source. *128*, 2085–2089.

Kreiman, J., Gerratt, B. R., & Antoñanzas-Barroso, N. (2007). Measures of the glottal source spectrum. *50*, 595–610.

Kreiman, J., Gerratt, B. R., Garellek, M., Samlan, R., & Zhang, Z. (2014). Toward a unified theory of voice production and perception. *1*, e009.

Kreiman, J., Gerratt, B. R., & Khan, S. D. (2010). Effects of native language on perception of voice quality. *38*, 588–593.

Kreiman, J., & Sidtis, D. (2011). . Oxford, England: Wiley-Blackwell.

Kuang, J. (2011). Production and perception of the phonation contrast in Yi. (MA thesis). UCLA.

Kuang, J. (2013). The tonal space of contrastive five level tones. *70*, 1–23.

Kuang, J. (2017). Covariation between voice quality and pitch: Revisiting the case of mandarin creaky voice. *142*, 1693–1706.

Kuang, J., & Cui, A. (2018). Relative cue weighting in production and perception of an ongoing sound change in southern Yi. *71*, 194–214.

Kuang, J., & Keating, L0iA20-284.6(in)]TJ1.7of the Ct79S91.467

Laver, J. (1981). . Cambridge: Cambridge University Press.

Lindau, M. (1984). Phonetic differences in glottalic consonants. , *12*, 147–155.

Lindsey, G., Hayward, K., & Haruna, A. (1992). Hausa glottalic consonants: A laryngographic study source. *B*, *55*, 511–527.

Lotto, A., Holt, L., & Kluender, K. (1997). Effect of voice quality on perceived height of English vowels. , *54*, 76–93.

(Luang)-Thongkum, T. (1986). An acoustic study of the register complex in Kui (Suai). , *15*, 1–20.

(Luang)-Thongkum, T. (1987). Another look at the register distinction in Mon. *C A*, *67*, 132–165.

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

Rycroft, D. K. (1980). The depression feature in Nguni languages and its interaction with tone. Communication No. 8, Department of African Languages, Rhodes University, Grahamstown.

Samely, U. (1991). Kedang (Eastern Indonesia): Some Aspects of its Grammar. Forum phoneticum.

Sapienza, C., Hicks, D. M., & Ruddy, B. H. (2011). Voice disorders. In N. B. Anderson & G. H. Shames (Eds.), [illegible] (8th ed., pp. 202–237). Boston, MA: Pearson.

Shue, Y.-L., Keating, P., Vicenik, C., & Yu, K. M. (2011). VoiceSauce: A program for voice analysis. Paper presented at: Proceedings of the 17th International Congress of Phonetic Sciences, Hong Kong. 1846–9.

Sidwell, P., & Rau, F. (2015). Austroasiatic comparative-historical reconstruction: An overview. In M. Jenny & P. Sidwell (Eds.), [illegible]. Boston, MA: Brill.

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

Silverman, D., Blankenship, B., Kirk, P., & Ladefoged, P. (1995). Phonetic structures of Jalapa Mazatec. [illegible], *37*, 70–88.

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

Svantesson, J.-O., & House, D. (2006). Tone production, tone perception, and Kammu tonogenesis. [illegible], *23*, 309–333.

Szakay, A. (2012). Voice quality as a marker of ethnicity in New Zealand: From acoustics to perception. [illegible], *16*, 382–397.

Thurgood, E. (2004). Phonation types in Javanese. [illegible], *43*, 277–295.

Thurgood, G. (2002). Vietnamese and tonogenesis. [illegible], *19*, 333–363.

Tian, J., & Kuang, J. (2019). The phonetic properties of the non-modal phonation in Shanghainese. [illegible], 1–27. https://doi.org/10.1017/S0025100319000148

Tian, J., Zhou, Y., & Kuang, J. (2019). Cross-linguistic variation in the phonetic realization of breathy voice. Paper presented at: Proceedings of 19th International Congress of Phonetic Sciences, Melbourne.

Traill, A. (1985). [illegible]. Hamburg, Germany: Buske.

Traill, A. (1986). The laryngeal sphincter as a phonatory mechanism in !Xóõ bushman. In R. Singer & J. K. Lundy (Eds.), [illegible] (pp. 123–131). Johannesburg, South Africa: Witwatersrand University Press.

Traill, A., & Jackson, M. (1988). Speaker variation and phonation type in Tsonga. [illegible], *16*, 385–400.

Traill, A., Khumalo, J. S. M., & Fridjon, P. (1987). Depressing facts about Zulu. [illegible], *46*, 255–274.

Uchihara, H. (2016). Tone and registrogenesis in Quiaviní Zapotec. [illegible], *33*, 220–254.

Watkins, J. (2002). [illegible]. Canberra, Australia: Pacific Linguisticss.),

AUTHOR BIOGRAPHIES

Christina M. Esposito is an associate professor of Linguistics at Macalester College. She researches the production and perception of phonation in various languages, such as White Hmong, Zapotec, and Gujarati.

Sameer ud Dowla Khan is an associate professor of Linguistics at Reed College. His research interests include intonation, phonation, and reduplication across various languages, with a focus on South Asia.

How to cite this article: Esposito CM, Khan SD. The cross-linguistic patterns of phonation types. [illegible] *C* [illegible]. 2020;e12392. https://doi.org/10.1111/lnc3.12392