Tone and phonation in Southeast Asian languages

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Abstract:

Southeast Asia is often considered a quintessential *Sprachbund* where languages from five different language phyla have been converging typologically for millennia. One of the common features shared by many languages of the area is tone: several major national languages of the region have large tone inventories and complex tone contours. In this paper, we suggest a more fine-grained view. We show that in addition to a large number of atonal languages, the tone languages of the region are actually far more diverse than usually assumed, and employ phonation type contrasts at least as often as pitch. Along the same lines, we argue that concepts such as *tone* and *register*, while descriptively useful, can obscure important underlying similarities and impede our understanding of the behavior of phonetic properties, typological regularities and diachrony. We finally draw the reader's attention to some issues of current interest in the study of tone and phonation in Southeast Asia and describe some technical developments that are likely to allow researchers to address new lines of research in years to come.

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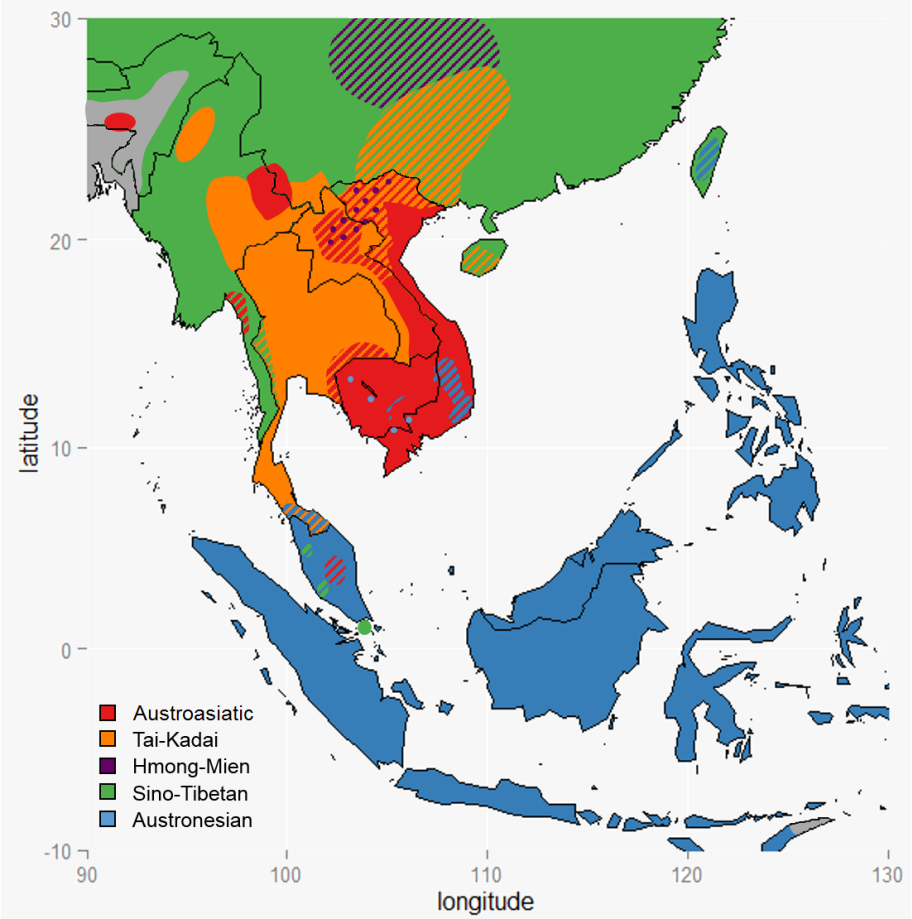
1. Introduction: the diversity and complexity of tone in Southeast Asia

Mainland Southeast Asia is the common designation for a geographically and linguistically diverse region comprising the modern states of Vietnam, Laos, Cambodia, Thailand, Burma (Myanmar), and peninsular Malaysia, along with portions of China south of the Yangtze River (Enfield & Comrie 2015). The languages of this region represent five major language phyla (Sino-Tibetan, Tai-Kadai, Hmong-Mien, Austroasiatic, and Austronesian), and Chinese and/or Indic cultures and languages have had a significant influence over most of the area. Mainland Southeast Asia is sometimes contrasted with *Insular* (or *Maritime*) *Southeast Asia*, a designation for Brunei, East Timor, Singapore, Indonesia, insular Malaysia and the Philippine archipelago, where most of the languages are of Austronesian stock. In addition to the fact that they share a surprising number of phonological and grammatical properties, the languages of Southeast Asia have attracted attention for the diversity and complexity of their tone systems, their use of different voice qualities or phonation types, and their contributions to our understanding of the historical process of phonologization (Hyman 1976).



Map 1: The Southeast Asian language phyla (simplified)

In this paper, we review what is known about tone and phonation in Southeast Asian languages, as well as what remains less well understood. Throughout, we wish to draw the reader's attention to two points that, in our opinion, have not been sufficiently appreciated, even in the specialist literature. The first is that when one looks carefully at the phonetic and phonological characteristics of Southeast Asian tone systems, one finds such a degree of diversity that one begins to question the utility of the term 'tone language'. The received knowledge is that Mainland Southeast Asia is a linguistic area where languages have large tone systems with many complex contours, while Insular Southeast Asia has languages are almost

devoid of such systems. However, while Mainland Southeast Asia is indeed home to languages with large number of tones in this conventional sense, we also find a considerable number of atonal languages, as well as languages in which voice quality, vowel quality, and pitch all play a crucial role in signalling phonological contrasts. While the received simplification is of course not intended to be completely free of exceptions, a greater appreciation of the range of diversity found in this region may enhance our ability to do accurate linguistic typology.

The second, related point is that although much literature, including the present work, makes extensive use of descriptive shortcuts such as *tone* and *register*, it must be emphasized that these are labels of convenience, and do not correspond to meaningful discrete categories. Rather than trying to group languages based on arbitrary assessments of the importance of individual phonetic properties, we would like to suggest that a more fruitful avenue of research is to see different systems as the outcome of multiple, overlapping articulatory settings, the acoustic consequences of which are perceived in a multidimensional phonetic space. We are of course not the first to make such a suggestion, but in the context of the complexity and diversity of the region's laryngeal systems, we believe it is worth repeating.

In the following pages, we will give an overview of the state of the field from four different perspectives. We will first discuss Southeast Asian tonation from a typological perspective and give readers a snapshot of the types of systems found in the area (§2) and of their diachronic development (§3). We will then highlight some topics of current active research interest (§4) and conclude with a discussion of the phonetic techniques that have shaped our understanding of tone in the region and of the important role technology plays, and will continue to play, in research on Southeast Asian tone systems (§5).

2. Typological issues

A. Phonetic diversity in the realization of tone

Southeast Asian languages make use of a variety of contrastive laryngeal properties that we may globally group under the label of *tonation* (Bradley 1982b). The most described type of tonation is the use of contrastive pitch to distinguish lexical items or to mark grammatical functions. The presence of 'lexically significant, contrastive, but relative pitch on each syllable' (Pike 1948: 3) is what is conventionally meant by the term 'tone'.

The tone language perhaps most familiar to Western scholars, Mandarin Chinese, has four tones whose contours (rising, falling, falling-rising, level) distinguish lexical items. Southeast Asian tone languages can have from two to eight tones, and while binary systems tend to have relatively flat tones (high vs. low pitch), languages with larger inventories normally have fairly complex contours. Another important component of tonation in Southeast Asian languages is *phonation type*, or differences in laryngeal setting conditioned by changes to stiffness and thickness of vocal folds, height of the larynx, and other glottal adjustments (Ladefoged 1971; Laver 1980; Ní Chasaide & Gobl 2010). The most common phonation types found in Southeast Asia are probably *breathy voice* and *creaky voice*, the former characterized by a high rate of transglottal airflow and minimal adductive tension of the vocal folds, the latter by low rates of airflow and strongly adducted vocal folds. However, other phonation types such as harsh voice, pressed voice, and tense voice are also observed (Ladefoged & Maddieson 1996; Edmondson *et al.* 2001; DiCanio 2009).

Southeast Asian languages use different combinations of pitch and phonation type to realize tonal contrasts, and nearly every imaginable combination is represented. At one extreme end of

the spectrum are what one might call 'pure' tone systems relying exclusively on differences in pitch to distinguish otherwise segmentally identical lexical items. Central Thai, a Tai-Kadai language whose 5 tones are distinguished by pitch height and contour (high, mid, low, falling and rising), is one such language; Kháng, a Khmuic language of northern Vietnam, is another (Edmondson 2010). An ostensibly quite different type of tonation, first described by Eugénie Henderson (Henderson 1952), is *register*, or the redundant use of pitch, voice quality, vowel quality and durational differences to distinguish (typically two) contrastive categories (Table 1). For example, in Eastern Cham, an Austronesian language spoken in south-central Vietnam, high register words have a high pitch, modal voice, relatively low vowels and relatively short rhymes, while low register words have low pitch, a breathy voice quality, higher vowels and longer rhymes (Brunelle 2005). Mon, an Austroasiatic language spoken throughout Myanmar and Thailand, is another example of a canonical register language, with vowels traditionally being classified into 'head register' (higher pitch, shorter duration, modal voicing, e.g. /cə/ 'to shield') and 'chest register' (lower pitch, longer duration, breathy voicing, e.g. /cə̤/ 'to bump into') (Lee 1983; L-Thongkum 1987a).

Table 1: Possible phonetic correlates of register. High register is typically associated with historically voiceless onsets, low register with historically voiced onsets.

High register (voiceless stops, [*pa])	*Low register* (voiced stops, [*ba])
Higher pitch	Lower pitch
Tense / modal voice	Lax / breathy voice
Monophthongs / shorter vowels	Diphthongs / longer vowels
Raised F1 / lower vowels / [+ATR]	Lowered F1 / higher vowels / [-ATR]
Plain stops / shorter VOT	Aspirated stops / longer VOT

It is important to emphasize that not all register languages preserve all of these acoustic cues, and that some languages eventually restructure, or end up realizing the contrast by means of a single acoustic property. One such example is the Kuai dialect of Suai, a Mon-Khmer language of Thailand, where perceptual evidence suggests the historical register distinction is being restructured primarily as a contrast between high and low pitch (Abramson & Nye 2004). On the other hand one finds languages such as Standard Khmer, the national language of Cambodia, in which historical differences in pitch and voice quality have been replaced by differences in vowel height alone (Table 2).

Table 2: Historical development of vowel height differences in Standard Khmer (after Huffman 1985)

Register	Stage 1: voicing	Stage 2: transitional	Stage 3: register	Stage 4: vowel height
1	kaa	kaa	káa	kaa
2	gaa	k'aa	kạ̈a	kiə

Besides pure tone and register, the tone systems of many Southeast Asian languages frequently make use of both pitch and phonation type. For example, at least three of the six tones in Northern Vietnamese sonorant-final syllables are systematically or canonically realized with a laryngealized voice quality (Figure 1), and perceptual research has shown that the strong glottalization of the low glottalized tone is normally sufficient for identification, largely overriding pitch cues (Brunelle 2009b). Another example is Black Miao, a Hmong-Mien language spoken in Guizhou province, China. Black Miao contrasts five level tones, but three of these tones are also characterized by laryngealized, tense, or breathy phonation, respectively, all of which are important cues for accurate native-speaker discrimination (Kuang 2013).

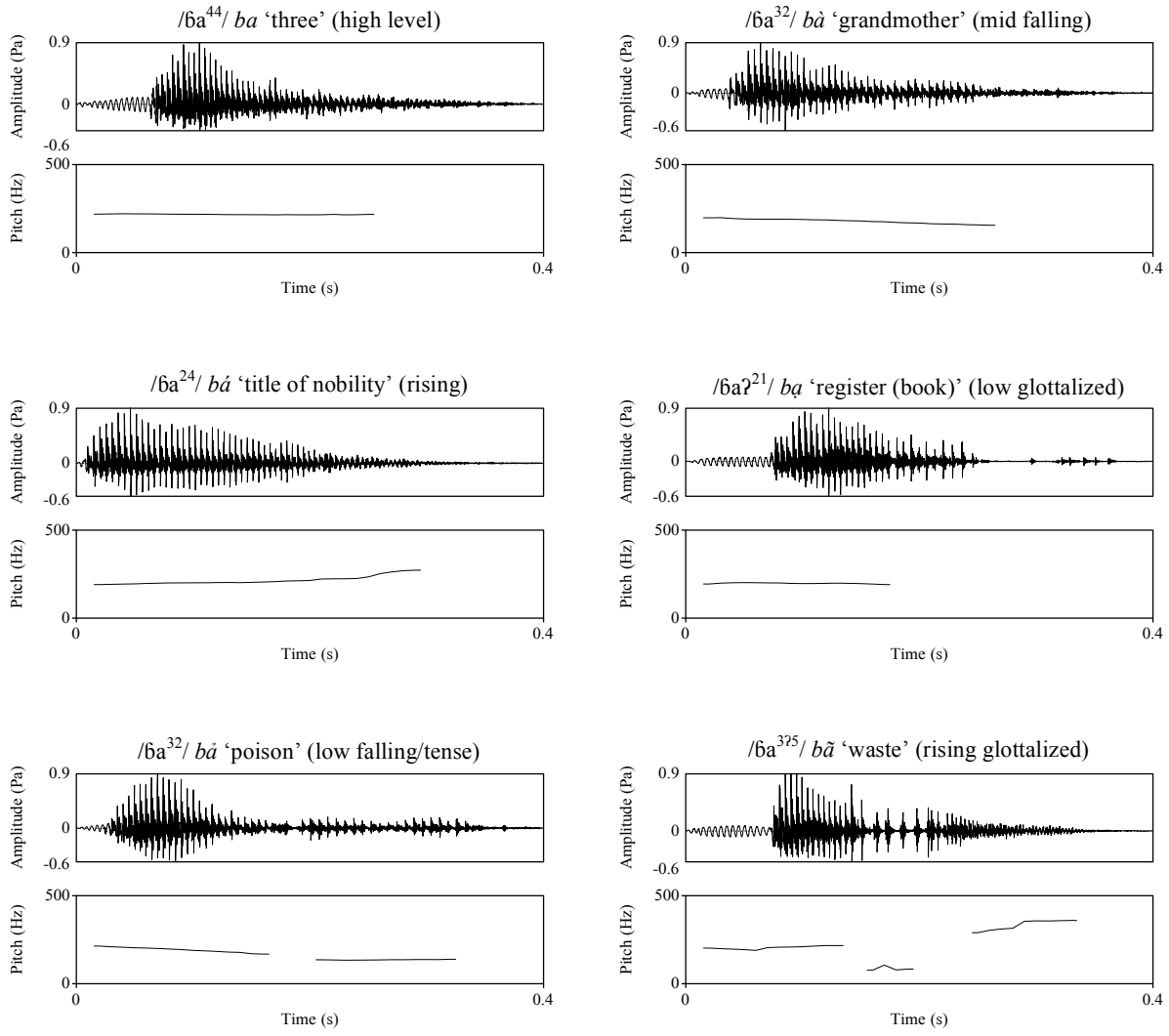


Figure 1: Audio and pitch tracks of Northern Vietnamese open-syllable tones spoken by a female speaker, illustrating the acoustic effects of the different phonation components. Vietnamese orthographic forms are provided following the IPA transcriptions (after Kirby 2010).

Languages such as Black Miao and Vietnamese highlight the difficulty of drawing a line in the sand separating ‘tone’ languages from ‘register’ languages. This problem is even more strikingly illustrated by Burmese (Table 3), which has been described both as a register system

(e.g. Bradley 1982a; Jones 1986) and as a tone language (e.g. Watkins 2001; Gruber 2011). While the precise details are somewhat complicated, Burmese syllables can bear one of four registers/tones, shown in Table 3. However, Gruber (2011) has shown that glottalisation, creakiness and the presence of a high pitch target are all important perceptual cues, thus demonstrating that, much like Vietnamese or Black Miao, Burmese should not be analyzed in terms of pitch or phonation type alone, nor is it straightforward to decide which property is the primary acoustic cue to the contrast.

Table 3: 'Tone' in Burmese. Examples and notation from Watkins (2001).

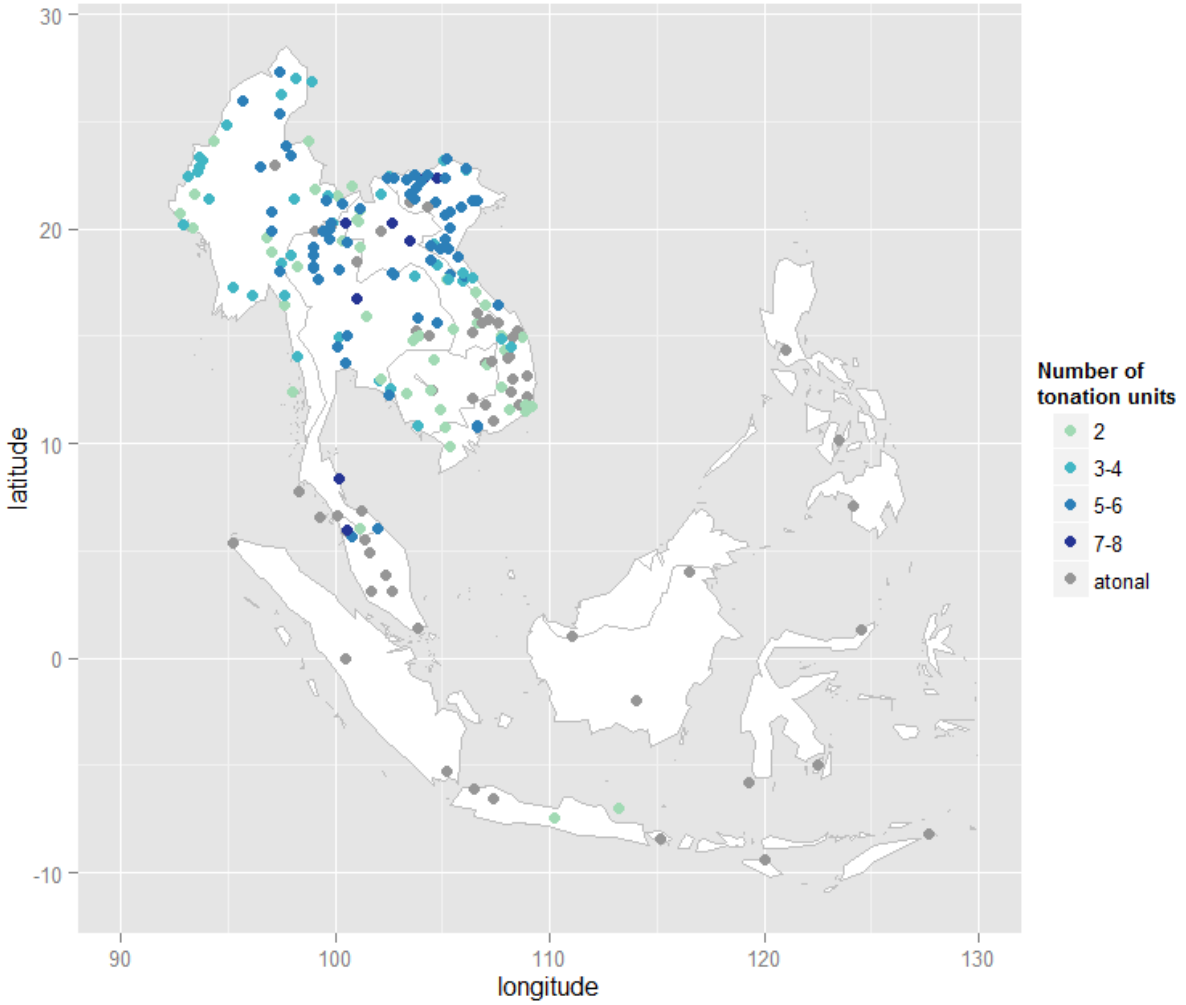
Low	/ma/	[maːɻ]	'hard'
High	/má/	[maːɬ]	'towering'
Creaky	/mą̰/	[mą̰ɴ̩]	'female'
Killed	/maʔ/	[maʔɴ̩]	'March'

If there is a fuzzy boundary between tone and register, then so too is there a fuzzy boundary between register and voicing. The Malayo-Polynesian language Javanese is sometimes described as having a contrast between 'light' and 'heavy' (Fagan 1988) or 'stiff' and 'slack' (Ladefoged & Maddieson 1996) consonants, but closer examination suggests the voicing contrast is redundantly cued by pitch, phonation type, and vowel quality (Hayward 1993, 1995; Thurgood 2004). Similar patterns are observed in neighboring languages of Indonesia such as Madurese (Cohn 1993; Cohn & Lockwood 1994; Misnadin *et al.* 2015) and Sundanese (Kulikov 2010), as well as further afield as in the Katuic (Austroasiatic) language Pacoh (Watson 1996). The fluidity and redundancy observed in the phonetic realization of tone in Southeast Asia thus suggests that tone and phonation (and perhaps even voicing more generally) are best regarded as

different manifestations of a single contrastive property rather than essentially distinct phenomena (Henderson 1967; Svantesson 1983; Mazaudon & Michaud 2008; Enfield 2011).

B. Geographic distribution of languages

The complexity of the geographical distribution of tonation in Southeast Asia was established relatively early (Henderson 1965). To oversimplify considerably, languages spoken in the northern regions of Southeast Asia (i.e. Myanmar, northern Vietnam, southern China) tend to have the most complex tonal systems, both in terms of sheer numbers of contrasts as well as in the complexity of their phonetic realizations, while languages in southern and insular Southeast Asia tend towards atonality (Map 2). The northern regions, especially on the Chinese borderlands, are home to a large number of languages from the Hmong-Mien and Sino-Tibetan phyla. Hmong-Mien languages tend to have a large number of contour tones that also involve different phonation types. Sino-Tibetan languages, which in Southeast Asia mostly belong to the Tibeto-Burman branch, tend to have fewer tones, often involving voice quality contrasts, but which in comparison with most other languages of the region are often involved in grammatical functions and tone alternations.



Map 2: Distribution of tonation contrasts in Southeast Asia (adapted from Brunelle & Kirby 2015)

The Tai-Kadai and Austroasiatic phyla, while also well represented in the borderland region, are distributed more widely throughout mainland Southeast Asia. Tai-Kadai languages tend to have sizeable tone inventories (4-7 tones) that involve complex pitch contours, but rarely have salient voice quality contrasts; notable exceptions here include Caolan (Gregerson & Edmondson 1998) and Southern Shan (Edmondson 2008). Austroasiatic languages, which in Southeast Asia all belong to the Mon-Khmer branch, are considerably more diverse: some are atonal (Mnong,

Stieng), some have two registers (Mon, Chanthaburi Khmer), some have been described as register systems that contrast more than two phonation types (Kri, Chong), some have purely pitch-based tone systems (Southern Vietnamese, Kháng), and some have complex tone systems involving both pitch and phonation type contrasts (Northern Vietnamese, Mang). Finally, languages of the Austronesian phylum, which includes virtually all the languages of insular Southeast Asia except a handful of Papuan languages in Eastern Indonesia, are mostly atonal. Exceptions here include the Chamic family, which displays a diversity comparable to that of Mon-Khmer languages, and some languages of Indonesia, such as Javanese and Madurese, which could be analyzed as register systems (see the end of Section 2.A. above).

The factors underlying the general north-south tonation gradient have been the subject of much speculation, with many authors attributing it to contact (Matisoff 1973; Pulleyblank 1986; Thurgood 1999; Abramson 2004). However, a recent study using a sizeable language database was unable to isolate an effect of geographical proximity independent of language phylum (Brunelle & Kirby 2015). While contact has surely played an important role in shaping the phonologies of the languages of Southeast Asia, the evidence for broad, areal convergence of tonation, independent of language phylum, remains limited.

3. Diachronic issues

Where does tone come from? The languages of Southeast Asia have played a crucial role in nearly every attempt to answer this question. The starting point for most modern discussions of tonogenesis is surely the work of André-Georges Haudricourt on the origin of tone in Vietnamese (Haudricourt 1954). In this work, Haudricourt demonstrated how the 6-tone system

of modern Northern Vietnamese originally developed in two stages: a three-way tone contrast conditioned by the loss of laryngeal codas followed by a two-way split conditioned by onset voicing (Table 4). In the first stage, final stops became a rising tone and final voiceless fricative a falling tone, with a level tone characterizing open or sonorant-final syllables. At some later point, the voicing contrast in initial stops split this three-tone system into six, as words beginning with voiced stops developed lower pitch than those beginning with voiceless ones.

Table 4: Schematization of tonogenesis in Vietnamese (after Haudricourt 1954).

		final consonant		
		open/nasal finals CV(N)	checked finals CVʔ	voiceless spirants CVs > CVh
onset consonant	voiceless	*pa>pa *high level*	*paʔ>pa *high rising*	*pas>pa *high falling*
	voiced	*ba>pa *low level*	*baʔ>pa *low rising*	*bas>pa *low falling*

While there is considerable historical-comparative evidence to support this scenario, many of the phonetic details remain unresolved. For one thing, while the acoustic basis of onset-induced tone splitting is reasonably well understood (Hombert *et al.* 1979), the phonetic basis of coda-induced tonogenesis is less clear. It seems the loss of coda -ʔ and -h would have been phonetically gradual, and that at some stage the tones resulting from their loss must have been creaky and breathy, respectively, given that (a) these phonation types survive to this day in many Vietnamese dialects and (b) many conservative Vietic languages have tonal systems in which phonation type remains as, if not more, important than pitch (Ferlus 1998; Enfield & Diffloth 2009). The importance of coda-conditioned differences in phonation type was also emphasized

by scholars studying tonogenesis in Chinese (Egerod 1971; Pulleyblank 1978; Sagart 1988). Phonation type differences may also play a role in conditioning tone splits. Haudricourt recognized early on that voicing was not only conditioning f0 modulations, but was also associated with variation in phonation type and vowel quality (Haudricourt 1965). These observations have led some scholars to make the strong claim that tonogenesis necessarily entails a stage at which the pitch contrast is dependent on voice quality (Thurgood 2002), but in the absence of evidence for a voice quality stage in many tonal languages, this remains controversial.

Much subsequent work has broadly validated the Haudricourt model and demonstrated that most of the tonal contrasts found in Southeast and East Asian languages can be traced back to the three-way and/or two-way splits. However, other tonogenetic paths are also attested. Simple tone systems have developed through the merger of a vowel length contrast in Hu (Svantesson 1991), through the intrinsic f0 associated with various vowel qualities in U (Svantesson 1988, 1989), and possibly through the loss of onset /r/ in some Khmer dialects (Wayland & Guion 2005; Filippi 2006; Kirby 2014a, 2014b). Furthermore, some Kam-Sui languages that originally had a three-way contrast between sonorants in initial position (plain, glottalized and aspirated) have undergone a corresponding three-way tone split (Haudricourt 1961).

In most cases, the complexity of the tone system that a language develops appears to be largely a function of whether coda or onset contrasts are neutralized first (if both types of neutralization indeed occur). Generally speaking, languages with complex pitch-based tones, regardless of whether or not they are accompanied by phonation type contrasts, normally develop from the loss of final laryngeals (followed by a split conditioned by onset voicing), while canonical register systems appear more likely to stem from the transphonologization of the multiple acoustic dimensions associated with onset voicing (where subsequent neutralization of

codas, if any, does not seem to trigger a tone split). This observation was foreshadowed by Haudricourt (1965), who proposed that the loss of a voicing contrast triggers registrogenesis in an atonal language, but a tone split in a language that is already tonal. Although there do exist languages that appear to have developed a pitch-based contrast *directly* from differences in onset voicing – presumably via the transphonologization of obstruent-induced onset f0 perturbations (Hombert *et al.* 1979) – the available evidence suggest that passing through a register stage first is significantly more common.

We would like to conclude this section on a difficult question that arises when considering the development of register from the neutralization of onset voicing: at what point should the acoustic dimensions used in the production of register be considered phonologically contrastive in their own right, rather than simply the acoustic expression of voicing? In other words, when a language goes from a stage in which the primary phonetic correlates of voicing are Voice Onset Time (VOT) and/or the vibration of the vocal folds together with some registral properties (e.g. vowel quality, phonation type, duration) to a stage in which VOT and (phonetic) voicing are neutralized, but registral properties are preserved, should this be considered a phonological change, or simply a reorganization of phonetic cues? A case in point is Kammu (also Khmu), a Mon-Khmer language indigenous to Laos and now spoken across northern Mainland Southeast Asia. While Eastern Kammu is atonal and preserves an onset voicing contrast, the voicing contrast has been (partially) neutralized in Northern and Western Kammu and replaced with a contrast between a high and a low tone (Table 5). One interpretation of these data is that the 'tone' contrast in the Northern and Western dialects is simply the surface realization of an underlying voicing contrast, a claim that is partly supported by mutual intelligibility between tonal and atonal dialects (Svantesson 1983; Svantesson & House 2006). Are we really talking

about a single underlying contrast with multiple dialect-specific phonetic realizations? In the case of Western Kammu, morphophonological alternations and evidence from poetry support the tone-as-voice analysis, but the question is much harder to tackle in languages that offer little in the way of morphophonological alternations.

Table 5: Tones in Kammu dialects (from Svantesson & House 2006). The initial voicing contrast maintained in (toneless) Eastern Kammu is transphonologized into a high-low pitch contrast between sonorants and unaspirated (in Northern Kammu) or aspirated stops (in Western Kammu).

Eastern	*Northern*	*Western*	*gloss*
taaŋ	táaŋ	táaŋ	'pack'
daaŋ	tàaŋ	tʰàaŋ	'lizard'
tʰaaŋ	tʰáaŋ	tʰáaŋ	'to clear'
r̥aaŋ	ráaŋ	ráaŋ	'tooth'
raaŋ	ràaŋ	ràaŋ	'flower'

4. Current issues of active research interest

In this section, we would like to discuss a few topics of special interest involving Southeast Asian tonation.

A. Phonological processes involving tone and phonation

The first is the issue of phonological processes and alternations involving tones. Most languages of the area have at least some tone-based alternations. Hmong-Mien languages, for instance, have complex tone sandhis (Ratliff 1987; Mortensen 2004), and even a radically

isolating language like Vietnamese has tonal reduplication rules (Ngô 1984; Phạm 2001). Several languages also use tone for grammatical purposes (Henderson 1967; Ratliff 1992). Moreover, there are a number of Tibeto-Burman languages that seem to have decomposable contour tones of the sort more familiar to Africanists, and that have alternations involving tone spreading and the Obligatory Contour Principle, for example the Naish (Michaud & Xueguang 2007) and Kuki-Chin languages (Hartmann-So 1989; Hyman & VanBik 2002; 2004; Hyman 2007; Watkins 2013). These languages are typologically very different from the stereotypical Southeast Asian tone system, in which tones are tightly bound to their tone-bearing segment. Because they are mostly spoken in regions of northeastern Myanmar that are not easily accessible for geographical and political reasons, such systems are critically underdescribed. However, there is also the possibility that researchers may have generally underestimated the extent of tonal alternations in Southeast Asia due to a pre-existing bias to expect languages of the region to be morphologically isolating.

B. Tone and intonation

Although there now exists a sizeable body of literature on the interaction of tone and intonation in languages of Europe, Africa, the Americas, Japanese and Korean, there is relatively little work on the interaction between tone and intonation in Southeast Asia (there is, however, significant research on typologically comparable Chinese varieties since the seminal work of Chao (1933)). Work on Vietnamese indicates that the pitch range of sentences can be shifted up or down to indicate communicative functions, without affecting patterns of contrasts between lexical tones (Trần 1967; Đỗ *et al.* 1998; Nguyễn & Boulakia 1999; Brunelle *et al.* 2012). Work on repair strategies, however, has shown that intonation can override the lexical tone of

backchannel particles and short utterances (Hạ 2010; Hạ & Grice 2010; Hạ 2012). Similar shifts in f0 range have been described for Thai (Luksaneeyanawin 1998), with additional evidence that some final particles systematically preserve their lexical tones, while others are overridden by boundary tones (Pittayaporn 2007). Studies of Kammu intonation also show that in the tonal dialect(s), the priority is to maintain the identity of lexical tones, even if this obscures boundary tones (Karlsson *et al.* 2007; House *et al.* 2009; Karlsson *et al.* 2010; Karlsson *et al.* 2012). We hope that the complexity and diversity of Southeast Asian tone systems begins to attract more attention from intonation researchers in the near future.

C. Perceptual integrality and the acoustic representation of phonation

Finally, we would like to raise two important phonetic issues that are, in our opinion, likely to shape our understanding of tonation over the next few years. The first is the issue of perceptual separability, or the *integrality* of the phonetic properties associated with tonation. By integrality, we refer to the observation that two or more acoustic cues produced simultaneously may result in a more distinct percept if they are acoustically similar and therefore reinforce one another (Kingston *et al.* 2008). Most phonetic studies of Southeast Asian tone systems make the tacit assumption that pitch, voice quality, vowel quality and closure voicing are perceptually independent, and that listeners treat them as distinct acoustic properties. However, several studies have shown that these properties may integrate perceptually (Li & Pastore 1995; Kingston *et al.* 1997; Silverman 2003; Kingston *et al.* 2008) and at least one suggests that this integrality can be language-specific (Brunelle 2012). If f0, voice quality and voicing are not fully independent, the distinction between a voicing contrast and a tone or register contrast is perhaps less meaningful to native speakers than it is to the phonetician. More (and more sophisticated)

perceptual studies, especially on languages with phonation type contrasts, promise to enhance our understanding of this issue (for some recent examples, see Abramson *et al.* 2007; Brunelle 2012; Kuang 2013).

The other phonetic issue is the complex relationship between the production of phonation types, their acoustic realizations, and the variable utility of different voice quality measures. While acoustic studies of voice quality and phonation type have been conducted for a variety of Southeast Asian languages (Lee 1983; Huffman 1987; L-Thongkum 1987a, 1987b, 1988, 1990, 1991; Hayward 1993, 1995; Andruski & Ratliff 2000; Watkins 2002; DiCanio 2009; Esposito 2012; Garellek *et al.* 2013; Kuang 2013), drawing inferences about the underlying laryngeal mechanisms remains a challenge. This is in part due to the many-to-one mapping between articulatory configurations and acoustic realizations: that is, while a measure such as H1-H2 (the relative amplitude of the first two harmonics of the speech spectrum) is broadly correlated with the open portion of the vocal fold cycle, one is not licensed to conclude that the same laryngeal configuration is responsible for identical H1-H2 values in two languages, speakers, or even utterances (Klatt & Klatt 1990; Simpson 2012). Moreover, there exists considerable variation in the extent to which a given acoustic dimension distinguishes one phonation type from another cross-linguistically. For example, Esposito (2006) found that while H1-H2 distinguished modal from breathy voicing in Hmong and Chong, it failed to do so for Mon and Tamang. The advent of increasingly sophisticated laryngeal vocal tract models (Esling 2005; Edmonson & Esling 2006; Titze 2006; Moisik 2008, 2013), together with more wide-ranging and detailed acoustic studies, promises to enhance our understanding of phonation type in Southeast Asia in the coming years.

5. Technological developments

A. Acoustic and perceptual studies

The kinds of research questions that have been asked at various times in the history of Southeast Asian studies have been led in part by technological developments. For example, experimental research on the f0 component of Southeast Asian tones started relatively early, thanks in no small part to the development of the sound spectrograph at Bell Labs during World War II (Koenig *et al.* 1946). This led to pioneering acoustic investigation of the tone systems of the major national languages of Southeast Asia conducted from the 1960s and onwards (Abramson 1962; Han 1969; Han & Kim 1974; Earle 1975; Abramson 1978; Abramson 1979; Gsell 1980; Vũ 1982; Seitz 1986). Apart from early work on Thai and Kammu (Abramson 1975; Gandour *et al.* 1978; Gandour & Harshman 1978), however, work on the perception of pitch-based tonal contrast in Southeast Asia has only developed more recently, largely thanks to technological developments facilitating f0 (re)synthesis (Burnham & Francis 1997; Svantesson & House 2006; Abramson *et al.* 2007; Zsiga & Nitisaroj 2007; Brunelle 2009b; Kirby 2010; Brunelle & Finkeldey 2011; Gruber 2011; Brunelle 2012; Brunelle & Jannedy 2013).

Although the role of voice quality in the production and perception of tone contrasts was noted very early (Maspero 1912), systematic investigation of the acoustics of voice quality in Southeast Asia only began in earnest in the 1980s, as increasing availability of robust tools for spectral analysis (and, again, the personal computer) allowed for more systematic study of a wider range of languages (see the references in §4.C. above). Recently, the development of user-friendly applications for voice quality measurement (Shue *et al.* 2011), which crucially incorporate correction of the influence of vocal tract configuration on harmonics (Iseli & Alwan 2004), have facilitated more reliable cross-linguistic acoustic comparison. However, perceptual

studies of phonation type are still limited, and very few explicitly manipulate a continuum of values in the manner normally seen in perceptual studies of pitch or vowel quality (but see Abramson *et al.* 2004; Brunelle 2012; Garallek *et al.* 2013).

B. Articulatory and physiological studies

After five decades of experimental research on tonation in Southeast Asian languages, we now have a fairly good picture of the acoustic realization of tone and register. However, the articulatory strategies and aerodynamic properties involved of their production are much less well understood, largely because of the costs and low portability associated with articulatory techniques, together with lack of access to research facilities in Southeast Asia where invasive work can be conducted.

Early work on the physiology of Southeast Asian tones was conducted using purpose-built instruments such as the thyroumbrometer (Ewan & Krones 1974) and cricothyrometer (Gandour & Maddieson 1976), both designed to measure larynx height displacement. Pioneering electromyographic research on Thai was also undertaken in the early 1970s (Erickson 1976; 1993; Erickson & Abramson 2013), but there is as far as we know no similar work on any other Southeast Asian language (but see Sagart *et al.* 1986; Hallé 1994 for EMG studies of Mandarin). The technique that may have the most potential for the investigation of tonation in the near future is laryngoscopy, the increasing use of which may highlight the surprising diversity of voice qualities and the role of specific articulators of the larynx and pharynx in their production (Edmondson & Esling 2006). Laryngoscopic videos have shown that articulators such as the aryepiglottic folds, the epiglottis and the ventricular folds can be used in the production of voice

quality contrasts in Yi and Bai (Edmondson *et al.* 2001), and a laryngoscopic and laryngographic study of Northern Vietnamese tones also suggests that glottal constriction is the main mechanism in f0 drop in at least one tone (Brunelle *et al.* 2010). So far, the main problems of this technique have been its relatively slow frame rate and the difficulty in quantifying results (Hayward *et al.* 1994; Edmondson *et al.* 2001; Brunelle 2010; Brunelle *et al.* 2010). However, the development of high-speed, high-resolution cameras will help to alleviate issues of data quality, while advances in image processing analysis will make it possible to more accurately quantify changes in laryngeal configurations (Moisik *et al.* 2014).

Semi-articulatory research on voice quality has been conducted using inverse filtering (Edmondson 1997; Nguyễn & Edmondson 1997) and electroglottography (EGG) (Michaud 2004; Michaud & Vũ 2004; Vũ *et al.* 2005; Brunelle 2009a). These techniques have the major advantage of not being too invasive, but interpretation of the results is not always straightforward. For inverse filtering, dynamic variation in formant bandwidths and frequencies and/or significant noise components make it difficult or impossible to insure that the recovered signal is an accurate representation of the glottal source wave, while the amplitude of the EGG signal varies with a number of factors including configuration and placement of electrodes, changes to the electrical contact between the electrodes and the skin, and amount and type of tissues surrounding the larynx. Furthermore, there are often physiological properties of the target population that complicate data acquisition using these techniques. Differences in facial morphology require customized inverse filtering masks to insure an adequate seal, and it can be difficult to obtain EGG signal of sufficient quality for quantitative analysis from smokers and speakers with small vocal fold masses, especially women. Nevertheless, EGG is still an

extremely valuable technique in that it is not uncomfortable to speakers and is completely non-invasive.

6. Conclusion

As shown in the sizeable body of literature published since the middle of the 20th century, the languages of Southeast Asia exhibit a wide range of tonal systems, and a significant proportion of them are atonal, even in Mainland Southeast Asia. In this paper, we have advocated that, although descriptive categories like tone and register can be convenient shortcuts, conceiving of tone and phonation as discrete categories is neither typologically or diachronically useful. Thanks to better access to the field and increasingly portable equipment, Southeast Asianists are in a good position to explore new phonological and phonetic questions pertaining to tonation and to approach old ones from new perspectives.

7. References

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