The Phonology and Phonetics of Laryngeal Stop Contrasts in Assamese[•]

This paper investigates the expression of the voicing and aspiration contrasts in the stop systems of Hindi, Bengali, and Assamese, with a focus on the latter. Three contexts are examined: intervocalic (baseline), word-final prepausal, and preconsonantal. The major results are as follows. First, in all three languages voicing contrasts are maintained word-finally while aspiration contrasts are less stable and subject to enhancement or neutralization. Second, in Assamese, the word-final aspirates spirantize and/or modify their minor place of articulation while plain stops remain unchanged. This shift is modeled as faithfulness for the auditory turbulence feature of the aspirate, realized either internal to the stop (/p^h/ -> [f], /k^h/ -> [x], or as a release whose spectral properties best match the underlying aspirate (/t^h/ -> [t̪]). Third, in preconsonantal position the voicing and aspiration contrasts are preserved before sonorants but largely neutralized before obstruents. The overall Assamese distribution is consistent with and supports the Licensing by Cue model of laryngeal stop contrasts proposed by Steriade (1997, 2009). Fourth, two of three Bengali speakers neutralize the aspiration contrast word-finally while Hindi-Urdu maintains the contrast. The word-final realizations of the aspiration contrasts are modeled as an OT typology with different rankings among faithfulness and markedness constraints and a fixed subordinate ranking with respect to voicing.

Keywords: typology, aspiration, voice, Assamese, Bengali

1. Introduction

Contrasts in voicing and aspiration are among the most common phonological distinctions in stop inventories (Ladefoged and Maddieson 1996:47). They are typically distributed over the entire system (Feature Economy of Clements 2003), though there are occasional gaps at particular points of articulation such as Arabic /t/ vs. /d/ but /b/ vs. */p/ and /k/ vs. */g/. Voicing and aspiration contrasts share similar phonetic resources, in particular VOT (voice onset time, Lisker and Abramson 1964). These features may function as alternative expressions of the same historical contrast, as in Dutch [±voice] vs. German [±spread gl] reflexes of Proto-

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Germanic (Jessen and Ringen 2002). Also, the same underlying phonemic category may distribute its allophones at different points along the VOT dimension, as in Korean where the underlying lax stops are realized with voicing intervocalically as [b, d, g] but as voiceless unaspirated [p, t, k] word or phrase initially, and as aspirated [p^h, t^h, k^h] in the current Seoul dialect of younger speakers, where they are distinguished from underlying aspirated stops by lower F0 in the following vowel (Silva 2006). Finally, voicing and aspiration contrasts have cross-linguistically similar distribution profiles with optimal realization before a modally voiced sonorant but a tendency towards neutralization at the end of the word or before an obstruent. Various researchers, most notably Lombardi (1995), unified such distributional restrictions in terms of feature licensing in the syllable onset, with a default to the unmarked voiceless, unaspirated categories in the complementary set of prosodic positions where consonants may be subject to additional assimilation to neighboring segments. This syllable-licensing model of laryngeal contrasts was challenged by Steriade (1997, 2009) who called attention to languages like Lithuanian, where an obstruent voicing contrast is preserved before sonorants (R) but is neutralized before other obstruents (O). Syllable licensing implies that OO and OR clusters differ in syllabification as hetero vs. tautosyllabic. But such a parsing is inconsistent with evidence from the prosody of the language. For example, standard grammars such as the *Lietuviu kalbos gramatika* and Senn (1966:61) state that prefix and compound junctures coincide with a syllable boundary. Nevertheless, O#R clusters preserve a voicing contrast while O#O clusters show neutralization and voicing assimilation in these contexts: *stab-meldyste* 'idolatry' vs. *silk-medis* 'silk-tree' but *smulk-žemis* [gž] 'landowner'. In the face of this finding, Steriade (1997) proposes an alternative string-based model for the licensing of laryngeal contrasts as a function of the segmental contexts in which the auditory cues to the contrasts are most robust. The optimal context is between sonorants (R__R), especially vowels, followed by less optimal word-final (__#) position, and finally least optimal pre-obstruent (__O) position. The string-based model predicts more fine-grained distinctions in the distribution of laryngeal contrasts compared to the essentially binary onset vs. coda division of the prosodic model. Steriade (1997) finds that the segmental contexts that license contrasts for voicing largely align with the contexts that license contrasts for aspiration, since VOT is a major cue for both features.

The Indic languages spoken in the North of the Indian subcontinent are particularly relevant to this line of inquiry since their stop systems are well known for freely combining phonological contrasts in both voicing and aspiration across three to five places of articulation. Phonologically, voiced and voiceless aspirates behave in tandem for a couple of significant alternations in Assamese (see section 2 below), showing that the aspirates form a natural class. Further evidence for this point is furnished by a dialect split in which an aspirated stop has been deaspirated when the preceding syllable contains another aspirate (Goswami 1966:6): cf. deaspirating Eastern Assamese *p^hopola* 'hollow' and *b^hok* 'hunger' vs. Western *p^hap^hla* and *b^hak^h*. Also, /C^h/ acts as a single consonant rather than as a cluster in the schwa syncope of Hindi-Urdu that applies in the context VC__CV (Narang and Becker 1971, Bhatia and Kenstowicz 1972) and for the raising of open mid vowels in the context __CV in Assamese (Goswami 1966:75, Mahanta 2007). These processes suggest that the aspirates cannot be reduced to a sequence of C plus /h/. Finally a couple of phonotactic constraints in Assamese make the same point. First, the voiceless and voiced aspirates parallel plain stops in combining with a following liquid /r/ in the formation of word-initial #CR clusters. Second, as observed by an anonymous reviewer, in word-initial Ch structures, the C must be a stop, a restriction that follows automatically if Ch is a single segment. In sum, in terms of phonological structure the Indic aspirates behave as single segments and [±voice] and [±spread gl] are independent distinctions that crosscut the stop systems.

Phonetically, the Indic /b/ vs. /p/ vs. /p^h/ contrasts align with the cross-linguistically common prevoiced vs. short lag vs. long lag VOT spectrum seen in languages like Thai (Lisker and Abramson 1964). But the voiced aspirates are anomalous from this VOT perspective. Phonetically, the abduction of the vocal folds implementing aspiration is prima facie antagonistic to the adduction required to generate phonation. This fact led Ladefoged (1975) to propose that voiced aspirates are murmured sounds: produced with one portion of the glottis open during stop closure and another portion adducted, comparable to the voiced /ɦ/ in English 'ahead'. An alternative approach to this articulatory conundrum appeals to phasing: voiced aspirates are like plain voiced stops in showing voicing during closure but are like voiceless aspirates in having an open glottis after release of the oral closure (Ingemann and Yadav 1978). Another phonetic issue concerns whether the extent of VOT is derivative from the magnitude of glottal opening, as proposed originally by Kim (1965) for Korean, or rather must be stipulated as a separate timing target. The fiber optic studies of Kagaya and Hirose (1974) for Hindi and Ingemann and Yadav (1978) for Maithili find a much larger glottal opening for the voiceless aspirates compared to the voiced ones; both reach their maxima in the vicinity of the release of the oral closure and, for the most part, terminate at comparable points in the following vowel. This finding suggests that for the Indic languages the point of resumption of glottal closure cannot be predicted from the degree of glottal opening, as proposed for Korean by Kim (1965).

In sum, the stop inventories of the Indic languages give rise to the following questions that are particularly relevant for the Licensing by Cue model of Steriade (1997, 2009). How are the phonetic cues apportioned for the two separate phonological distinctions of [±voice] and [±spread gl]? Will we find the same hierarchy of licensing contexts for both features? If not, is one contrast more susceptible to neutralization? If so, why?

In this paper we address these questions with respect to four members of the Indic family. Our principal focus is Assamese and Bengali with comparisons to what is known from the literature on Hindi-Urdu and Sanskrit. We argue that each language represents a distinct niche in the overall typology of the licensing of the voicing and aspiration contrasts in prepausal, word-final position. In all three of the modern languages voicing contrasts are stable in this position while aspiration contrasts are more varied in their realization. In particular, we show that in Assamese the underlying contrast between aspirated and plain stops is maintained by various enhancement strategies while in Bengali the contrast is largely neutralized. In Hindi-

Urdu the aspiration contrast is maintained along with the voicing contrast; but even here there is evidence that the aspiration contrast is less secure in word-final position. Finally, in Sanskrit both the voicing and the aspiration contrasts are neutralized word-finally. What is noticeably missing from the typology is a language that retains the aspiration contrast but neutralizes voicing in final position. We propose that this gap is not accidental but reflects a UG (universal grammar) bias that is grounded in the phonetic correlates to the two contrasts.

The rest of this paper is organized as follows. In section 2, we overview the phonological distribution of the laryngeal stop contrasts in Assamese. Section 3 reports the phonetic correlates of these contrasts in both word-medial and word-final positions. The motivation for a spirantization process is argued to be acoustic-auditory in nature in section 4. Section 5 examines the laryngeal stop contrasts in presonorant vs. preobstruent positions and shows that the predictions of the cue-licensing model are largely consistent with our data. Sections 6 and 7 compare the Assamese treatment of the laryngeal stop contrasts in word-final position with those of Bengali and Hindi-Urdu, respectively. Section 8 summarizes our findings and analyses and concludes.

2. Assamese phonemic inventory

Assamese phonology has the phonemic inventory shown in (1) below (Mahanta 2012). While there are a variety of dialects, the table represents the contrasts for the standard eastern variety. The data discussed in this paper are based on the speech of the first author, who is a native speaker of this variety from the Sonitpur region of Upper Assam.

(1) Phonemic inventory of Assamese

	Vowels			Consonants				
	Front	Back		Bilabial	Alveolar	Palatal	Velar	Glottal
High	i	u, ʊ	Plosive	p	t		k	
Mid	e	o		b	d		g	
	ɛ	ɔ		pʰ	tʰ		kʰ	
Low		a		bʰ	dʰ		gʰ	
			Nasal	m	n		ŋ	
			Fricative		s, z		x	h
			Approximant		ɹ	j	w	
			Lateral		l			

Ignoring loanwords, the close mid vowels /e/ and /o/ are allophones of the corresponding open vowels /ɛ/ and /ɔ/ when the following syllable contains a high vowel or another /e/ and /o/.

See Mahanta (2007) for documentation and analysis. Stop and nasal place contrasts are restricted to the labial, alveolar, and velar regions. As in Hindi-Urdu, voicing and aspiration are fully crossed in Assamese resulting in 12 contrasting stops. (However, the voiced velar /g^h/ seems to be relatively infrequent compared to the other stops.) The aspirates are found in both the native *tadbhava* vocabulary ([b^{h}ori] 'foot', [p^{h}oriŋ] 'cricket') as well as in Sanskrit (*tatsama*) loans ([b^{h}ɔsmɔ] 'ashes', [p^{h}agun] 'February-March'). Fricatives appear at the alveolar and velar positions but are absent from the labial region (a fact that will be come important later). For the fricatives the laryngeal contrasts are governed by common markedness preferences. There are no aspiration contrasts in the fricative series, showing the cross-linguistic bias against aspirated fricatives. A voicing contrast is found for the alveolars while the velar fricatives are restricted to the unmarked voiceless. Finally, voiced /z/ is optionally realized as a palatal affricate.

Figure 1 from Mahanta (2012) shows minimal quadruples at the three places of articulation for the laryngeal contrasts in stops.

CONSONANT	TRANSCRIPTION	ORTHOGRAPHY	GLOSS
p	pɑl	পাল	'to rear'
p^h	p^{h}ɑl	ফাল	'to split'
b	bɑl	বাল	'male child'
b^h	b^{h}ɑl	ভাল	'good'
t	tɑl	তাল	'Palmyra tree'
t^h	t^{h}ɑl	থাল	'plate'
d	dɑl	দাল	'branch'
d^h	d^{h}ɑl	ধাল	'shield'
k	kɑl	কাল	'time'
k^h	k^{h}ɑl	খাল	'ditch'
g	gɑl	গাল	'cheek
g^h	g^{h}ɑt	ঘাত	'stroke'

Figure 1. Minimal pairs illustrating laryngeal stop contrasts of Assamese in word-initial position (Mahanta 2012:218)

The table in (2) gives more examples from our data of these contrasts in word-medial, intervocalic position.

(2) Assamese laryngeal contrasts: (near) minimal pairs in intervocalic position

[kɔpal]	'forehead'	[bɔta]	'prize'	[pɔka]	'concrete'
[baba]	'father	[badam]	'almonds'	[bɔga]	'white'
[sɔp^{h}a]	'clean'	[bɔt^{h}a]	'oars'	[pɔk^{h}a]	'weed'
[xɔb^{h}a]	'meeting'	[bad^{h}a]	'setback'	[pɔg^{h}a]	'rope'

In word-final position there is a striking modification of the aspirated stops along the dimensions of place and manner of articulation (Goswami 1966, Dutta Baruah 1992, Rhee 1998).

We summarize the phenomenon in (3) based on our data. Examples appear in (4). See 3.2 for discussion of dialectal variation.

(3) a. bilabial aspirate stops are realized as labio-dental fricatives [f] and [v]
b. alveolar aspirate stops are realized as dental stops [t̪] and [d̪]
c. the voiceless aspirated stop /kʰ/ is optionally realized as the fricative [x]

(4) realization of laryngeal contrasts in word-final position

/p/	[sap˺]	‘pressure’	/t/	[bɔt˺]	‘tree’	/k/	[mak˺]	‘mother’
/pʰ/	[saf]	‘clean’	/tʰ/	[kat̪]	‘wood’	/kʰ/	[sɔx ≈ sɔkʰ]	‘interest’
/b/	[dab]	‘coconut’	/d/	[rod]	‘sun’	/g/	[dag]	‘spot’
/bʰ/	[lav]	‘profit’	/dʰ/	[bɔd̪]	‘kill’	/gʰ/	[bagʰ]	‘tiger’

The Assamese aspirate shift occasions alternations in the inflectional and derivational phonology of both nouns and verbs. Examples appear in (5).

(5) alternations in the realization of underlying aspirates in Assamese

noun inflection

citation	[lav]	[bɔrɔf]	[krʊd̪]	[kat̪]	[dukʰ] ≈ [dux]
ergative	[labʰ-ɛ]	[bɔrɔpʰ-ɛ]	[krʊdʰ-ɛ]	[katʰ-ɛ]	[dukʰ-ɛ]
accusative	[labʰ-ɔk]	[bɔrɔpʰ-ɔk]	[krʊdʰ-ɔk]	[katʰ-ɔk]	[dukʰ-ɔk]
	‘profit‘	‘ice’	‘anger’	‘wood’	‘sadness’

verb inflection

imper. familiar	[lʊv]	[saf]	[rand̪]	[gat̪]	[lɛkʰ] ≈ [lɛx]
imper. formal	[lʊbʰ-ɔk]	[sapʰ-ɔk]	[randʰ-ɔk]	[gatʰ-ɔk]	[lɛkʰ-ɔk]
infinitive	[lʊbʰ-i]	[sapʰ-i]	[randʰ-i]	[gatʰ-i]	[lekʰ-i]
	‘be greedy’	‘to clean’	‘to cook’	‘to tie’	‘to write’

derivation

[maf]	‘forgive, imper.’	[mapʰ-i]	‘forgiving’
[lʊv]	‘be greedy, imper.’	[lʊbʰ-i]	‘greedy person’
[kat̪]	‘wood’	[katʰ-oni]	‘wooded place’
[band̪]	‘bind, imper.’	[bandʰ-oni]	‘bond’
[lɛkʰ] ≈ [lɛx]	‘write, imper.’	[lɛkʰ-ɔk]	‘writer’

In sum, both the voicing and aspiration contrasts are stable in prevocalic word-initial and word-medial (syllable-onset) positions but differ in their realizations word-finally. The [±voice] distinction is expressed in essentially the same way across all three of these positions while the aspirates exhibit a striking modification in their manner and minor places of articulation in word-final position.

3. Phonetic correlates

In this section we report the phonetic correlates of the Assamese voicing and aspiration contrasts based on an analysis of the speech of the first author.

3.1 Word-medial position

A corpus of 130 words (see Appendix A) was constructed that varied the voicing and aspiration stop contrasts across the labial, alveolar, and velar places of articulation for intervocalic and word-final positions. Where possible the adjacent vowels were restricted to nonhigh and back to provide a consistent context for segmentation. Each word was recorded in a randomized list with five repetitions to give a total of 650 data points. The words were recorded in a sound insulated booth with a Shure Unidirectional Head-Worn Dynamic Microphone and USB 2 Preamp at a sampling rate of 44.1 kHz, 16 bits. Statistical analyses (t-tests and linear regressions) were done in R (Bates and Maechler 2013). The following measurements were taken in Praat version 5.3.39 (Boersma and Weenink 1992-2013): the duration of stop closure as well as the interval from stop release to the onset of voicing in the following vowel (VOT) as determined by visual inspection of the waveforms and spectrograms. For this measure of VOT the cessation of random energy in the waveform was taken to coincide with the onset of the vowel even though there may have been some voicing during the aspiration period. Deciding where to draw the line within the aspiration period itself was deemed to be too tricky. The duration of voicing during stop closure until the cessation of oscillation above and below the baseline was estimated and then the ratio of closure voicing to total closure duration was calculated. Measures of the duration of the vowel preceding the stop as well as the F0 in the first observable pitch period of the vowel following release of the stop were also collected. These factors are known to be phonetic correlates of a voicing contrast in many languages (Lisker 1986, Kingston and Diehl 1994). Our results are summarized in the following tables in (6). The first shows the correlates for the voicing and aspiration contrasts across all consonants while the second breaks them down for the four individual sets. The first table also reports independent T-tests over the phonetic correlates as a function of the voicing and aspiration categories.

(6) Averages (and standard deviations) for phonetic correlates of laryngeal stop contrasts in medial position; T-tests of laryngeal categories

closure dur (ms)	[+voice]	[−voice]	[+spread gl]	[−spread gl]
mean (sd)	75 (16)	109 (18)	88 (23)	97 (24)

F-statistic: 316.2 on 1 and 337 df, $p < 0.001$ Adjusted R-squared: 0.48			F-statistic: 12.04 on 1 and 337 df, $p = 0.005$; Adjusted R-squared: 0.03	
voice ratio	[+voice]	[−voice]	[+spread gl]	[−spread gl]
mean (sd)	.80 (.20)	.09 (.07)	.39 (.35)	.50 (.40)
F-statistic: 1782 on 1 and 337 df, $p < 0.001$ Adjusted R-squared: 0.84			F-statistic: 6.9 on 1 and 337 df, $p = 0.008$; Adjusted R-squared: 0.01	
V1 duration (ms)	[+voice]	[−voice]	[+spread gl]	[−spread gl]
mean (sd)	84 (22)	67 (15)	76 (20)	75 (21)
F-statistic: 72.15 on 1 and 337 df, $p < 0.001$ Adjusted R-squared: 0.17			F-statistic: .23 on 1 and 337 df, $p = 0.63$; Adjusted R-squared: 0.002	
V2 F0 (Hz)	[+voice]	[−voice]	[+spread gl]	[−spread gl]
mean (sd)	135 (8)	144 (10)	140 (10)	138 (10)
F-statistic: 73.87 on 1 and 337 df, $p < 0.001$ Adjusted R-squared: 0.17			F-statistic: 4.52 on 1 and 337 df, $p = 0.03$; Adjusted R-squared: 0.01	
VOT (ms)	[+voice]	[−voice]	[+spread gl]	[−spread gl]
mean (sd)	47 (45)	63 (41)	89 (25)	12 (11)
F-statistic: 11.5 on 1 and 337 df, $p < 0.001$ Adjusted R-squared: 0.03			F-statistic: 1847 on 1 and 337 df, $p < 0.001$; Adjusted R-squared: 0.84	

medial	p, t, k	p^h, t^h, k^h	b, d, g	b^h, d^h, g^h
closure dur	115 (15)	103 (19)	80 (18)	70 (11)
voice ratio	.10 (.06)	.08 (.07)	.85 (.21)	.74 (.18)
V1 duration	63 (15)	70 (15)	86 (21)	83 (23)
V2 F0 (Hz)	142 (11)	145 (10)	134 (8)	135 (8)
VOT	19 (11)	97 (15)	6 (6)	88 (25)

Voiced stops have significantly shorter closure duration than voiceless ones, presumably reflecting the difficulty of sustaining voicing during the oral closure. There is a substantial difference in closure voicing, with the voiced stops showing phonation over roughly 80% of their duration compared to the voiceless stops' c. 9%. The duration of the preceding vowel and the F0 just after the release of oral closure also distinguish voiced from voiceless stops in the expected directions, with shorter vowels preceding the voiceless stops and higher F0 following them. Thus, the [±voice] contrast is associated with a variety of cues (acoustic correlates), with closure voicing being most robust in magnitude and significance and supported by smaller differences in the duration of the preceding vowel and F0 in the following vowel.

As far as the contrast in aspiration is concerned, the most reliable correlate is, not surprisingly, VOT. There is a large and statistically reliable difference between the aspirated C^h 89 (25) ms. vs. plain C 12 (11) ms. stops. There is also a small effect of voicing, with voiceless stops having longer VOT values than voiced ones in both the aspirated and the unaspirated categories. Unpaired t-tests found these differences to be significant: [b^h, d^h, g^h] vs. [p^h, t^h, k^h] ($t = 2.8$; F-statistic: 8.4 on 1 and 177 df 135, $p = .004$; Adjusted R-squared = 0.04) and [b, d, g] vs. [p, t, k] ($t = 9.1$; F-statistic: 82.23 on 1 and 158 df, $p = < 0.001$; Adjusted R-squared = 0.33). Maddieson and Gandour (1976) found a small difference in the length of the vowel before the voiced aspirates (longer) compared to their plain voiced counterparts in Hindi-Urdu, but no such difference holds in our Assamese data. The voiced aspirates [b^h, d^h, g^h] have shorter closure durations and smaller voicing ratios compared to their plain counterparts. Unpaired t-tests found these differences to be significant: closure duration ($t = 4.2$; F-statistic: 17.71 on 1 and 167 df, $p < 0.001$; Adjusted R-squared = 0.09) and voicing ratio ($t = 5.37$; F-statistic: 28.85 on 1 and 166 df, $p = < 0.001$; Adjusted R-squared = 0.14). These results would be consistent with the assumption that during the articulation of the voiced aspirates the glottis starts opening during the stop closure phase, as suggested by the fiber optic studies of Hindi by Kagaya and Hirose (1974) and of Maithili by Ingemann and Yadav (1977). Finally, voice quality (breathiness) in the following vowel was shown by Dutta (2007) to be another significant correlate of the aspirated stops in Hindi. We made a smaller number of measurements of this factor (H1 – H2) in the low back vowels in our corpus that follow a word-initial stop and found a similar result (not reported here).

In sum, both the [±voice] and the [±spread gl] contrasts are reliably distinguished in intervocalic position. They differ however in that there are more cues for the voicing contrast and the most robust one (closure voicing) is internal to the stop itself while the [±spread gl] distinction is signaled primarily by cues found in the following vowel, requiring a sequencing of the glottal closing and opening gestures.

3.2 Word-final prepausal position

In comparison to what is reported for other Indic languages (in particular Hindi-Urdu), the Assamese word-final aspirated stops undergo a shift in their manner and place of articulation, as indicated in section 2. Based on the preceding literature, there appears to be a significant amount of dialectal variation in the details of the process. But what is striking is that the shift only affects underlying aspirates and is confined to final position. Word-initial and word-medial aspirates are stable. We first summarize what is reported by Goswami (1966) and then by Dutta Baruah (1992).

Goswami (1966) states that while the present-day standard variety of Assamese is based on the eastern dialect of Sibsagar, in earlier stages of the language the western dialect prevailed over the entire country. The author is from the west. He reports that all aspirates word-finally are lenis. “There is a tendency to spirantize in some of the dialects, all except /dɦ/ and /gɦ/ into their homorganic spirants, i.e. /p^h, t^h, k^h, b^ɦ/ have the allophones [ɸ, θ, x, β] respectively” (p. 14). The author adds in a footnote that the realizations of /t^h/ as [θ] and /k^h/ as [x] are “dialectal”, commenting further that the former is not very frequent or rather is a free variant and the latter is always distinctive of some caste dialects. In (7) below are examples of the spirantization excerpted from Goswami’s discussion, using his notation.

(7)	map^h	[maɸ]	≈	[map^ɸ]	‘remission, weight’
	sap^h	[saɸ]	≈	[sap^ɸ]	‘clean’
	alɛ́p	[alɛ́ɸ]	≈	[alɛ́p^ɸ]	‘inverted comma’
	lab^h	[laβ]	≈	[lab^β]	‘income, gain’
	lob^h	[loβ]	≈	[lob^β]	‘greed’
	k^{h}job^h	[k^{h}joβ]	≈	[k^{h}job^β]	‘anger’
	zet^h	[zeθ]			‘second month of the Assamese year’
	pit^h	[pit^θ]	≈	[pit^h]	‘place, region’
	dɛk^h	[dɛk^h]			‘to see’

Dutta Baruah’s (1992) description of the eastern Sibsagar dialect reports spirantization of the word-final labials (pp. 41, 44), citing examples such as those in (8).

(8)	nip^h	[niɸ]	‘nib’
	map^h	[maɸ]	‘excuse’
	sap^h	[saɸ]	‘clean’
	lab^h	[laβ]	‘profit’
	xulɐb^h	[xulɐβ]	‘cheap’
	pab^h	[paβ]	‘a kind of fish’

From these two prior descriptions we infer that spirantization of the word-final labial aspirates is more widespread, while for the alveolars and velars the process is more “dialectal”. Also, for younger, more educated speakers, the bilabials seen in (7) and (8) are being replaced by labio-dentals. Below, we summarize the state of affairs for the first author’s speech, who is representative of this younger generation. Clearly, more research is needed to document the range of dialectal variation. For our purposes, the important point is that spirantization only affects underlying aspirates and is restricted to word-final position.

First, the voiceless velar stop /k^h/ is optionally realized as the fricative [x] (9). As indicated earlier, /x/ is an independent phoneme in the language and so the free variation between [k^h]

and [x] leads to a neutralization. It should be noted that for the words in (9), underlying /x/ never alternates with [k^h]. Aside from /x/ itself, only /k^h/ may be realized as [x]; /k/ may not. Minimal pairs include /duk^h/ > [duk^h] ≈ [dux] 'sadness' vs. /dux/ > [dux], *[duk^h] 'fault' and /rak^h/ > [rak^h] ≈ [rax] 'to keep' vs. /rax/ > [rax], *[rak^h] 'a Hindu festival'. Moreover, the spirantization of /k^h/ is not found word-medially or in initial position.[1]

(9) realizations of /k^h/ and /x/ in different positions of the word

	/k^h/		/x/	
initial	/k^{h}aru/	[k^{h}aru,] *[xaru] 'bangles'	/ xɔk^{h}a/	[xɔk^{h}a], *[k^{h}ɔk^{h}a] 'friend'
medial	/ak^{h}ɔr/	[ak^{h}ɔr], *[axɔr] 'letter'	/ɔxɔmia/	[ɔxɔmia], *[ɔk^{h}ɔmia] 'Assamese'
final	/mak^h/	[mak^h] ≈ [max] 'unit of measure'	/bax/	[bax], *[bak^h] 'to dwell'
	cf./mak/	[mak], *[max] 'mother'		

Second, the aspirated bilabial stops are obligatorily realized as labio-dental fricatives (10). The fricatives [f] and [v] are only found in this position in Assamese and may not appear word-initially or word-medially. Indeed, loanwords with /f/ and /v/ in these positions are adapted as aspirated stops (see below). Furthermore, it is only the underlying aspirates that are fricativized. Plain stops /p/ and /b/ do not alter their manner of articulation.

(10) realizations of /p^h/ and /b^h/ vs. /p/ and /b/ in different positions of the word

/sap^h/	[saf]	'to clean'	/pap/	[pap˺]	'sin'
/map^h/	[maf]	'to forgive'	/sap/	[sap˺]	'pressure'
/bɔrɔp^h/	[bɔrɔf]	'ice'	/d^{h}ap/	[d^{h}ap˺]	'slope'
/lab^h/	[lav]	'profit'	/bab/	[bab]	'designation'
/lʊb^h/	[lʊv]	'greed'	/dub/	[dub]	'to drown, sink'
/xourɔb^h/	[xourɔv]	'fame'	/kabab/	[kabab]	'kabab'

Third, the underlying coronal stops change their place of articulation from alveolar to dental (11). This change in point of articulation only affects the aspirates. Plain /t/ and /d/ remain alveolar. The dentalization of /t^h/ and /d^h/ does not apply to word-initial or word-medial stops. Only in word-final position does this process apply. We assume that the dentalized [t̪] corresponds to what Goswami (1966) transcribes as [t^θ].

[1] Mahanta's (2012:219) description of the speech of an eastern Assamese speaker from Jorhat indicates that spirantization for the velar /k^h/ occurs in word-medial position. The process is said to be dependent on the individual speaker and speech rate and formality.

(11) realizations of /t^{h}/ and /d^{h}/ vs. /t/ and /d/ in different positions of the word

/kat^{h}/	[kat̪]	'wood'	/bɔt/	[bɔt˺]	'Indian banyan'
/mɔt^{h}/	[mɔt̪]	'temples'	/d^{h}ɔpat/	[d^{h}ɔpat˺]	'tobacco'
/zɛt^{h}/	[zɛt̪]	'May-June'	/dupat/	[dupat˺]	'pair'
/bɔd^{h}/	[bɔd̪]	'to kill'	/rod/	[rod]	'sunshine'
/krʊd^{h}/	[krʊd̪]	'anger'	/mɔd/	[mɔd]	'alcohol'
/bud^{h}/	[bud̪]	'Wednesday'	/dɔrɔd/	[dɔrɔd]	'pain'
/t^{h}ɔga/	[t^{h}ɔga]	'artefact'			
/mat^{h}a/	[mat^{h}a]	'head'			
/d^{h}ɔni/	[d^{h}ɔni]	'wealthy'			
/rad^{h}a/	[rad^{h}a]	'Radha'			

A final relevant point is that words ending in /h/ are not modified. Only aspiration as a secondary feature in the stop system leads to a change.

(12) realization of word-final /h/

/kɔpah/	[kɔpah]	'cotton'
/bɔtah/	[bɔtah]	'wind'
/sah/	[sah]	'tea'
/dɔh/	[dɔh]	'ten'

In sum, word-final position is the site of three disparate modifications of the place and manner of articulation of underlying aspirate stops in Assamese. The voiceless velar /k^{h}/ is optionally spirantized to [x], merging with underlying /x/. The bilabials /p^{h}/ and /b^{h}/ are fricativized to [f] and [v], and lastly the alveolars /t^{h}/ and /d^{h}/ are realized as dentals [t̪] and [d̪]. Plain stops do not participate in these modifications nor does /h/.

3.3 [±voice] in word-final position

The plain stops retain the voicing contrast in word-final position. Mahanta (2012:218) states that syllable-final voiceless stops are unreleased while Goswami (1966) reports variation in release for word-final position. For a sample of the first three repetitions of our data, the nonrelease of plain voiceless stops varied as a function of place of articulation: [p˺] 23/24, [t˺] 10/19, [k˺] 10/24. The table in (13) shows that closure voicing and preceding vowel duration continue to distinguish the [±voice] contrast. We also provide the results for the plain consonants, which have been separated out from the spirantized aspirated stops. They have essentially the same differences as the overall set and so the various spirantization effects noted above do not alter the voicing contrast. The magnitude of the closure voicing is reduced compared to word-medial position but is still significantly different from the corresponding voiceless stops. The duration of the preceding vowel is almost twice as long as in medial position, presumably reflecting a lengthening before pause. We also checked the F0 in the vowel offset and found that it has a small effect in the expected direction (higher before voiceless).

(13) Averages (and standard deviations) for phonetic correlates of underlying laryngeal stop contrasts in word-final prepausal position

voice ratio	[+voice]	[−voice]	[b,d,g]	[p,t,k]
mean (sd)	.58 (.26)	.07 (.08)	.66 (.22)	.09 (.09)
t	-24.83			

F-statistic: 616.5 on 1 and 308 df, $p < 0.001$
Adjusted R-squared: 0.66

V1 duration (ms)	[+voice]	[−voice]	[b,d,g]	[p,t,k]
mean (sd)	151 (28)	126 (24)	151 (27)	124 (24)
t	-8.1			

F-statistic: 67.05 on 1 and 308 df, $p < 0.001$
Adjusted R-squared: 0.66

V1 F0 (Hz)	[+voice]	[−voice]	[b,d,g]	[p,t,k]
mean (sd)	140 (12)	144 (12)	138 (11)	140 (13)
t	3.03			

F-statistic: 9.17 on 1 and 308 df, $p = 0.002$
Adjusted R-squared: 0.02

final	p	p^h	b	b^h
voice ratio	.09 (.09)	.04 (.05)	.66 (.22)	.45 (.28)
V1dur	124 (24)	129 (24)	151 (27)	152 (29)
F0	140 (13)	148 (10)	138 (11)	142 (14)

In sum, the word-final [±voice] contrast in Assamese is robust and is expressed with the same phonetic correlates as in word-medial position. On the other hand, the aspirates are noticeably modified in their phonetic realization as either spirants or dentals. In the next section we discuss the motivation for this shift.

4. Motivation for Aspirate Shift

What is the motivation for the shift in the realization of the underlying aspirates in word-final position compared to their stable realization word-medially and initially? Our suggestion is that it is a maneuver of the phonology/phonetics designed to maintain/enhance the plain vs. aspirate contrast in a context where the cues to the contrast are either unavailable or significantly minimized in quantity and/or magnitude. Recall that in medial position the major correlates of [$\pm$spread gl] are the stop-external cues of VOT and the voice quality effects on the following vowel. In word-final, prepausal position there is no following vowel and so the acoustic/auditory reflexes of the open glottis will be significantly reduced. We can see this effect with the velar stop /k^h/, which has two variants in final position: the spirantized [x] and unspirantized [k^h]. The average intensities of the aspiration for a period of 30 ms after stop release in the medial prevocalic and word-final contexts for [k^h] were as follows: word-medial 55.21 dB (2.78) vs. word-final 49.54 dB (2.71). Remembering that the decibel scale is not linear, this is a significant difference in magnitude: Welch two sample t-test: $t = 5.81$, 24 df, $p = < 0.001$.

Given that there is motivation to enhance the aspiration contrast beyond simple release vs. unreleased, why is spirantization chosen rather than other possible changes such as preaspiration? First, there is cross-linguistic evidence for a close relationship between aspirated stops and the corresponding fricatives. In the loanword adaptation of fricatives into languages that lack the fricative but have a plain vs. aspirated contrast, the aspirate adaptation is chosen. This is seen in the examples in (14). Recall from the table of Assamese phonemes in (1) that the language lacks fricatives in the labial and interdental regions. English loans with these sounds are adapted as the corresponding aspirated stops in word-initial and medial positions. But due to the aspirate shift in final position, they can be accommodated directly in the case of the labials and as a dental stop in the case of /θ/. Korean lacks the labio-dental [f] entirely but has a three-way contrast of plain (lax), tense (fortis), and aspirated voiceless stops. The systematic choice of [p^h] rather than [p] reflects preservation of the frication in the aspirated release of the stop.

(14) Assamese

	$f > p^h$	[p^hrai] 'fry', [p^hɛn] 'fan', [telip^{h}un] 'telephone', [kɔf] 'cough'
	$v > b^h$	[b^hɛn] 'van', [b^hut] 'vote', [b^hɛlu] 'value', [lav] 'love'
	$θ > t^h$	[t^hri] 'three', [t^hiŋkar] 'thinker', [eit̪] 'eighth'

Korean

$f > p^h$	film > [p^hilɨm] (not [pilɨm]), coffee > [k^hap^{h}i], chef > [sjɛp^{h}u]

The Nilotic language Dinka lacks fricatives but has a dental vs. alveolar contrast in its stops and affricates (Remijsen and Manyang 2009). Arabic loans with /t, d/ are adapted as alveolar stops, while /s/ is nativized to a dental stop. This choice of dental over alveolar for the adaptation of /s/ parallels the Assamese realization of the aspirated /t^h/ as a dental. In both cases the alveolar (apical) place of articulation is replaced by a dental (laminal) one.

(15) (examples from Idris 2004)

cá̤a̤a̤ṯ < šaahi**d** 'witness'

rêeeṯ < raʔii**s** 'president'

ṯúuk < **s**uuk 'market'

Also, well known sound changes in the history of the Indo-European languages shift aspirates to the corresponding fricatives such as PIE *b^h, *d^h, *g^h > Greek Φ, θ, x and the Old-High German consonant shift of Proto-Germanic *p^h, *t^h, *k^h > f, t^s/s, x. See Vaux (1998) and Vaux and Samuels (2005) for more discussion of the connection between aspiration and fricatives.

Another question concerns the basis of the spirantization. Both the /p^h/ -> [f], and /k^h/ -> [x] alternations involve change to a continuant manner of articulation. Such changes are often associated with lenitions. But, as observed by Rhee (1998), the Assamese consonant shift does not have the profile of a typical lenition since it does not apply intervocalically—the canonical lenition site—nor does it affect the plain stops. We might view the spirantization as a reassociation of the opening gesture implemented by the glottis in the release and post-release phase of the aspirated stop to coincide with the oral constriction gesture implemented by the lips and tongue dorsum, changing the degree of constriction from closure to narrow stricture. But this would not explain the change of alveolar to dental where the consonant remains a stop. Moreover, it would be inconsistent with Padgett's (1991) generalization that the assimilation or spread of a stricture gesture only occurs when accompanied by an assimilation of place as well. See however Scheer (2003) for an analysis along these lines.

Our suggestion is that the similarity between the aspirated stops and the corresponding segments involved in the Assamese shift is rather to be found in the acoustic (auditory) domain. Both involve a significant degree of turbulent airflow distributed through the spectrum. This can be seen in the screenshots of the waveforms and spectrograms in (16) below. The first pair shows a word-medial aspirated [p^h] from the word [ep^hal] 'one piece' and its spirantized allophone [f] in final position from the word [saf] 'clean'. The second pair illustrates the two alternative realizations of a word-final velar aspirate from the word /mak^h/ 'unit of measurement'. In each case the fricative is associated with significant turbulence that is comparable to the random energy found in the aspirate.

(16)

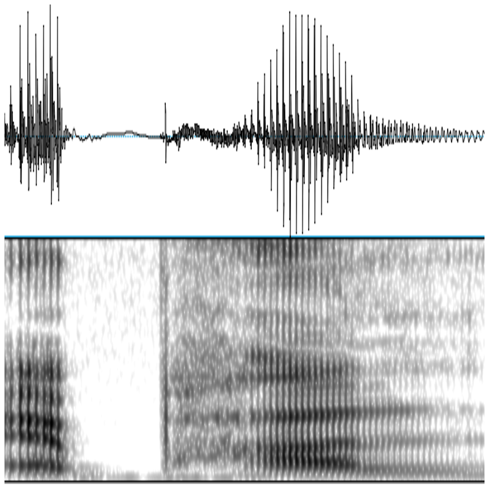


Figure 1: [$e p^h a l$] 'one piece'

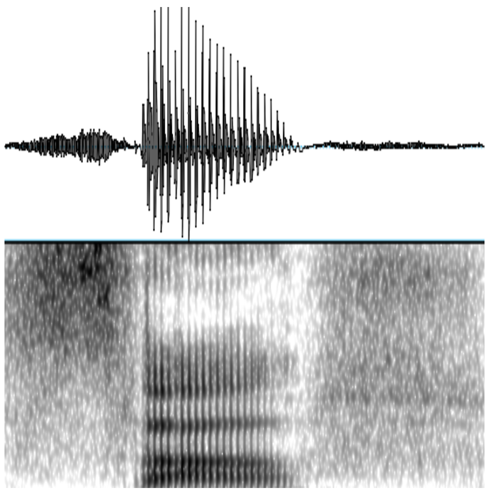


Figure 2: [saf] 'clean'

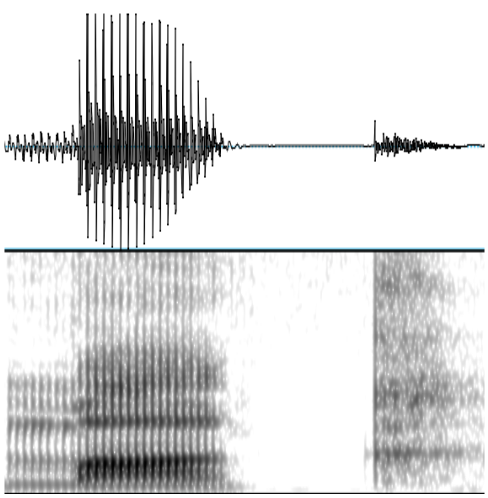


Figure 3: [$m a k^h$] 'unit of measure'

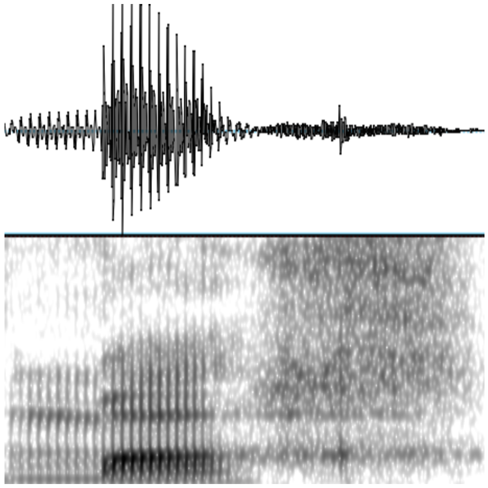


Figure 4: [max] ‘unit of measure’

Turning now to the coronal stops, we propose that the change from an alveolar to dental point of articulation is also motivated by acoustic similarity. The alveolar fricative [s] corresponding to the stop [t^h] has its turbulence concentrated in the upper region of the frequency spectrum while the dental [θ] mentioned by Goswami (1966) and the release phase of our [t̪] have a more diffuse spectrum that provides a better acoustic match to the aspiration. This is apparent from comparison of the /s/ in [saf] ‘clean’ in (16) with the release phases of [t^h] of [mat^ha] ‘head’ and the [t̪] in /mɔt^h/ > [mɔt̪] ‘temple’ in (17) and their corresponding FFT’s. The [s] has energy concentrated in the central region of the spectrum around 10,000 Hz while the release phases of [t^h] and [t̪] concentrate their energy in the lower regions. In other words, [t̪] is a closer acoustic match for [t^h] than [s] is. In addition, as noted by an anonymous reviewer, the shift to dental point of articulation enhances the contrast with the plain stops, which retain their alveolar place.

(17)

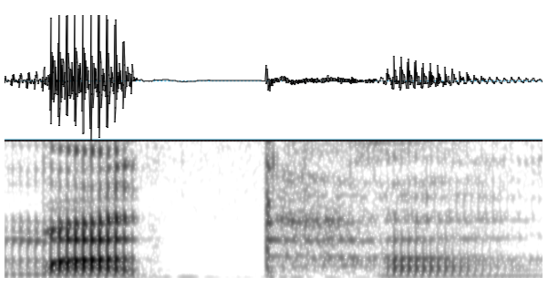


Figure 5: [mat^ha] ‘head’

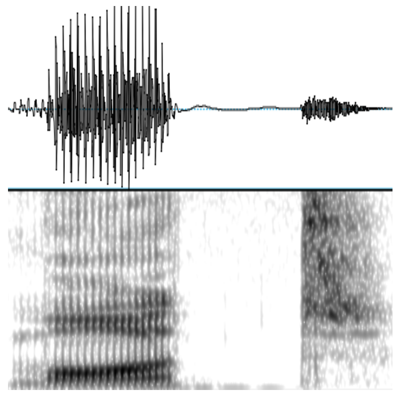
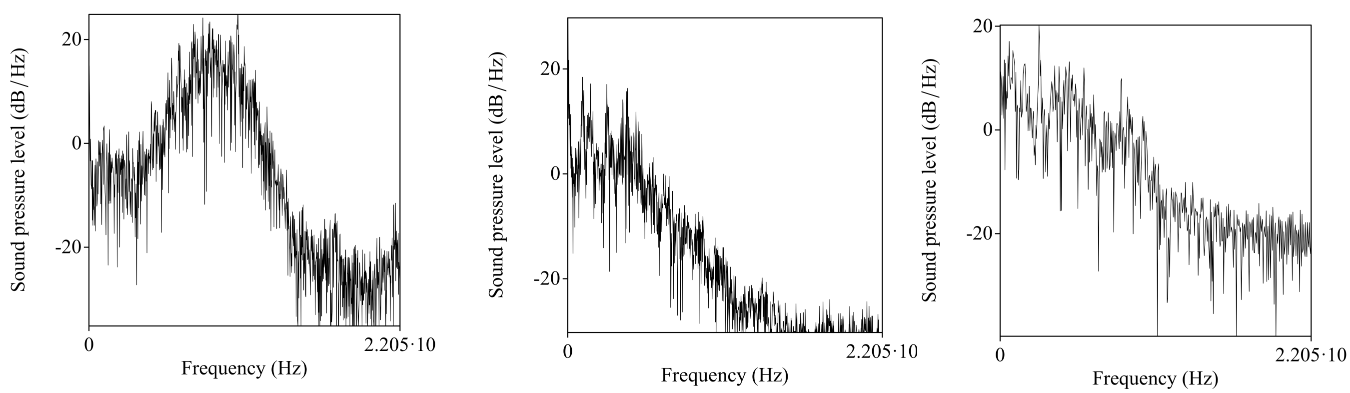


Figure 6: /mɔt^h/ > [mɔt̪] 'temple'



[s] of [saf] 'clean' [t^h] of [mat^{h}a] 'head' [t̪] of [mɔt̪] 'temple'

Figure 7. FFT's of three turbulent coronal consonants

The table in (18) shows center of gravity and skew measurements taken over 20 ms. intervals of the word-final segments involved in the Assamese spirantization using a Praat script due to Hoole (ND). For the stops the measurements were made over the release phases.

(18) center of gravity and skew measures of various word-final segments

segment	N	center of gravity	skew
f	15	4412 (1212)	0.41 (0.56)
v	11	2569 (950)	1.99 (1.16)
k^h	14	1780 (282)	3.41 (1.55)
x	16	2453 (1212)	2.86 (3.16)
s	10	8453 (502)	-.94 (.32)
t̪	12	4182 (1141)	.45 (0.59)

d	8	2722 (783)	1.0 (1.39)
d̪	9	1950 (301)	1.7 (.45)

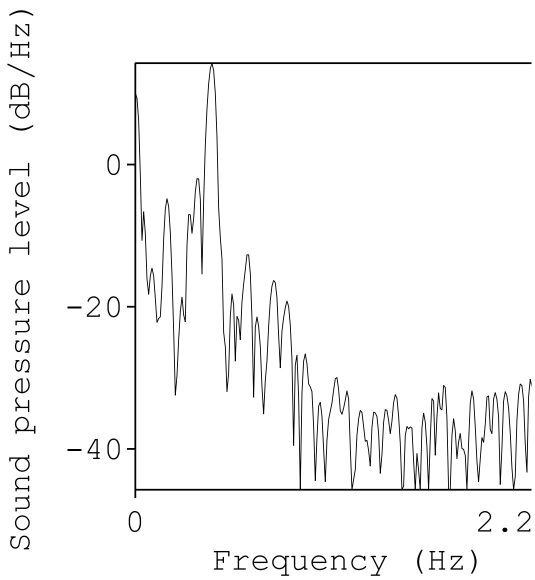


Figure 8: spectrum of [d] (1-10KHZ)

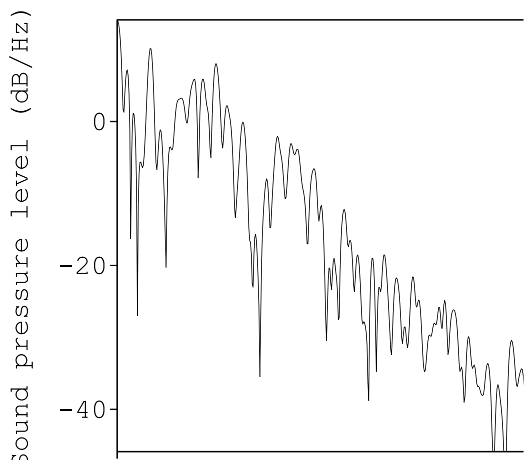


Figure 9: spectrum of [d̪] (1-10KHZ)

The alveolar [s] has a high center of gravity and a negative skew indicating that most of the turbulence is concentrated in the upper region of the spectrum, reinforcing the point that it is a poor acoustic match for the aspiration of [t^h] compared to the release phase of [t̪]. Comparison of [f] vs. [v] and the release phases of [t̪] vs. [d̪] indicate that voicing appears to concentrate more energy in the lower part of the spectrum, suggesting an overall decrease in intensity. Also, comparison between the releases of word-final (plain) alveolar [d] vs. underlying aspirate [d̪] found a significant difference in the center of gravity ($t = 2.8$, 15 df, $p = 0.02$) but not the skew ($t = 1.42$, 15 df, $p = 0.17$). Paired t-tests found small but significant differences in F2 trajectories from vowel mid point to vowel offset over a set of 25 /CaX/ minimal pairs (Appendix B): F2 alveolar [t] 148 Hz (54 Hz) vs. dental [t̪] 98 Hz (46 Hz), ($t = 4.25$, 24 df, $p < 0.001$). The shallower F2 slopes for the dental [t̪] is consistent with a more anterior point of articulation. Ijaz and Anwar (ND) report a similar result for the dental vs. alveolar distinction in Urdu, where the low vowel [a] has an F2 offset of 1500 Hz before dental [t̪] vs. 1700 Hz for alveolar [t]. Finally, we have the impression that the dental [t̪] and [d̪] differ from the alveolar [t] and [d] as laminal vs. apical. This difference in tongue posture would be consistent with the flatter spectra of the release phases of [d̪] vs. the more peaked spectra of [d] seen in the samples in Figures 9 and 10 above and observed by Dart (1990:139) for a similar contrast in 'O'odham.

Our phonological analysis of the Assamese shift is couched in the Optimality model (Prince and Smolensky 2004) and has the following ingredients. First, we assume that there is an auditory-acoustic based feature of [±turbulence] whose acoustic signature is randomly distributed energy in the spectrum. Aspirated stops and [h] share this feature with fricatives and the release phases of affricates and the Assamese dental stops [t̪] and [d̪]. In the face of the markedness constraint banning word-final aspirates, Assamese preserves the turbulence of the aspirate in the fricative at the cost of infidelity for [continuant] and [distributed], which are demoted below Ident-[turbulence].

(19) $*C^h\#$, Ident-[turbulence] » Ident-[contin], Ident-[distr]

/lab^h/	$*C^h\#$	Ident-[turbulence]	Ident-[contin]
> lav			*
lab^h	*!		
lab		*!	

/kat^h/	$*C^h\#$	Ident-[turbulence]	Ident-[distr]
> kat̪			*
kat^h	*!		
kat˺		*!	
kas		*!	

As seen in (20) below, for the velar /k^h/ the rankings between $*C^h\#$ and the faithfulness constraints are variable, producing two outputs: the faithful [k^h] and the spirantized [x]. In addition to the fact that the fricative [x] is already present in the phonemic inventory, the velar stop typically has a longer VOT than coronal and labial stops cross-linguistically, which could help to explain why its aspiration is (optionally) retained vis a vis the labial and coronal stops, which obligatorily shift their manner and/or place. For our Assamese data, the VOT measures in medial position align with this place hierarchy: [p^h] 88 (14) ms, [t^h] 96 (14) ms, [k^h] 105 (19) ms.

(20) $*k^h\#$, Ident-[turbulence] » Ident-[contin]

/mak^h/	$*k^h\#$	Ident-[turbulence]	Ident-[contin]
mak^h	*!		
> max			*
mak˺		*!	

Ident-[contin], Ident-[turbulence] » $*k^h\#$

/mak^h/	Ident-[contin]	Ident-[turbulence]	$*k^h\#$
>mak^h			*!
max	*!		
mak˺		*!	

5. Preconsonantal position

If Assamese follows Lithuanian, Russian, and Klamath, we expect that the laryngeal stop contrasts will be preserved before (modally voiced) sonorant consonants but will be neutralized before obstruents. To pursue this point we collected and analyzed two data sets. First, we looked at word-initial stop sonorant clusters. Such structures are limited in number in Assamese. The liquid is restricted to the rhotic and quite a few of the aspirates arise from loanwords. Examples appear in (21). See the Appendix C for the full data set, which were recorded in five repetitions. In these data the aspiration overlapped the [r]. In order to estimate the effect of the aspiration compared to clusters with a plain stop, the duration from stop release to the onset of the vowel was measured. On average, the rhotic is 30 ms longer in the aspirated condition: aspirate 99 ms (37), plain 70 ms (31), Welch two-sample t-test: $t=3.17$, F-statistic: 10.1, 55 df, $p = 0.002$; Adjusted R-squared: 0.14. This suggests that the C vs. C^h contrast is maintained in the presonorant context.

(21)	[prɔt^{h}ɔm]	'first'	[p^{h}rai]	'fry'
	[bristi]	'rain'	[b^{h}rɔmɔn]	'journey'
	[tritijɔ]	'third'	[t^{h}ristar]	'three-star'
	[dristi]	'vision'	[d^{h}rubɔ]	'universal'

To further investigate the laryngeal contrast in preconsonantal position, a set of 24 words whose final stops were balanced for place, voicing, and aspiration was constructed (see Appendix D). They were followed by the particles *–nai* 'no, none', *-tʊ* definite marker, and *–dur hol* 'away went' and repeated five times to give a data set of 360 items.

The table below shows the results before the sonorant *–nai*. The voicing contrast is maintained for the same factors that operate word-medially before a vowel, especially the closure-voicing ratio. And the plain vs. aspirated contrast is most reliably expressed by VOT.

(22) phonetic correlates of [±voice] and [±spread gl] before *–nai*: mean (st dev) and t-test

C1 / -nai	closure dur	voice ratio	V1 duration	F0	VOT
[+voice]	97 (27)	.53 (.36)	133 (23)	142 (12)	13 (20)

[−voice]	125 (37)	.08 (.02)	115 (22)	137 (21)	44 (41)
[−spread gl]	106 (29)	.39 (.39)	128 (23)	142 (14)	18 (26)
[+spread gl]	120 (41)	.17 (.28)	117 (24)	136 (20)	42 (42)
t-test p: (63 df)					
[±voice]	0.001	<0.001	0.002	0.296	<0.001
[±spread gl]	0.115	0.012	0.058	0.125	0.007

Before the voiceless consonant of *–tʊ* there is neutralization of the voicing contrast for C1 with apparent assimilation of the voicelessness of the following consonant. This can be seen in the .08 closure voicing ratio for underlying voiced stops.

(23) phonetic correlates of underlying [±voice] before *-tʊ*: mean (st dev) and t-test

C1 / -tʊ	closure dur	voice ratio	V1 duration	F0
[+voice]	113 (18)	.08 (.18)	135 (22)	133 (23)
[−voice]	119 (15)	.03 (.07)	127 (30)	133 (28)
t-test p: (58 df)	0.204	0.115	0.276	0.968

But before the voiced stop of *–dur*, the underlying voicing contrast for C1 seems to be retained for the key correlates of closure duration and voicing ratio, suggesting that there is incomplete assimilation of voicing in the context of the voiced stop.

(24) phonetic correlates of underlying [±voice] before *–dur*: mean (st dev) and t-test

C1 / -dur	closure dur	voice ratio	V1 duration	F0
[+voice]	80 (13)	.89 (.29)	138 (24)	139 (19)
[−voice]	96 (25)	.49 (.45)	134 (28)	136 (25)
t-test p: (58 df)	0.003	< 0.001	0.530	0.630

But when the data are broken down in terms of the plain vs. aspirated categories for C1 then there is a significant difference for the voicing ratio, with underlying plain stops showing an average closure-voicing ratio of .84 while underlying aspirates lag behind at .52, a significant difference ($t = -3.17$, 58 df, $p = 0.002$). This suggests that the underlying [+spread gl] gesture for the aspirated consonants may inhibit C1's assimilation of voicing from C2. More data are needed to test this hypothesis; see Kenstowicz, Abu-Mansour, and Törkenczy (2000) and Wetzels and Mascarò (2001) for examples of voicing assimilation restricted to just [+voice] or to just [-voice].[2]

[2] It should be noted that the *–tʊ*, *-nai*, and *–dur* morphemes do not derive from the same underlying syntactic structures. In particular, while – *tʊ* is a suffix, the items with *-nai* and with -

In sum, our data are largely consistent with the predictions made by the Licensing by Cue model. Before the nasal of *–nai* the closure voicing ratio, closure duration, and V1 duration distinguish the voiced from voiceless stops on an order of magnitude and reliability comparable to word-final position. And for the aspiration contrast, while the 42 ms VOT of aspirated stops is quite a bit less than the c. 90 ms found word-medially before a vowel, it is still reliably distinct from the plain stops' 18 ms. In position before the voiceless stop *–tu* there is neutralization of the underlying voicing contrast in C1. Before the voiced stop of *–dur*, underlying plain stops assimilate the voicing of the following voiced stop while underlying aspirates do so to a significantly smaller degree.

6. Bengali

Bengali is cited (Kenstowicz 1994:193-4) as a language with a dialect split with one variant following Hindi in maintaining the voicing and aspiration contrasts in word final position while the other neutralizes the aspiration contrast but preserves the voicing contrast.[3] As observed by Steriade (1997), this asymmetry is expected in the licensing by cue model if the major cues to the aspiration contrast are the stop-external ones of VOT and burst intensity while the voicing contrast relies on the internal correlates of closure voicing and duration as well as V1 duration. We attempted to document this dialect asymmetry by collecting data from three female speakers of Colloquial Bengali from Bangladesh. The speakers are students at MIT and range in age from 20 to 25 years. In terms of language background, the speech of the first two subjects is based on the capital Dhaka while the third is from Dinajpur in the northwest. A word list of 66 items (Appendix E) was constructed that distributed the voicing and aspiration contrasts across three stop places of articulation in medial and final positions. The speakers pronounced each target word in isolation and before the negative particle *–nai*.

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dur are subject-predicate structures. Differences in junctural cohesion could thus conceivably have influenced the results. But in no case was there a pause between the target word and the following particle.

[3] In their structural phonemic analysis of Standard Colloquial Bengali based on data collected from a speaker from Calcutta, Ferguson and Chowdhury (1960:45) state that "In (prejunctural) position there is a greatly reduced contrast between unaspirated and aspirated stops, and between h and zero. It is almost possible to say that there is no contrast here, since it is only in very careful speaking styles or in dialectally colored pronunciations that any contrast at all is made". They also note that /p^h/ and /b^h/ are optionally realized as spirants [ɸ] and [β] and that /t^h/ is sometimes pronounced with affrication as [t^θ] (p. 45). As noted by one of our reviewers, the neutralization of word-final aspiration but maintenance of voicing contrasts in Bengali was also observed by Chatterji (1926: 441-442) and Pattanyak (1966).

In word-medial intervocalic position the four-way contrast was reliably supported by voicing ratio (with only a trend for closure duration) and by VOT for aspiration. In our statistical modeling the predictor variables were the aspiration and voicing categories of the stops and their interactions while word and speaker were random intercepts. P values were estimated with R's pvals.fnc.

(25) phonetic correlates of [±voice] and [±spread gl] in word-medial position: mean (st dev) and linear regression

closure dur (ms)	[+voice]	[−voice]
mean (sd)	71 (28)	91 (19)
asp	$t = 0.08$, $p = 0.934$	
voice	$t = 1.45$, $p = 0.152$	
asp*voice	$t = 0.30$, $p = 0.765$	

voice ratio	[+voice]	[−voice]
mean (sd)	.99 (.02)	.11 (.13)
asp	$t = 0.35$, $p = 0.729$	
voice	$t = 25.09$, $p < 0.001$	
asp*voice	$t = 0.44$, $p = 0.661$	

V1 dur (ms)	[+voice]	[−voice]
mean (sd)	121 (23)	111 (23)
asp	$t = 0.51$, $p = 0.611$	
voice	$t = 0.08$, $p = 0.936$	
asp*voice	$t = 1.04$, $p = 0.301$	

VOT (ms)	[+spread gl]	[−spread gl]
mean (sd)	85 (22)	8 (13)
asp	$t = 10.41$, $p < 0.001$	
voice	$t = 1.06$, $p = 0.445$	
asp*voice	$t = 2.58$, $p = 0.015$	

In word-final, prepausal position the voicing contrast was significantly correlated with the stop closure duration, closure voicing, and V1 duration (26).

(26) phonetic correlates of [±voice] in word-final position: mean (st dev) and linear regression

closure dur (ms)	[+voice]	[−voice]
mean (sd)	107 (29)	144 (35)

asp	t = -0.46, p = 0.624	
voice	t = 2.60, p = 0.011	
asp*voice	t = 1.80, p = 0.074	

voice ratio	[+voice]	[−voice]
mean (sd)	.91 (.18)	.08 (.15)
asp	t = 0.86, p = 0.386	
voice	t = 17.81, p < 0.001	
asp*voice	t = 0.23, p = 0.818	

V1 dur (ms)	[+voice]	[−voice]
mean (sd)	121 (23)	111 (23)
asp	t = 1.61, p = 0.108	
voice	t = 2.65, p = 0.009	
asp*voice	t = 0.68, p = 0.492	

As for the aspiration contrast, there was a significant effect of VOT (as measured by the duration of turbulence visible in the narrow band spectrograms) and burst intensity (27).

(27) phonetic correlates of [±spread gl] in word-final position: mean (st dev) and linear regression

VOT (ms)	[+spread gl]	[−spread gl]
mean (sd)	80 (36)	55 (36)
asp	t = 2.60, p = 0.011	
voice	t = 0.31, p = 0.761	
asp*voice	t = 0.47, p = 0.637	

burst (dB)	[+spread gl]	[−spread gl]
[+spread gl]	52.8 (5.9)	51.1 (6.3)
asp	t = 0.58, p = 0.563	
voice	t = 2.26, p = 0.026	
asp*voice	t = 2.47, p = 0.015	

However, when the data were broken down by subject with multiple comparisons (Tukey), only the third speaker from Dinajpur evidenced a reliable difference in VOT, as seen in (28) below. We may therefore conclude that compared to the voicing contrast, the aspiration contrast is less reliable in word-final position.

(28) VOT by speaker in word-final position: mean (st dev) and linear regression with multiple

comparisons (Tukey)

	Speaker 1	Speaker 2	Speaker 3
[+spread gl]	98 (36)	65 (37)	66 (25)
[−spread gl]	84 (30)	40 (23)	31 (24)
Pr (>|t|)	0.12	0.14	<0.001
Tukey	Sp 1 – Sp 2	Sp 1 – Sp 3	Sp 2 – Sp 3
Pr (|z|)	0.642	<0.001	<0.001

In order to test the contrast before the sonorant *–nai*, the data had to be restricted to words terminating in a voiceless stop since voiced stops often lacked a measurable release in this context. We took two measures to estimate the aspiration. The first was simply the interval between stop release and the onset of voicing in the following nasal. With this measure there was no significant difference between underlying aspirated vs. plain voiceless stops. We also estimated the aspiration by the duration of the visible frication after the release of the stop in narrow band spectrograms, a period that was typically shorter than the classic VOT definition. In this case, a reliable difference emerged, as seen below in (29).

(29) phonetic correlates of aspiration before *–nai*

	VOT	Turbulence period
[+spread gl]	96 (33)	67 (29)
[−spread gl]	82 (42)	44 (26)
Pr (>|t|)	-0.44	0.003

We tentatively conclude that, at least for two of our Bengali speakers, the [±spread gl] contrast is not reliably maintained in word-final position compared to the stability of the [±voice] contrast. It should be noted that the apparent neutralization of C^h vs. C does not clearly result in the unmarked unaspirated variant but rather in more uncertainty and gradience. For these speakers the ranking in (30) may be proposed.

(30) *C^h#, Ident-[continuant] » Ident-[turbulence]

7. Hindi-Urdu

Hindi-Urdu is described as a language that preserves both the voicing and aspiration contrasts of stops in word-final as well as word-initial and word-medial positions (Ohala 1983). Concrete evidence affirming the presence of the voicing and aspiration contrasts word-finally is presented by Ahmed and Agrawal (1968). In their study a set of 870 CVC nonsense syllables varying the 29 consonantal phonemes of Hindi-Urdu in onset and coda were constructed. The syllables were recorded by three speakers (two males and one female) and presented to six native speaker listeners. The authors provide confusion matrixes summarizing the 15,660 responses. We extracted from their tables the responses for the bilabial, alveolar, and velar stops and categorized them for [±spread gl] and [±voice] for both positions. The data are summarized in (31). What is remarkable is the high hit rate, affirming the presence and stability of the laryngeal contrasts. Nevertheless, even here there are more errors with the aspiration contrast than with the voicing contrast in word-final position.

(31) confusion matrices for [±spread gl] and [±voice] based on data from Ahmed and Agrawal (1968); P = voiceless stop (plain and aspirated) and B = voiced stop (plain and aspirated)

Word-initial

	C	C^h		P	B
C	3234	6	P	3217	22
C^h	11	3230	B	32	3203
d'	5.60			4.79	

Word-final

	C	C^h		P	B
C	2903	72	P	2947	42
C^h	191	2810	B	10	2973
d'	3.49			4.90	

Linear regression with the probit link finds the difference in position within the word to be at the edge of significance for the aspiration contrast in comparison to no reliable difference for the voicing contrast (32). This suggests that the distinction between internal and external cues still shows up in what otherwise is a very high (near ceiling) response pattern.[4]

(32) regression statistics on [±spread gl] and [±voice] contrasts by position in word

[±spread gl]	Estimate	Std. Error	z value	Pr (>|z|)
intercept	0.02311	0.01124	2.056	0.039
position	0.04274	0.02248	1.901	0.057

[±voice]	Estimate	Std. Error	z value	Pr (>|z|)
intercept	0.002953	0.011243	0.263	0.793

[4] Analysis of the confusion matrices in Bhatia's (1976) study of Hindi stops found a similar asymmetry for word-final position: [±voice] $d' = 2.85$ vs. [±spread gl] $d' = 2.02$.

position	-0.00387	0.022487	-0.151	0.880

Hindi-Urdu thus occupies the third niche in the possible rankings of the markedness constraints banning an aspiration contrast in final position (33). Marathi (Pandharipande 1997) also maintains a fully crossed voicing and aspiration contrast: [saap] 'snake' vs. [saap^h] 'clean'; [ved] 'the Veda (sacred text)' vs. [ved^h] 'attraction'. Punjabi (Bhatia 1993) has lost the doubly marked voiced aspirates but maintains a ternary voiced, plain voiceless, and voiceless aspirated contrast in initial, medial, and final position. Examples of the latter include [jad] 'when', [rat] 'blood', [rat^h] 'chariot'.

(33) Ident-[continuant], Ident-[turbulence] » *C^h#

8. Summary and conclusion

In this paper we have documented a three-way distinction in the typology of laryngeal stop contrasts in the modern Indic languages instantiated by the constraint rankings in (34).

(34)	Hindi-Urdu:	Ident-[continuant], Ident-[turbulence] » *C^h#
	Assamese:	*C^h#, Ident-[turbulence] » Ident-[continuant]
	Bengali:	*C^h#, Ident-[continuant] » Ident-[turbulence]

Second, we have proposed that the basis of the Assamese spirantization of the aspirates is acoustic-auditory in nature. Aspirated stops share with fricatives the random distribution of acoustic energy in the frequency spectrum during their release and post-release phases. We also suggested that this helps to explain loanword adaptations and sound changes linking these two sound classes. Third, the typology makes sense given the Licensing by Cue model of Steriade (1997, 2009). The aspirated stops are enhanced or neutralized in a context where the cues to the contrast are diminished. A striking additional fact is that in all three languages reviewed here the voicing contrasts are maintained in word-final, prepausal position. We can understand the stability of the [±voice] contrasts vis a vis the relative instability of the [±spread gl] contrasts by the phonetic correlates associated with these laryngeal oppositions. The voicing contrast is associated with an ensemble of cues (closure duration, closure voicing ratio, V1 duration) that are distributed across a broad region within which the stop is realized while the [±spread gl] opposition is signaled primarily by the turbulence after stop release and secondarily by voice quality in the beginning of the following vowel. These cues are diminished or absent before pause. This suggests in turn a default UG ranking of Ident-[voice] » Ident-[spread gl] that predicts the absence of a language that neutralizes a distinction in [±voice] while preserving a contrast in [±spread gl] in final position. To the best of our knowledge, such a language is not attested in Indic or elsewhere.

For the languages in (34) Ident-[voice] dominates the markedness constraint banning final voiced obstruents *[+voice]# and this ranking holds for other Indic languages such as Maithili, Punjabi, and Marathi. In this regard Sanskrit becomes interesting since this language neutralized not only [±spread gl] but also [±voice] in word-final position (Allen 1953:70). Thus, in comparison to Sanskrit the modern languages have promoted faithfulness for voicing. Possibly related to this difference is the fact that Sanskrit—at least at its earliest stages—was a pitch accent language with lexical contrasts signaled by F0. In the modern Indic languages stress is predictable from syllable weight or distance from the edge of the word and F0 is associated with a rising contour across the accentual phrase. If the phonetic correlates of the Sanskrit laryngeal stop contrasts were similar to what is found in the modern languages (except possibly for F0) then closure voicing should have been available to distinguish /b/ from /p/. According to the "default model" of voicing proposed by Westbury and Keating (1986), in prepausal position closure voicing in a stop consonant will naturally cease at some point before oral release unless additional articulatory actions are taken to sustain phonation. From this perspective, the modern languages such as Hindi-Urdu must draw on more articulatory resources to maintain the laryngeal contrasts. A key objective of future research should be to determine if this is true and if so, how it is done. More generally, while the laryngeal stop contrasts in the Indic languages have been studied for over forty years with a variety of instrumentations, research has (quite properly) focused on the contexts in which the contrasts are most clearly expressed. This has provided a firm foundation for investigations like this one into how the contrasts are realized in different contexts, particularly those that are relevant to cue-based vs. prosody-based models of laryngeal licensing.

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Appendix A

ɔpɔra	personal name	zux	‘to measure’
kɔpah	‘cotton’	max	‘unit of measurement’
kɔpal	‘forehead’	nɔx	‘nails’
sɔpɔnia	‘dependent son-in-law’	sɔx	‘interest’

p^{h}ɔpɔra	‘dappled’
pap	‘sin’
sap	‘pressure’
bap	‘father’
d^{h}ap	‘slope’
rap	‘interest’
map	‘measurement’
b^{h}ap	‘vapors’
sɔp	food item
dɔba	‘chess’
ɛbar	‘one time’
baba	‘small child’
buba	‘dumb’
duba	‘to drown’
suburi	‘neighborhood’
subua	‘to chew’
bab	‘designation’
kabab	meat item
kub	‘to whip’
dub	‘to drown’
dab	‘coconut sp.’
b^{h}ab	‘thoughts’
dɔrɔb	‘medicine’
ɛp^{h}al	‘one piece’
xop^{h}ura	folk culture item
kup^{h}a	‘omen’
sɔp^{h}a	‘clean’
dɔp^{h}a	‘chapter’
d^{h}ɔpɔla	‘dappled’
sap^{h}	‘clean’
map^{h}	‘to forgive’
bɔrɔp^{h}	‘ice’
kɔp^{h}	‘phlegm’
dup^{h}	‘to get hurt’
ɛb^{h}ar	‘unit of measure’
ɛb^{h}ori	‘unit of measure’
ɔb^{h}ab	‘scarcity’
xɔb^{h}a	‘meeting’
mux	‘face’
juk^{h}	‘to measure’
mak^{h}	‘unit of measurement’
nɔk^{h}	‘nails’
sɔk^{h}	‘interest’
muk^{h}	‘fact’
pɔka	‘ripe’
ɔkɔra	‘stupid’
dɔbɔka	placename
suka	‘brilliant’
kɔka	‘grandfather’
bɔk	‘crane’
kak	‘whom’
zak	‘group’
zʊk	‘leech’
mak	‘mother’
kɔkak	‘grandfather’
pɔta	‘flattened grinder’
bɔta	folk culture item
bɔtɔl	‘bottle’
bɔtah	‘wind’
bɔtɔr	‘weather’
tɔpɔt	‘hot’
kɔpɔt	‘shrewd’
d^{h}ɔpat	‘tobacco’
dupat	‘two piece item’
bɔt	‘tree sp.’
kat^{h}i	‘toothpick’
kɔt^{h}a	‘talks’
mat^{h}a	‘head’
bɛt^{h}a	‘grief’
bɔt^{h}a	‘oars’
kat^{h}	‘wood’
mɔt^{h}	‘temple’
rɔt^{h}	‘charriot’
zɛt^{h}	name of month
badam	‘almonds’
bɔdɔn	‘body’

gab^{h}oru	‘young girl’
lab^h	‘profit’
k^{h}job^h	‘anger’
lʊb^h	‘greed’
xourɔb^h	‘fragrance’
bad^{h}a	‘obstacle’
rad^{h}a	mythological character
ad^{h}a	‘half’
lɛd^{h}a	‘lazy’
sid^{h}a	‘straight’
ɔd^{h}ɔm	‘man of bad character’
bɔd^h	‘to kill’
krʊd^h	‘anger’
bud^h	‘Wednesday’
ak^{h}ɔr	‘alphabets’
ak^{h}ɔra	‘practice’
pɔk^{h}ɔra	‘shabby’
pok^{h}ila	‘butterfly’
pɔk^{h}a	‘plant’
xɔk^{h}a	‘friend’
nɔik^{h}ɔtrɔ	‘star’
zɔk^{h}ɔla	‘ladder’
bodoru	personal name
bidai	‘farewell’
rod	‘sun’
mɔd	‘alcohol’
dɔrɔd	‘pain’
bad	‘to avoid’
bɔga	‘white’
bɔgɔra	‘to wrestle’
t^{h}ɔga	folk culture item
sɔga	‘bird’
dɔga	‘unit of measurement’
sagoli	‘goat’
ag	‘front part’
dag	‘mark’
b^{h}ag	‘share’
b^{h}ʊg	‘to enjoy’
ɛg^{h}ɔr	‘one household’
og^{h}ori	‘gypsy’
pɔg^{h}a	‘rope’
ɔg^{h}ɔtɔn	‘untoward incident’
log^{h}un	‘to fast’
bag^h	‘tiger’
sag^h	‘reduplicated word’

Appendix B

kat	'to cut'	pat^h	'path'
kat^h	'wood'	mat	'voice'
bat	'way'	mat^h	'nonsense'
bat^h	'bath'	tat	'there'
pat	'leaves'	tat^h	'nonsense'

Appendix C

prɔtʰɔm	'first'	bʰrismɔ	name of a character
pristʰa	'page'	dristi	'vision'
pʰrai	'to fry'	drɔibbɔ	'substance'
pʰrend	'friend'	dʰrubɔ	'universal'
tritijɔ	'third'	dʰritiman	'patient'
tʰri:star	'three-star'	grɔhɔn	'acceptance'
brihɔt	'large'	gram	'village'
bristi	'rain'	gʰrina	'hatred'
brikkʰɔ	'tree'	gʰran	'scent'

Appendix D

bap	'father'	dɔrɔd	'pains'
pap	'sin'	kɔtʰ	'mat'
kub	'whip'	katʰ	'woods'
bab	'post'	rɔtʰ	'charriot'
kɔpʰ	'phlegm'	krʊdʰ	'anger'
bɔrɔpʰ	'ice'	mak	'mother'
labʰ	'profit'	zuk	'leech'
lʊbʰ	'greed'	dag	'mark'
dʰɔpat	'tobacco'	sɔkʰ	'interest'
kut	'coat'	nɔkʰ	'nail'
rod	'sun'	bagʰ	'tiger'

Appendix E

tʃʰagɔl	'goat'	tʃap	'pressure'
kɔpʰ	'plegm'	ʈʰakur	'community'
pakʰa	'fan'	aʈʰ	'eight'

apel	‘apple’	lob^{h}	‘greed’
kãd^{h}	‘shoulder’	ag^{h}at	‘wound’
bɔrop^{h}	‘ice’	lab^{h}	‘profit’
map^{h}	‘to forgive’	ʃak	‘leafy greens’
paʈ^{h}a	‘goat’	k^{h}am	‘envelope’
aʈa	‘wheat’	kɔt^{h}a	‘talk’
sap^{h}	‘clean’	ʃat	‘seven’
maʈ^{h}	‘ground’	bud^{h}	‘Wednesday’
p^{h}asi	‘to hang’	bid^{h}an	‘ways’
dag	‘stain’	nɔk^{h}	‘nails’
pat	‘plate’	dɛk^{h}	‘to see’
hoʈ^{h}at	‘suddenly’	rak^{h}	‘to keep’
sɔp^{h}or	‘journey’	ɔbak	‘surprised’
nɔk^{h}	‘nails’	kak	‘crow’
bad^{h}a	‘obstacles’	nak	‘nose’
d^{h}an	‘paddy’	ʃak	‘nonsense’
ʃad^{h}	‘wedding’	ʈak	‘bald’
ada	‘ginger’	bad	‘to avoid’
pap	‘sin’	tʃad	‘roof’
ɔb^{h}ab	‘to think’	mɔrod	‘male’
kaʈ^{h}	‘wood’	ʃud	‘nonsense’
p^{h}ul	‘flower’	bɔd^{h}	‘to kill’
rad^{h}a	personal name	bud^{h}	‘Wednesday’
tarik^{h}	‘date’	bɔb	personal name
bag^{h}	‘tiger’	ʃob	‘all’
bad	‘avoid’	ʈɔb	‘flower vase’
ʃaban	‘soap’	k^{h}ob^{h}	‘anger’
adab	‘greetings’	lob^{h}	‘greed’
adek^{h}	‘inexperienced’	lab^{h}	‘profit’
paʈ^{h}	‘lesson’	durlɔb^{h}	‘rare’
p^{h}ãki	‘excuse’		

The Phonology and Phonetics of Laryngeal Stop Contrasts in Assamese

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