Breathy Nasals and /Nh/ Clusters in Bengali, Hindi, and Marathi

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Abstract

Previous work on breathiness in Indic languages has focused primarily on the acoustic properties of breathy (also known as voiced aspirated) oral stops in languages like Hindi (/**b**aːl/ 'hair' vs. /**bʱ**aːl/ 'forehead') and Bengali (/**b**ati/ 'bowl' *vs*. /**bʱ**ati/ 'kiln'). However, contrastive breathiness in some Indic languages also extends to nasal stops, as in Marathi (/**m**aːɾ/ 'beat' *vs*. /**m̤**aːɾ/ 'Mahar caste'). It is not clear if languages such as Hindi and Bengali have breathy nasals in addition to breathy oral stops. This study addresses the following question: in Bengali and Hindi, are underlying sequences of a modal nasal (/N/) followed by breathy-voiced /ɦ/ phonetically realized as singleton breathy nasals ([N̤]), or as clusters ([Nɦ])? To answer this question, simultaneous audio, aerodynamic, and electroglottographic recordings were made of Hindi, Bengali, and Marathi speakers. Within- and cross-language comparisons were made, and phonological evidence was examined. While some within-language comparisons gave inconclusive results for Hindi and Bengali, other comparisons with Marathi and within-language phonological evidence pointed to the lack of breathy nasals in Hindi and an uncertain status for breathy nasals in Bengali.

1 Introduction

The Indic languages are typologically unusual, possessing a four-way oral stop contrast that includes both voiceless and voiced aspirates.[1] This is exemplified in Table 1, with data from two Indic languages, Bengali and Hindi.

	Bengali	**Hindi**
Voiceless unaspirated	**p**ati 'mat'	**p**a:l 'take care of'
Voiceless aspirated	**p^{h}**ati 'I burst'	**p^{h}**a:l 'knife blade'
Voiced unaspirated	**b**ati 'bowl'	**b**a:l 'hair'
Breathy-voiced aspirated	**b^{ɦ}**ati 'kiln'	**b^{ɦ}**a:l 'forehead'

Table 1: Examples of the four-way oral stop contrast in Bengali and Hindi.

In some Indic languages, including Marathi, Konkani, and Rajasthani (Masica 1991), the aspiration contrast extends to nasal stops as well, producing breathy nasals. An example from Marathi is presented in Table 2.[2]

	Marathi	
	Oral	**Nasal**
Voiceless unaspirated	**p**a:l 'cloth or large blanket'	
Voiceless aspirated	**p^{h}**a:l 'fruit'	
Voiced unaspirated/modal	**b**a:l 'strength'	**m**a:ɾ 'beat'
Voiced aspirated/breathy	**b^{ɦ}**a:l 'spearhead, arrowhead'	**m̤**a:ɾ 'Mahar' (a caste)[3]

Table 2: Example of the aspiration/breathiness contrast in both the oral and nasal stops in Marathi. Shaded areas denote sounds that are not possible in Marathi.

However, in languages conventionally described as having an aspiration contrast only in the oral stops, such as in Bengali and Hindi, there are sequences of nasal consonants (/N/) followed by /ɦ/ (*e.g.* Bengali /ʃiŋɦo/ 'lion', Hindi /t̪ʊmhẽ:/ 'you-*acc.*').[4] On the surface, it is not clear if these sequences are phonetically realized as breathy nasals ([N̤]) or simply as [Nɦ] clusters. For Hindi, different researchers have presented conflicting views (this will be discussed further in section 3); for Bengali, there has not yet been any acoustic analysis on this topic, although several phonological studies suggest these sequences are realized as clusters rather than breathy nasals (as discussed in section 3). Thus, the goal of this paper is to answer the following question:

- In Bengali and Hindi, are phonemic sequences of /N/+/ɦ/ produced as single breathy nasals ([N̤]), or as [Nɦ] clusters?

To answer this question, phonetic and phonological evidence was examined. Before addressing this question, we will first present some background information on the languages being studied, a review of previous literature on the issue of breathiness and aspiration in Indic languages, and information on phonation contrasts and measuring phonation in general. After this, we will present the methodology, followed by the results and discussion of the data.

2 Language Background

2.1 Bengali

Bengali (*Bangla*) is an Indo-European language spoken primarily in the People's Republic of Bangladesh and in the neighboring Indian states of West Bengal, Assam, and Tripura. Approximately 171 million people use it as a first language, with over 40 million second-language speakers (Gordon 2005). Speakers of Bengali are typically fluent in more than one dialect; most Bengalis speak a regional variety alongside *Choltibhasha,* the standard dialect used in all media and education. The variety of Bengali examined in this study is *Choltibhasha*. Bengali, along with many other eastern Indic languages, is written in the Eastern Nagari script, often called the Bengali-Assamese script. As previously mentioned, Bengali has contrastive aspiration both in voiceless and voiced oral stops.

2.2 Hindi

Hindi is an Indo-European language spoken primarily in a large belt across north-central India, including the states of Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh, Rajasthan, Haryana, Himachal Pradesh, and the Union Territory of Delhi. Roughly 180 million people use it as a first language, with 120 million second-language speakers (Gordon 2005). While a number of different regional varieties of Hindi exist (such

as Braj and Bhojpuri), the form examined here is Modern Standard Hindi, the language of literature, media, and education. While this form of Hindi originally existed mainly as a *lingua franca* for speakers of the regional varieties, it is now spoken natively by many people, especially those from urban areas (Masica 1991). Hindi is written in the Devanagari script. As previously mentioned, Hindi contrasts both voiceless and voiced aspirated oral stops.

2.3 Marathi

Marathi is an Indo-European language spoken in the state of Maharashtra, located in west-central India. Major cities found in this region include Pune (Poona), Mumbai (Bombay), and Nagpur. Marathi has roughly 68 million native speakers, with 300,000 second-language speakers (Gordon 2005). While a number of different regional varieties of Marathi exist (such as Cochin and Kasargod), the form examined here is Modern Standard Marathi. Like Hindi, Marathi is written in the Devanagari script. As previously mentioned, Marathi has contrastive aspiration in voiceless and voiced oral stops, as well as in nasal stops.

3 Previous research on breathiness/aspiration in Hindi and Bengali

Most previous work on breathiness in Indic languages has focused on oral stops (Ohala 1983 and Dixit 1987, to name a few). However, four studies on Urdu, a language mutually intelligible with Hindi, suggest the existence of breathy nasals. Bokhari (1985, 1991) and Khan (1997) include /m^{h}/ and /n^{h}/ (following their transcription) in the phoneme inventory of Urdu. In one acoustic study, Aziz (2002), word-initial, word-medial, and word-final /N/ + /ɦ/ sequences were recorded and analyzed. In word-initial position, spectrographic evidence revealed that speakers consistently inserted a schwa between the nasal (/N/) and the /ɦ/ (*e.g.* /nɦaː/ → [nəɦaː] 'bath').[5] Due to the separation of the nasal (/N/) and the /ɦ/, there was no breathiness realized during the nasal. In word-medial position, the

underlying /ɦ/ was often not phonetically realized. In cases with word-medial clusters of coronal /n/ and /ɦ/, there was no breathiness/aspiration during the [n] closure, even when the /ɦ/ was realized (*e.g.* /nənɦaː/ → [nənaː]~[nənɦaː] 'little'). However, in word-medial clusters of labial /m/ and /ɦ/, some speakers occasionally produced some breathiness/aspiration during the [m] closure (*e.g.* /kʊmɦlaːnaː/ → [kʊm̤laːnaː]~ [kʊmlaːnaː]). In word-final position, speakers did not produce the underlying nasal consonant (/N/), but nasalized the preceding vowel; the word-final /h/ was only occasionally realized, thus creating [ṽ(ɦ)] sequences from underlying /VNɦ/ (*e.g.* /baːnɦ/ → [bãːɦ]~[bãː] 'arm'. In sum, Aziz (2002) suggests there is little evidence for phonetically breathy nasals in Urdu in any word position. Nisar & Baqir (2003), a phonological study of Urdu, finds that potentially breathy nasals in Urdu are realized as modal nasals when following a long vowel (*e.g.* /baːnɦ/ → [baːn] 'arm'), and as a coda nasal followed by an onset /ɦ/ when following a short vowel (*e.g.* /t̪ʊmɦẽː/ → [t̪ʊm.ɦẽː] 'you-*acc*'). Like Aziz (2002), Nisar & Baqir (2003) conclude that there is no evidence for phonetically breathy nasals in Urdu.

In general, there appears to be disagreement in the literature over the status of breathy nasals in Hindi. Some authors treat the /Nɦ/ sequence in Hindi as a cluster (Ohala 1983; Botma 2004) while others regard it as a single breathy nasal (Maddieson 1984; Hinskens and van de Weijer 2003).

While there have not been any acoustic studies regarding the phonetic realization of Bengali /Nɦ/, a number of phonological studies have been conducted. Some authors mention the existence of word-medial nasal aspirates *mh* and *nh* (following their transcription) in very careful speech (Ferguson & Chowdhury 1960; Chatterjee 1962). While acknowledging their existence, Ferguson & Chowdhury (1960) do not define the status of *mh* and *nh*, listing them neither in the table of word-medial clusters (*p.* 48) nor in the table of consonantal phonemes

(*p.* 53). More recent research, however, finds that potentially breathy nasals (/N/+/ɦ/) (*e.g.* /brɔmɦo/ 'Brahma', /tʃinɦo/ 'sign', /ʃiŋɦo/ 'lion') behave as consonant clusters, given distributional and durational evidence (Sen Gupta 1980; Bhattacharya 1984). Unlike breathy oral consonants, but like clusters beginning with a nasal, /N/+/ɦ/ clusters are described as being restricted to word-medial position, and are found to undergo lengthening of the nasal (*e.g.* /tʃinɦo/ → [tʃinːɦo] 'sign', *cf.* /bɹinḍo/ → [bɹinːḍo] 'group of people'). In contrast, breathy oral consonants can occur both word-medially and word-initially, and show no lengthening word-medially. Bhattacharya (1984) describes the phonological behavior of breathy nasals by stating "these so called [nasal] aspirates do not follow the regular distributional pattern of the other [oral] aspirates. Hence they are not 'unit phonemes' as the regular [oral] aspirates are. They are sequences of two phonemes," (*pp.* 89-91).

4 Overview of Phonation across Languages

In this section, we will present an overview of phonation – the production of sound generated by the vibration of the vocal folds. This includes the three main types of phonation that occur cross-linguistically: modal, breathy, and creaky voice (although this paper will only be concerned with modal and breathy phonations). Modal phonation is the neutral phonation to which other phonations are compared; it is characterized by vocal folds with normal adductive and longitudinal tension. Breathy phonation is characterized by vocal folds that vibrate without much contact.[6] During breathy phonation, there is minimal adductive tension and little longitudinal tension in the vocal folds (see Figure 1).

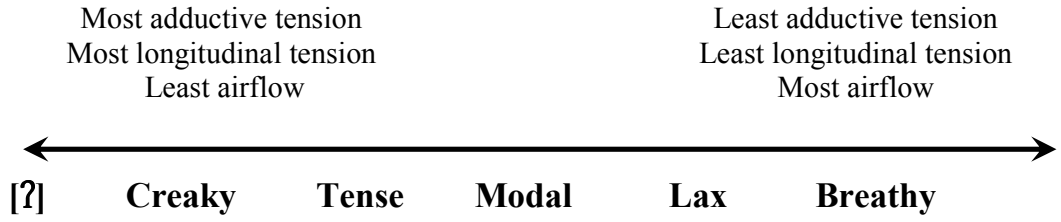


Figure 1. Phonetic continuum of phonation types.

Some languages contrast breathy and modal phonation on consonants (*e.g.* Hindi, Bengali, Marathi, Tsonga, *etc*.); other languages contrast breathy and modal phonation on the vowels (*e.g.* Tamang, Santa Ana del Valle Zapotec, *etc*.). A few languages contrast breathy and modal phonation on both consonants and vowels (*e.g.* Gujarati).

Furthermore, non-modal phonation is often phonetically realized only on a particular portion of the segment to which it is associated. For example, in Jalapa Mazatec, a language that contrasts modal, breathy, and creaky phonation on vowels, the creakiness and breathiness are only realized during the first portion of the vowel, while the second portion of the vowel continues with a more modal phonation (Silverman 1997, Blankenship 1997). In Indic languages, breathy voiced stops also show localized realization of phonation; the initial portion of a phonemically breathy voiced oral consonant (/D$^{\text{ɦ}}$/) is produced with modal phonation, and only the later portion of the consonant involves breathy phonation (Esposito *et al.* 2005a). This localization is also described for potentially breathy nasals (underlying sequences of /N/+/ɦ/) in Bengali (Hai 1958).

5 Measuring Non-Modal Phonation

There are numerous acoustic and auditory properties that can be useful measures of non-modal phonation, especially for vowels (*e.g.* spectral tilt, periodicity, acoustic intensity, *etc*.). However, when measuring the phonation of consonants, there are fewer options. In this section, we will briefly discuss two ways to measure the phonation of consonants, using aerodynamics equipment and an electroglottograph.

5.1 Aerodynamics

As previously mentioned, modal phonation is produced with a more constricted glottis than breathy phonation. Therefore, during modal phonation, there is less airflow than

during breathy phonation. The amount of oral and/or nasal airflow produced during speech can be measured with masks that fit securely around the speaker's mouth and nose. Aerodynamic properties have been a reliable measure of phonation in Jingpho, Wa, Yi, and Haoni (Maddieson & Ladefoged 1985).

5.2 Electroglottograph

The electroglottograph (EGG) is a non-invasive device that indexes the contact area between the vocal folds by measuring electrical impedance. While human tissue is a fairly good conductor of electricity, air is not. During phonation, the vocal folds (*i.e.* human tissue) are, at times, separated by the glottis (*i.e.* air). As the vocal folds move apart, the glottis opens, thereby increasing the electrical impedance across the larynx. When the vocal folds come closer together, the size of the glottis decreases, thereby decreasing the electrical impedance across the larynx.

The most common EGG measure is CQ (for Closing Quotient or Contact Quotient), which is a measure of the closed portion of the glottal cycle. During breathy phonation, the vocal folds are far apart, producing a low closed quotient value. During modal phonation, the vocal folds are closer together than for breathy phonation; therefore, the closed quotient value is higher for modal phonation than for breathy phonation.

EGG measures have been applied to the study of linguistic phonations in various languages (*e.g.* Watkins 1999 on Wa, Guion *et al*. 2004 on Maa, Michaud 2004a and Michaud & Tuân 2004 on Vietnamese, and Esposito 2005 on Santa Ana del Valle Zapotec, to name a few).

6 Current Study

The goal of the current study is to determine if /Nɦ/ sequences in Bengali and Hindi are breathy nasals, like Marathi [N̤], or if they are [Nɦ] clusters instead. To answer this

question, simultaneous audio, aerodynamic, and electroglottographic (EGG) recordings were made for Bengali, Hindi, and (to provide a point for comparison) Marathi. Within-language comparisons of the breathy-voiced oral stops and the potentially breathy nasals were made in both Bengali and Hindi. In addition, cross-language comparisons of the potentially breathy nasals in Bengali and Hindi to the breathy nasals in Marathi were made. We also examined phonological evidence to see if /Nɦ/ in Bengali and Hindi behaves like a cluster or like a single segment. In the next section, we will begin by discussing the within-language comparisons, followed by the cross-language comparisons in section 8, and the phonological evidence in section 9. Section 10 provides a discussion and conclusion of the study.

7 Within-language comparisons

For the within-language comparisons, breathy-voiced aspirated oral stops (/Dɦ/) were compared to potentially breathy nasal ones (/Nɦ/) in Bengali and Hindi. If breathy nasals do exist in Bengali and Hindi, then it is expect that they will share some features with breathy-voiced aspirated oral stops (except, of course, for nasality). More specifically, the following hypotheses were made:

(1) If /Nɦ/ is realized as a cluster, then its duration should be more similar to a cluster such as /Dɦ/ than to a single consonant such as [Dɦ].

(2) If /Nɦ/ is realized as a cluster, then its CQ value should be more similar to a cluster such as /Dɦ/ than to a single consonant such as /Dɦ/.

7.1 Methods

7.1.1 Speakers

For Bengali, three adult male and two adult female speakers were recorded for this study. All the speakers were born in the Dhaka Division of Bangladesh and speak the *Choltibhasha* dialect of Bengali. For Hindi, one adult female speaker was recorded. All speakers spoke English in addition to the language studied.

7.1.2 Speech Materials

The Bengali and Hindi speakers produced words that included the sounds given in Table 3:

Consonant/cluster type	Label	Bengali Example	Hindi Example
1. Modal Nasals	/N/	/ba**n**alam/ 'I made'	/kʊ**m**aːɾ/ 'boy'
2. Potentially Breathy Nasals (nasals followed by /ɦ/)	/Nɦ/	/na**mɦ**aɹa/ 'nameless'	/kʊ**mɦ**aːɾ/ 'potter'
3. Voiced Unaspirated Stops	/D/	/be**d̪**ana/ 'pomegranate'	/kʊ**b**eːɾ/ 'god of wealth'
4. Voiced Stops Followed by /ɦ/	/Dɦ/	/a**bɦ**aoa/ 'weather'	/ʃʊ**bɦ**aː/ 'mistrust'
5. Voiced Aspirated Stops	/Dʱ/	/ʃa**d̪ʱ**aɹon/ 'general'	/lʊ**bʱ**aːnaː/ 'to tempt'
6. Glottal Fricative	/ɦ/	/be**ɦ**ala/ 'fiddle'	/sʊ**ɦ**aːg/ 'husband'

Table 3: A list of the consonants and clusters recorded for both Bengali and Hindi.

The modal nasal /N/ and the voiced unaspirated /D/ were recorded as controls. There is the possibility that breathy segments and/or /Nɦ/ clusters are nothing more than the combination of a modal consonant with /ɦ/. Thus, modal consonants were recorded for purposes of comparison. The voiced stop followed by /ɦ/ (/Dɦ/) was recorded as an example of a modal consonant followed by an /ɦ/; if /Nɦ/ is realized as a sequence of [N] + [ɦ], it should be similar to /Dɦ/, which is realized as a sequence of [D] + [ɦ]. The /Dʱ/ was recorded as a breathy voiced consonant to compare to /Nɦ/; if /Nɦ/ is a single breathy nasal, it should share some features with /Dʱ/. The glottal fricative /ɦ/ was recorded as an example of a single segment that contains only breathiness. These consonants and consonant clusters were produced intervocalically. Six words per consonant/cluster were produced. Each word contained one and only one of the consonants/clusters in question.

7.2 Procedure

Each word was repeated three times in the carrier sentence [ʃe ____ bollo] 'He/she said ____' for Bengali, and [ab ____ kahie:] 'Please say ____ now' for Hindi. Simultaneous electroglottographic, aerodynamic, and audio recordings were made for each speaker. Tokens were digitized and analyzed at a sampling rate of 22 kHz using AcQuirer software (Scicon RD). Figure 1 shows the audio, oral flow, nasal flow, and EGG signals, respectively, for Hindi [paka:na:] 'to cook (transitive)' as displayed in AcQuirer (Scicon RD). The aerodynamic data (*i.e.* the oral and nasal flow data), are relevant to the cross-language comparison, Section 6.

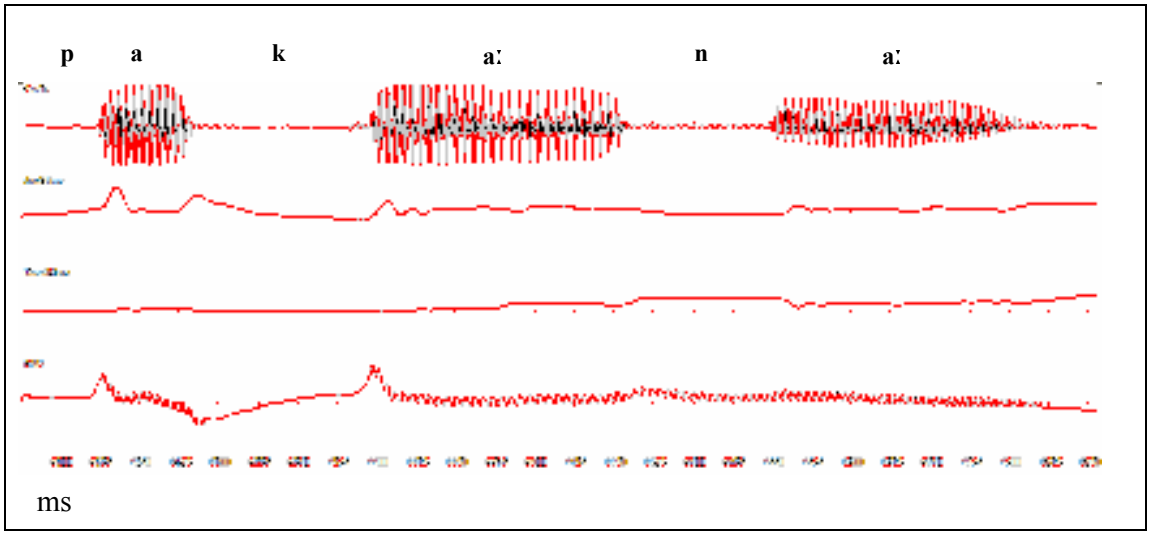


Figure 2: Audio, oral flow, nasal flow, and EGG signal of Hindi [paka:na:] 'to cook (transitive)'

Duration and closed quotient were measured for each token. In the next section, we detail how and where each measurement was taken.

7.2.1 Description of measures

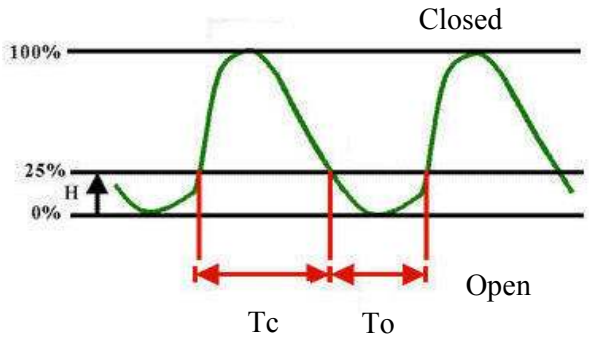
7.2.1.1 Duration

For each segment, the duration of the modal/unaspirated portion and the duration of the breathy (-aspirated) portion were measured in milliseconds (ms) using spectrograms created from the audio signal. Here and throughout, breathiness was characterized on the

waveform as diminished energy and on the spectrogram as visible noise distributed across a wide range of frequencies during a period of visibly clear voicing. For the unaspirated voiced stops (/D/), the modal nasals (/N/), and /ɦ/, which are all produced with only one phonation type each, the duration of the entire segment was measured.

7.2.1.2 Closed Quotient

Closed quotient (CQ) was measured automatically with AcQuirer by dividing the amount of vocal fold closure (Tc) by the sum of the amount of vocal fold closure plus the amount of vocal fold opening (To) for each glottal pulse. Figure 3 shows this equation and how it was derived from a glottal pulse from the EGG signal.



Closed quotient = Total closure / (Total closure + Total open)

Figure 3: Closed quotient and how it was calculated from the EGG signal. *H* represents a default 25% threshold (which is used to determine the point at which the signal moves from open to closed). Tc = total closure. To = total open (Image adapted from http://aune.lpl.univ-aix.fr/~ghio/images/fig-egg3.gif)

CQ was measured at two points: (1) the middle of the modal/unaspirated portion (2) the middle of the breathy/aspirated portion. Spectrograms were used to determine the modal/unaspirated and breathy/aspirated portions of the segment. Because they only involve one phonation type each, CQ was measured at only one point for the unaspirated voiced stops (/D/), the modal nasals (/N/), and /ɦ/.

7.3 Results and Discussion

We begin by presenting the results and discussion of the within-language comparison for Bengali, and then continue with Hindi.

7.3.1 Bengali

7.3.1.1 Duration

Figure 4 is a graph of the average duration of the breathy/aspirated and modal/ unaspirated portion of the segments /N/, /Nɦ/, /D/, /Dɦ/, /Dʱ/, and /ɦ/. Duration is graphed on the *y*-axis in ms. Due to typographical limitations, breathiness/aspiration is represented by an apostrophe < ' > and /ɦ/ is presented with an <h> in all graphs.

Duration (Bengali)

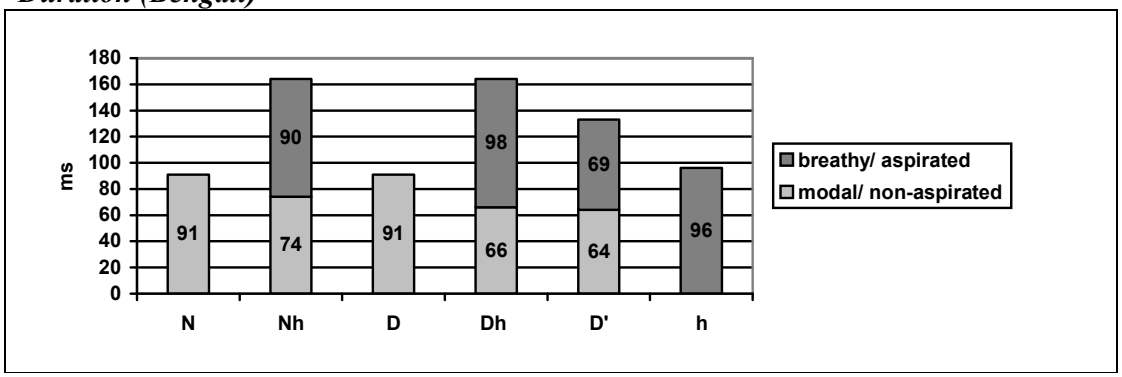


Figure 4: Graph of the average duration of the breathy/aspirated and modal/unaspirated portion of /N/, /Nɦ/, /D/, /Dɦ/, /Dʱ/, and /ɦ/ for Bengali.

The data presented here suggest that the duration of /Nɦ/ is similar to that of /Dɦ/. Like /Dɦ/, the duration of /Nɦ/ is longer than the single segment /Dʱ/. The data indicate that the duration of /Nɦ/ is more like that of a sequence than that of a single segment.

7.3.1.2 Closed Quotient

Figure 5 is a graph of the average CQ value for /N/, /Nɦ/, /D/, /Dɦ/, /Dʱ/, and /ɦ/. Lower values indicate increased breathiness.

Closed Quotient (Bengali)

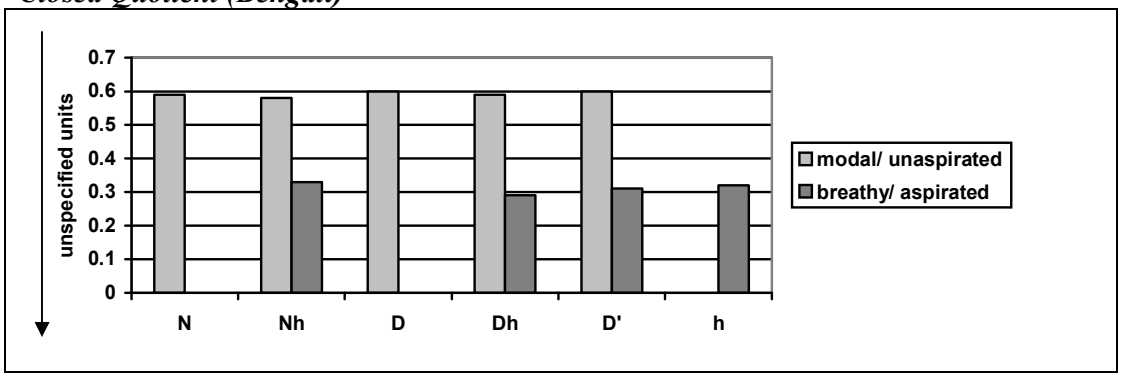


Figure 5: Graph of the average closed quotient of /N/, /Nɦ/, /D/, /Dɦ/, /Dʱ/, and /h/ for Bengali. The arrow indicates the direction of increased breathiness.

Figure 5 tells us little about the status of breathiness in general. The CQ data fails to distinguish even the phonemic distinction between /Dʱ/ and /Dɦ/; the CQ values of the unaspirated portions of both consonant types are similar to that of the corresponding modal consonant /D/, while the CQ values of the aspirated portions of both consonant types are similar to that of /ɦ/. As for the question of breathy nasals in particular, the CQ values of /Nɦ/ pattern with both /Dʱ/ and /Dɦ/, making the data ambiguous for Bengali.

7.3.1.3 Summary of results for Bengali

The within-language comparison of the Bengali data, in general, is ambiguous. While duration indicates that /Nɦ/ is more like the cluster /Dɦ/ than like /Dʱ/, evidence from CQ measurements is ambiguous at best. The CQ data indicate that /Nɦ/ behaves like both the cluster /Dɦ/ and the single segment /Dʱ/. Thus, it is not clear from the within-language data whether /Nɦ/ is a cluster or a single segment in Bengali.

We will now move on to the results and discussion of data for Hindi.

7.3.2 Hindi

7.3.2.1 Duration

In Hindi, underlying sequences of /D/+/ɦ/ were consistently split up by schwa epenthesis, yielding [Dəɦ]. Some of the /N/+/ɦ/ tokens were also split up in this same way,

yielding some productions of [Nəɦ]. This phonetic variation even occurred across tokens of the same word. As the epenthesized schwa could potentially confound many of the acoustic measurements taken, all tokens with schwa epenthesis were excluded from the measurements of duration, CQ, peak airflow, and duration of peak airflow, including all the graphs below.

Figure 6 is a graph of the average durations of the breathy/aspirated and modal/unaspirated portions of the segments /N/, /Nɦ/, /D/, /Dɦ/, and /ɦ/. Duration is graphed on the *y*-axis in ms.

Duration (Hindi)

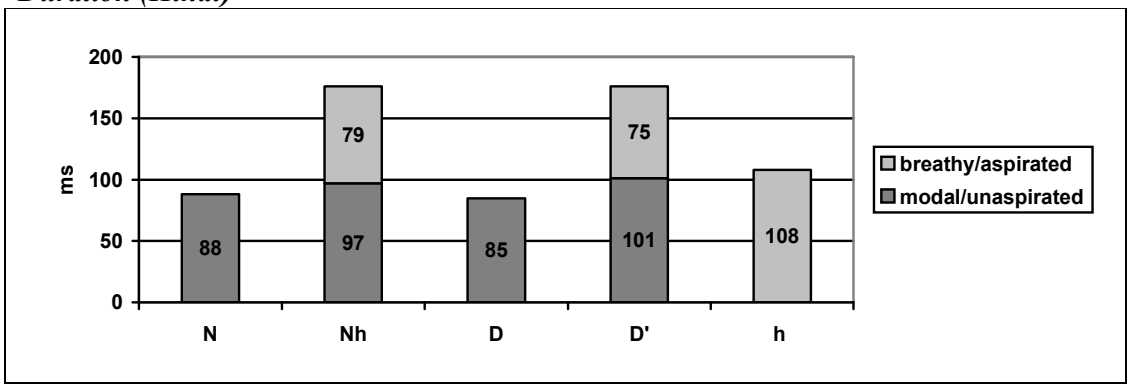


Figure 6: Graph of the average duration of the breathy/aspirated and modal/unaspirated portion of /N/, /Nɦ/, /D/, /Dɦ/, and /ɦ/ for Hindi.

The duration of /Nɦ/ is twice that of /N/, suggesting that it is a cluster of two consonants. However, the duration of the phonemically breathy-aspirated singleton consonant /Dɦ/ is also twice that of its modal counterpart /D/, suggesting that /Nɦ/ and /Dɦ/ are actually behaving in a similar pattern. In this respect, /Nɦ/ seems to be patterning like other breathy singleton consonants in Hindi.[7] However, it is hard to draw a firm conclusion from the duration data,, as the /Dɦ/ cluster data needed to serve as a point of comparison were not produced without schwa epenthesis ([Dəɦ]).

Despite the ambiguity of the duration results, the fact that schwa epenthesis occasionally breaks up /Nɦ/ into [Nəɦ] is in itself a strong indication that /Nɦ/ is a cluster,

because a single segment like /Dʱ/ is never split up by the sort of epenthesis consistently produced in tokens of /Dɦ/ clusters.

7.3.2.2 Closed quotient

Figure 7 is a graph of the average CQ value for Hindi /N/, /Nɦ/, /D/, /Dʱ/, and /ɦ/. Lower values indicate increased breathiness.

Closed Quotient (Hindi)

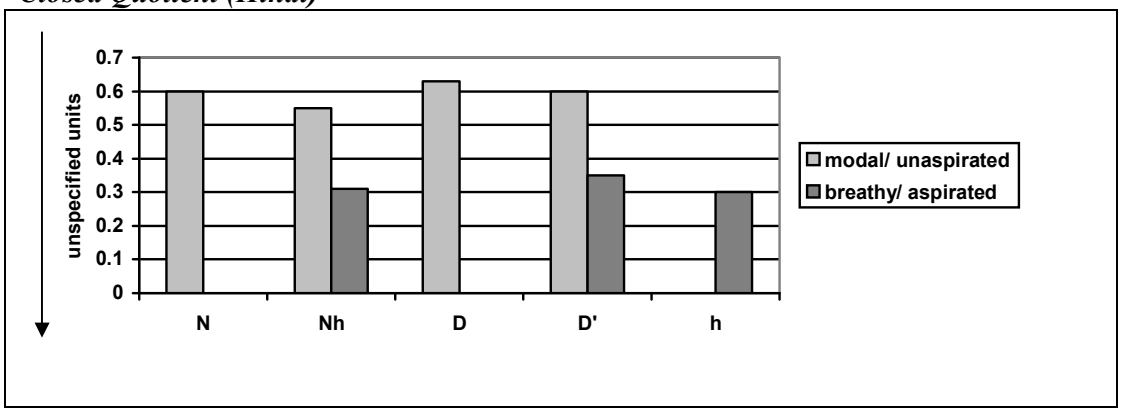


Figure 7: Graph of the average closed quotient of the breathy/aspirated and modal/unaspirated portion of /N/, /Nɦ/, /D/, /Dʱ/, and /ɦ/ for Hindi. The arrow is pointing in the direction of increased breathiness.

The CQ data for the Hindi are inconclusive due to the lack of /Dɦ/ tokens without epenthesis. From the data that could be analyzed, it was found that the CQ value of /Nɦ/ does not pattern as we would expect it to if it were a sequence of /N/ followed by /ɦ/ in that the modal portion of the /Nɦ/ is actually breathier (*i.e.*, has a lower CQ value) than modal /N/. This is an indication that the entire /Nɦ/ sequence is produced breathier than what might be expected of a cluster of modal /N/ and breathy /ɦ/. The CQ of /Nh/ also patterns with the CQ of breathy-aspirated oral /Dʱ/, in that the stop closure part of /Dʱ/ is also more aspirated (breathier) than that of the phonemically modal segment /D/. However, this cannot be taken to be conclusive as there is no corresponding CQ value available for tokens of /D/+/ɦ/ (which, as previously mentioned, were all produced with schwa epenthesis, complicating the reliability of the CQ measurement). Unless it can be shown that the CQ value of /Dɦ/

(without epenthesis) is substantially higher than that of phonemically breathy /Dʱ/, the Hindi data are inconclusive.

7.3.2.3 Summary of results for Hindi

To summarize, the within-language comparison of the Hindi data is inconclusive because a direct comparison can not be made of /Nɦ/ to /Dɦ/ (due to the fact that /Dɦ/ always surfaced as [Dəɦ]). With the data available, it was found that while duration indicates that Hindi /Nɦ/ is more like the single segment /Dʱ/, the phenomenon of schwa epenthesis suggests it is more like a cluster. The CQ data are ambiguous, indicating that /Nɦ/ behaves both like a cluster and like a single segment.

We will now present the cross-language comparison.

8 Cross-language comparison

For the cross-language comparison, the potentially breathy nasals (/Nɦ/) in Bengali and Hindi were compared to the phonemically breathy nasals (/N̤/) in Marathi. If Bengali and Hindi possess true breathy nasals (/N̤/), then they should share some phonetic features with the breathy nasals of Marathi.

8.1 Methods

8.1.1 Speakers

The same Bengali and Hindi speakers that participated in the previous experiment were also recorded here. In addition, one adult female speaker of Marathi was recorded.

8.1.2 Speech Materials

8.1.2.1 Marathi

The Marathi speaker produced the sounds given in Table 4:

Consonant/cluster type	Label	Marathi Example
1. Nasals	/N/	/**n**aːʊ/ ‘name’
2. Breathy nasals	/N̤/	/**m̤**aːɾ/ ‘Mahar caste’

Table 4: A list of the consonant types recorded for Marathi.

These consonants were produced intervocalically, with six words per consonant type. Each word contained one and only one of the consonant types in question.

8.1.2.2 Bengali and Hindi

The /N/ and /Nɦ/ words from Part 7 were used again in this part of the study.

8.2 Procedure

For Marathi, each word was repeated three times in the carrier sentence [t̪o: ____ ʃəbd̪a: ʊa:ts] 'He said the word _____'. For Bengali and Hindi, the same carrier sentences that were used in Part 5 of the study were used here. Simultaneous aerodynamic, EGG, and audio recordings were made for each speaker. (For Bengali, aerodynamic data could only be collected for one male and one female speaker.) Tokens were digitized and analyzed at a sampling rate of 22 kHz using AcQuirer software (Scicon RD). CQ was taken following the same procedure used in Part 5. In additional, peak airflow and duration of peak airflow were measured following the procedures described below.

8.2.1 Description of measures

8.2.1.1 Airflow

The peak airflow (that is, the greatest amount of oral or nasal airflow, depending on the segment being measured) was taken at two points, (1) the middle of the modal/ unaspirated portion and (2) the middle of the breathy/aspirated portion. Spectrograms were used to determine where the modal/unaspirated and breathy/ aspirated portions of each segment were, following the same procedure established in the previous section. For /N/, there would naturally only be one measurement, within the non-aspirated portion, and for the /ɦ/ only within the aspirated portion.

8.2.1.2 Duration of peak airflow

After careful examination of a sample of the airflow data, it was noted that the peak airflow during the breathy/aspirated segments consistently surpassed 100 ml/s during the

segments under study. (The airflow during modal/unaspirated segments was always less than 100 ml/s). Thus, duration of peak airflow was measured as the length of time during which the airflow exceeded this threshold of 100 ml/s in ms. An example of the oral flow exceeding 100 ml/s is presented in Figure 7.

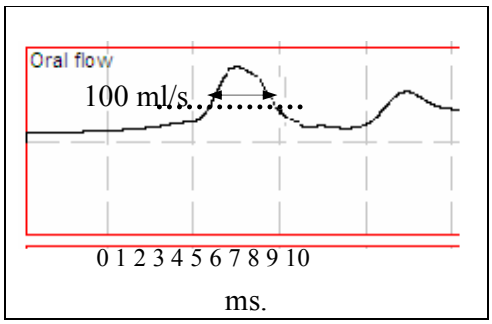


Figure 8: An example of how the duration of peak airflow was measured from the oral flow signal. Only the first 10 ms. are marked along the horizontal dimension.

In Figure 8, the dashed line represents the 100 ml/s threshold. The arrows indicate the amount of time the flow exceeded this threshold (measured in ms.). In this example, the oral flow is greater than 100 ml/s for approximately 3 ms. (At approximately, 6 ms the oral flow exceeds 100 ml/s. This continues until approximately 9 ms, after which time the oral airflow decreases.) Thus, the duration of peak oral airflow is 3 ms. The same procedure was applied to nasal flow as well.

8.2.1.3 Closed Quotient

Closed quotient was measured following the same procedure established in section 7.2.1.2.

8.3 Results and Discussion

8.3.1 Airflow

Figure 9, Figure **10**, and Figure **11** are graphs of the average peak oral and nasal airflow of /N/ and /N̪/ for Marathi, and /N/ and /Nɦ/ for Bengali and Hindi, respectively.

Airflow is represented in ml/s on the *y*-axis. The /Nɦ/ in Bengali and Hindi and the /N̤/ in Marathi all have mostly nasal flow, but also include some oral flow towards the end of the breathy portion. Thus, both oral and nasal flow (in ml/s) are graphed in the figures below. As previously mentioned, breathiness/aspiration on both nasal and oral consonants is represented by an apostrophe < ' > in all graphs in this paper due to typographical limitations.

Airflow (Marathi)

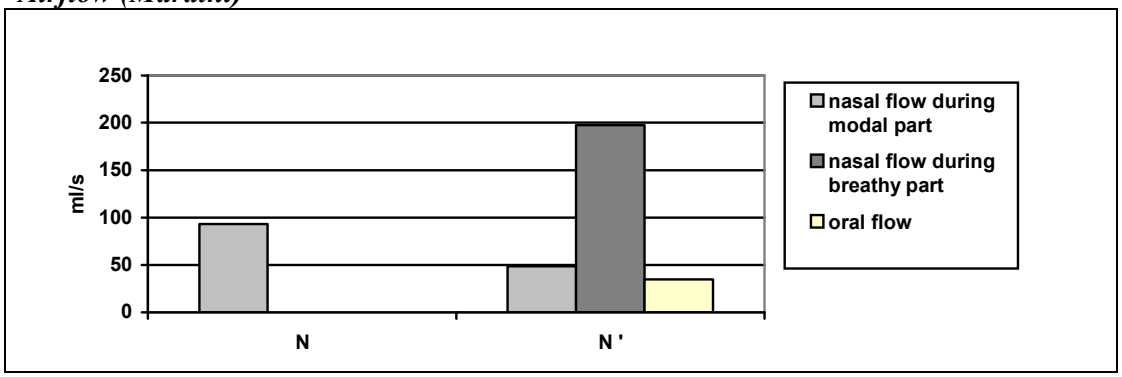


Figure 9: Graph of the average peak oral and nasal flow of /N/ and /N̤/ for Marathi.

Airflow (Bengali)

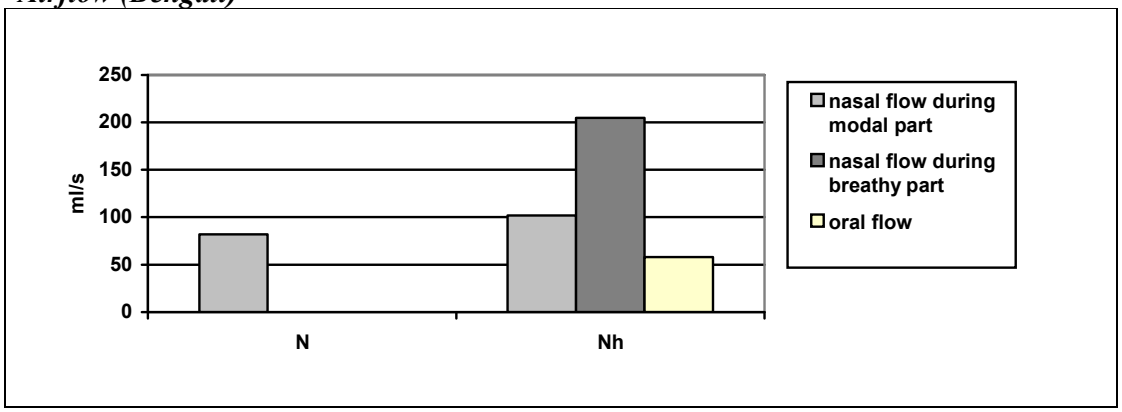


Figure 10: Graph of the average peak oral and nasal flow of /N/ and /Nɦ/ for Bengali.

Airflow (Hindi)

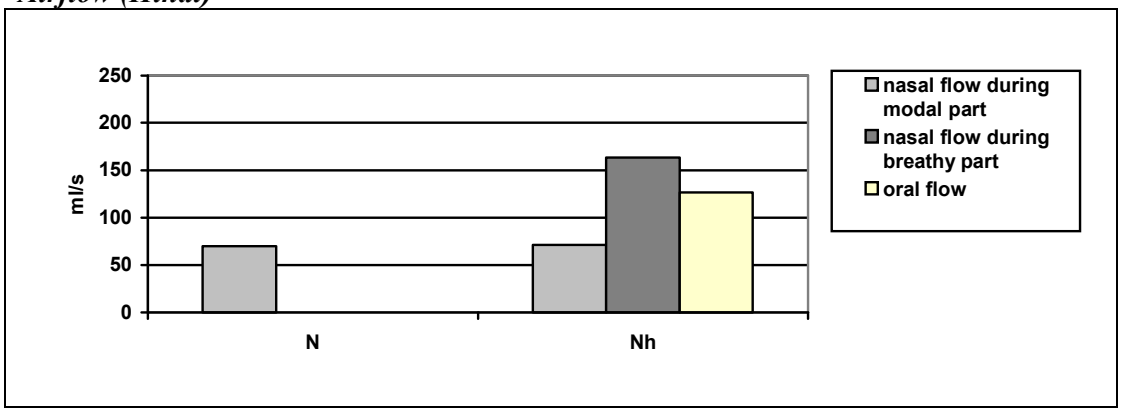


Figure 11: Graph of the average peak oral and nasal flow of /N/ and /Nɦ/ for Hindi.

The /N̤/ of Marathi has mostly nasal flow, with only a small amount of oral flow. This is similar to the Bengali /Nɦ/, which is also composed of mostly nasal flow. On the

other hand, Hindi /Nɦ/ has a great deal of oral flow in addition to the nasal flow. This substantial oral flow suggests that the Hindi /Nɦ/ behaves like two distinct segments ([Nɦ]), one nasal ([N]) and another oral ([ɦ]), with some coarticulation, rather than like a single breathy nasal [N̤].

8.3.2 Closed Quotient

Figure 12, Figure 13, and Figure 14 are graphs of the average CQ value of the /N/ and /N̤/ for Marathi, and /N/ and /Nɦ/ for Bengali and Hindi. In each figure, an arrow is pointing in the direction of increased breathiness.

Closed Quotient (Marathi)

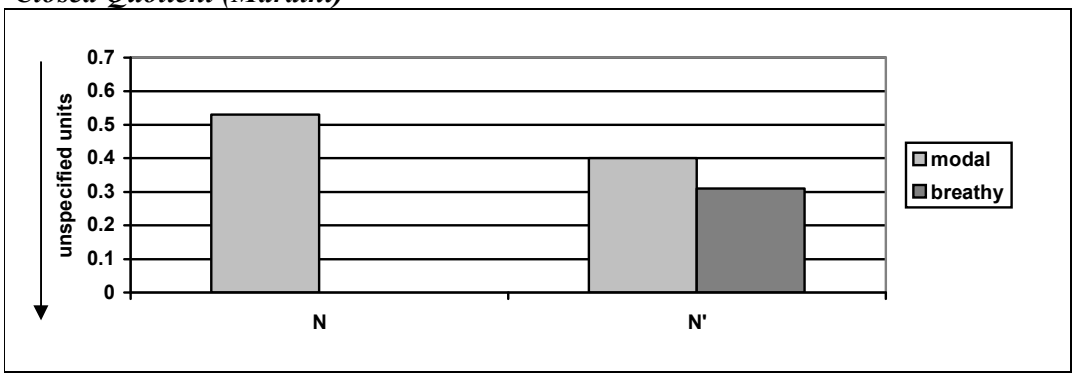


Figure 12: Graph of the average closed quotient value of /N/ and /N̤/ in Marathi.

Closed Quotient (Bengali)

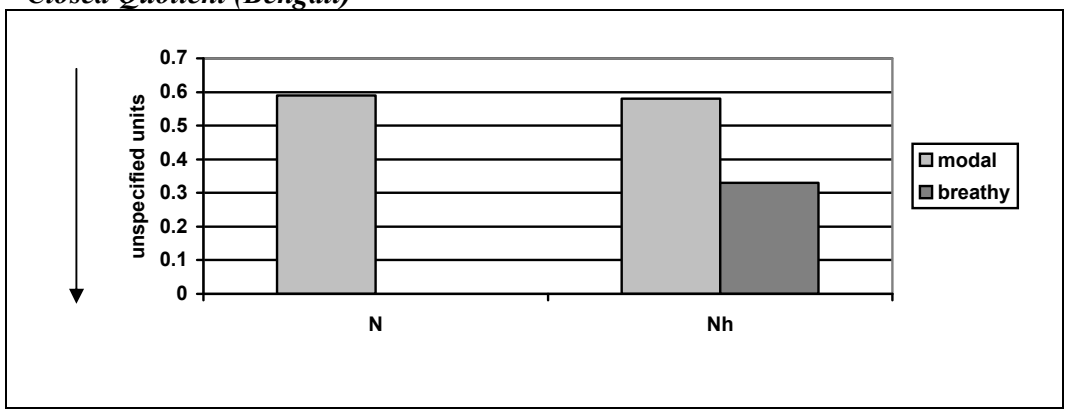


Figure 13: Graph of the average closed quotient value of /N/ and /Nɦ/ in Bengali.

Closed Quotient (Hindi)

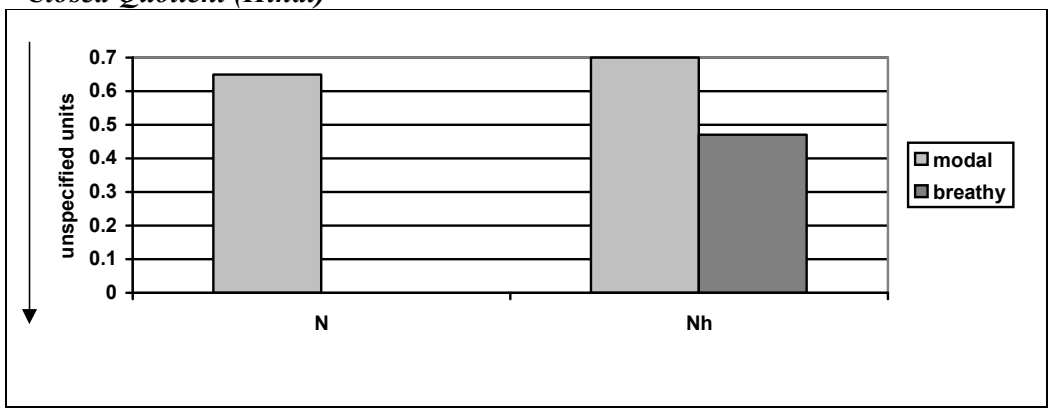


Figure 14: Graph of the average closed quotient value of /N/ and /Nɦ/ in Hindi.

In Marathi, /N̤/ has an overall lower CQ (*i.e.*, is breathier) than modal /N/. Even the initial modal portion of the /N̤/ is substantially more breathy than the modal /N/. This is not

true of Bengali or Hindi, where the /Nɦ/ has a substantially lower CQ only during the [ɦ] portion; the modal portion of the /Nɦ/ has a similar CQ value to the modal /N/. (In Bengali, the CQ of the /N/ in /Nh/ is only narrowly lower than that of modal /N/, while the Hindi /Nɦ/ begins with an even higher CQ – indicating less breathiness – than the phonemically modal /N/.) Thus the /Nɦ/'s of Bengali and Hindi are not like the /N̤/ of Marathi with respect to CQ.

8.3.3 Duration of peak airflow

Figure 15, Figure 16, and Figure 17 represent the average duration of peak airflow for /N̤/ in Marathi, and /Nɦ/ in Bengali and Hindi. Duration is graphed on the *x*-axis in ms.

Duration of peak airflow (Marathi)

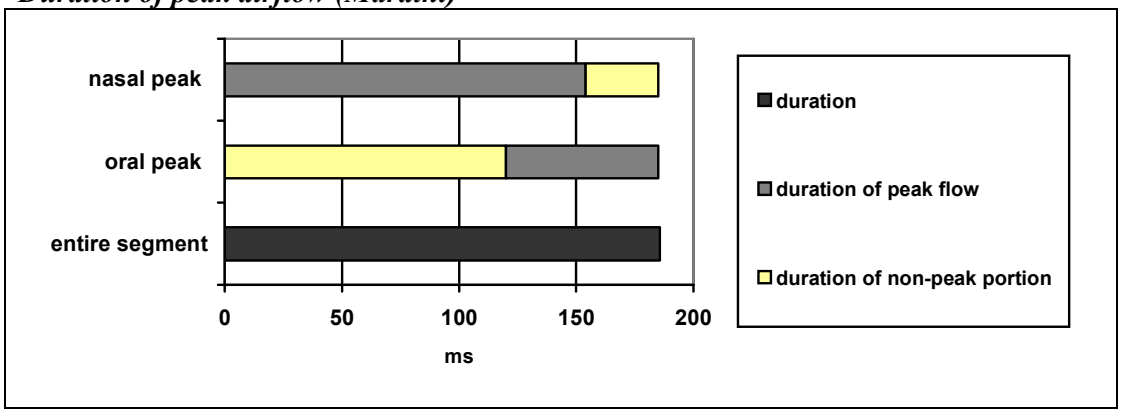


Figure 15: Graph of the average duration of peak airflow in Marathi /N̤/.

Duration of peak airflow (Bengali)

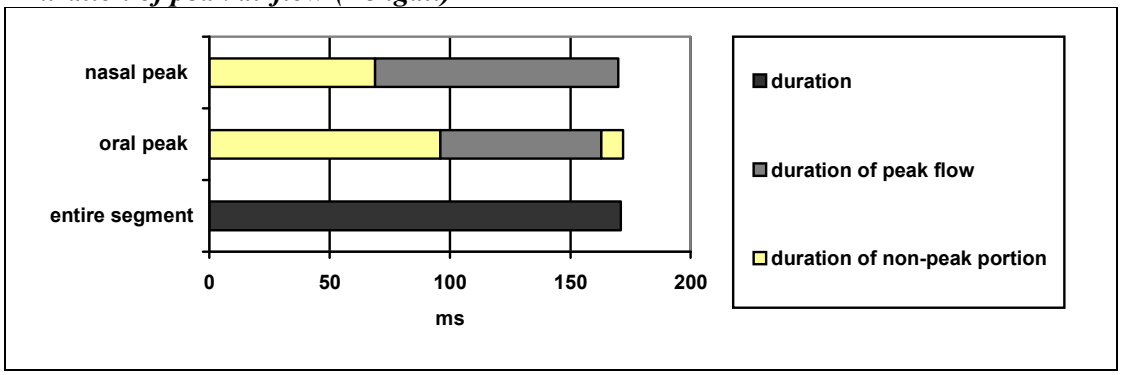


Figure 16: Graph of the average duration of peak airflow in Bengali /Nɦ/.

Duration of peak airflow (Hindi)

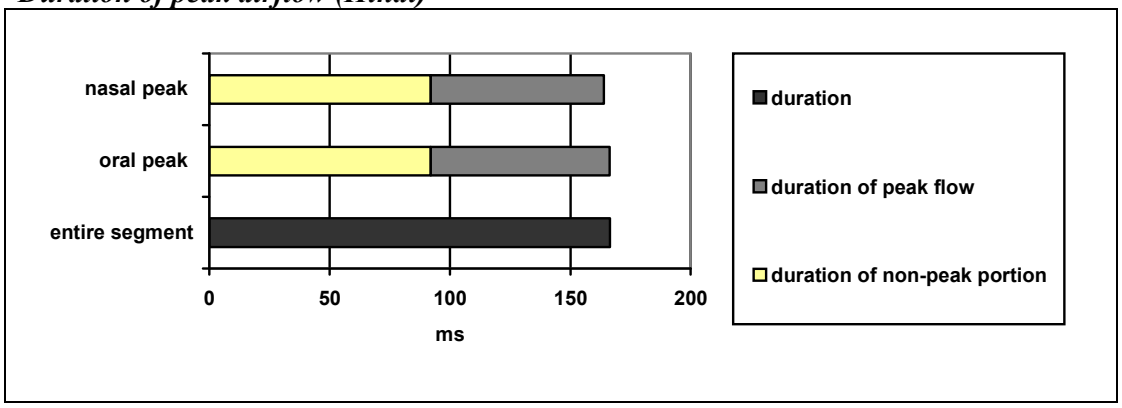


Figure 17: Graph of the average duration of peak airflow in Hindi /Nɦ/.

In Marathi, the /N̤/ is composed mostly of nasal flow, with a small amount of oral flow near the end of the segment. This is not the case for Bengali and Hindi. In these

languages, the /Nɦ/ is composed of similar parts nasal and oral flow, both taking place near the end of the segment, suggesting that these languages lack the type of breathy nasal found in Marathi.

8.3.4 Summary of cross-language comparison

For the most part, the Bengali and Hindi data do not pattern like that of Marathi, suggesting that the /Nɦ/ sequences in these languages are not breathy nasals. For example, when looking at duration of peak airflow, the Bengali and Hindi /Nɦ/ is composed of similar parts nasal and oral flow at the end of the segment, as opposed to Marathi, where the [N̤] has peak nasal flow throughout most of the consonant. In addition, according to the CQ value, the Bengali and Hindi /Nɦ/ is breathy only during the [ɦ] portion, unlike Marathi, where the /N̤/ is breathier than its modal counterpart /N/ for most of the segment. The only evidence that the Bengali /Nɦ/ might be a single segment comes from peak airflow, where /Nɦ/ has mostly nasal flow, just like Marathi. However, in Hindi, the /Nɦ/ has considerable oral (in additional to nasal) flow, suggesting the Hindi /Nɦ/ is behaving more like a cluster.

9 Vowel length

In addition to the comparisons made above, we also examined phonological evidence to determine the status of the /Nɦ/ sequences in Bengali and Hindi. In these two languages, vowels are phonetically longer in certain environments:

- **Bengali**: vowels are longer in open syllables (Esposito, *et al.* 2005a)
- **Hindi**: vowels are longer before a breathy/aspirated consonant (Maddieson & Gandour 1977)

These facts can be used as a simple diagnostic to provide further insight into the question of /Nɦ/ sequences. In Bengali, if vowels are longer before an /Nɦ/ sequence, they are behaving as though they are in an open syllable, suggesting that /Nɦ/ is behaving as a single

segment ([…V.N̤V…]). Two segments would likely create a closed syllable ([…VN.ɦV…]), removing the environment where the longer vowel appears. In Hindi, vowels are longer before breathy consonants; if vowels are longer before an /Nɦ/ sequence than before modal /N/, then /Nɦ/ is presumably a single breathy segment ([N̤]), rather than a sequence of a modal [N] followed by [ɦ].

9.1 Methods

9.1.1 Speakers

The same Bengali and Hindi speakers who participated in the first part of the study participated in this section.

9.1.2 Speech Materials

The Bengali speakers were asked to produce words with /aC_0V/ sequences, where each sequence was one of the following:

Consonant/cluster type	Label	Bengali Example
1. Voiced aspirated oral stop	/a.Dʱ̤V/	/ad̤ʱ̤a/ ‘half’
2. Voiced unaspirated oral stop	/a.DV/	/ad̤a/ ‘ginger’
3. Potentially breathy nasal stop	/aNɦV/	/namɦara/ ‘nameless’
4. Modal nasal stop	/a.NV/	/namalam/ ‘I lowered’
5. Clusters	/aD.CV/ /aN.CV/ /aD.ɦV/	/abɹiṯ̤ṯ̤i/ ‘recitation’ /and̤olon/ ‘movement’ /abɦaoa/ ‘weather’

Table 5: A list of the consonants (and clusters) recorded for Bengali.

The vowels being measured were always stressed /a/’s.

The Hindi speaker was asked to produce words with /ʊC_0V/ sequences, where each sequence was one of the following:

Consonant/cluster type	Label	Hindi Example
1. Voiced aspirated oral stop	/ʊDʱ̤V/	/lʊbʱ̤aːnaː/ ‘to tempt’
2. Voiced unaspirated oral stop	/ʊDV/	/kʊbeːɾ/ ‘god of wealth’
3. Potentially breathy nasal stop	/ʊNɦV/	/kʊmɦaːɾ/ ‘potter’
4. Modal nasal stop	/ʊNV/	/kʊmaːɾ/ ‘boy’

Table 6: A list of the consonants (and clusters) recorded for Hindi.

In Hindi, the vowels being measured were unstressed /ʊ/'s.

9.2 Procedure

Each word was recorded in the carrier sentences used in section 7 of the study. The duration (in ms) of the vowel before each consonant (or consonant sequence) was measured for each language. Tokens were controlled for vowel quality, word position, and stress.

9.3 Results and Discussion

9.3.1 Bengali

Figure 18 graphs the average duration of /a/ in seven different environments. The length of the vowel in each environment type is plotted in ms along the *y*-axis.

Vowel length (Bengali)

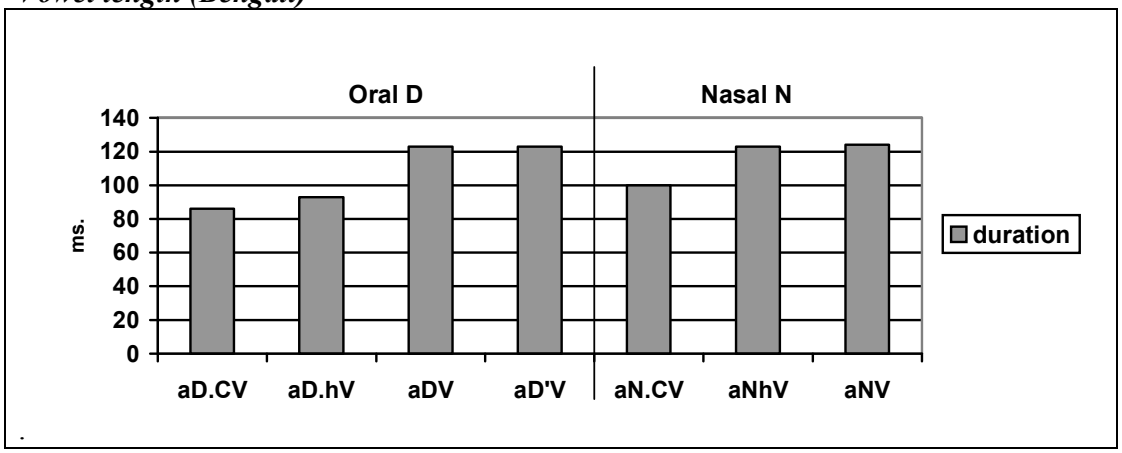


Figure 18: Graph of the vowel duration in the sequences /aD.CV/, /aD.ɦV/, /a.DV/, /a.Dʱ V/, /aN.CV/, /aNɦV/, and /a.NV/.

As stated previously, Bengali vowels followed by a single segment (/D/, /Dʱ/, /N/) are longer than those followed by clusters (/D.C/, /D.ɦ/, and /N.C/). The duration of the vowel is longer than 120 ms in each of the environments where a single segment followed the vowel, while the duration of the vowel is consistently shorter than 100 ms in all of the closed-syllable environments (*i.e.*, where the vowel is followed by a sequence of two consonants). It turns out that vowels followed by either /N/ or /Nɦ/ are in fact consistently longer than 120 ms, while vowels followed by a cluster of a nasal and another consonant (/NC/) are

consistently shorter than 100ms. This suggests that /Nɦ/ is behaving more like a single segment ([N̤]) than like a cluster of [N.ɦ] in terms of syllabification, the same way that vowels before the single consonants /D/ and /Dʱ/ are consistently longer than those before clusters of an oral stop and another consonant (/DC/), including when the second consonant is /ɦ/ (/Dɦ/). Thus, /Nɦ/ patterns with singleton consonants such as /N/, /D/, and /Dʱ/ and not with clusters of consonants such as /NC/, /DC/, and /Dɦ/ with respect to syllabification.

9.3.2 Hindi

Figure 18 is a graph of the average duration of /ʊ/ in /ʊNV/, /ʊNɦV/, /ʊDV/, and /ʊDʱV/. Duration is graphed on the *y*-axis in ms. Please note that due to typographical limitations, the vowel /ʊ/ is represented as /u/ in Figure 19.

Vowel length (Hindi)

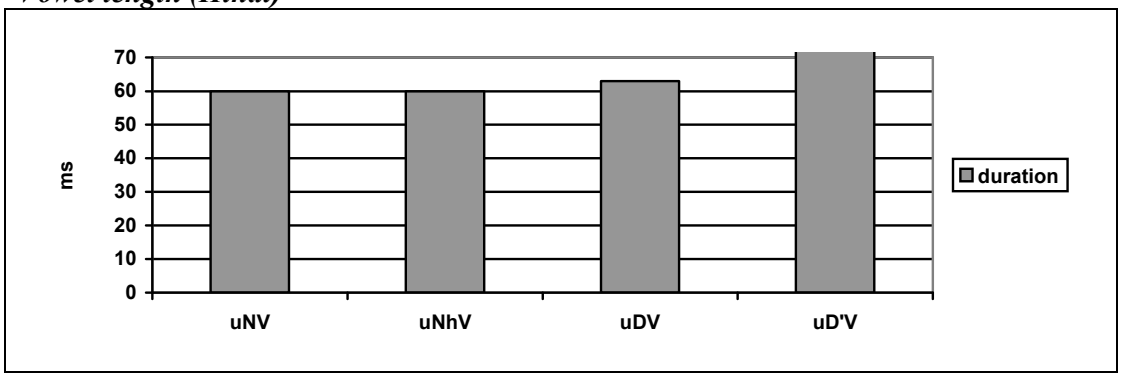


Figure 19: Graph of the vowel duration in the sequences /ʊNV/, /ʊNɦV/, /ʊDV/, and /ʊDʱV/.

The vowel /ʊ/ is produced with longer duration before the breathy-voiced aspirated oral stops (/Dʱ/) than before their (modal-voiced) unaspirated counterparts (/D/). However, vowels are not longer before /Nɦ/ than before modal /N/, suggesting that /Nɦ/ is phonologically not the aspirated counterpart of modal /N/. It is likely that /Nɦ/ is (at least phonologically) a cluster beginning with a modal nasal, rather than a single breathy nasal.

9.3.3 Summary

In Bengali, vowels preceding an /Nɦ/ sequence were found to be longer than those preceding /N.C/ and other clusters, and more similar in length to vowels preceding the single segments /D/, /Dɦ/, and /N/. In Hindi, vowels preceding /Nɦ/ were found to be the same length as vowels preceding /N/. The phonological evidence here indicates that /Nɦ/ sequences in Bengali are behaving like single (breathy) segments, but that these sequences in Hindi behave as if they were clusters beginning with a modal segment.

10 Conclusion

To summarize, the Bengali data is ambiguous. For example, some data in the within-language comparison, (such as duration) point to cluster status for the /Nɦ/, while other data (such as vowel length), suggest that /Nɦ/ is a single segment. The results of the measures of duration, CQ, duration of peak airflow, peak airflow, and vowel lengthening in Bengali are presented in Table 7.

Measurements	Within-language comparison	Cross-language comparison
Duration	Cluster	
CQ	Inconclusive	Cluster
Duration of peak airflow		Cluster
Peak Airflow		Single Consonant
Vowel lengthening	Single Consonant	

Table 7: Summary of results for Bengali. Shaded areas denote measurements not taken.

However, for Hindi, the majority of data suggest that the /Nɦ/ behaves more like a cluster than like a single breathy nasal. The results of duration, schwa epenthesis, closed quotient, duration of peak airflow, airflow, and vowel lengthening in Hindi are presented in Table 8.

Measurements	Within-language comparison	Cross-language comparison
Duration	Inconclusive	
Schwa epenthesis	Cluster	
CQ	Inconclusive	Cluster
Duration of peak airflow		Cluster
Peak Airflow		Cluster
Vowel lengthening	Cluster	

Table 8: Summary of results for Hindi. Shaded areas denote measurements not taken.

In determining the phonetic status of underlying /Nɦ/ in Bengali and Hindi, within-language comparisons did not allow us to draw any clear conclusions. However, the data for Hindi leaned strongly towards a cluster analysis. Cross-language comparisons with Marathi, however, indicated that Bengali and Hindi /Nɦ/ sequences are not phonetically realized like the Marathi /N̤/. Phonological evidence in Bengali and Hindi illustrated that, in terms of preceding vowel length, Bengali /Nɦ/ is being treated as a single segment, while Hindi /Nɦ/ is patterning with modal/unaspirated sounds.

From the results found here, it appears that there is little reason to posit breathy nasals for Hindi; neither phonetic nor phonological evidence points to their existence. Bengali, on the other hand, may phonologically have a breathy nasal that simply lacks some of the phonetic attributes of its Marathi counterpart.

The results obtained in this study raise an interesting issue about the typology of breathy nasals in South Asia. Based on the evidence examined here, it appears that there might be three different treatments of /Nɦ/'s in Indic languages: phonemic breathy nasals (as in Marathi /N̤/), [Nɦ] clusters (as in Hindi), and a possible transitional state between the two (as in Bengali). It is necessary to examine /Nɦ/ data from a variety of other Indic languages (*e.g.* Nepali, Gujarati, Punjabi, *etc.*) to see if this predicted three-way classification holds true for throughout the family.

Colophon

We would like to thank our speakers for their assistance with this project, as well as the members of the UCLA Phonetics Lab for their helpful comments. An earlier version of this paper was presented at the 149th meeting of the Acoustical Society of America, Vancouver, BC, May 2005 and appeared in the UCLA Working Papers in Phonetics volume 104.

[1] Throughout this paper, we will be using the term 'aspirate' to refer to both voiceless aspirated stops (T^{h}) and breathy-voiced oral stops ($D^{ɦ}$). We will use the term 'breathy' to refer to both breathy nasals ([N̤]) and breathy-voiced oral stops ($D^{ɦ}$). This reflects the traditional terminology used for Indic languages.

[2] Often, the historical source of breathy nasals in Indic languages is the merger of a nasal with historical /ɦ/ or /s/. For example, Sanskrit [maɦiṣa] > Marathi [m̤aiʃ] 'bull' (*cf.* Hindi [maɦeːʃ], Bengali [moɦiʃ]), and Sanskrit [snaːna] 'bath' > Marathi [n̤aːn] (*cf.* Hindi [naɦaː-], Bengali [snan] and [na-]).

[3] This word is pronounced [maɦaːɾ] in some other dialects of Marathi. The transcription shown here reflects the production of speakers such as the one found in the UCLA Phonetics lab online archive (http://phonetics.ucla.edu/appendix/languages/marathi/marathi.html).

[4] Although we use the breathy-voiced glottal symbol [ɦ] between /slashes/, this should not be taken as a claim of a phonemic distinction between /ɦ/ and /h/. For our purposes, these can be considered equivalent.

[5] The transcriptions of Urdu examples have been partially adjusted to accord with the conventions used in this paper. Underlying /Nɦ/ clusters correspond to /$N^{ɦ}$/ in Aziz (2002). Phonetically breathy nasals are transcribed as [N̤] here and as [$N^{ɦ}$] in Aziz (2002). Nasalization is shown as a tilde [ṽ] here and as a superscript [V^{n}] in Aziz (2002).

[6] Traditionally, 'aspiration' differs from 'breathiness' in that 'aspiration' is a period of voicelessness ([h] or [C^{h}]), while 'breathiness' is voiced ([ɦ], [$C^{ɦ}$], or [C̤]). The term 'breathy-voiced aspiration' often refers to the aspirated release of a voiced stop ([$C^{ɦ}$]) as well.

[7] In the Hindi data, place of articulation of the nasal consonants did not affect breathiness as it did in Urdu (as discussed in section 3).

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