# BREATHINESS CONTRASTS IN CONSONANTS AND VOWELS: A COMPARATIVE STUDY OF GUJARATI AND WHITE HMONG

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## ABSTRACT

Only a small handful of languages are known to distinguish breathy and modal voice in both consonants and vowels. Two of these languages, Gujarati and White Hmong, boast CV sequences in which phonetic breathiness can be phonologically associated either with the consonant or with the vowel. Complicating matters, consonant breathiness is phonetically realized as a breathy-voiced aspirated release into the following vowel, so how do speakers distinguish breathiness associated with a consonant release [CʱV] from breathiness associated with a vowel [CV̤], if at all? The current study investigates acoustic and articulatory (electroglottographic) properties of consonantal and vocalic breathiness in ambiguous contexts, discovering that speakers of both languages consistently differentiate the two underlying sequences in the relative timing/ duration and magnitude of the phonetic realization of breathiness.

**Keywords:** phonation, breathy, Gujarati, White Hmong, electroglottography

## 1. INTRODUCTION

Contrastive breathy voice is widespread, with Indic languages such as Hindi [16] and Bengali [10] distinguishing breathy (voiced aspirated) consonants from modal (voiced unaspirated) consonants, and Zapotec languages [3][15] distinguishing breathy vowels from modal vowels. However, only a small handful of languages use breathy voice contrastively on both consonants *and* vowels; these include Gujarati, White Hmong, and Khoisan languages [14] [19].

What makes this small group of languages particularly interesting is that they exhibit CV sequences where breathy voice could potentially be associated with the consonant [Cʱ] or with the vowel [V̤]. Crucially, since (stop) consonant breathiness is realized not during the closure itself but as a breathy-aspirated release into the vowel, how do speakers distinguish [CʱV] (with a breathy-voiced aspirated consonant) from [CV̤] (with a breathy vowel), if at all?

The current study answers the following questions, using acoustic and electroglottographic data from Gujarati and White Hmong:

- Is consonant breathiness distinguished from vowel breathiness in the *timing/duration* of its realization?
- Is consonant breathiness distinguished from vowel breathiness in the *degree* of realization?
- How do these sounds differ across Gujarati and White Hmong?

By comparing these two unrelated languages, we hope to discover the articulatory and acoustic similarities and differences in the production of these sequences.

## 2. METHODS

### 2.1. Subjects

The subjects in the current study are all literate in their native language, either Gujarati or White Hmong. All were residents of the US at the time of recording. Ten speakers of Gujarati (3 male, 7 female) were recorded in Los Angeles; their ages ranged from 20-50. Twelve speakers of White Hmong (6 male, 6 female) were recorded in St. Paul; their ages ranged from 24–58.

### 2.2. Recording

For both languages, three types of words were recorded based on their target CV sequence:

- “Breathy V”: breathy vowels [CV̤]
- “Breathy-asp. C”: breathy consonants [CʱV]
- “Modal”: no breathiness [CV]

The Gujarati stimuli consisted of minimal and near-minimal triplets, produced at a natural speech rate at the beginning of sentences that subjects themselves created (e.g. [ba̤ɾ ʈʰəɳɖi ʧʰe] ‘It’s cold outside.’). This approach was used to minimize the known effects of slow, formal, read speech [2].

The White Hmong stimuli consisted of near-minimal triplets, produced in the carrier phrase

*Rov hais* X *dua* [ʈɔ24 hai22 X duə33] 'Say X again'.

### 2.3. Measurements

The measures used in the current study include those that have been shown in previous studies of Gujarati [1], [4],[9], [11] and White Hmong [3] [5] [9] to be successful at distinguishing breathy and modal vowels in the two languages. These include the following:

- **H1*–H2***, the amplitude difference between the first and second harmonics, corrected for the effects of adjacent formants [6] [8].
- **H1*–A3***, the corrected amplitude difference between the first harmonic and third formant.
- **Cepstral peak prominence (CPP)**, a measure of noise and/or aperiodicity [7].
- **Closed quotient (CQ)**, the portion of time the glottis is open per pulse, measured using the hybrid method with a 25% threshold.
- **Derivative-EGG closure peak amplitude (DECPA)**, the peak positive value for each pulse in the derivative of the EGG signal [13].

Measurements were taken automatically using the acoustic and electroglottographic analysis programs VoiceSauce [17] and EggWorks [18], respectively, at every millisecond of vowel duration and then averaged within nine parts of equal length. Since we assume that the relevant distinctions across the phonation categories will be concentrated at the beginning and middle of the vowel's duration, only the first five of these nine averages (i.e. the first five "timepoints", T1–T5) were subjected to statistical analysis.

The following terminology is used in the results to refer to the three categories:

- "**Breathy**": phonemically breathy vowel [V̤]
- "**Post-aspirated**": V following breathy C [ʱV]
- "**Modal**": no breathiness [V]

## 3. RESULTS

### 3.1. Overview

Results of ANOVAs and post-hoc pair-wise comparisons for each measure at each timepoint determined if there was a significant ($p \leq .001$) difference between the three vowel types: breathy, post-aspirated, and modal. The measures that significantly distinguished post-aspirated vowels from either breathy or modal vowels are summarized below in Table 1 for Gujarati and in Table 2 for White Hmong.

**Table 1:** Measures that significantly distinguish post-aspirated vowels from breathy and modal vowels ($p \leq 0.001$) across five timepoints in Gujarati.

| Timepoint | Breathy | Modal |
|---|---|---|
| T1 | (none) | H1*–H2*, H1*–A3*, CQ |
| T2 | H1*–H2*, H1*–A3*, CPP | H1*–H2*, H1*–A3*, CPP, CQ |
| T3 | H1*–H2*, CPP | H1*–H2*, H1*–A3*, CPP, CQ |
| T4 & T5 | (none) | H1*–H2*, H1*–A3*, CPP, CQ |

**Table 2:** Measures that significantly distinguish post-aspirated vowels from breathy and modal vowels ($p \leq 0.001$) across five timepoints in White Hmong.

| Timepoint | Breathy | Modal |
|---|---|---|
| T1 | H1*–H2*, CPP, CQ, DECPA | H1*–H2*, CQ, DECPA |
| T2 | CPP, CQ DECPA | H1*–H2*, CQ, DECPA |
| T3 | CPP, CQ, DECPA | DECPA |
| T4 & T5 | CPP, CQ, DECPA | (none) |

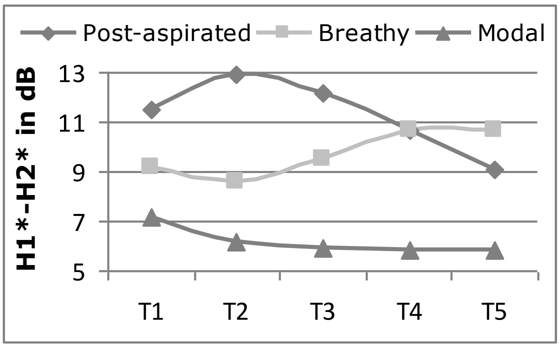
### 3.2. Gujarati

#### *3.2.1. Acoustic*

Along spectral measures H1*–H2* and H1*–A3*, modal, breathy, and post-aspirated vowels in Gujarati are all indistinguishable at the consonant release. However, by T3, post-aspirated vowels exhibit a significantly higher value than breathy vowels, which exhibit a significantly higher value than modal vowels. By T5, post-aspirated and breathy vowels are statistically indistinguishable from each other, but both show statistically higher H1*–H2* and H1*–A3* values than modal vowels. H1*–H2* values for all three categories are shown in Figure 1 below.

Like the spectral measures, CPP is also unsuccessful at distinguishing categories at the onset, and also shows a delayed peak in breathy vowels relative to that of post-aspirated vowels. However, CPP differs from spectral measures in that the values rise across the five timepoints for all three categories. Only the steepness of the rise distinguishes them: modal vowels rise in CPP the fastest, and breathy vowels the slowest, while post-aspirated vowels show an intermediate level.

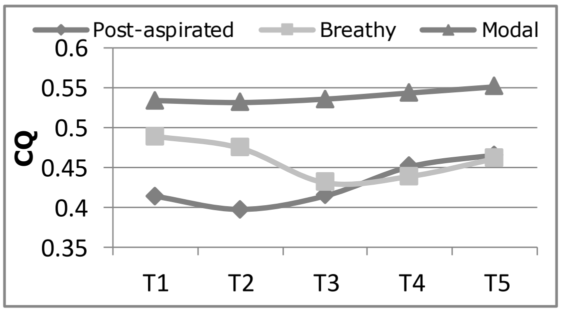
**Figure 1:** H1*–H2* values across T1–T5 in breathy, post-aspirated, and breathy vowels in Gujarati. Higher values are associated with greater breathiness.




### 3.2.2. Electroglottographic

Electroglottographic results largely match the acoustic patterns. CQ (Figure 2) distinguished post-aspirated from modal vowels across all five timepoints, but the CQ of breathy vowels showed more dynamic behavior. Breathy vowels started out more modal and later merged with the post-aspirated category at T3; at no point, however, are post-aspirated vowels statistically distinguished from breathy vowels by CQ. DECPA did not distinguish any two categories at any timepoint.

**Figure 2:** CQ values across T1–T5 in breathy, post-aspirated, and breathy vowels in Gujarati. Lower values are associated with greater breathiness.

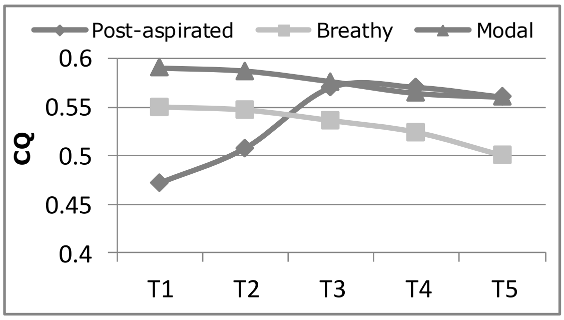



## 3.3. White Hmong

### 3.3.1. Acoustic

White Hmong post-aspirated vowels start out at T1 with an H1*–H2* value (Figure 3) significantly higher than that of breathy vowels, which have a significantly higher value than that of modal vowels. However, the H1*–H2* of post-aspirated vowels decreases and essentially merges with the modal category by T3, and becomes statistically distinct from post-aspirated vowels by T5, where the latter category increases in breathiness. H1*–A3*, however, was not successful at distinguishing any contrasts in White Hmong.

**Figure 3:** H1*–H2* values across T1–T5 in breathy, post-aspirated, and breathy vowels in White Hmong. Higher values are associated with greater breathiness.

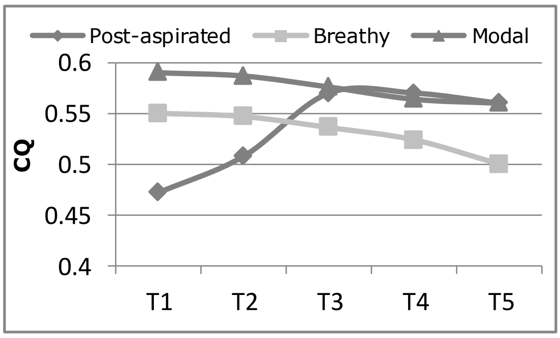



In terms of CPP, White Hmong vowels are divided into two statistically-distinct categories: breathy vowels show a lower value while modal and post-aspirated vowels are higher and not distinguished from each other.

### 3.3.2. Electroglottographic

Electroglottographic results indicate that White Hmong vowels can be distinguished by phonation category along both CQ and DECPA parameters. In CQ (Figure 4), post-aspirated vowels start out with an extremely low CQ, significantly lower (i.e. breathier) than modal or breathy vowels across T1 and T2. However, this quickly changes by T3, where post-aspirated vowels lose their breathiness and essentially merge with modal vowels, taking on statistically higher CQ than breathy vowels.

**Figure 4:** CQ values across T1–T5 in breathy, post-aspirated, and breathy vowels in White Hmong. Lower values are associated with greater breathiness.




DECPA distinguishes post-aspirated vowels from breathy vowels from T1 through T3, with post-aspirated vowels exhibiting the highest values. Then, this category loses breathiness and becomes statistically distinct from breathy vowels at T4, while it remains statistically separate from the modal category through T5.

## 4. DISCUSSION

Speakers of both Gujarati and White Hmong distinguished consonantal and vocalic breathiness by the timing/duration of the realization of breathy voice. The realization of consonantal breathiness was concentrated within the onset of the vowel, while vocalic breathiness was produced more evenly across the first half of the vowel. This short, early realization of breathiness in post-aspirated vowels presumably indicates that it is associated with the preceding stop and not with the vowel.

Arguably more surprising was the consistent distinction in the relative magnitude of breathy voice. In both languages, consonantal breathiness was realized with a more extreme production than vocalic breathiness. We hypothesize that this amplification of consonantal breathiness serves to compensate for its aforementioned short duration, thus ensuring its salience to the hearer.

Besides the cross-linguistic similarities, there are language-specific properties. Some involve the success of measures, e.g. H1*–A3* distinguishes categories only in Gujarati while DECPA is useful only in White Hmong. Other differences include the shorter duration of post-aspirated breathiness in White Hmong and the fact that Gujarati post-aspirated vowels more closely resemble breathy vowels along more measures at more timepoints, while in White Hmong, they more closely resemble modal vowels. These factors suggest that non-native listeners would more likely group post-aspirated vowels with breathy vowels in Gujarati and with modal vowels in White Hmong.

## 5. CONCLUSION

Gujarati and White Hmong are exceptional in that both languages have independently generated a contrast between breathy consonants and breathy vowels, a phonological opposition not even seen in their closest relatives (e.g. Hindi, Green Mong). What is particularly striking is how speakers of these unrelated languages consistently maintain this distinction in a very similar way: breathy consonants exhibit a short period of magnified breathiness in the following vowel, while breathy vowels are characterized by subtler cues of breathiness distributed across a longer duration. These realizations of breathiness are evident in both languages, along multiple acoustic and articulatory/electroglottographic parameters.

Naturally, language-specific differences were found, and the next logical step in this research is a perception study, ideally also including Khoisan languages (the only other reported languages with breathy vowels and consonants) for a stronger typological perspective. Given the cross-linguistic similarities, will listeners be able to correctly associate breathy voice with consonants and vowels, or will language-specific biases prove stronger? Such a follow-up will help further reveal characteristics of this very rare phenomenon.

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