Pitch discrimination during breathy versus modal phonation
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HYPOTHESIS
(1) Listeners are better at discriminating pitches implemented during modal phonation than pitches implemented during breathy phonation

MOTIVATION FOR HYPOTHESIS
(2) Pitch is probably determined by glottal pulse period and harmonic structure (e.g. the spectrotemporal model of Moore 1989).

(3) Glottal pulse period in breathy vowels is irregular in Jalapa Mazatec (an Otomanguean language of Oaxaca, Mexico; Kirk, Ladefoged and Ladefoged 1993); spectrum of Jalapa Mazatec breathy vowels involves a lower signal-to-noise ratio (Silverman, Blankenship, Kirk, and Ladefoged 1995, Silverman, 1995, 1998)

(4) Certain linguistic typological facts (to be discussed later)

(5) Pitch differences may be less reliably discriminable during breathy phonation than during modal phonation
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**STIMULI**

(6) Digitized natural speech from Jalapa Mazatec:

![Spectrogram of speech waves]

ng iŋ g a aŋ (he fastened)
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m m æ æ↑ (he wants)
Both breathy portion and modal portion extracted from each word.

Pitch of modal portions lowered to equal pitch of breathy portions (with SoundEdit16.2 "bender" feature).

Amplitude of six spectra normalized for peak amplitude.

Onsets and offsets ramped to avoid click artifacts.

Frequency of each portion increased in increments of approximately 3 Hz up to one whole tone, resulting in six continua with nine steps each.

All forms converted to 200 msec in length.

All possible within-continuum pairs produced, up to one-half tone difference (61 pairs per continuum, for a total of 366 stimulus pairs).

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<th>.375</th>
<th>.5</th>
<th>.625</th>
<th>.75</th>
<th>.875</th>
<th>1 tone</th>
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SUBJECTS/PROCEDURE

10 non-Jalapa Mazatec-speaking UCLA graduate students.

1000 trials/listener (501 “different” pairs; 499 “same” pairs), presented in blocks of 50 pairs. Inter-stimulus interval = 300 msec; inter-trial interval = 3 sec.

In a sound booth, subjects judged for each pair whether the two stimuli were the same or different in pitch.
RESULTS

(18) Subjects performed more accurately on modal vowel pairs than on breathy vowel pairs (p<.05). No significant learning took place.

(19) Moreover, at the 3- and 6-Hz intervals, performances was significantly worse than performance at the 9- and 12-Hz intervals (p<.05) (see “□” in 18).

(20) Thus, not only was subject performance significantly worse overall on breathy token pairs, but also, subjects performed increasingly worse as the pitch interval between tokens fell to approx. 6 Hz and below.
DISCUSSION

(22) The results of this study may be seen as complementing those of Rosenberg (1965), who found that when a pulse train varies, or jitters, by more than 10%, an otherwise just-noticeable pitch difference within the 300-1000 Hz range is rendered indiscriminable. Thus whether jittered (an acoustic correlate of vocalic ‘creak’) or reduced in signal-to-noise ratio (an acoustic correlate of vocalic breathiness), pitch perception during non-modal phonation suffers.

(23) These findings may be viewed as consistent with certain typological linguistic facts: Tone and breathy phonation are very rarely implemented simultaneously (Silverman 1995, 1998).

(24) Some languages are tonal.
   - **Mandarin** tones (D.S.):
     - high \( th\text{a}n\text{ŋ} \) greedy
     - mid-rising \( th\text{a}n\text{ŋ} \) deep
     - low (-rising) \( th\text{a}n\text{j} \) perturbed
     - high-falling \( th\text{a}n\text{ŋ} \) spy

(25) Some languages have contrastive breathiness.
     - t\text{ʃ}\text{r} mor d\text{ud}
     - b\text{i} d\text{ɔr} p\text{ɛlo}
     - s\text{ɛd}\text{ʒ} k\text{ɔ} t\text{əro}
     - m\text{ɛk} k\text{ɔ} w\text{ɛli}
     - b\text{a}r p\text{ɔr} k\text{ɔɾi}

(26) Some tonal languages possess non-modal phonation contrasts on vowels. While a full array of tonal patterns is found on modally phonated vowels, non-modally phonated vowels never contrast for tone.
     - High tau\text{ŋ} pumpkin
     - Rising tau\text{ŋ} to dam up (water)
     - Low tau\text{ŋ} axe
     - Mid (normal) tau\text{ŋ} to be able
     - Falling (normal) tau\text{ŋ} sp. of grass
     - Creaky “tone” tau\text{ŋ} bean
     - Breathy “tone” tau\text{ŋ} to follow
Some languages (e.g. Otomanguean languages such as Jalapa Mazatec) possess vowels in which tone and non-modal phonation fully cross-classify. As pitch (<tone) is more reliably distinguished during modal phonation, a portion of the vowel is given to plain voicing, where tone contrasts are presumably more salient. The remaining portion of the vowel, however, is breathy (or creaky).

- **Jalapa Mazatec**:  

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Meaning</th>
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<tr>
<td>m̃ñ xéː ː</td>
<td>wants</td>
</tr>
<tr>
<td>ññ aː</td>
<td>my tongue</td>
</tr>
<tr>
<td>ññ aːː</td>
<td>nine</td>
</tr>
<tr>
<td>j̃j̃ æː j̃</td>
<td>boil</td>
</tr>
<tr>
<td>w̃w̃ oː</td>
<td>hungry</td>
</tr>
</tbody>
</table>

Of course, experimental data cannot be generalized directly to natural linguistic data. However, the results of the present study suggest that tonal and phonation contrasts have the distributions they do for good reason.

More specifically, although it is only in an experimental setting, as opposed to a natural linguistic setting, that listeners may be called upon to determine just- and near-just-noticeable differences in pitch, it should not be surprising that languages might evolve to avoid less-good contrasts in favor of better ones.

That is, phonetic distinctions that are never employed in phonological systems might nonetheless constitute the ‘phylogenetic’ origin of phonetic distinctions that *are* linguistically relevant. Non-linguistic phonetic experimentation may thus serve as a jumping-off point for this potentially fruitful area of theorization.
A note on the SoundEdit16.2 “bender” feature
The SE16.2 “bender” slows down or speeds up the playback of a sound. The playback sample rate is manipulated and the sound is resampled to the original (and constant) sample rate. The spectra are equally shifted in frequency and thus the ratios of the component frequencies are preserved. Given the spectral shift involved, some slope distortion may be added to the modified signal: a shift up in formants for sped-up playback, and a shift down for slowed-down playback. But given the very minor signal adjustments employed in this study (roughly 3 Hz per step), spectral shifts are exceedingly minor, increasing, of course, as more steps are made.
Pitch tracks of base stimuli

(gi-ŋg)  a  a↑ (he fastened)

(nd)  a  a↑ (hard)

(mɔŋ)  æ  æ↑ (he wants)
REFERENCES
Patel, M.S. and J.J. Mody (1961) The vowel system of Gujarati. Faculty of education and psychology, Maharaja Sayajirao University of Baroda, Baroda.

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