PHY 103
Voice

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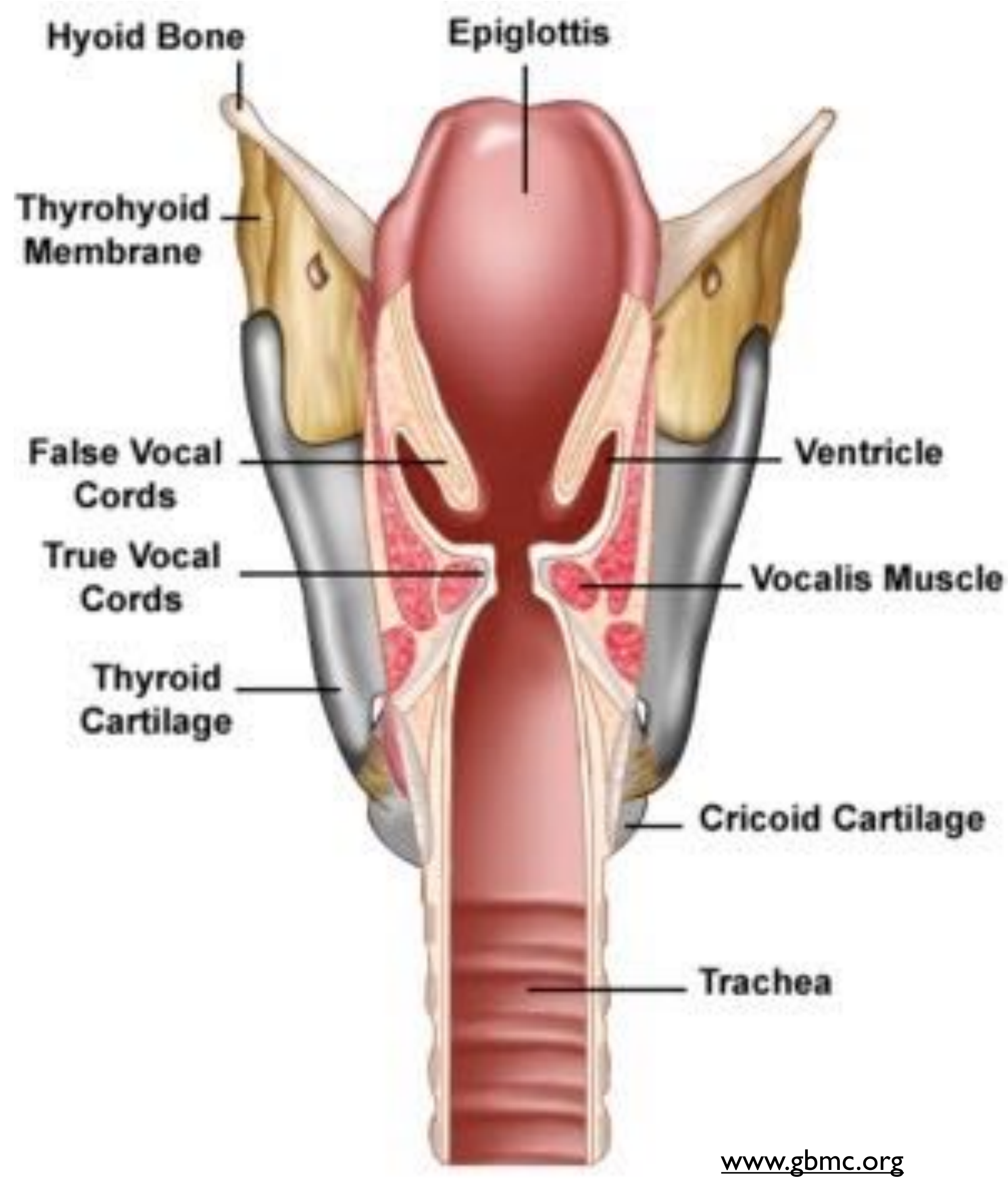
Reading

- Reading for this week:
  - Heller, Ch. 17

Cutaway View of Larynx

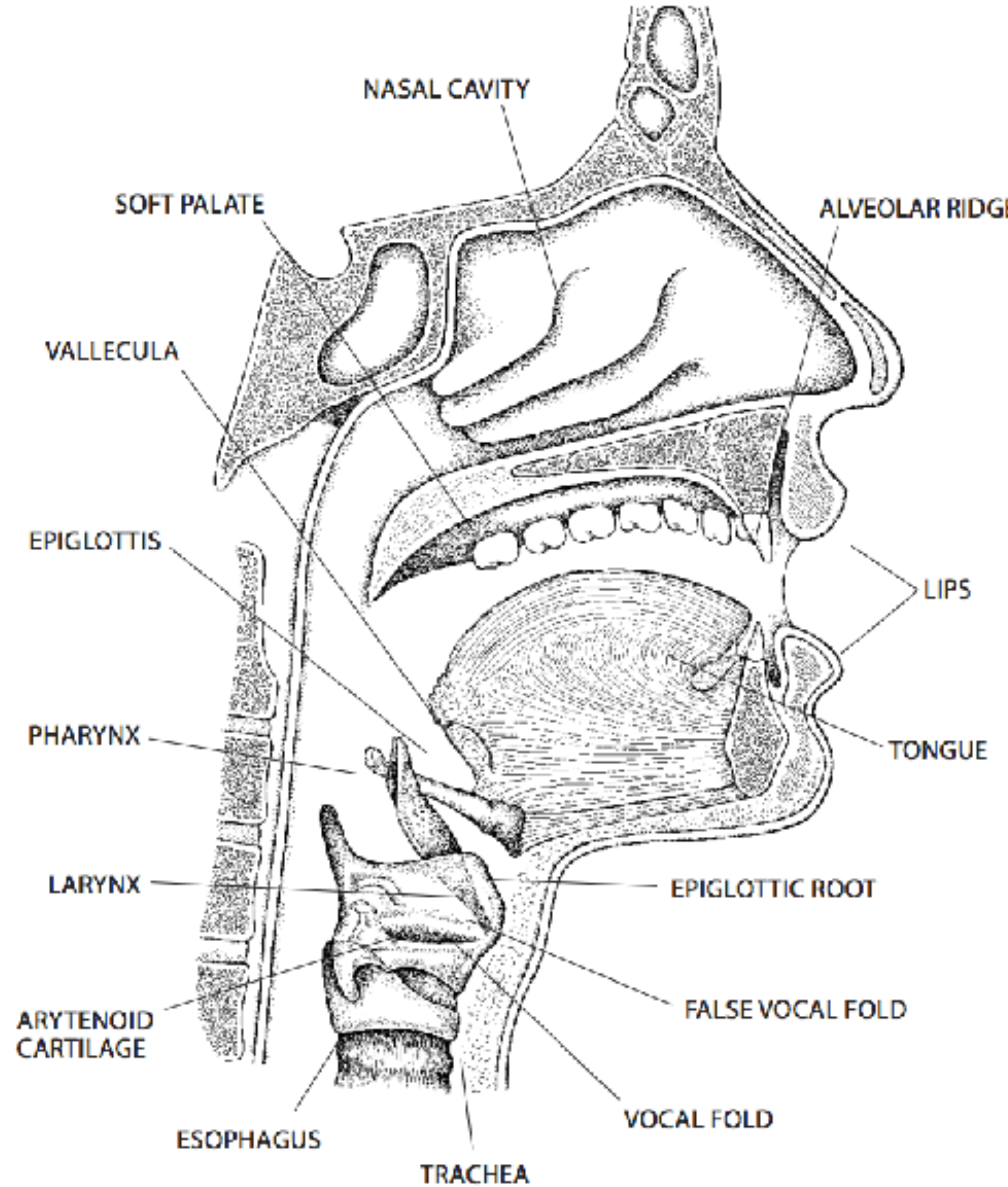
- Basic components of the voice:
  - Power supply: lungs, providing air in the trachea
  - Oscillator: vocal folds (or cords)
  - Resonator: vocal tract + nasal cavity



www.gbmc.org

Vocal Tract

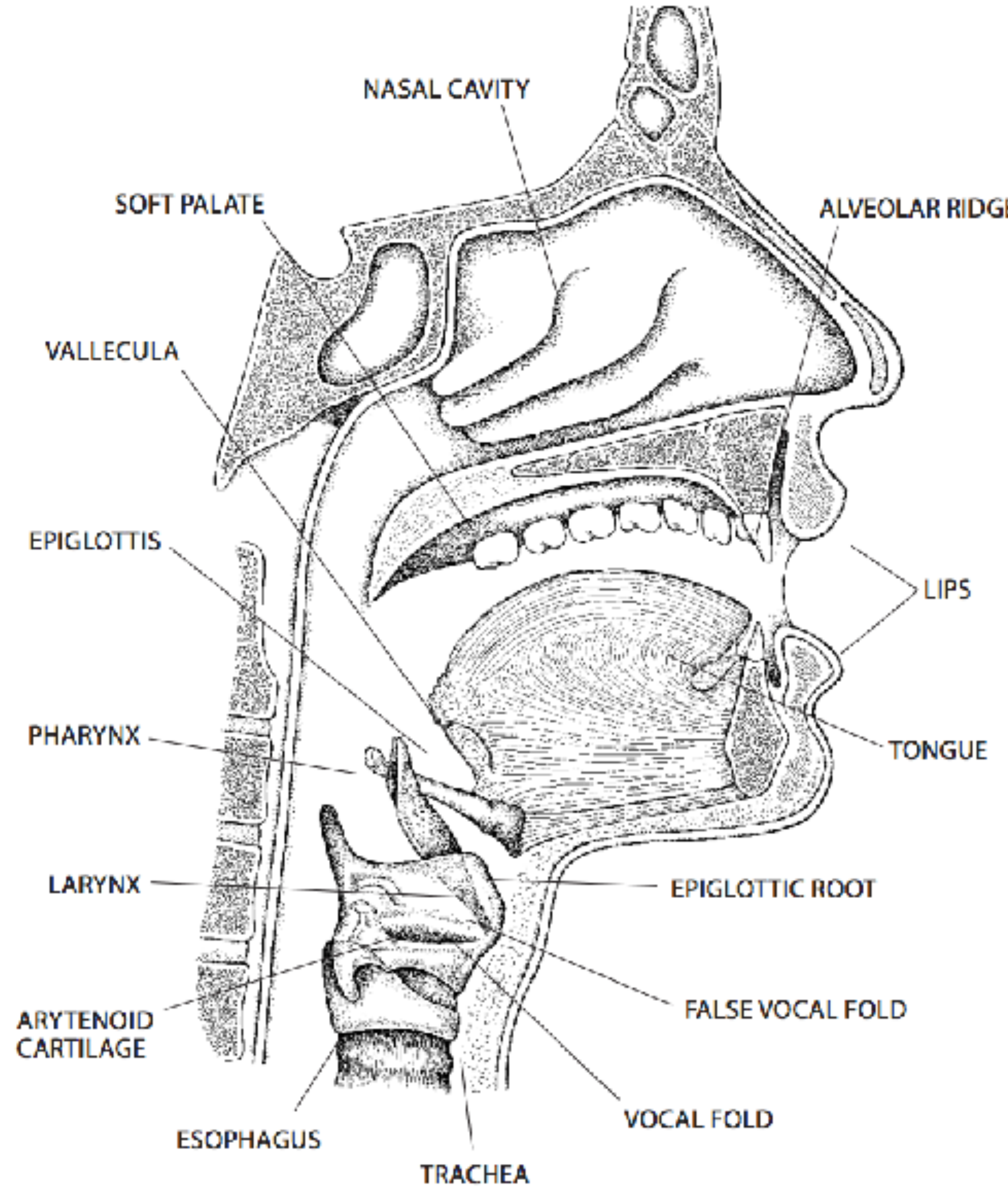
- The vocal folds (or vocal cords) are made of ligament and controlled by the arytenoid cartilages
- Glottis: open space between the vocal folds
- Arytenoids are spaced far apart for breathing, and close together for voicing



T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

Whispering

- Normal voicing: folds vibrate such that they open and shut
- Whispering: folds are constricted and air is forced through
- But the folds do not vibrate open and shut
- Result: a "breathy" whispering voice



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Vocal Fold Tension

- This video is taken with a stroboscope to slow down the vibrations of the folds (120 - 300 Hz). Note how the folds tense as the notes increase and decrease

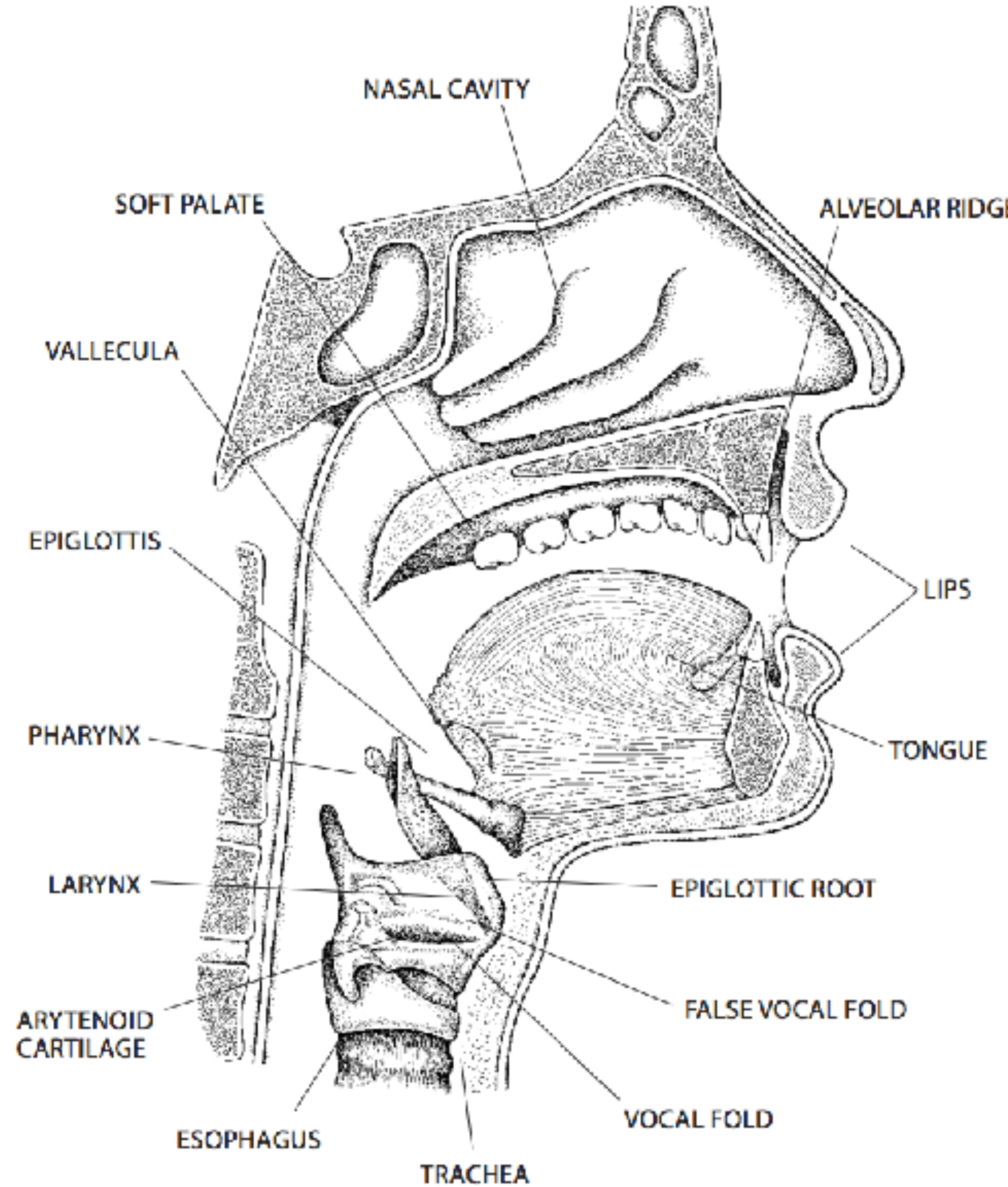
Northside ENT (youtube)

- Under a given tension, the folds have a resonance frequency, which drives the vocal tract

- Speech: men: 100-125 Hz; women: 210 Hz; children: >300 Hz

Vocal Tract Shape

- The position of the tongue, jaw, and lips changes the shape of the vocal tract
- The resonant frequencies of the tract can be quickly altered
- The resonances are known as formants, or zones of frequencies enhanced by the vocal tract



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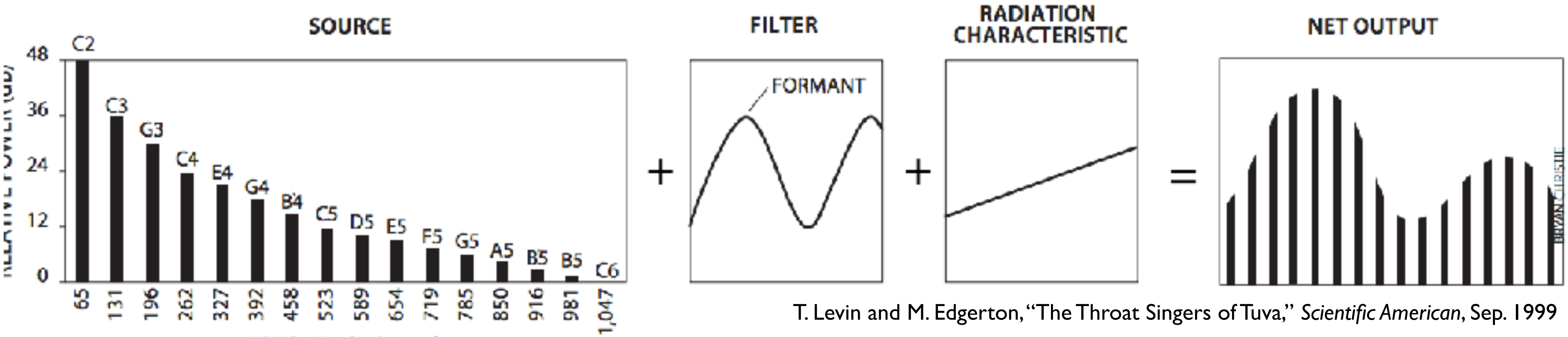
Source-Filter Model

- Vocal folds are a high-impedance drive, i.e., their vibrations are not affected much by the vocal tract
- Contrast: trumpet, w/ feedback between lips and tube

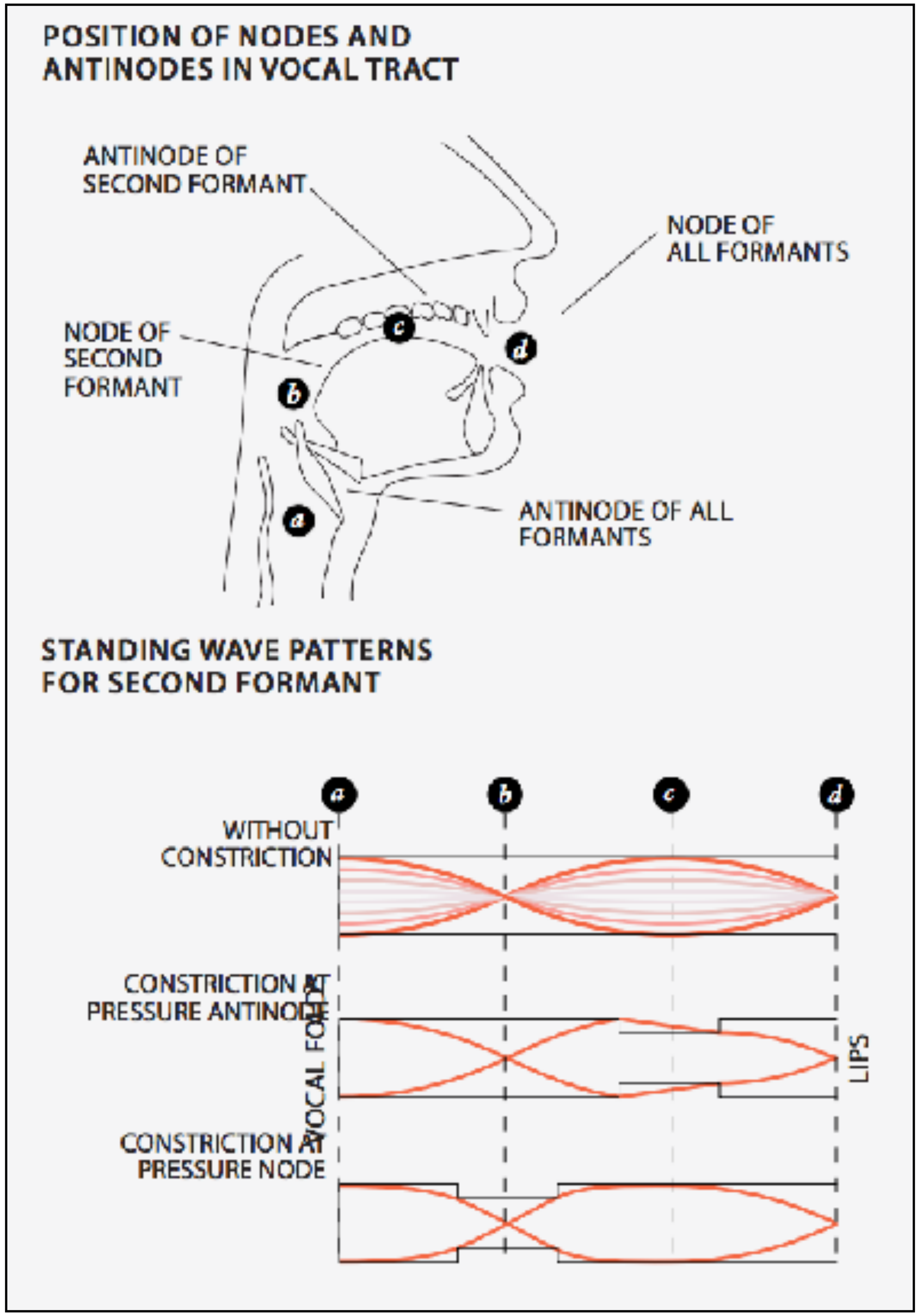


T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

- Vocal fold fundamental is below vocal tract resonances
- Vocal tract resonantly amplifies overtones of the folds

Modes of the Vocal Tract

- The vocal tract is a half-open tube (1/4-wave resonator):
  - Pressure antinode @ larynx (**a**)
  - Pressure node @ lips (**d**)
- Second formant:
  - Pressure node between pharynx and tongue (**b**)
  - Pressure antinode at palette (**c**)



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Constricting the Vocal Tract

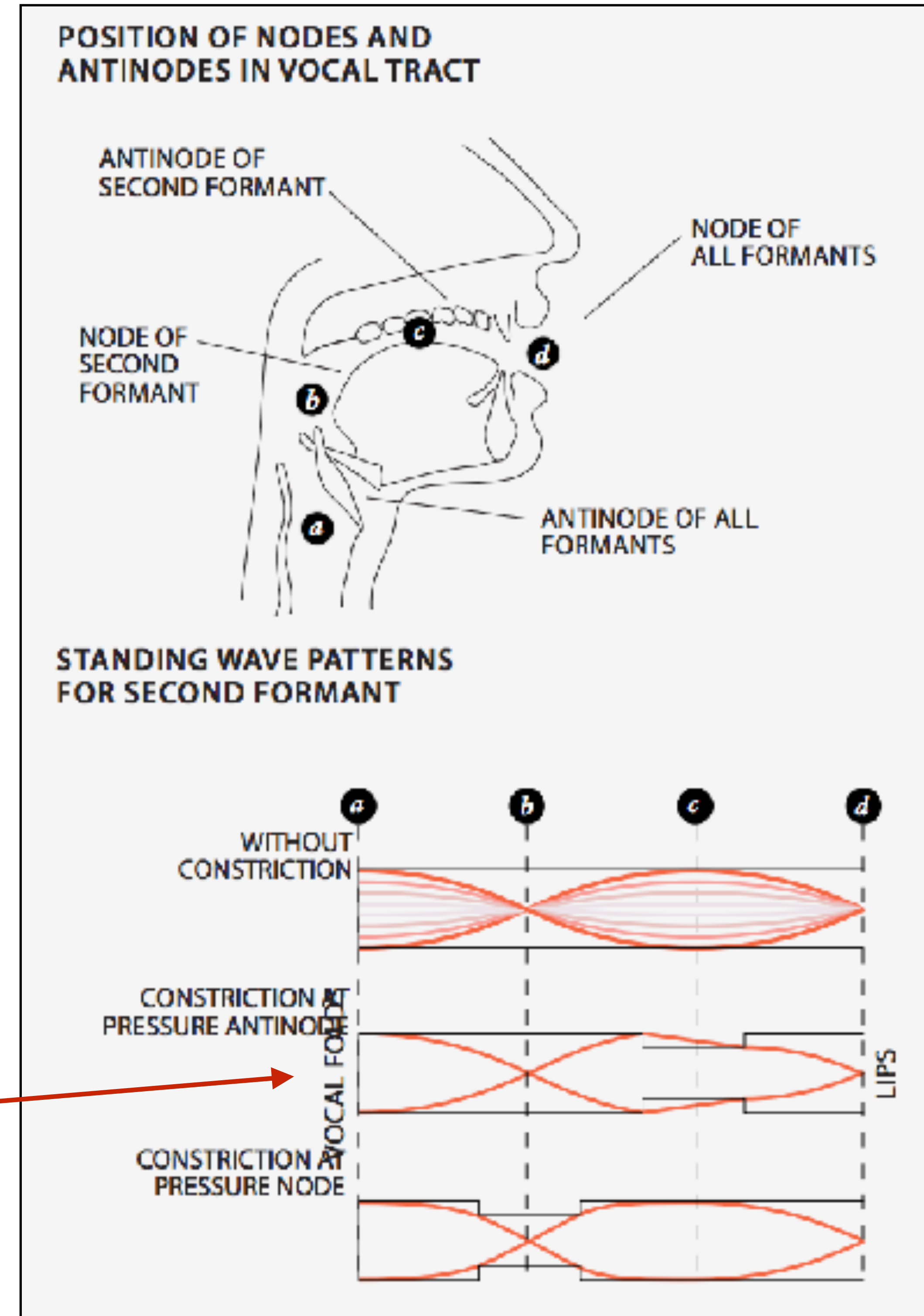
- The vocal tract is a tube that changes shape as we move the vocal folds, jaw, and lips
- Suppose the second mode (f_2) is excited
- Imagine we constrict the vocal tract at the position of a pressure antinode (i.e., we place a thin "wall" at that position). What happens?
- At a pressure antinode the air doesn't move at all; recall that it is an air displacement node
- Constricting the tube there has no effect, since the air is already stationary

Constricting the Vocal Tract

- Suppose we constrict the vocal tract at the position of a pressure node inside the tube. Will the frequency go up or down?
- Second mode has $f_2 = 3v/4L$
- Node is at position $L/3$, so constricted tube has length $L' = 2L/3$
- Fundamental of constricted tube is $f'_1 = v/4L' = 3v/8L$
- $f'_1 < f_2$ so the frequency goes down!
- Similarly, opening the tube wider at the node will increase the frequency

Modes of the Vocal Tract

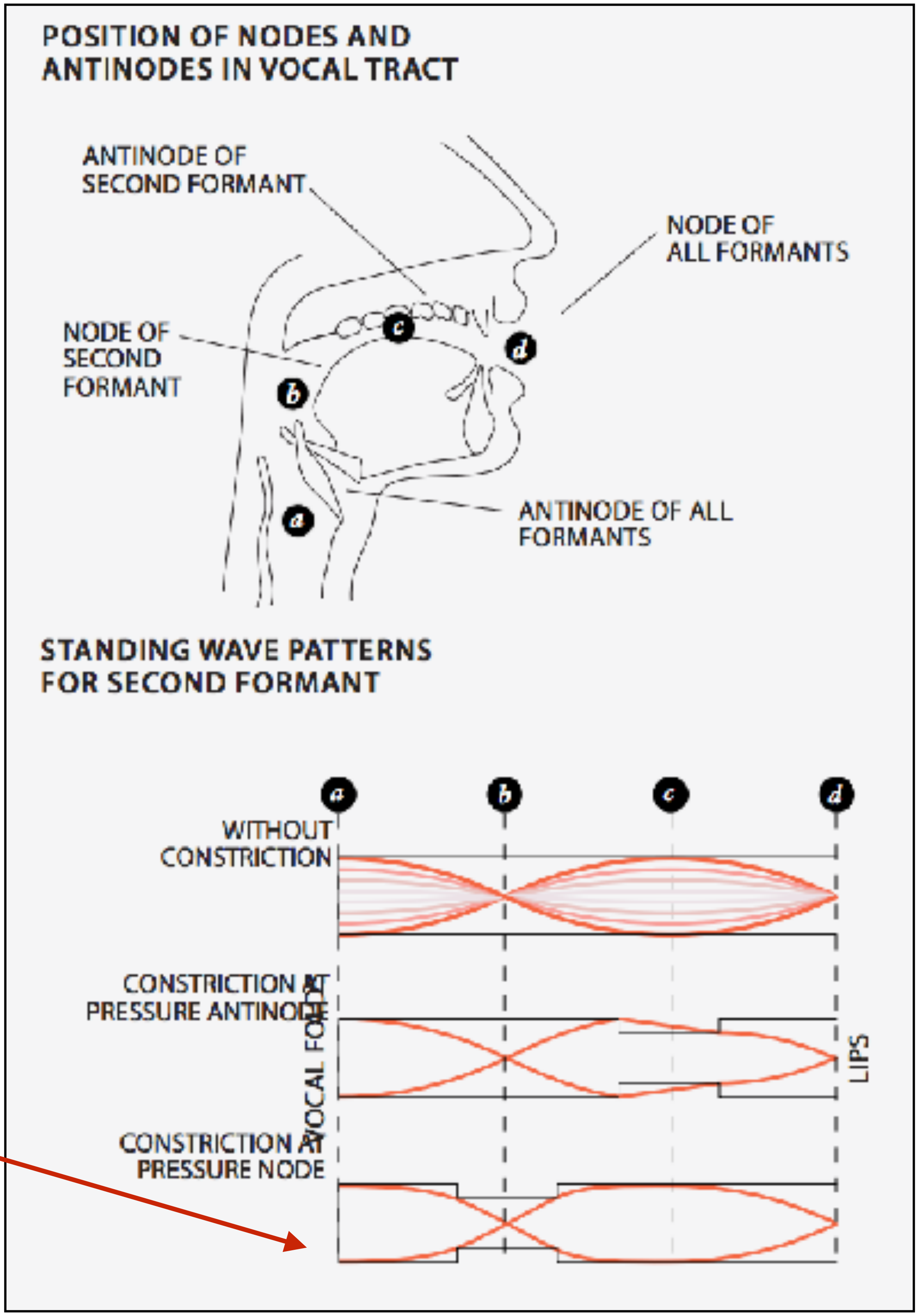
- Compressing the vocal tract by raising the tongue (**c**)
  - Compresses standing waves at pressure antinode
  - Volume of tract decreases; density and pressure of air increases
  - Wave frequency increased at the antinode (the tongue doesn't act like a thin wall)



T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

Modes of the Vocal Tract

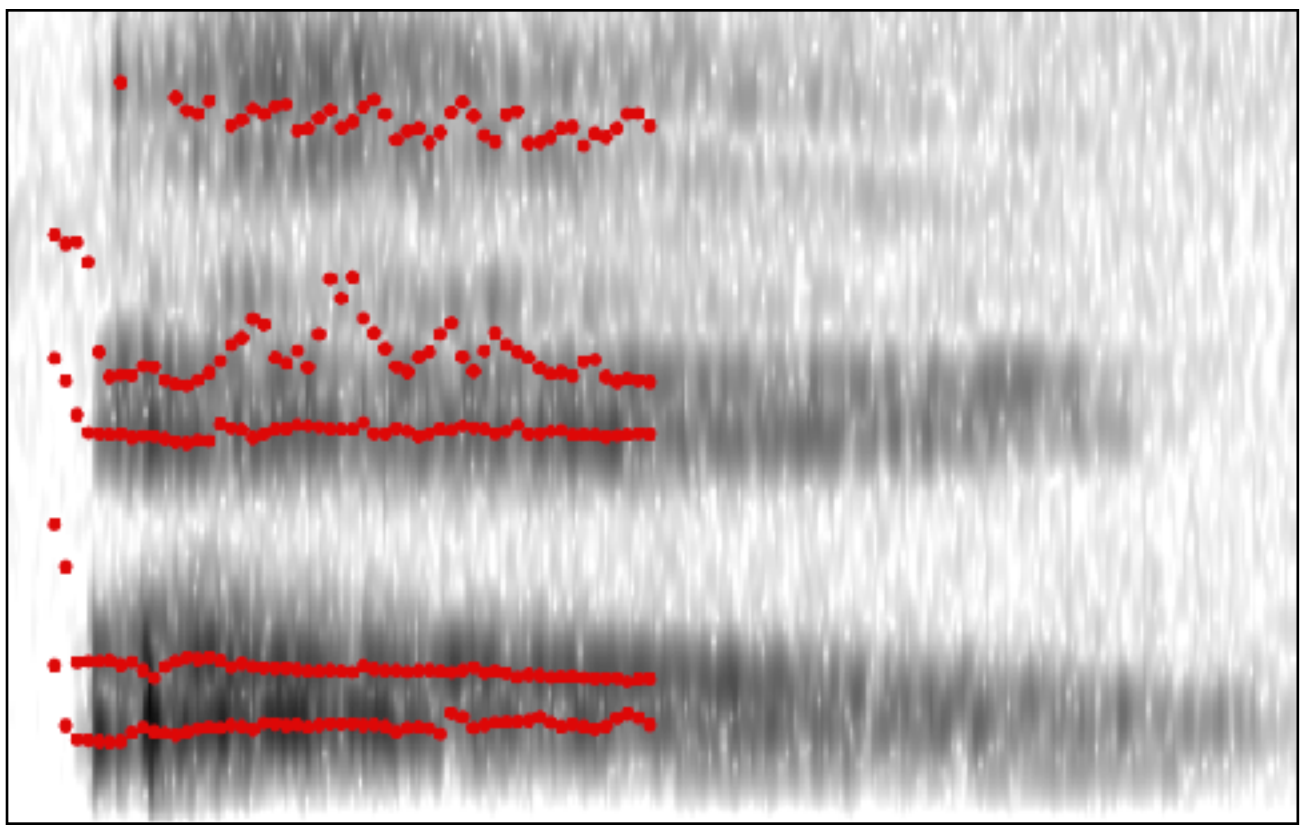
- Compressing the vocal tract by drawing the tongue back (**d**)
  - Compresses standing waves at pressure node
  - Air molecules pass through a narrower opening, taking longer to move throw
  - Wave frequency slows down at the node

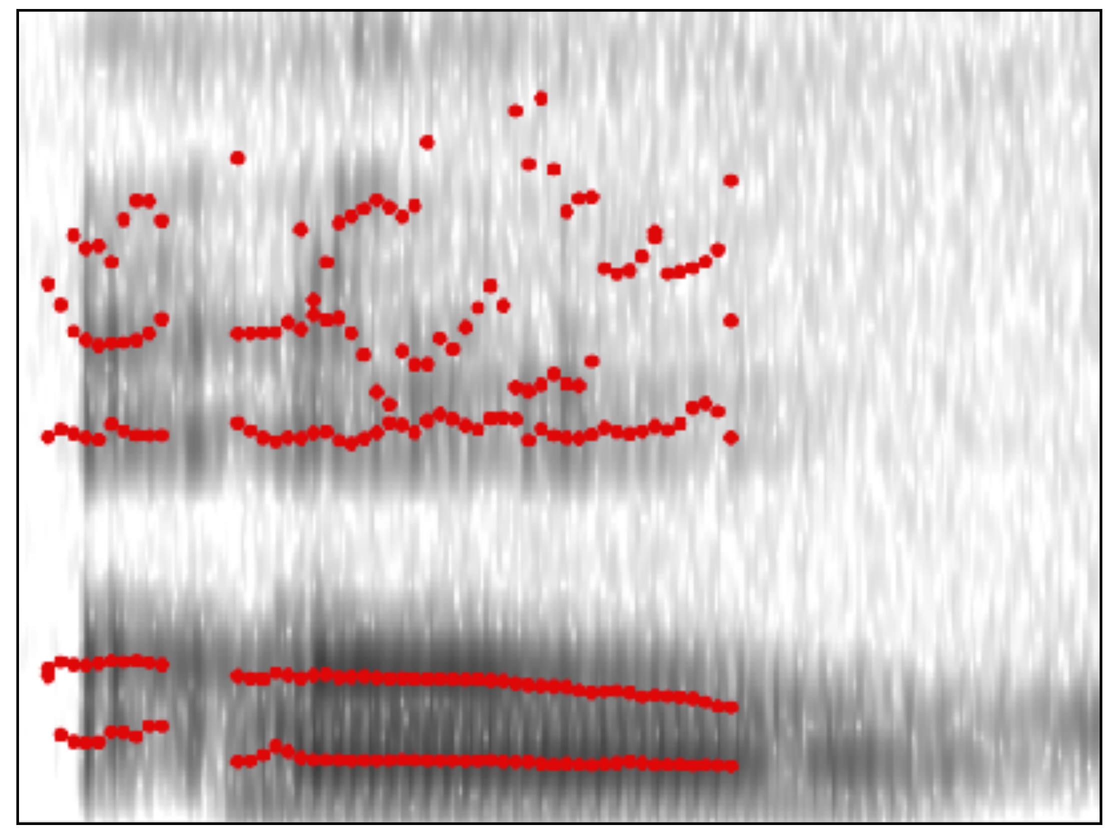


T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

Formants of “Ohh…” Sound

- Two recordings: spoken “oh” and whispered “oh”
- Can you guess which is which?

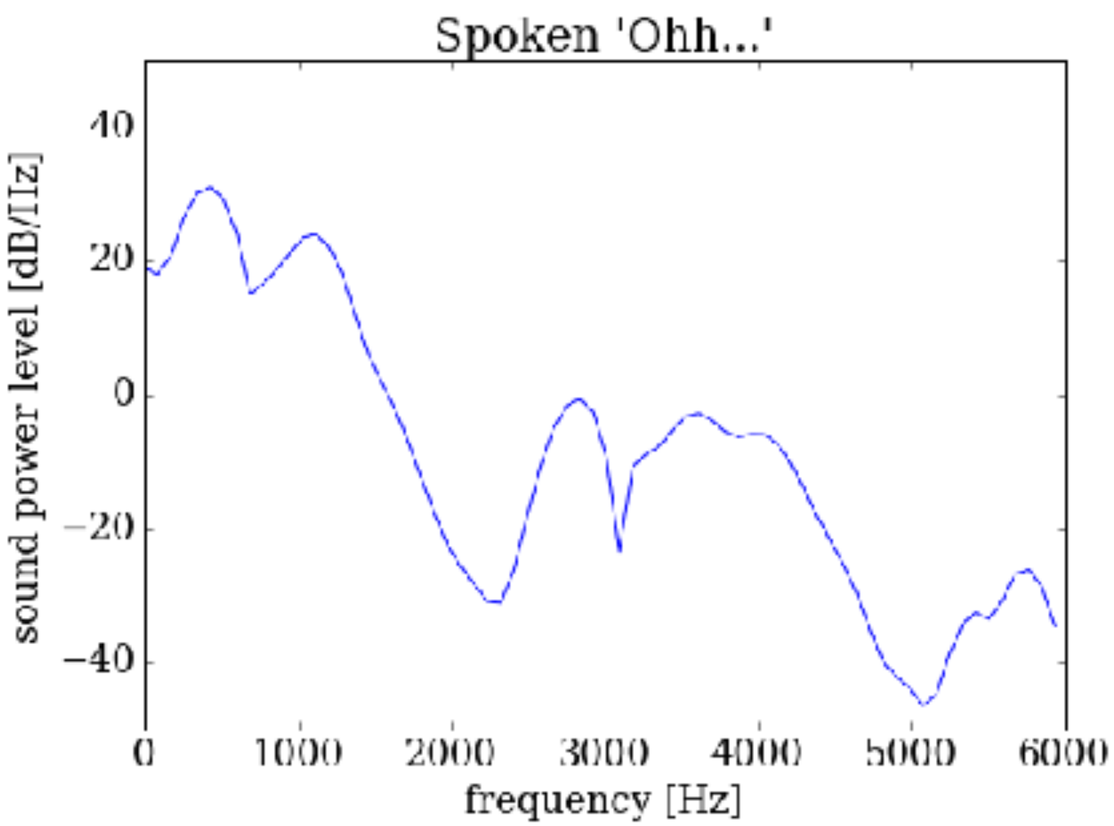


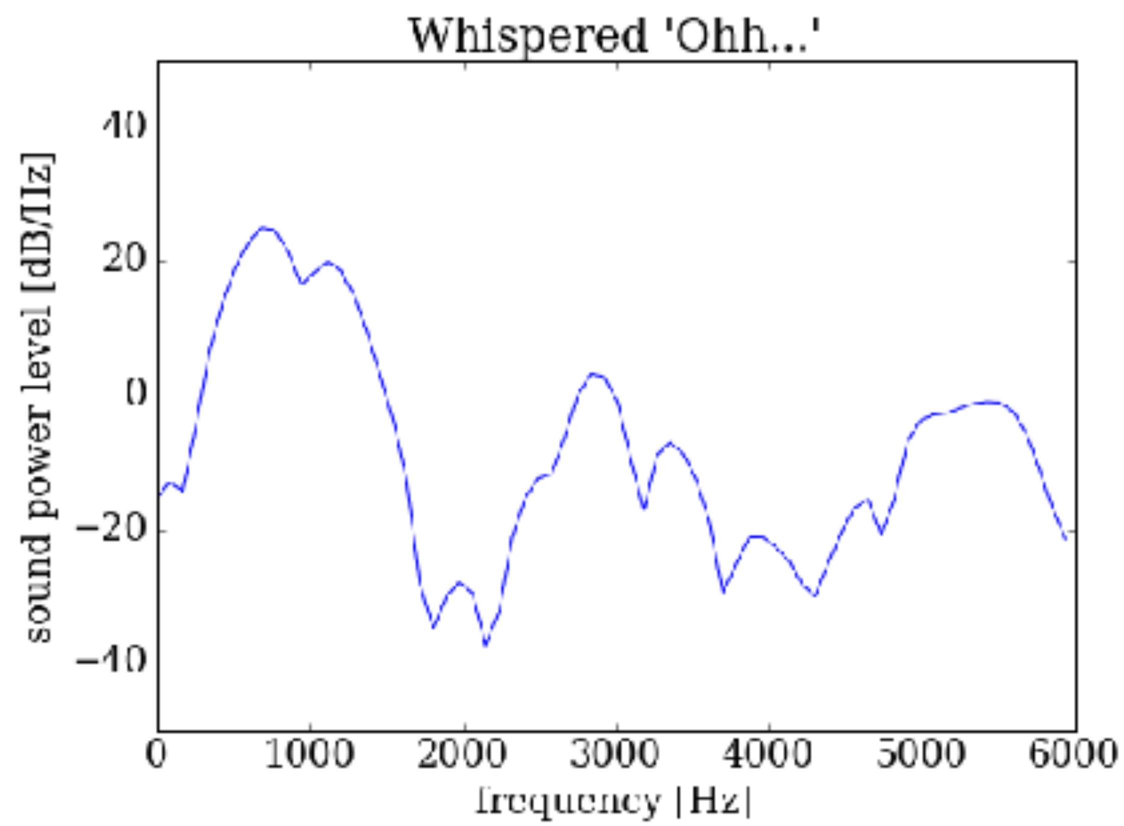


- Formants highlighted in red using Praat software

Formants of "Ohh…" Sound

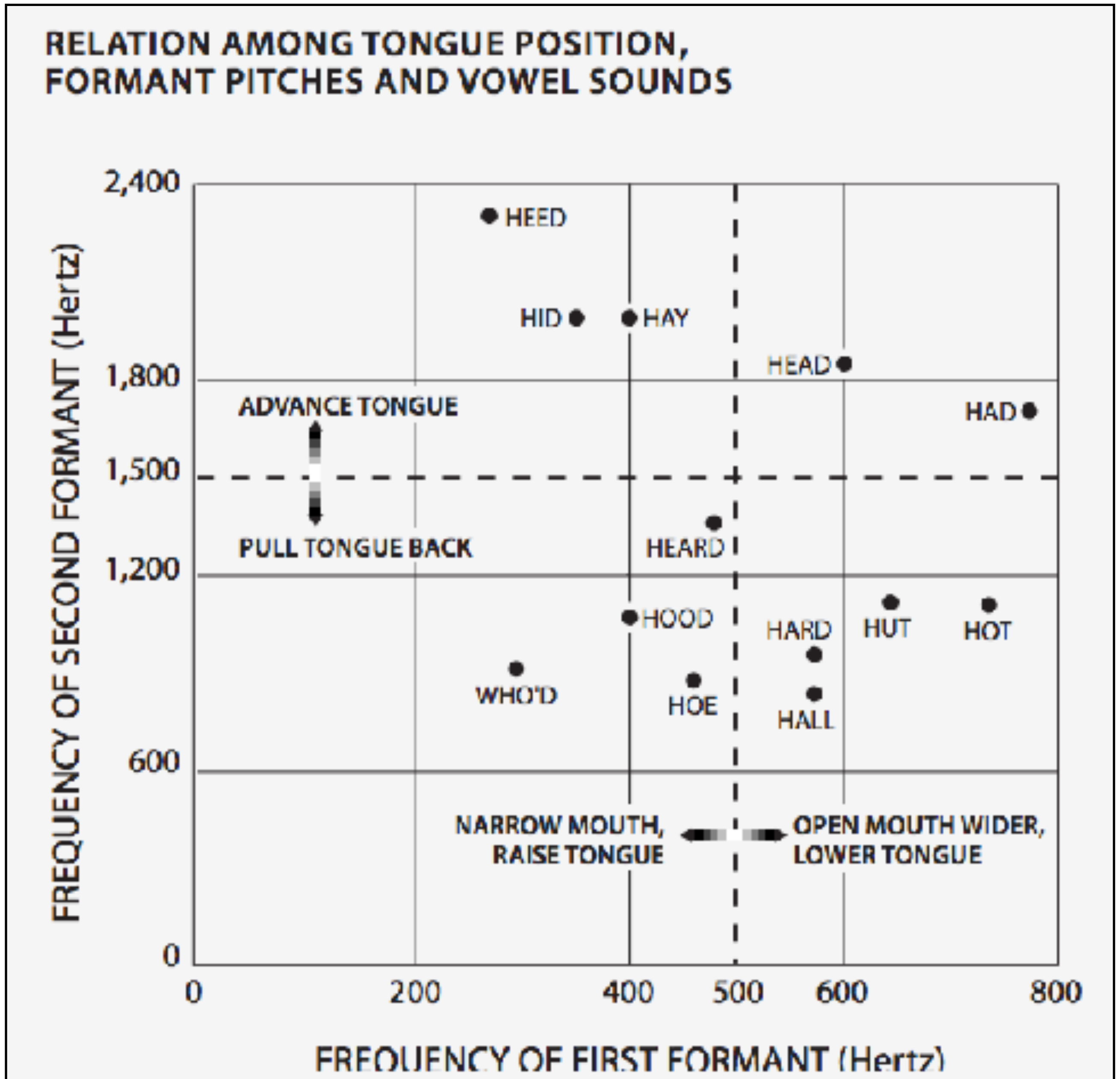
- Spectral slices of the "ohh" samples at a given time:





- Interesting how the same basic vowel sound has rather different formants at high frequency
- Due to vocal folds? Or due to subtle changes to the shape of the vocal tract? Or both?

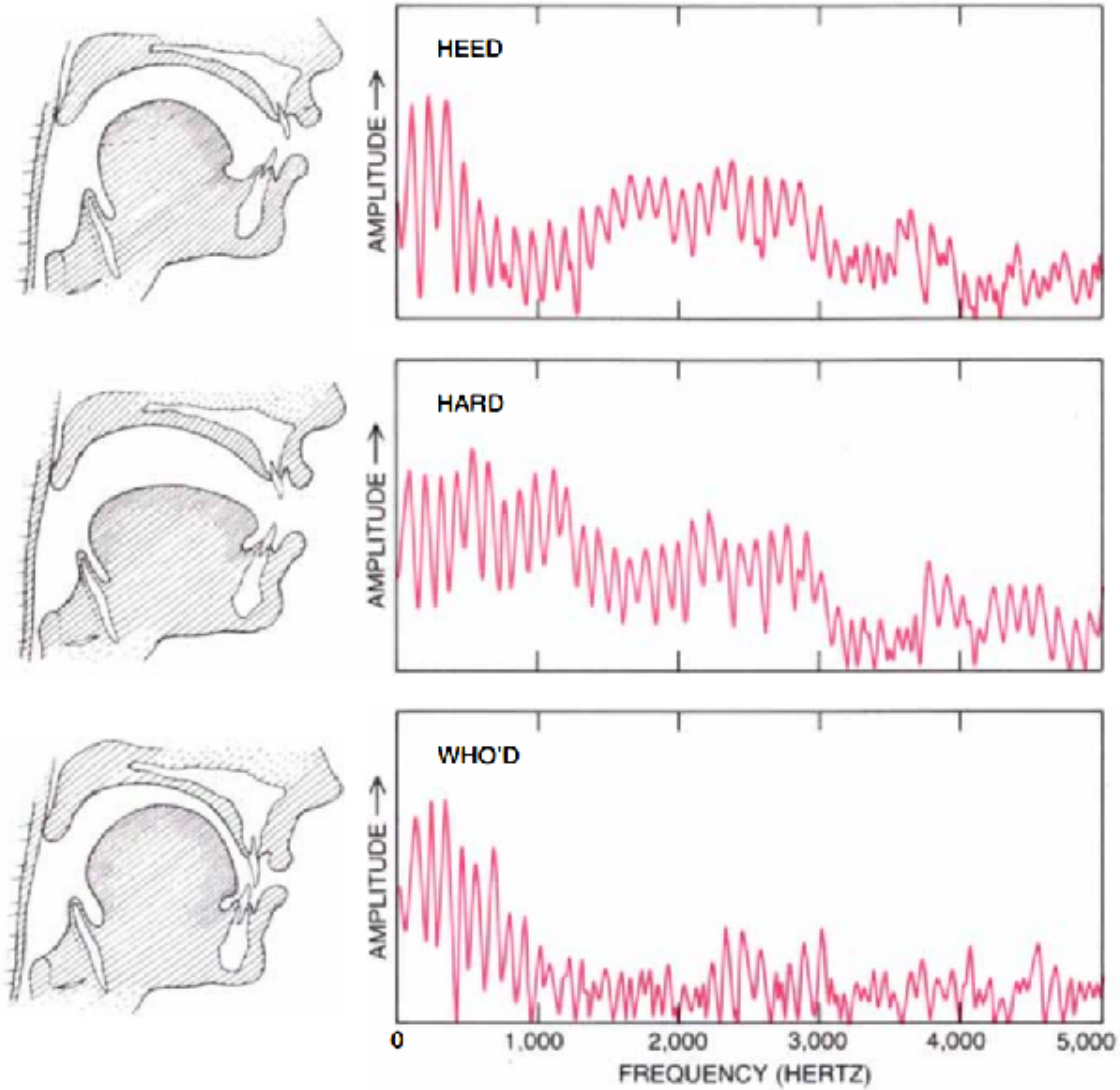
Formants of Vowels



T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

- We make changes to our vocal tract when speaking
- We do it without even thinking about it, but the changes are pretty significant
- Two formants in vowels:
  1. 300-700 Hz: change by opening the mouth and/or raising the tongue
  2. 700-2300 Hz: move tongue forward or backward

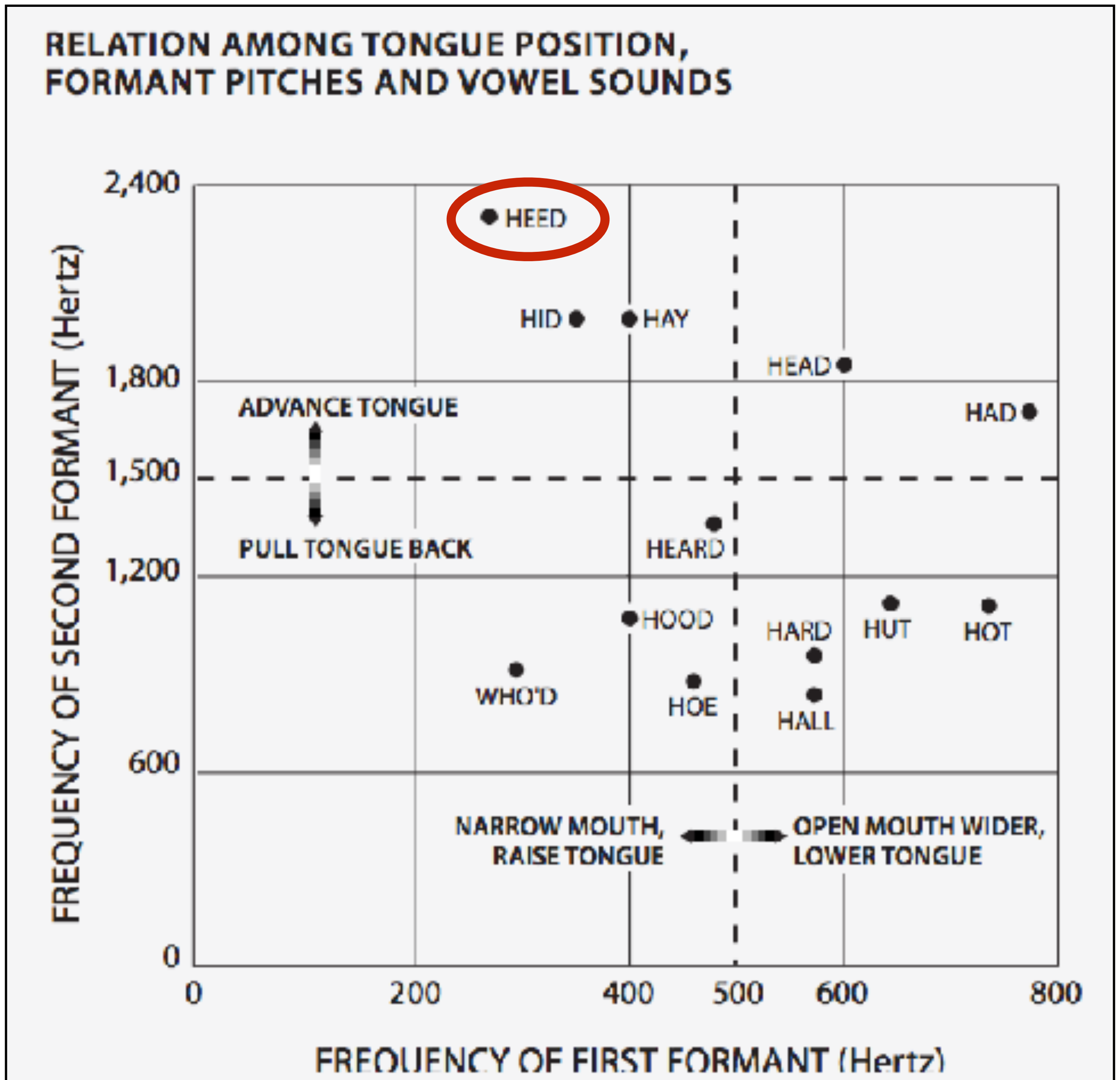
Vowels: Tongue and Mouth

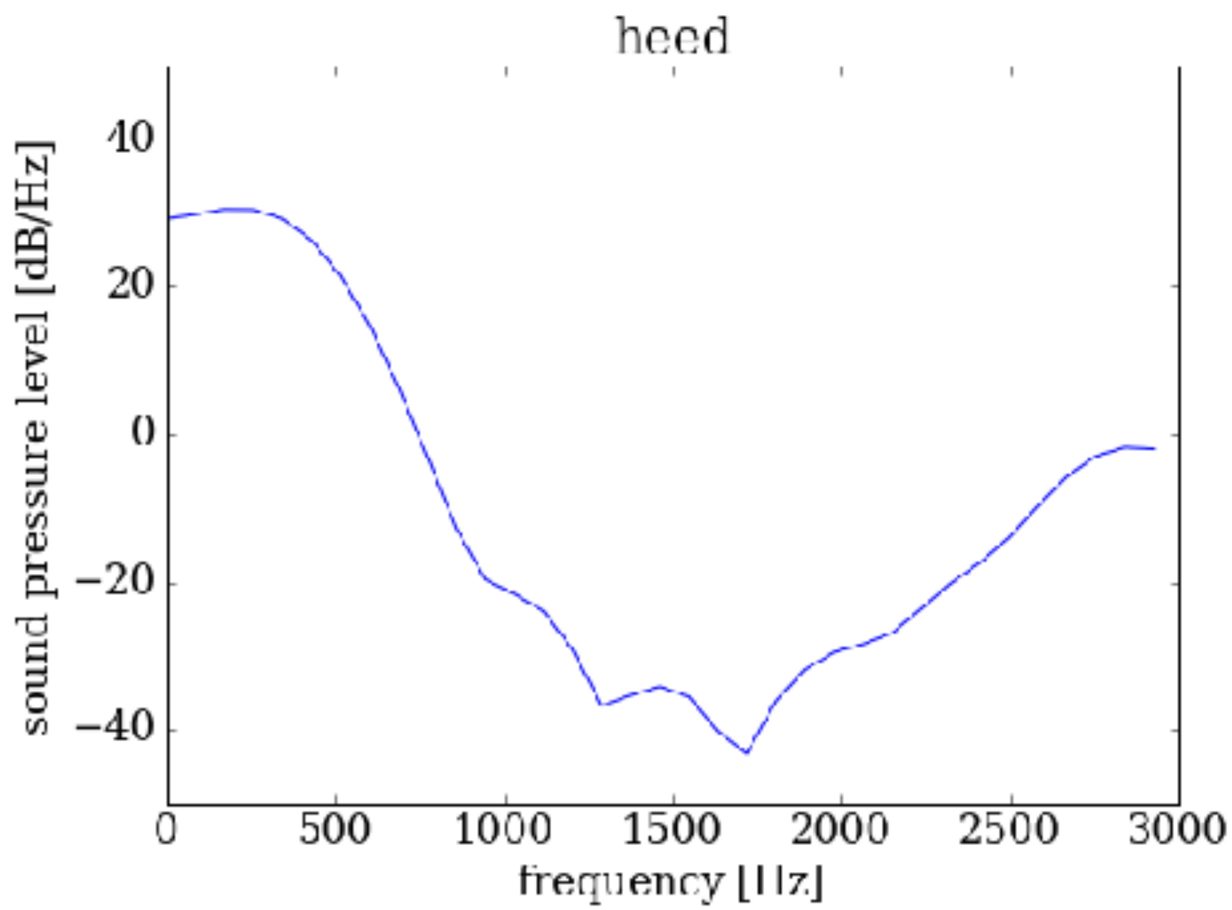


J. Sundberg, The Acoustics of the Singing Voice, *Scientific American*, Mar. 1977

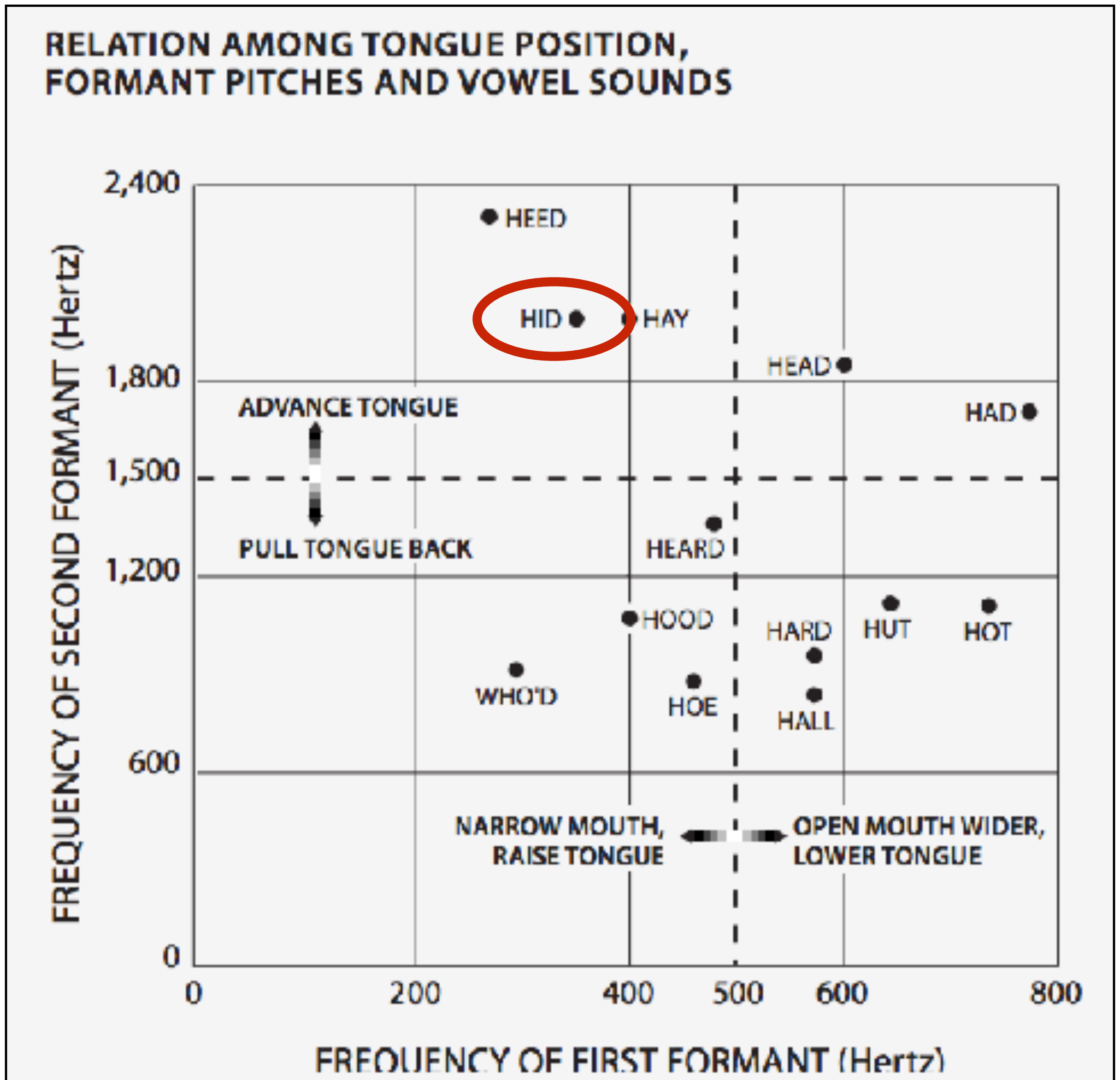
Formants of "Heed"

T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999





Formants of “Hid”



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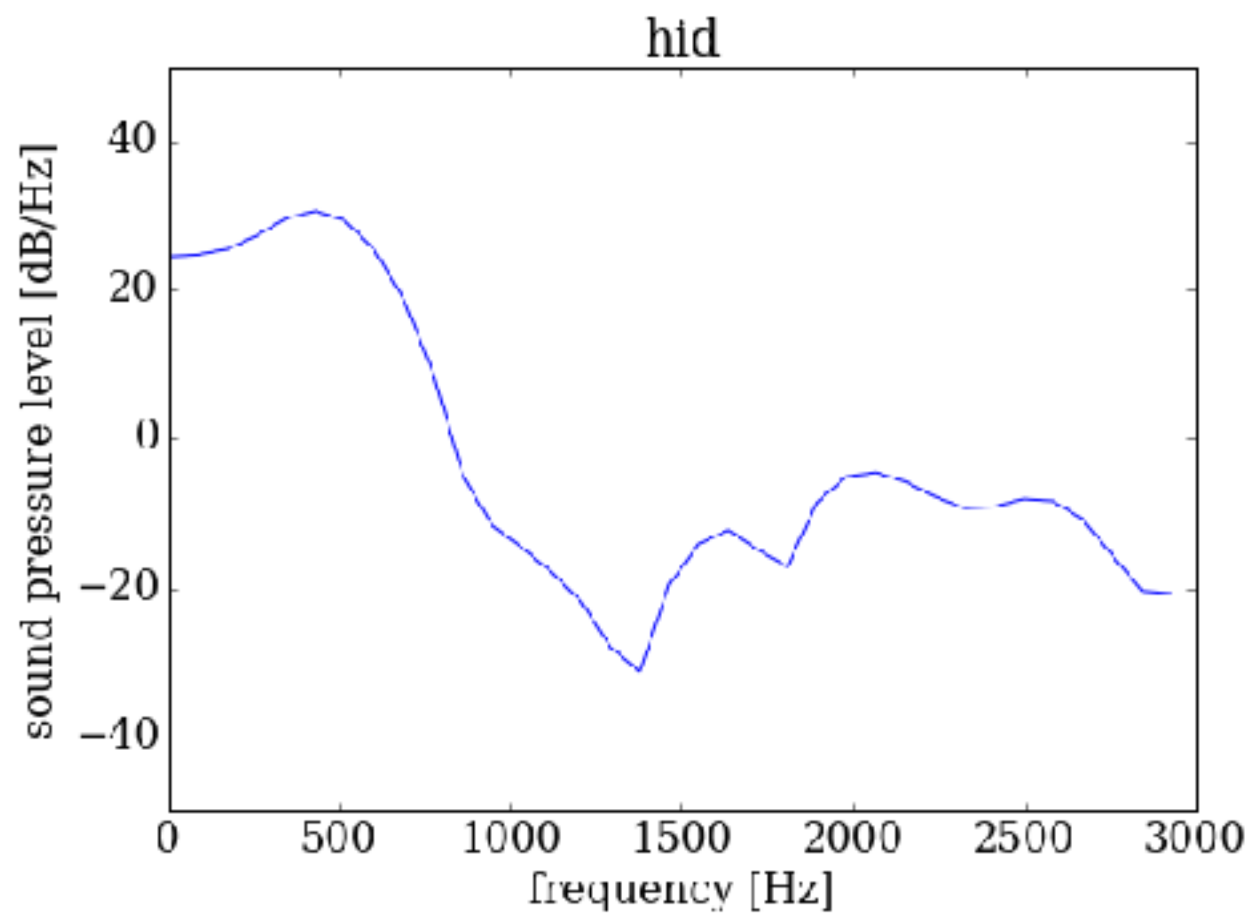
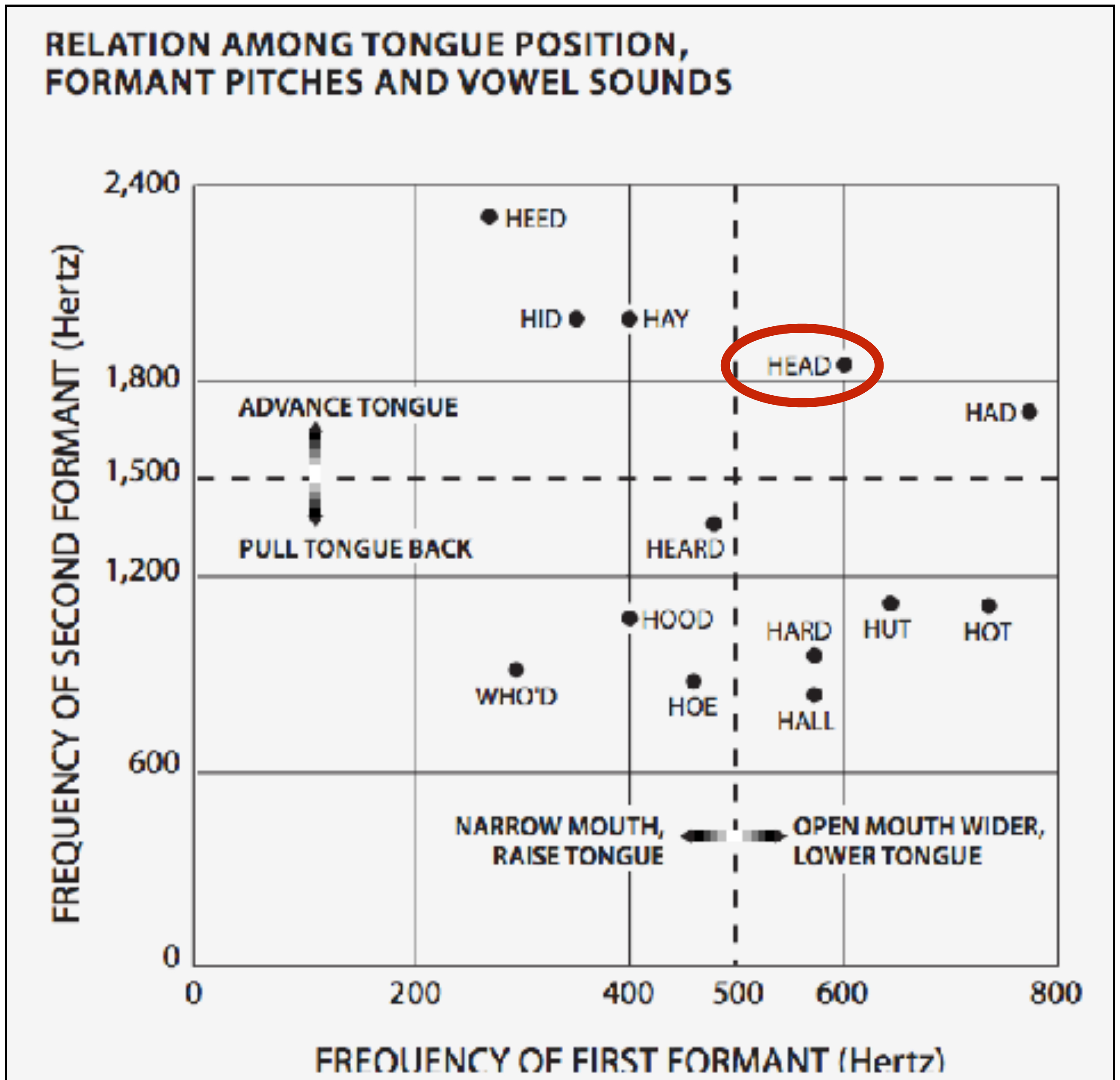
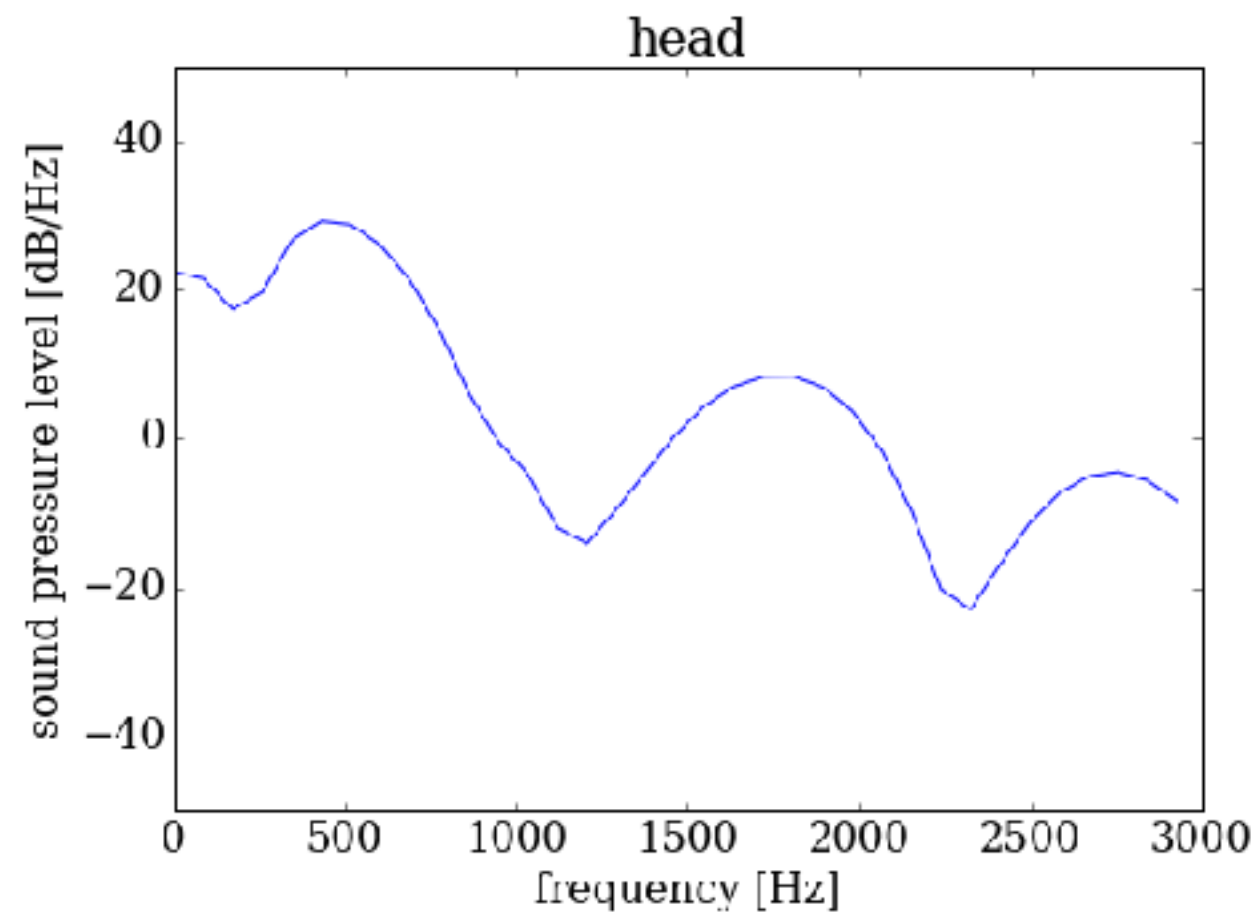


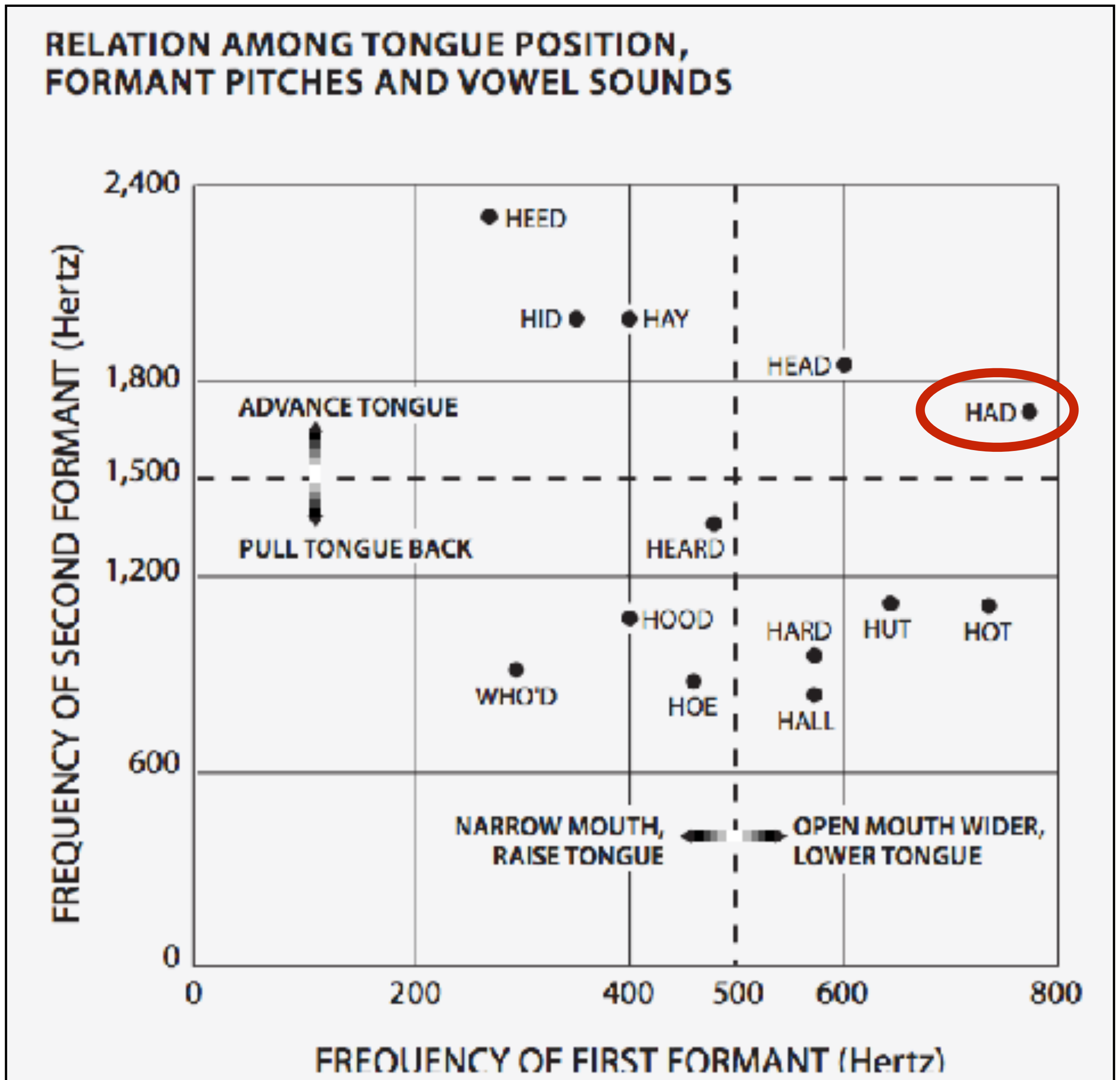
Formants of "Head"

T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999





Formants of "Had"



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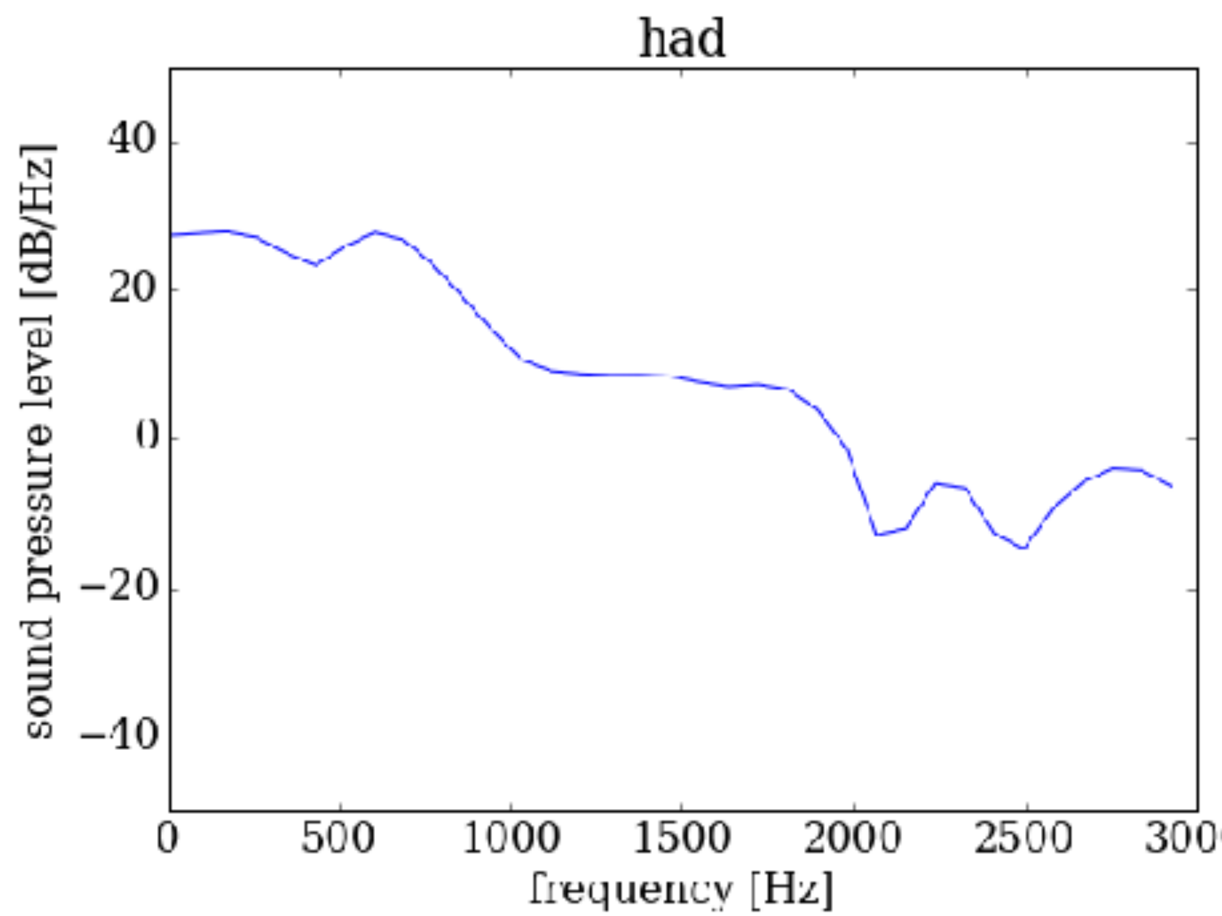
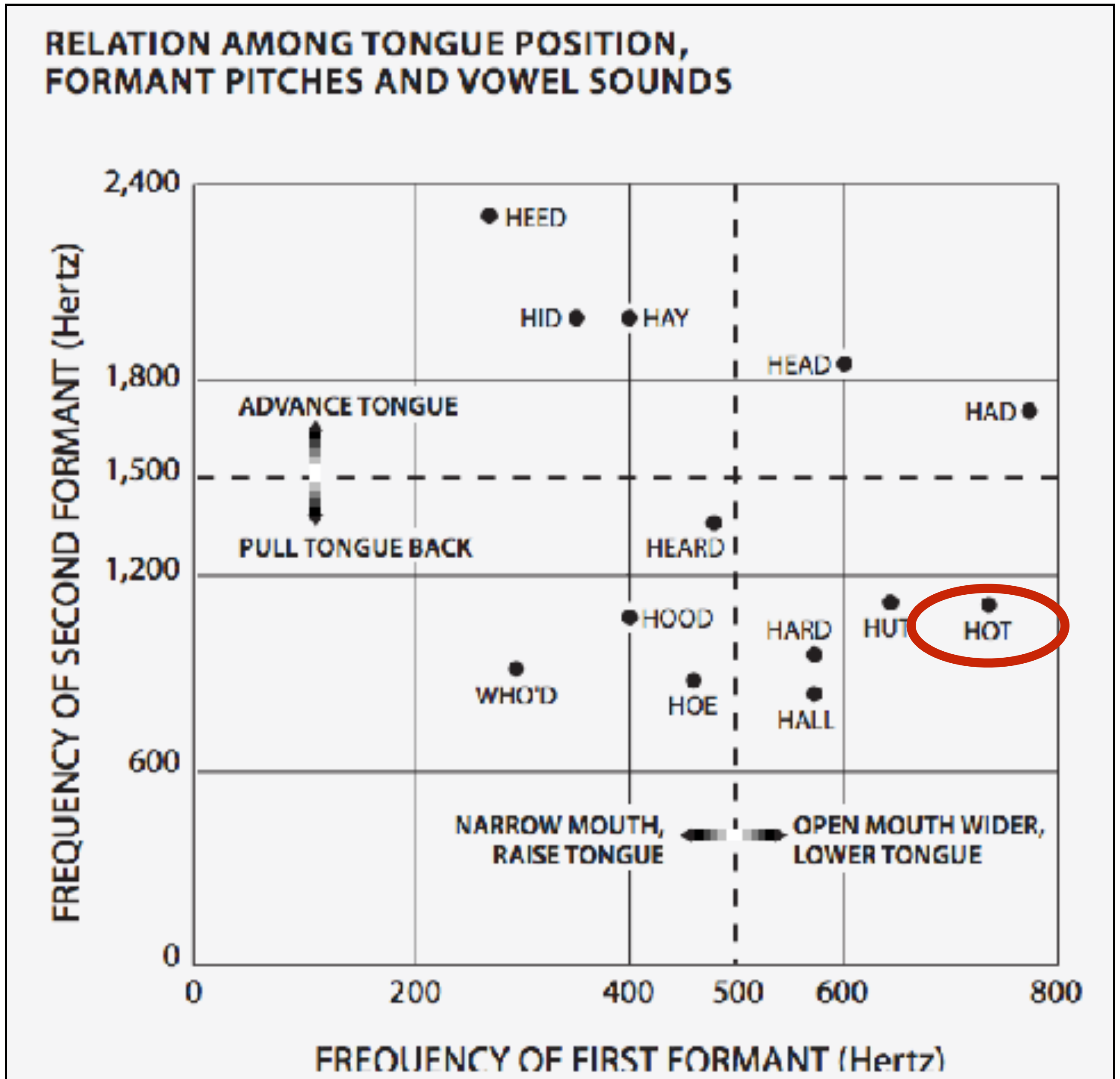
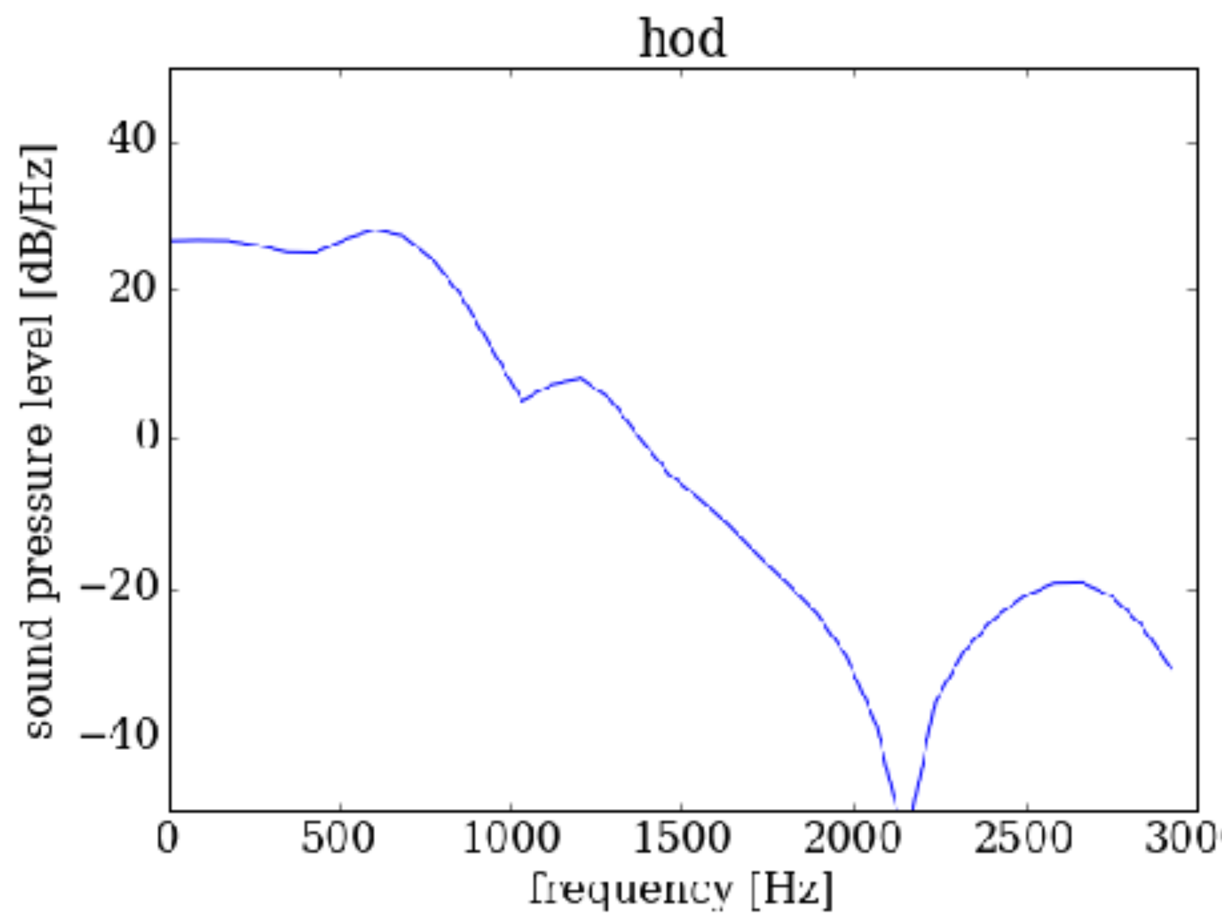


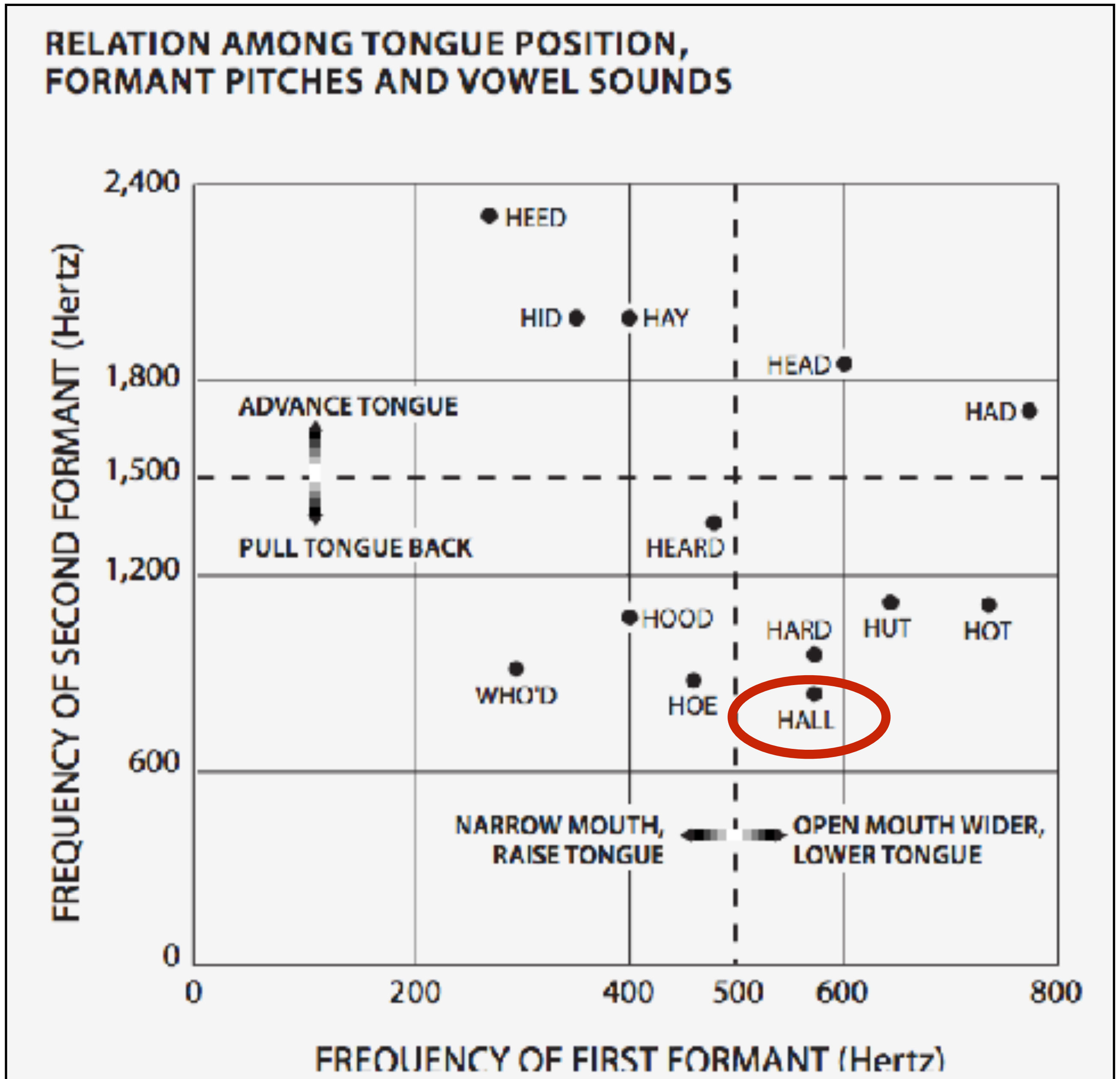
Formants of "Hod"

T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999





Formants of "Hawed"



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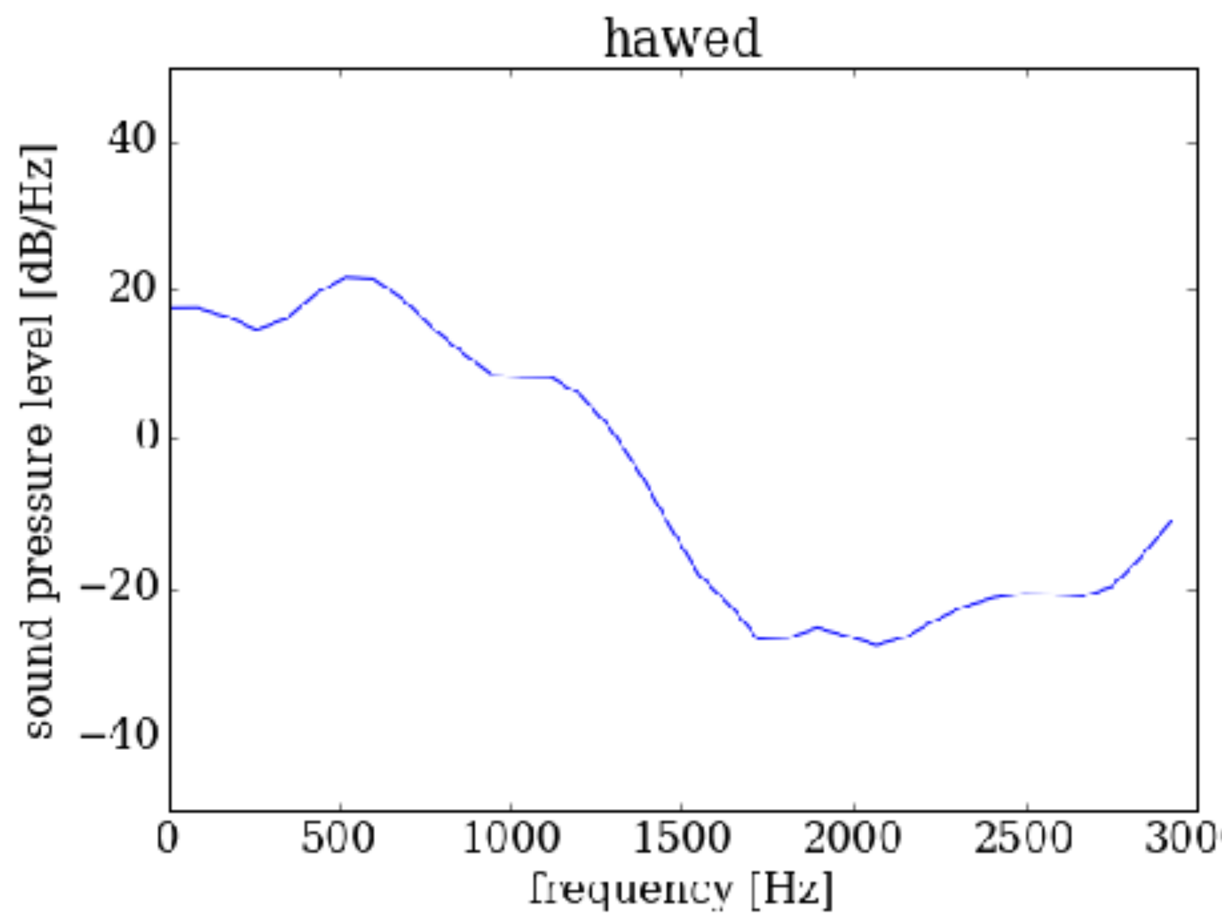
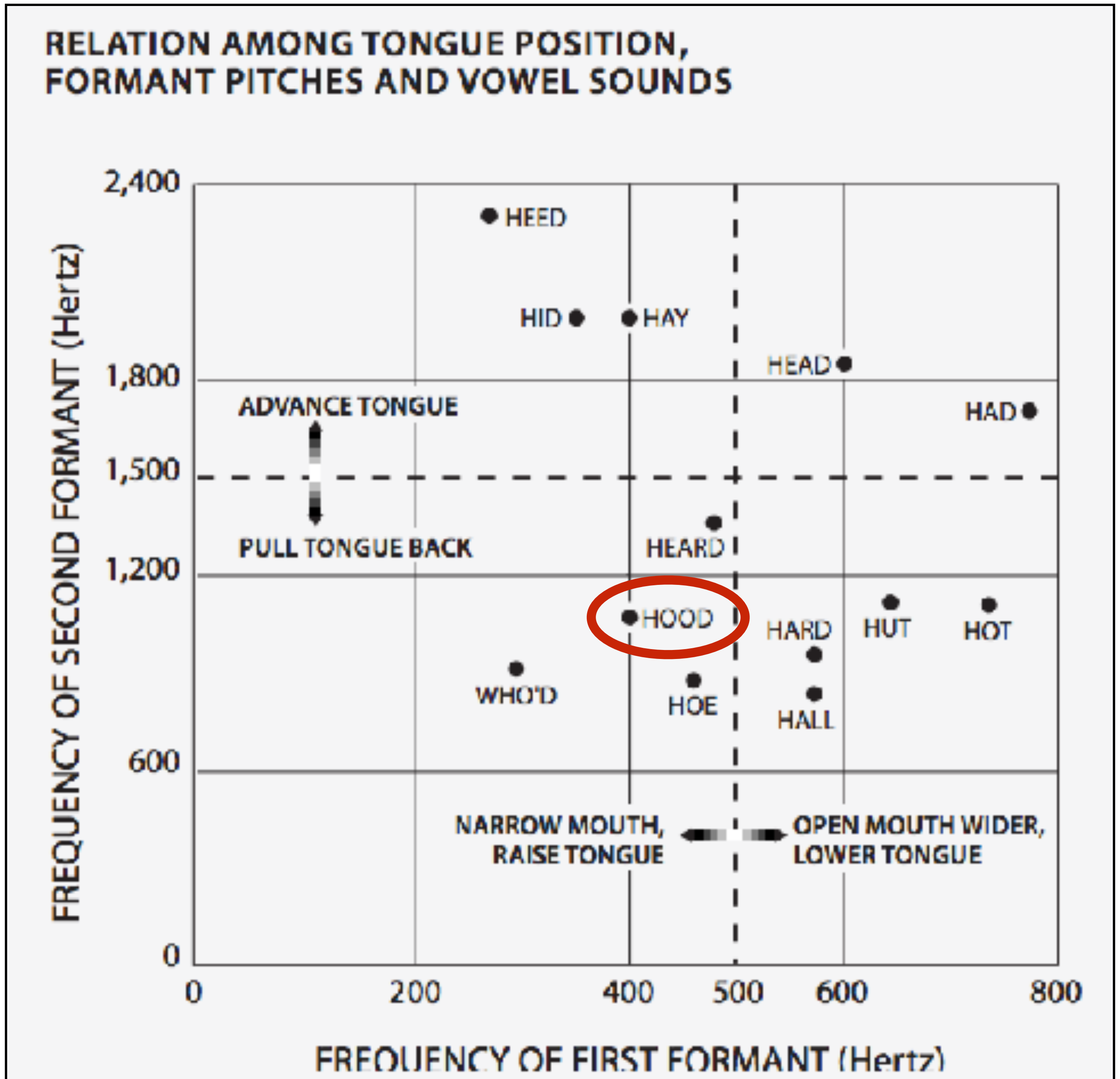


Formants of "Hood"



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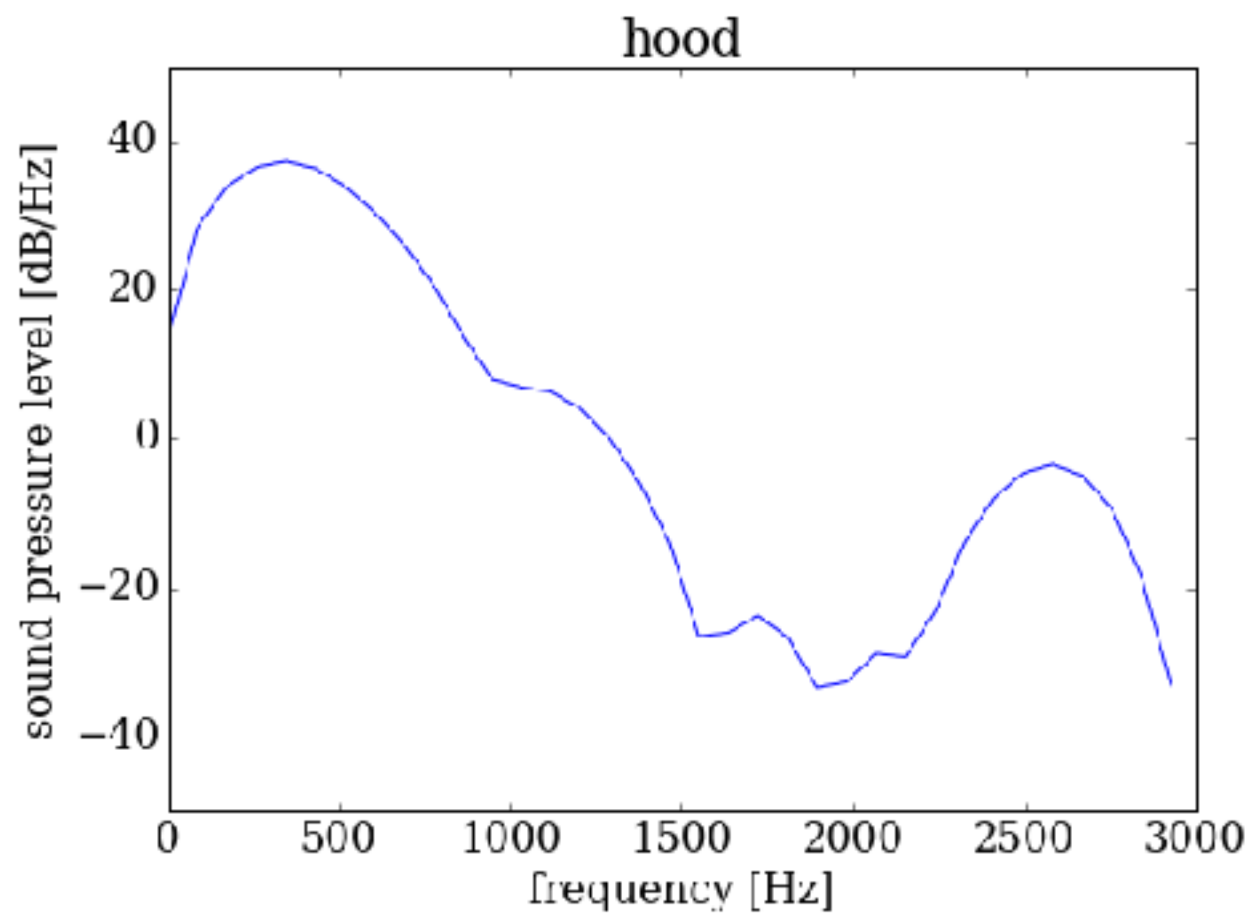
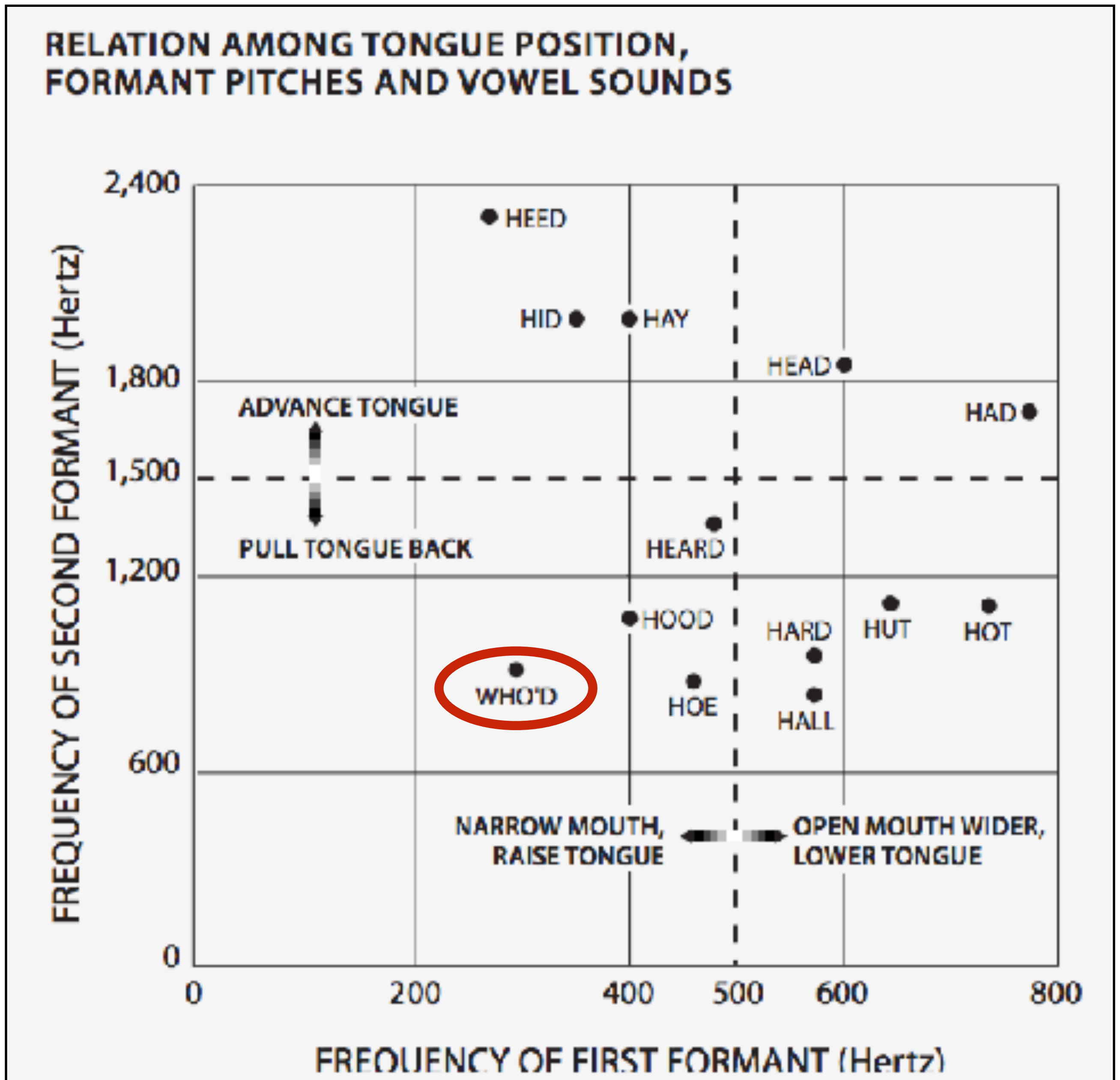
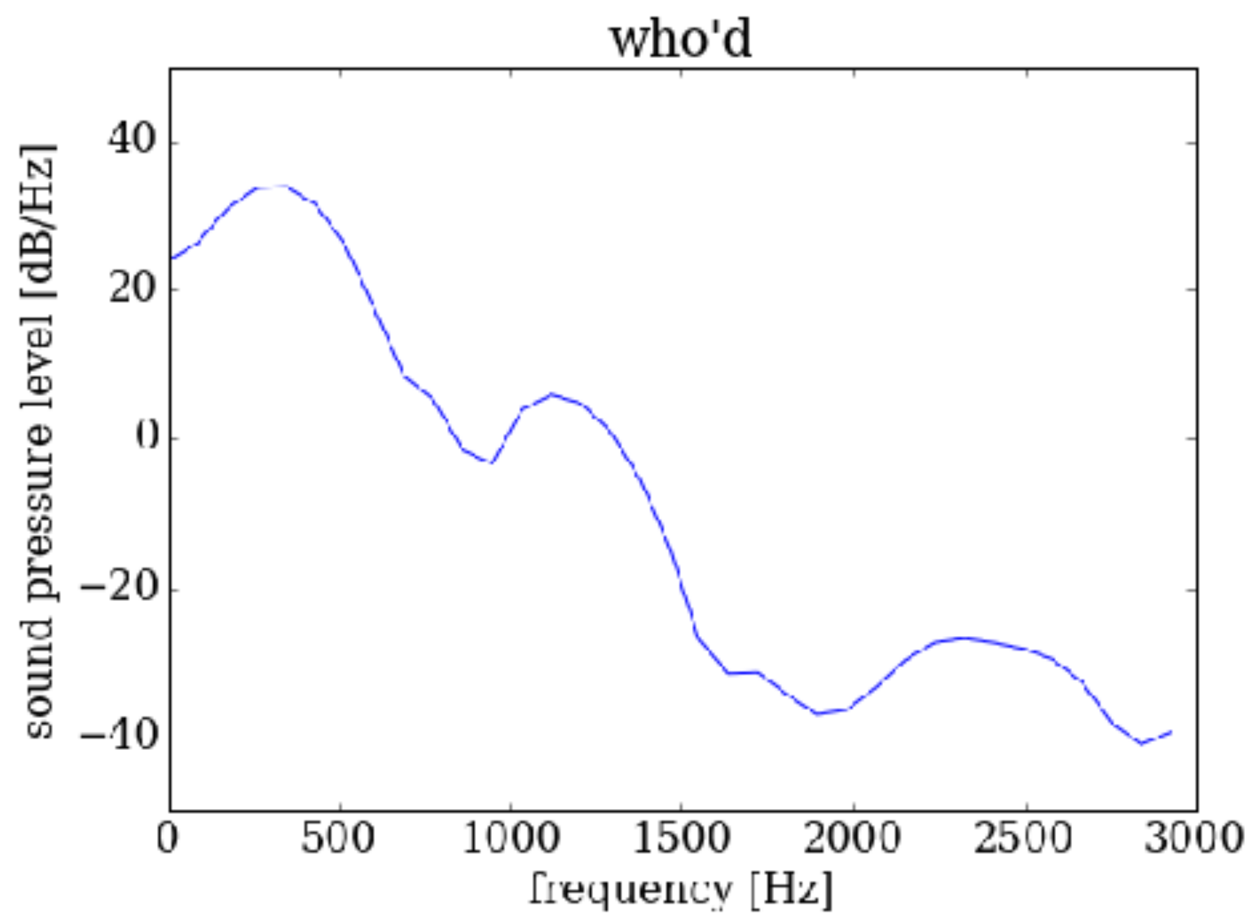


Formants of “Who’d”

T. Levin and M. Edgerton, “The Throat Singers of Tuva,” *Scientific American*, Sep. 1999





Singing

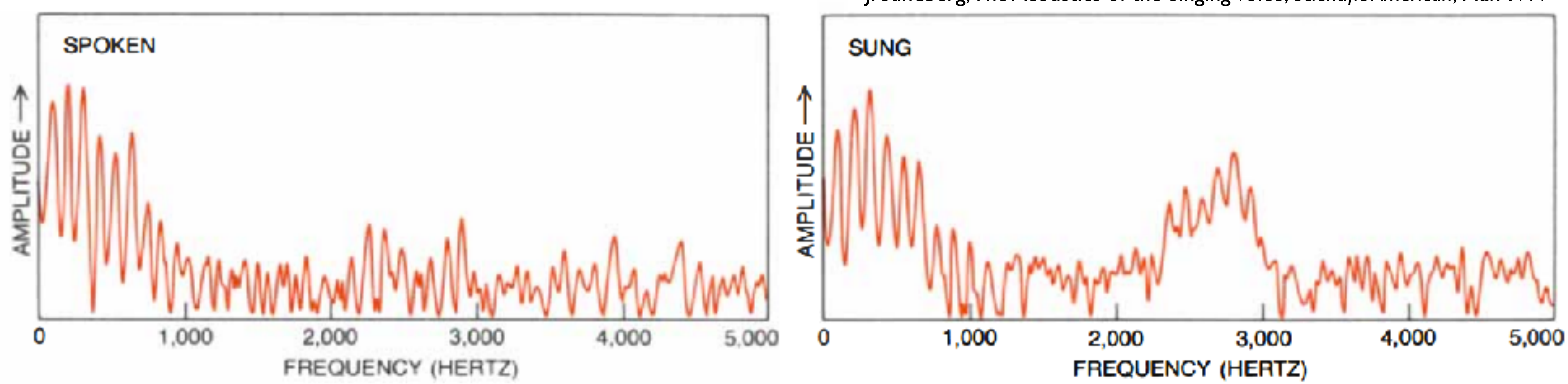
- How do singers make themselves heard above an accompanying orchestra (and hit those high notes)?

Diana Damrau, "Der Hölle Rache," Die Zauberflöte

Singer's Formant

- Power spectra of sung vs. spoken vowels show an extra formant between 2500 and 3000 Hz

J. Sundberg, The Acoustics of the Singing Voice, *Scientific American*, Mar. 1977



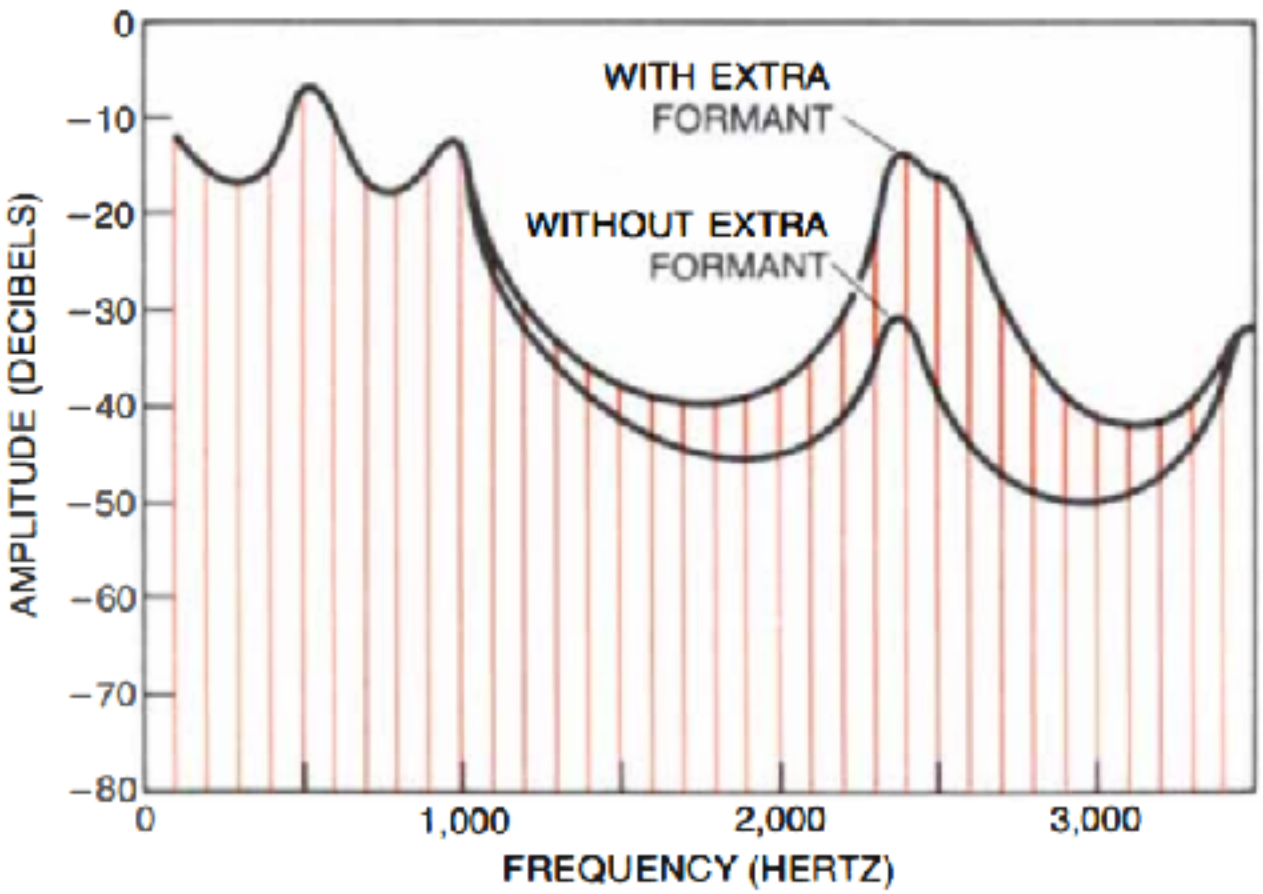
- There is an extra cavity in the vocal tract created by the false vocal folds

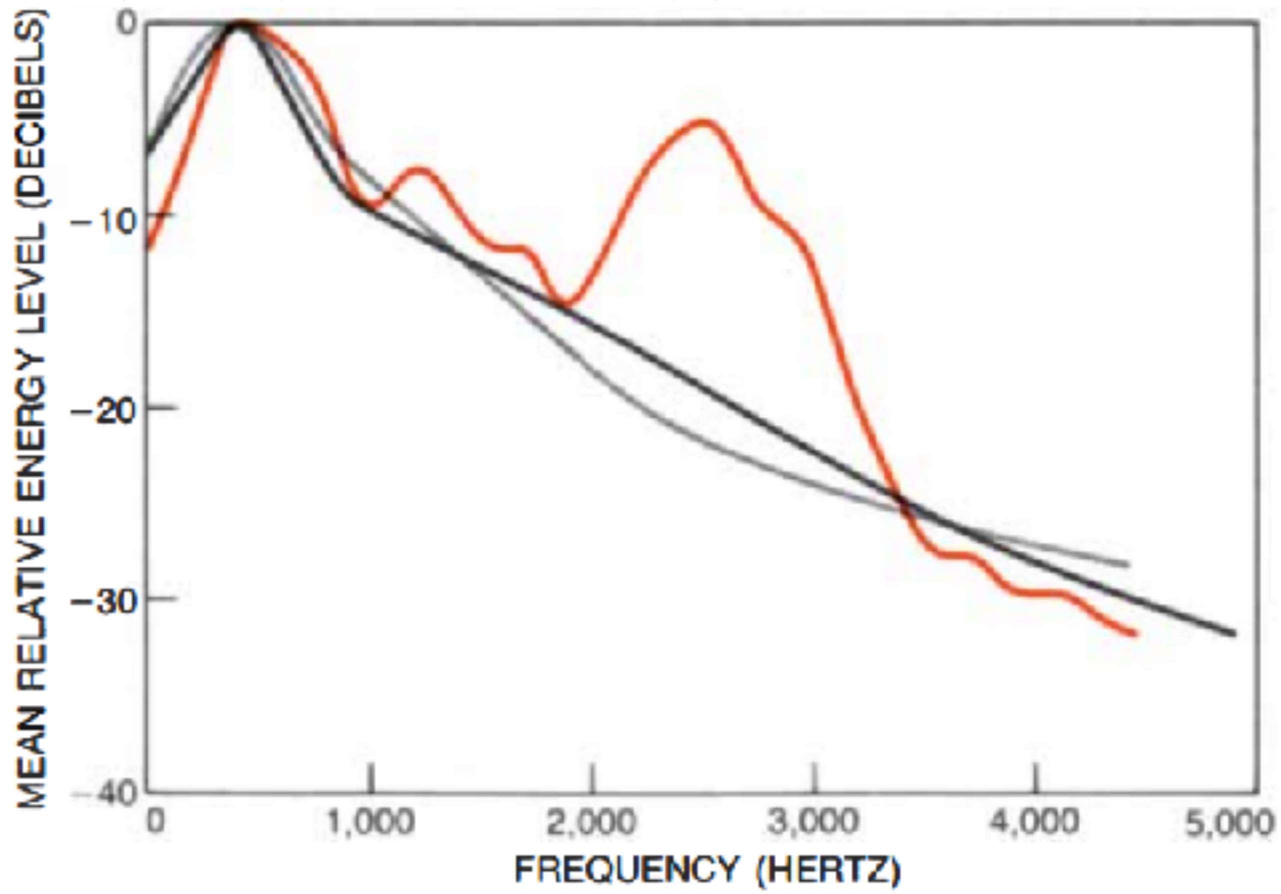
- The cavity is a closed-open tube (1/4-wave resonator) with a fundamental mode between 2500 and 2800 Hz

Singer's Formant

- Trained singers use the extra formant to make themselves heard above the orchestra

J. Sundberg, The Acoustics of the Singing Voice, *Scientific American*, Mar. 1977



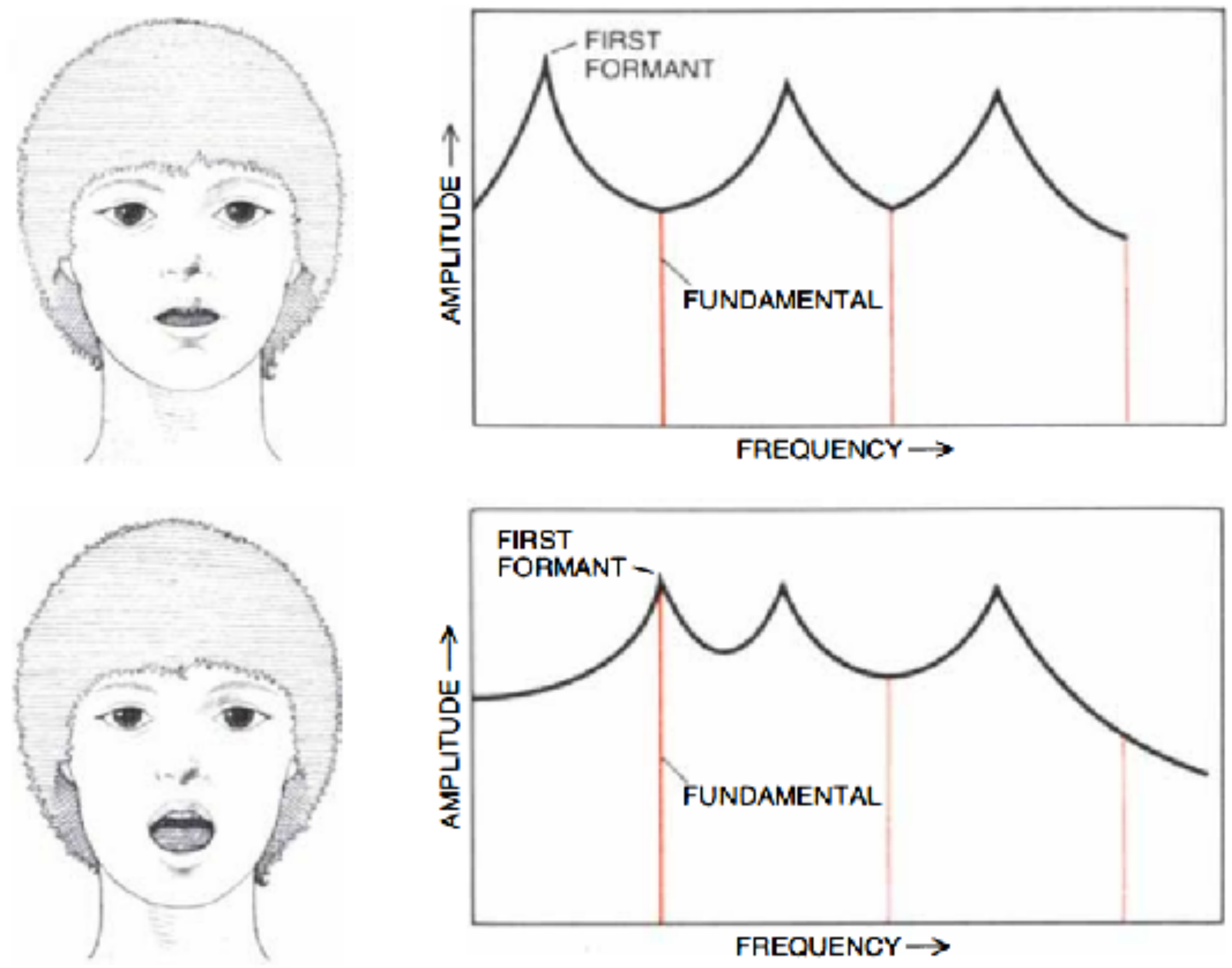


- Untrained singers do not show this ability

Wide Jaw Opening

- Why do sopranos open their mouths so wide for high notes?
- Sopranos sing tones with fundamental > first formant of the vowel being sung
- Opening the jaw raises the pitch of the first formant, enhancing the amplitude of the fundamental tone

J. Sundberg, The Acoustics of the Singing Voice, *Scientific American*, Mar. 1977

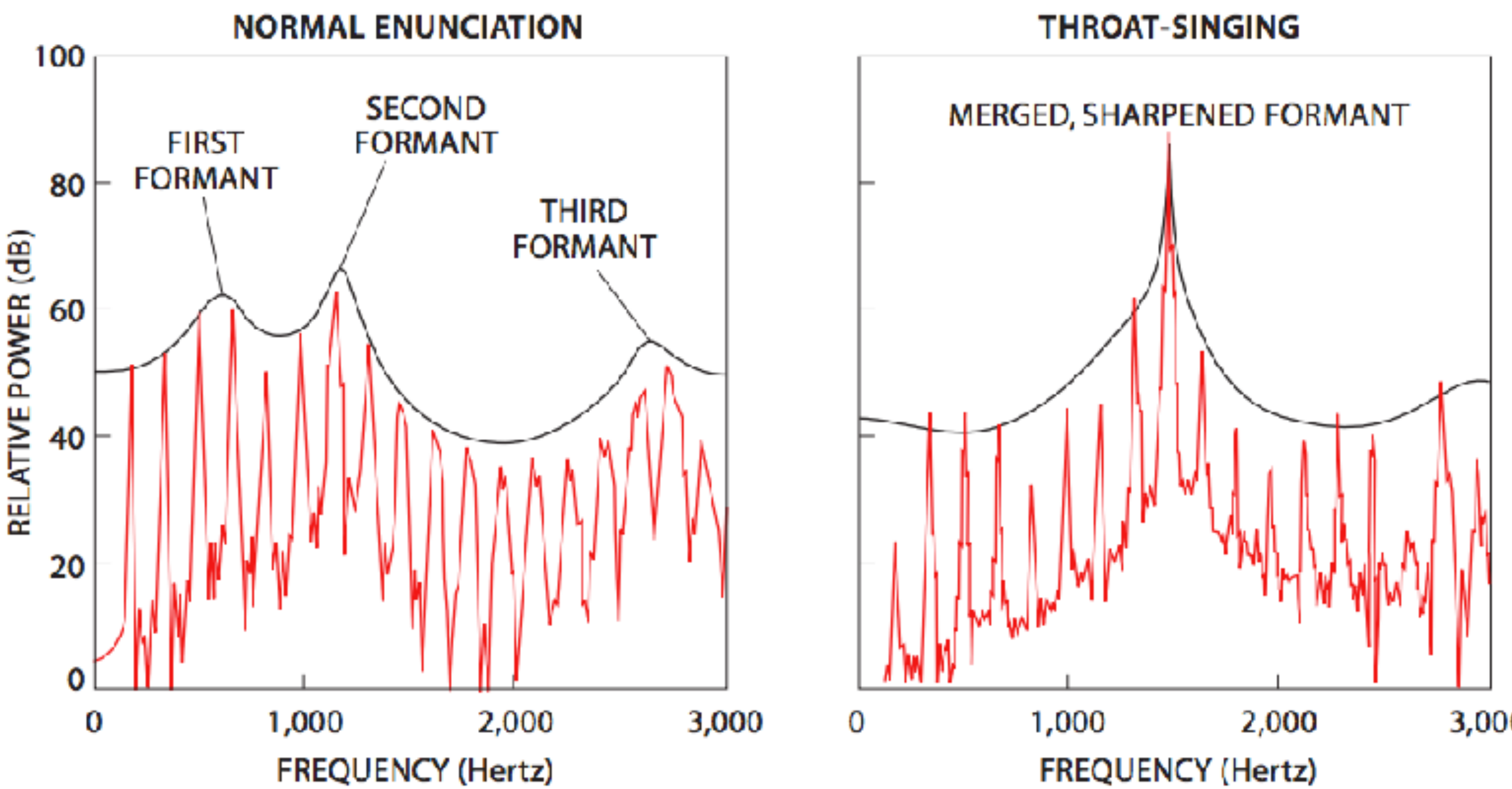


Shaping the Vocal Tract

- With proper training, the vocal tract can be reshaped to produce surprising effects
- Throat singing: formants are merged to produce a sharp resonance peak, enhancing an overtone of the vocal folds
- The overtone can be heard clearly above the other frequencies in the tone, allowing two tones to be sung at once
- Polyphonic/multiphonic singing!

Throat Singing

- The vocal tract is shaped to merge the formants and amplify a very high overtone of the vocal folds



T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

Tuvan Throat Singing

- *Arty-sayir*, Vasili Chazir, Smithsonian Folkways Recordings

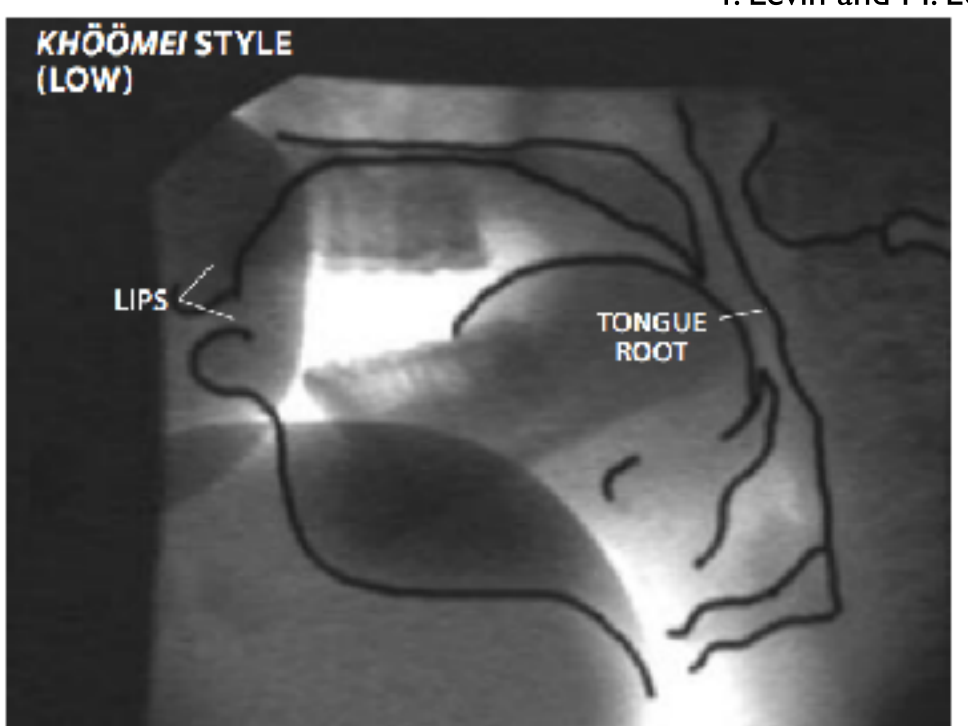
T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999

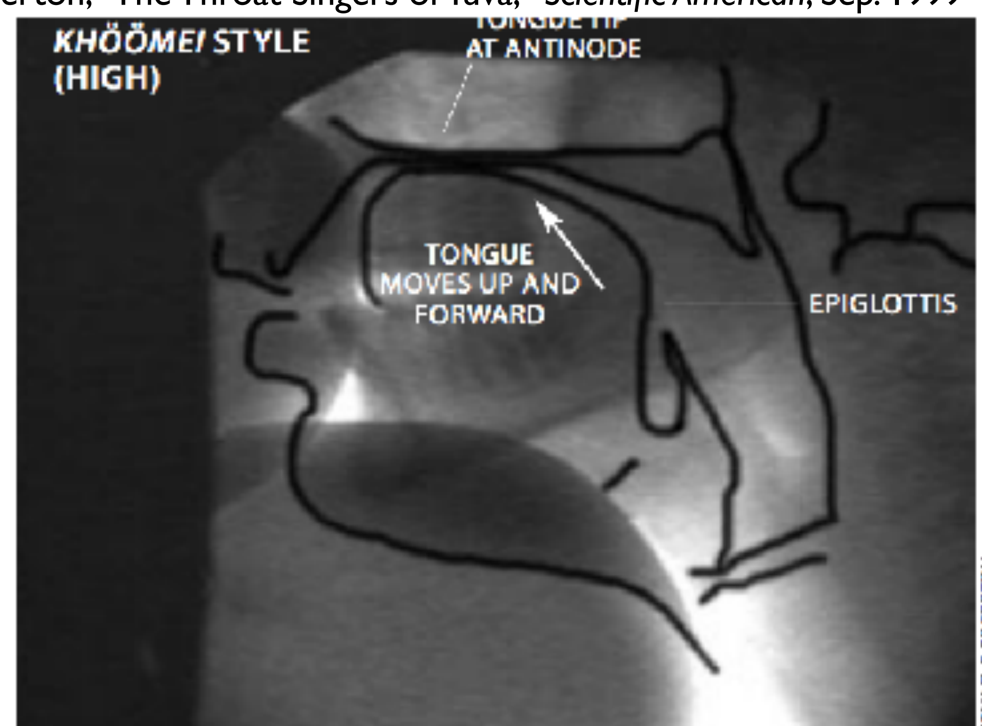
Khöömei Style

- Low pitch: tongue root near back of mouth, tongue tip depressed
- Pitch rise: entire tongue moves high toward the roof of the mouth and teeth

Alexander Glenfield (youtube)

T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999



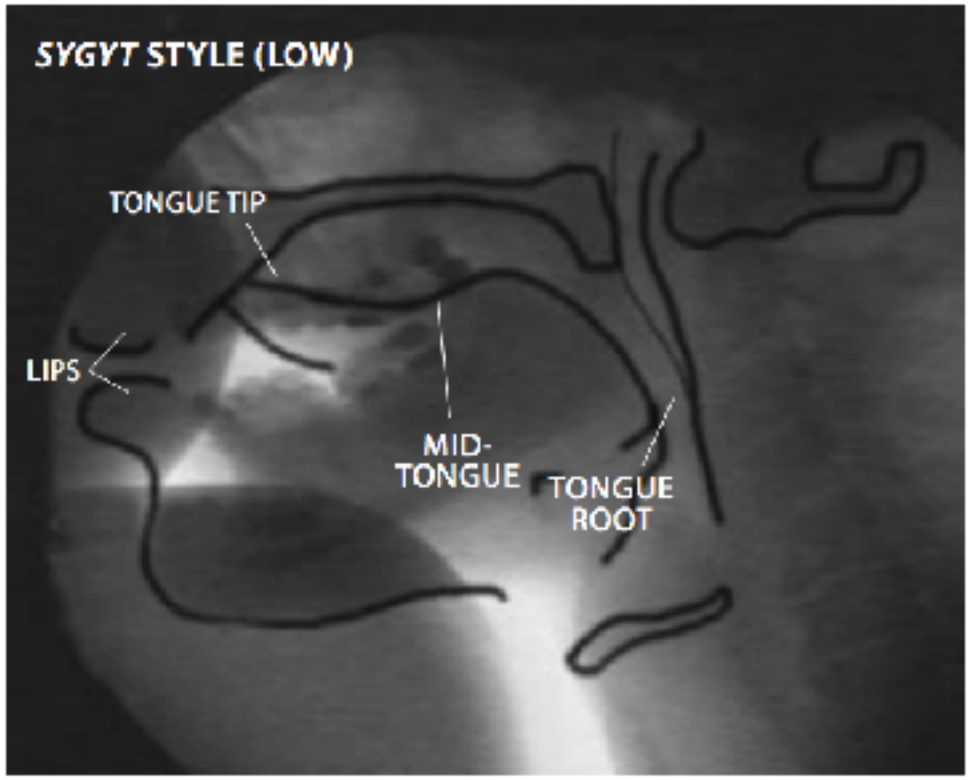


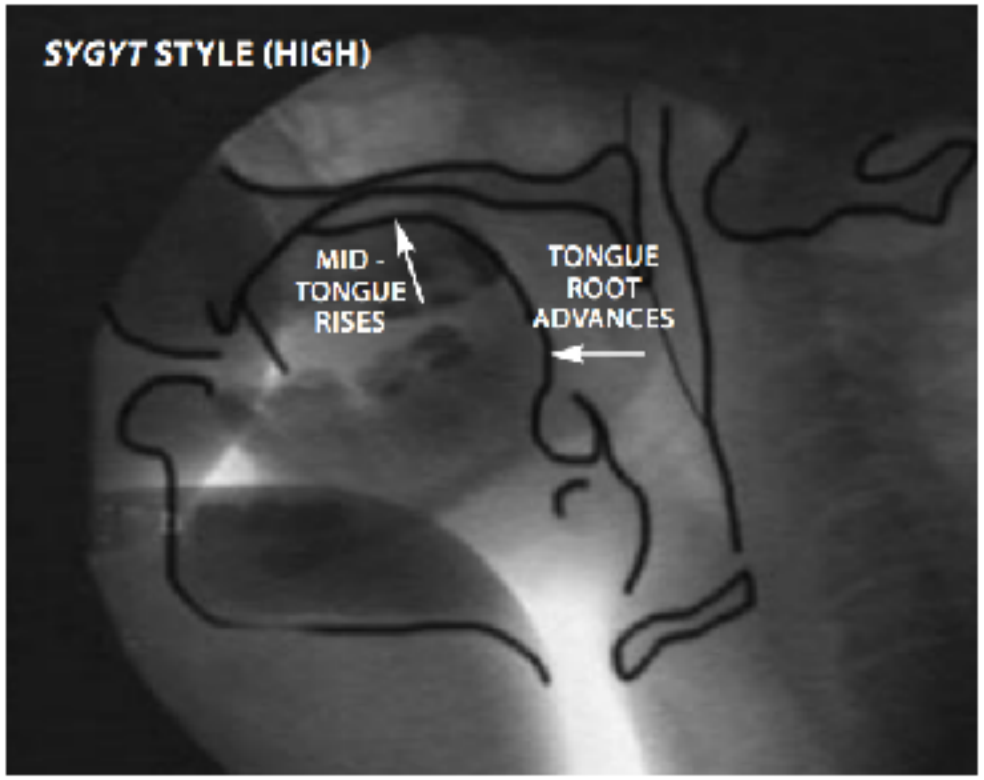
Sygyt Style

Alexander Glenfield (youtube)

- Sygyt style ("whistling")
- Tip of the tongue is behind the top teeth (alveolar ridge)
- Mid-tongue rises, root moves forward for high notes

T. Levin and M. Edgerton, "The Throat Singers of Tuva," *Scientific American*, Sep. 1999





Overtone Singing

- “Multiphonic” singing: two notes at once

Anne-Maria Hefele (youtube)

- Question: is she really singing two different notes?

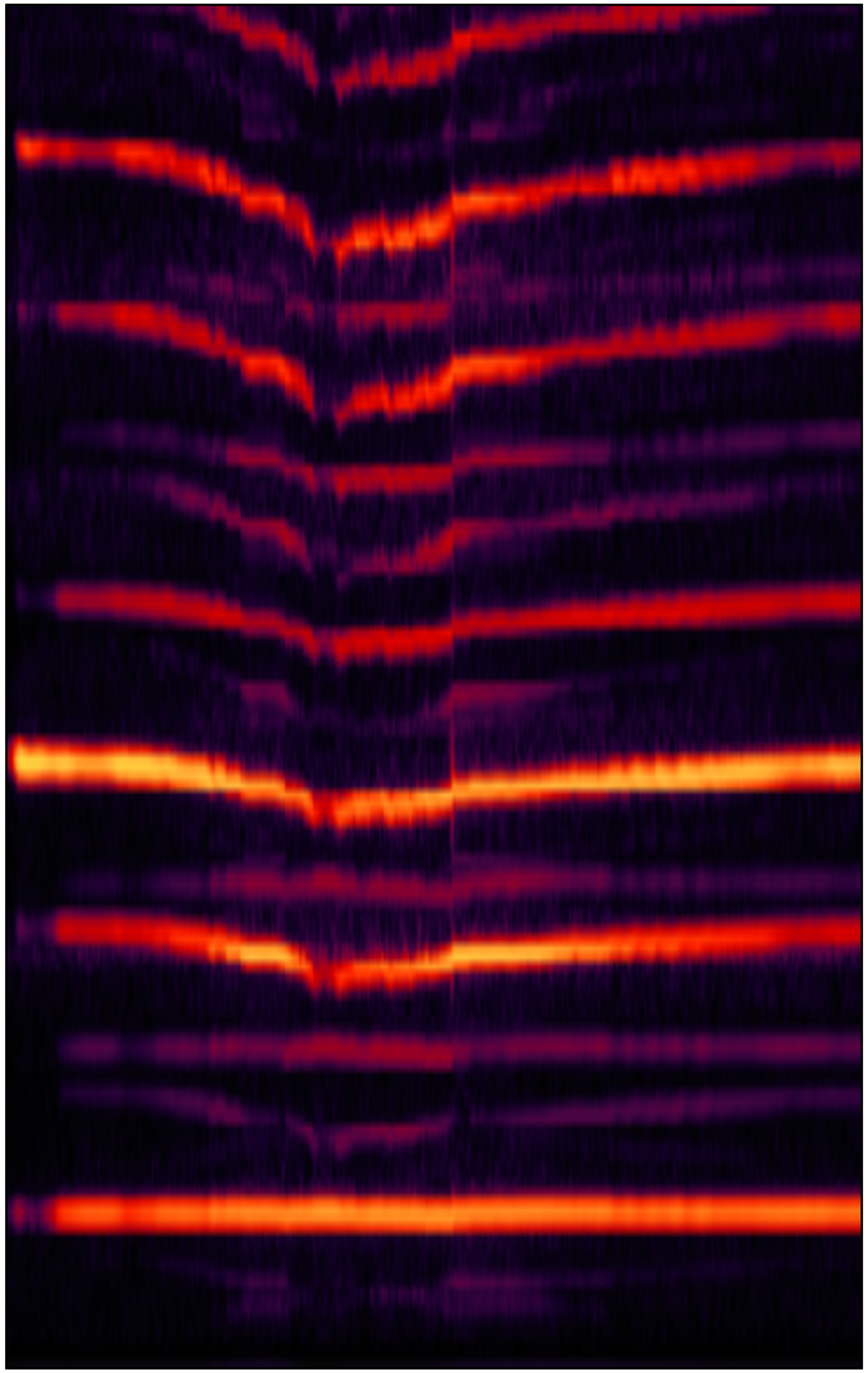
Pseudo Multiphonics

- Actually, overtone singing isn't really singing different notes, in the sense of different fundamental tones
- As we said, the vocal tract is being reshaped to strongly amplify particular harmonics of the fundamental
- So this is really pseudo-multiphonic, being related to our perception of pitch
- Pitch and timbre greatly affect our ability to perceive separate melodies

Clarinet Multiphonics

- True multiphonic clarinet tone
- Lowest partial is held fixed
- Upper partials sweep through non-integer multiples of the lowest partial
- This is not just amplification of particular overtones
- Two inharmonic series are played simultaneously

J.-F. Charles (from E. Heller)



Other Sounds

- It's possible to make other sounds without using the vocal folds at all
- Clicks, rolls, hisses, whistles, etc. You can build a language out of it:

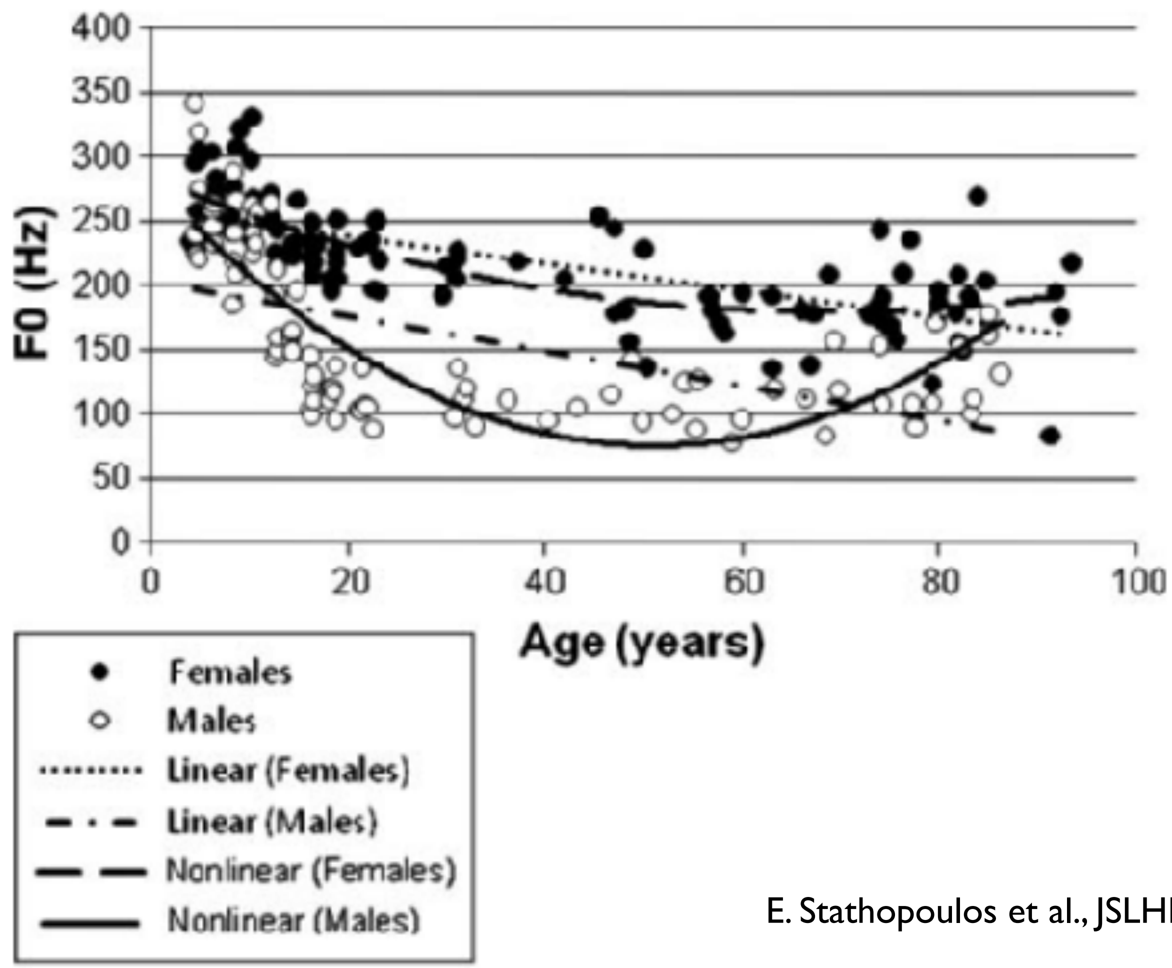
Xhosa tongue-twisters, youtube

Gender Differences

- Men
  - Large larynx, 17-25 mm vocal folds
  - 90-150 Hz fundamental
- Women
  - Smaller larynx, 12.5-17 mm vocal folds
  - 170-220 Hz fundamental
- Interesting fact: it's easier for a man to raise the pitch of his vocal fold oscillations into the female range than vice-versa

Gender Differences

- Change in pitch of vocal fold fundamental frequency over time, broken down by gender:



E. Stathopoulos et al., JSLHR **54**:1011, 2011

- Men's vocal pitch drops with age, then rises after age 50. Women's voices continue to deepen with age