- **Airstream mechanisms:**
  Ejectives, implosives, clicks
- **Phonation types**

Optional reading for more information:

- *V&C* Ch 13, sec 13.8-13.9 (ejectives, implosives)
- *V&C* Ch 14, sec 14.5 (clicks)
- *AAP* Ch 8, pp 175-6 (ejectives, implosives, clicks)
- *V&C* Ch 13, sec 13.4-13.7 (phonation types)
- *AAP* Ch 8, sec 8.1.1, “Phonation types”

0. Today's objectives

After today's class, you should be able to:

- Explain the role of **air pressure** in **egressive** and **ingressive** airflow
- Explain the articulation that initiates airflow in **pulmonic**, **glottalic**, and **velaric** sounds
- **Distinguish** voiceless plosives from ejectives, and voiced plosives from implosives, in Praat
- Recognize **breathy** and **creaky** phonation by ear / in Praat
- Understand what the **open quotient** of phonation predicts about the **H1–H2** relationship

1. Airstream mechanisms

Warm-up

Review from voicing discussion (fireplace bellows!)

- What conditions are necessary to cause a **gas to move** from one container into another?
- Assuming a flexible container, what **change to the container's volume** will cause a gas to move?

1. Airstream mechanisms

Warm-up

Review from voicing discussion (fireplace bellows!)

- What conditions are necessary to cause a **gas to move** from one container into another?
    - Gas moves from high pressure to low pressure
- Assuming a flexible container, what **change to the container's volume** will cause a gas to move?
    - Volume **up** → pressure **down** → gas moves **in**
    - Volume **down** → pressure **up** → gas moves **out**

1. Airstream mechanisms

- In order for there to be sound, there must be **moving air** (or other medium: water, helium, …)
- In speech, something must set the air in motion

  → This is known as an **airstream mechanism**
- So far, all the speech sounds we have discussed have had air moving **outward**, initiated by the **lungs**
  - This is the **pulmonic egressive** airstream mechanism
- There are three other possibilities…

1. Airstream mechanisms

- Terminology for **airstream mechanisms**

Air set in motion by	***Adjectival form***	***Direction of airstream***	***Name for this class***
lungs	pulmonic	egressive	**plosives** (*if oral stop*[1])
glottis	glottalic	egressive	**ejectives**
glottis	glottalic	ingressive	**implosives**
velum	velaric	ingressive	**clicks**

[1]Most non-oral-stop consonants, all vowels are also pulmonic egressive

2. Pulmonic airstream mechanisms

- **Pulmonic egressive** — most common airstream mechanism
  - Most speech sounds are pulmonic egressive
  - This includes all sounds of (standard) English

- How to get air to move **out** using the **lungs**?
  - Compress their volume → higher pressure → air moves out

2. Pulmonic airstream mechanisms

- **Pulmonic ingressive** airstream mechanism?
  - Physically possible (try talking while breathing in!)
  - Sometimes used for expressions of surprise, affirmation, etc. in different cultures
    [examples from Wikipedia]
  - Extremely rare or nonexistent in speech sounds

3. Glottalic airstream mechanisms

- The **articulatory configuration** for producing a **glottalic** airstream mechanism
  - Close the glottis (as if producing a glottal stop [ʔ])
  - Form another stop constriction in the oral tract
  - Air is now trapped between the glottis and the other constriction
    - You should be *unable to breathe through your nose* while holding the two closures — why?

3. Glottalic airstream mechanisms

Ejectives (glottalic egressive)

- Language examples:
  - WALS map (ejectives in red or purple)
  - Sound file examples from *V&C*: see especially Quechua

- Most ejectives are (oral) **stops** or **affricates**, but **fricatives** are also possible

- There is a systematic convention for **transcribing** ejectives in the IPA — what is it? (see *V&C*)

3. Glottalic airstream mechanisms

Ejectives (glottalic egressive)

- An **ejective** is **glottalic egressive**
  - What do we need to do with the glottis to cause air to move **out of** the mouth when the oral closure is released?

3. Glottalic airstream mechanisms

Ejectives (glottalic egressive)

- An **ejective** is **glottalic egressive**
  - What do we need to do with the glottis to cause air to move **out of** the mouth when the oral closure is released?
    - Volume between glottal and oral closures must get *smaller* → pressure **up** → air **out**
  - Raise the larynx!
    - Then, release oral closure
    - Last, release glottal closure

3. Glottalic airstream mechanisms

Ejectives (glottalic egressive)

- In an ejective, the glottis remains tightly closed until just after the oral closure is released
  - Can an ejective be **voiced**? Why or why not?
    - See diagram

3. Glottalic airstream mechanisms

Ejectives (glottalic egressive)

- In an ejective, the glottis remains tightly closed until just after the oral closure is released
  - Can an ejective be **voiced**? Why or why not?
  - **Impossible**: vocal folds can't vibrate while glottis is tightly closed

3. Glottalic airstream mechanisms

Ejectives (glottalic egressive)

- What should an ejective stop look like on a waveform/spectrogram?
  - The **burst** is usually **more salient** than in a voiceless plosive — why?
  - If the sequence of events is *oral release — glottal release — (vowel),* what do we expect this to look like on the **waveform**?

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- Language examples
  - WALS map (implosives in blue or purple)
  - Sound file examples from *V&C*: see especially Sindhi, Owerri Igbo

- Implosives are nearly always (oral) **stops**

- What characteristic do IPA symbols for **transcribing** implosives have in common? (*V&C*)

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- An **implosive** is **glottalic ingressive**
  - What do we need to do with the glottis to cause air to move **into** the mouth when the oral closure is released?

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- An **implosive** is **glottalic ingressive**
  - What do we need to do with the glottis to cause air to move **into** the mouth when the oral closure is released?
    - Volume between glottal and oral closures must get *larger* → pressure **down** → air **in**
  - Lower the larynx!
    - Timing of release of oral and glottal closures probably less critical than in ejectives

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- An implosive is almost always **voiced**
  - What happens to supraglottal air pressure if the glottis is vibrating while it is lowered?

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- An implosive is almost always **voiced**
  - What happens to supraglottal air pressure if the glottis is vibrating while it is lowered?
- Consequences:
  - Air pressure may not be lower than zero (atmospheric pressure) in oral cavity when larynx is lowered
  - Air may not actually rush into mouth when oral closure is released

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- What should an implosive look like on a waveform/spectogram?
  - Should the stop have a burst? If so, should it be weak or strong? Why?

3. Glottalic airstream mechanisms

Implosives (glottalic ingressive)

- A difference between implosives and voiced plosives visible on the waveform
  - In an implosive, the **amplitude** of the voicing during closure generally *increases* (or at least does not decrease) leading up to the stop release
  - This indicates: it is **easier to maintain voicing** in an implosive, compared to a voiced plosive
  - Think about our discussion of voicing in plosives: **Why** might implosives be easier to voice?

4. Velaric airstream mechanisms

- The starting point for producing a **velaric** airstream mechanism
  - Form a closure at the **velum**
    (just as for a velar stop)
  - Form another closure **forward** of the velum
    - Labial, dental, alveolar, postalveolar

- What effect does forming this configuration have on the ability to produce...
  - voicing?
  - nasality?

4. Velaric airstream mechanisms

- The starting point for producing a **velaric** airstream mechanism
  - Form a closure at the **velum**
    (just as for a velar stop)
  - Form another closure **forward** of the velum
    - Labial, dental, alveolar, postalveolar

- What effect does forming this configuration have on the ability to produce...
  - voicing? | no effect! voiceless/voiced possible
  - nasality? | no effect! oral/nasal possible

4. Velaric airstream mechanisms

Clicks (velaric ingressive)

- Clicks are possible at various places of articulation (see IPA chart for symbols)
    - bilabial click (like a flat-lipped 'kiss' sound)
    - dental click (like the sound that indicates disapproval)
    - (central) alveolar click
    - lateral alveolar click (like the noise made to get a horse to move)
    - palatoalveolar click

4. Velaric airstream mechanisms

Clicks (velaric ingressive)

- To indicate whether a click is produced with **nasality**, or whether it is **voiced** or **voiceless**, it can be written together with a velar stop [k g ŋ]
  - By convention, the click sound is understood to be simultaneous with the preceding velar stop

- Language examples
  - WALS map (clicks in red)
  - Sound file examples from *V&C*: see especially Nama, Zulu, Xhosa

4. Velaric airstream mechanisms

Clicks (velaric ingressive)

- A **click** is a **velaric ingressive** sound
  - What do we need to do for air to move **into** the mouth when the oral closure is released?

4. Velaric airstream mechanisms

Clicks (velaric ingressive)

- A **click** is a **velaric ingressive** sound
  - What do we need to do for air to move **into** the mouth when the oral closure is released?
    - Volume between closures must get *larger* → pressure **down** → air **in**
  - Slide the tongue body down/back while maintaining the velar closure!
    - Then release forward closure, then velar
  - X-ray of a click, from V&C

4. Velaric airstream mechanisms

- What might we predict about the acoustics of **bursts** in clicks? Why?
  - Note that the **change in volume** of the space between closures (before the forward closure is released) is proportionally **large** because the space itself is relatively small

4. Velaric airstream mechanisms

- A **velaric egressive** sound is physically possible, but they are not known to occur as speech sounds
  - What would you have to do with a velaric airstream configuration to get the air to move **out**?

Reminder: Objectives

After today's class, you should be able to:

…

- Recognize **breathy** and **creaky** phonation by ear / in Praat
- Understand what the **open quotient** of phonation predicts about the **H1–H2** relationship

5. States of the glottis

- Review: What is the position of the vocal folds during modal (typical) voicing?

5. States of the glottis

- What happens when the vocal volds are wide open, or when they are tightly closed?

VF wide open	VF adducted (not too tightly)	**VF tightly closed**
	voicing/phonation	

.

5. States of the glottis

- What happens when the vocal volds are wide open, or when they are tightly closed?

VF wide open	VF adducted (not too tightly)	VF tightly closed
voicelessness	voicing/phonation	**glottal stop** (also voiceless)

5. States of the glottis

- What predictions can we make for the acoustics of a **glottal stop** in the source-filter model?
  - What do we predict during the **closure** phase?
  - Do we predict a **stop burst**? Why or why not?
  - What do we predict about **formant transitions**?
    - Turns out, there are essentially no formant transitions for a glottal stop

5. States of the glottis

- Additional **phonation types** along this continuum

<table>
<tr><th>VF wide open</th><th colspan="3">VF adducted (not too tightly)</th><th>VF tightly closed</th></tr>
<tr><td rowspan="2">voicelessness</td><td colspan="3">voicing/phonation</td><td rowspan="2">glottal stop (voiceless)</td></tr>
<tr><td></td><td>modal</td><td></td></tr>
</table>

5. States of the glottis

- Additional **phonation types** along this continuum

VF wide open	**VF adducted (not too tightly)**			VF tightly closed
voicelessness	**voicing/phonation**			glottal stop (voiceless)
	breathy	**modal**	**creaky**	

6. Creaky phonation

- Vocal folds are **open** during a **lower** percentage of the phonation cycle than in modal phonation

Open quotient:

- Creaky: VF open for approx. 1/3 of cycle
- Modal: VF open for approx. 1/2 of cycle

- Configuration of vocal folds for creaky voicing
  - Generally adducted more tightly
  - May be totally closed along part of their length and vibrating only along another part

6. Creaky phonation

- Used in English for sociolinguistic effects
  - Older upper-class British speakers
  - Younger American speakers

- Sometimes known as "vocal fry"
  - See various posts critiquing discussions of vocal fry in the media from Language Log

6. Creaky phonation

- Used in other languages to **distinguish phonemes** (speech sound categories)
  - How do we **transcribe** creaky phonation?
  - **Sound files** — see Mazatec (from *V&C*)
  - See also the South American Phonological Inventory Database for more languages
  - WALS map: Red symbols show languages with "glottalized resonants" (i.e., sonorants, most likely with creaky phonation)
- Creaky voice can be **phonologically** associated with either consonants or vowels (→ phonetics?)

7. Breathy phonation

- Vocal folds are **open** during a **higher** percentage of the phonation cycle than in modal phonation

  Open quotient:

  - Modal: VF open for approx. 1/2 of cycle
  - Breathy: VF open for approx. 2/3 of cycle

- Configuration of vocal folds for breathy voicing
  - Generally adducted more loosely
  - May be wide open along part of their length and vibrating only along another part
    - There may be a salient **aperiodic** source!

7. Breathy phonation

- In English, breathy voice may be a characteristic of individual speakers (or correlated with gender?)
- Used in other languages to **distinguish phonemes** (speech sound categories)
  - How do we **transcribe** breathy phonation?
  - **Sound files** — compare Hindi ("voiced aspirated") and Mazatec (from *V&C*)
- As with creaky voice, breathy voice can be **phonologically** associated with either consonants or vowels (→ phonetics?)

8. Acoustics of phonation types

- 2 ways of looking at **acoustics** of phonation types
  - Open quotient and H1 relative amplitude
  - Periodicity and other cues

- The characteristics discussed here may be relied upon to different degrees in different languages!
  - Moreover, languages may use breathy or creaky voice together with other phonetic effects, complicating the picture

9. Open quotient and H1 relative amplitude

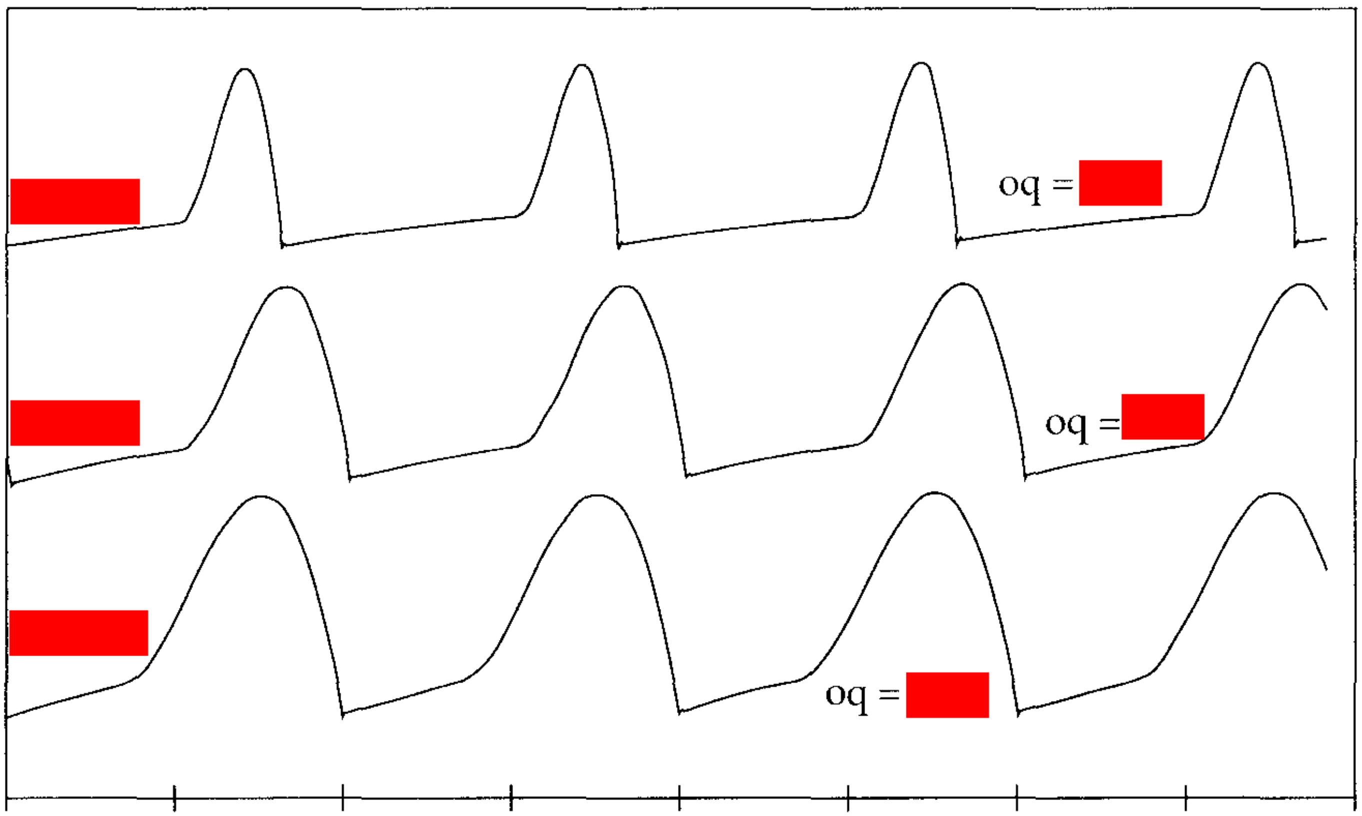
- One articulatory difference among phonation types is the **open quotient** — the proportion of each cycle of VF vibration during which the glottis is open
  - Breathy: VF open for approx. 2/3 of cycle
  - Modal: VF open for approx. 1/2 of cycle
  - Creaky: VF open for approx. 1/3 of cycle

- This difference predicts acoustic consequences for the **spectrum** of the **glottal source wave**

9. Open quotient and H1 relative amplitude

- Glottal-source **waveforms** (synthesized) | *AAP* Fig 8.2

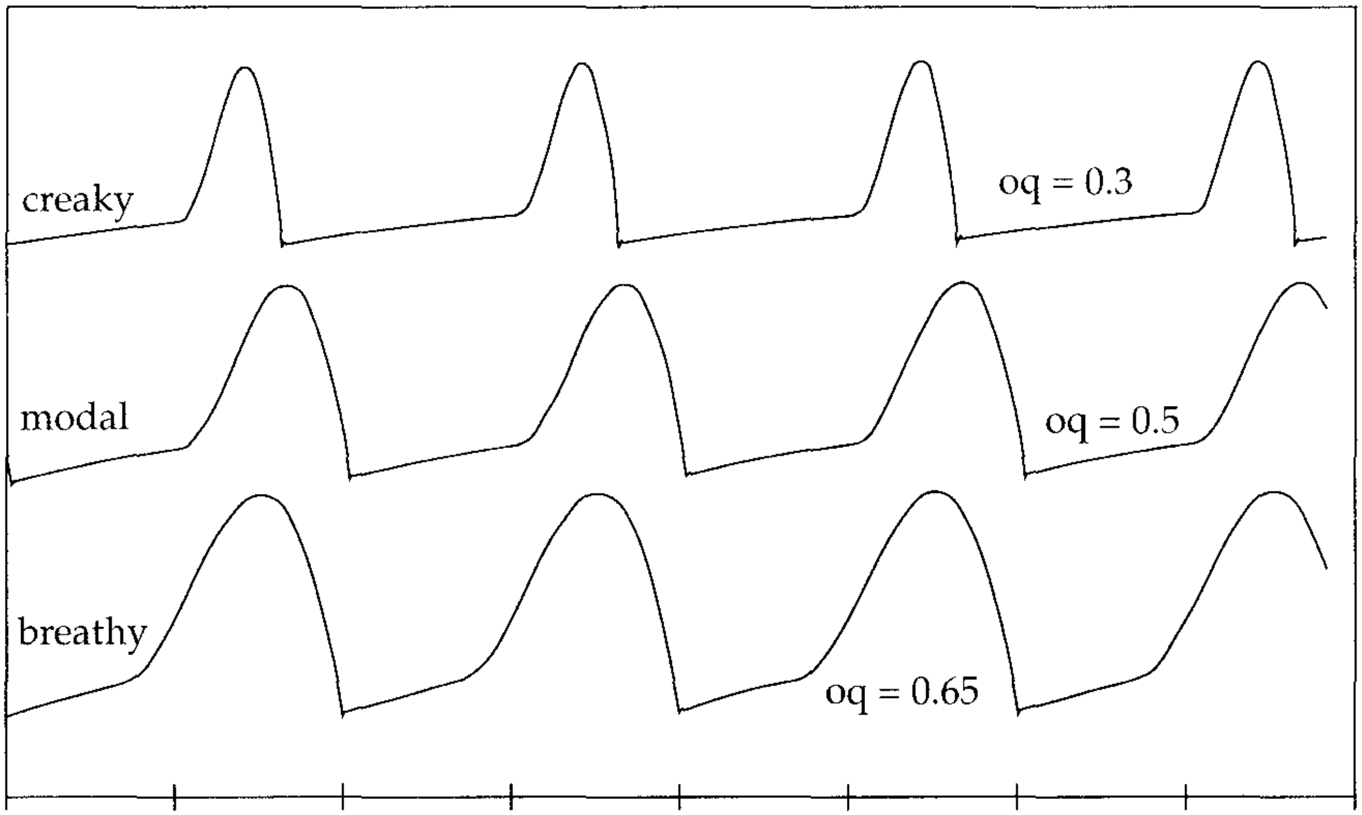
  Which phonation type matches which diagram?



9. Open quotient and H1 relative amplitude

- Glottal-source **waveforms** (synthesized) | *AAP* Fig 8.2

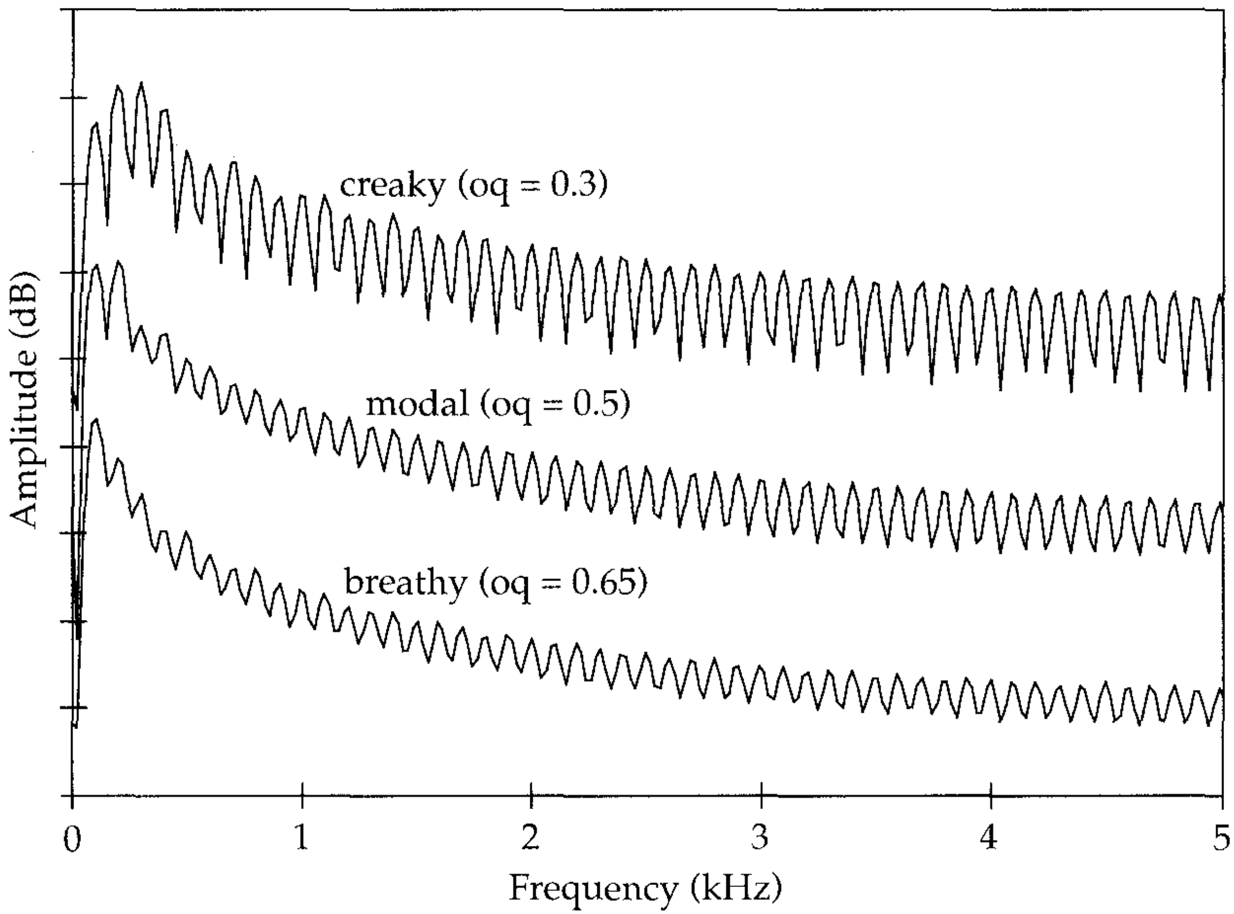
  Which diagram is most like a **sine wave**?



9. Open quotient and H1 relative amplitude

- Glottal-source **spectra** (synthesized) | *AAP* Fig 8.3

  Which diagram is most like a **sine wave**? How?



9. Open quotient and H1 relative amplitude

- Prediction: Breathy ph. — most like a sine wave
  - **First glottal harmonic (H1)** has **highest** amplitude
  - **Spectral slope:** Relative amplitudes of harmonics drop off most quickly

- Note: These characteristics might not be visible for cases of breathy phonation where the **aperiodic** sound source is predominant
  - See Mazatec example above

9. Open quotient and H1 relative amplitude

- We predict that modal, creaky phonation get progressively more different from breathy
  - **First glottal harmonic (H1)** has amplitude **similar** to second in **modal** phonation
  - **First glottal harmonic (H1)** has amplitude **lower** than next few in **creaky** phonation
  - **Spectral slope:** Relative amplitudes of harmonics drop off less quickly in **modal** phonation and least quickly in **creaky** phonation

9. Open quotient and H1 relative amplitude

- Reminder: We've been talking about properties of the **glottal-source** waveform
  - What do we need to be careful about in inferring properties of the glottal-source spectrum in **speech sounds**?

    → What else might affect the **relative amplitude of glottal harmonics** besides differences in phonation type?

10. Periodicity and other cues

- **Creaky voice**: Waveform/spectrogram
  - Stiff vocal folds often vibrate more slowly and irregularly, leading to **lower** fundamental frequency and glottal pulses that are visibly **further apart** (possibly also irregularly spaced)
  - On waveform, component corresponding to F1 may be very salient
  - "Arrowhead" effect often visible in waveform

10. Periodicity and other cues

- **Breathy voice**: Waveform/spectrogram
  - Longer open quotient may lead to portions of the phonation cycle that are similar to aspiration

    → as noted above, may have a considerable **aperiodic** component
  - Often has **lower amplitude** than modal voice
  - Waveform may show **less well-defined** effect of formants (because breathy phonation doesn't excite vocal-tract resonances as well)

11. Summary: Phonation types

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<tr><th>VF wide open</th><th colspan="3">VF adducted (not too tightly)</th><th>VF tightly closed</th></tr>
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