24.915/24.963

Linguistic Phonetics

Source-filter analysis of fricatives

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Readings:

- Johnson chapter 5 (speech perception)
- 24.963: Fujimura et al (1978)

Noise source

- Turbulence noise - random pressure fluctuations.
- Turbulence can result when a jet of air flows out of a constriction into a wider channel (or open space).

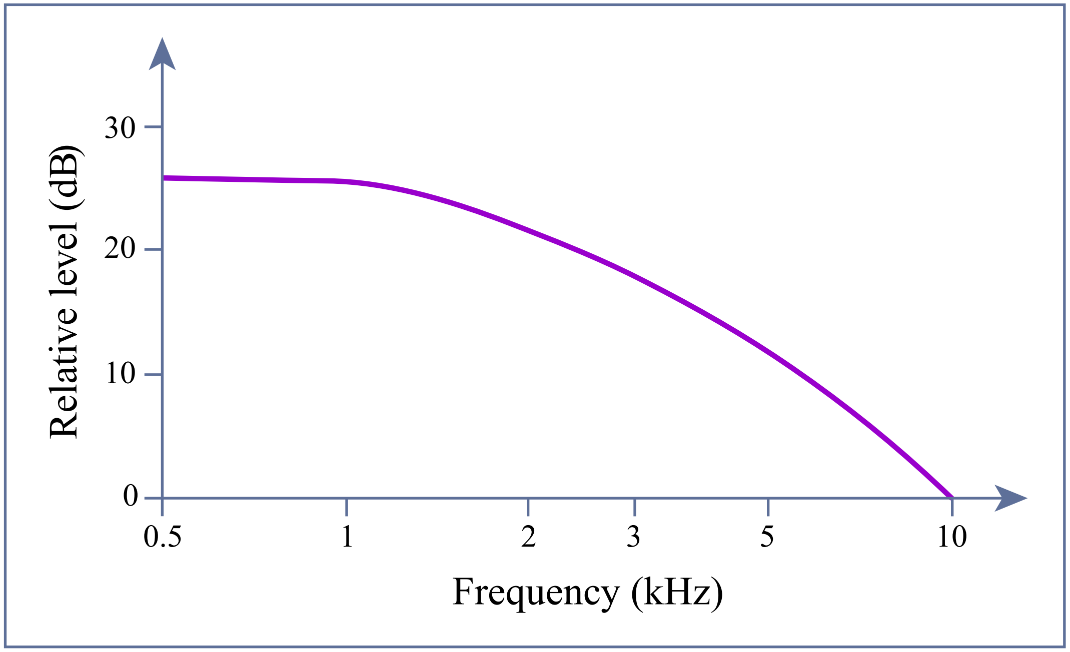


Image by MIT OCW.
Adapted from Stevens, K. N. "On the quantal nature of speech." *Journal of Phonetics* 17 (1989): 3-46.

Noise source

- Turbulence can result when a jet of air flows out of a constriction into a wider channel (or open space).
- The intensity of turbulence noise depends on particle velocity.
- For a given volume velocity, particle velocity will be greater if the channel is narrower, so for a given volume velocity, narrower constrictions yield louder frication noise.

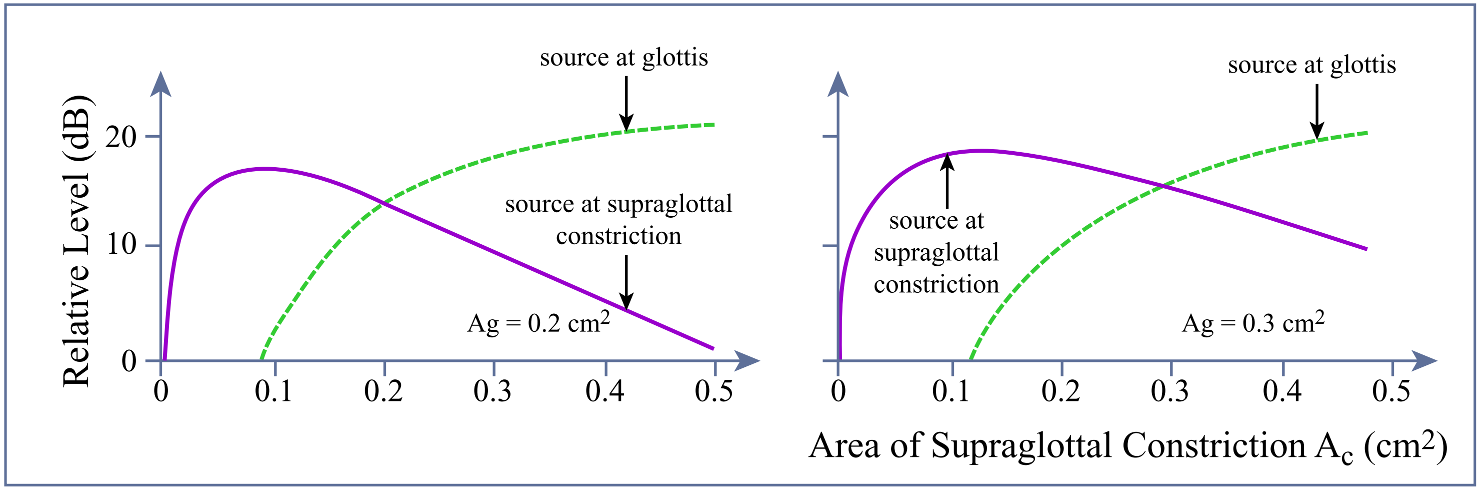
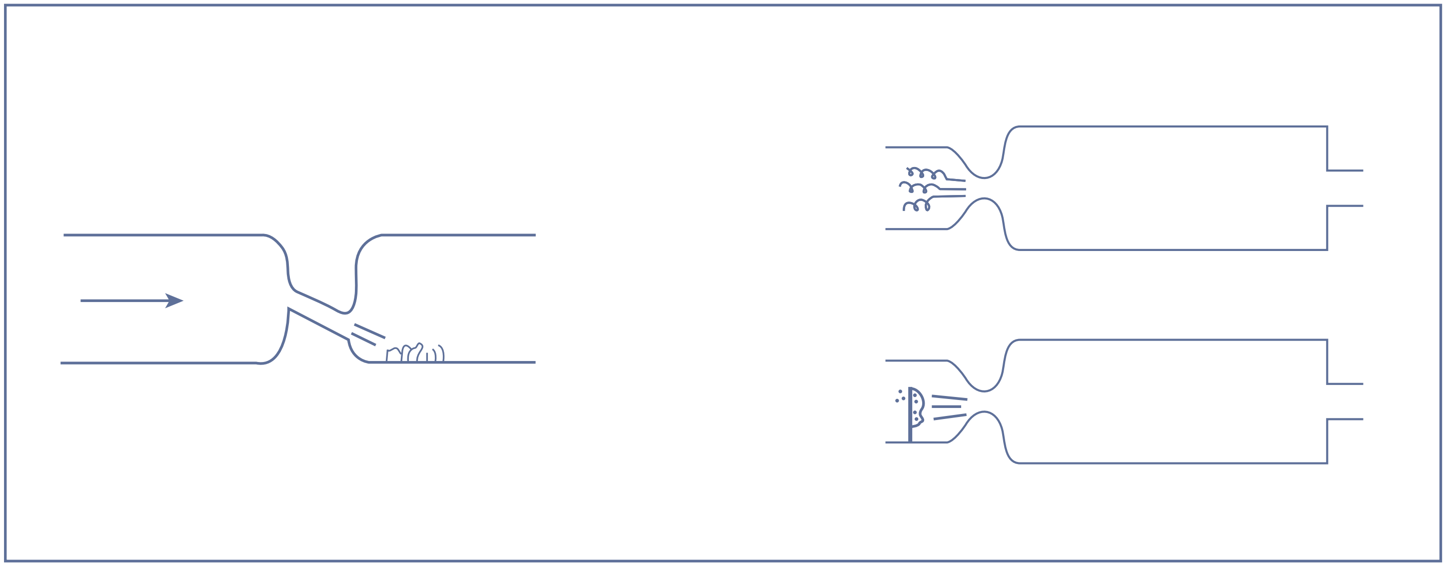


Image by MIT OCW.
Stevens, K. N. *Acoustics Phonetics*. Cambridge, MA: MIT Press, 1999.

Noise source

- Turbulence is also produced when an airstream strikes an obstacle (e.g. the teeth in [s]).
- The orientation of the obstacle to the direction of flow affects the amount of turbulence produced - the teeth are more or less perpendicular to the airflow in [s] and thus produce significant turbulence.
- The louder noise of strident fricatives is a result of downstream obstacles.



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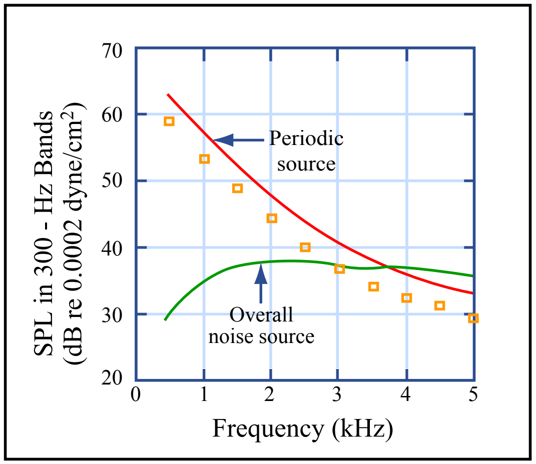
Stevens, K. N. *Acoustic Phonetics*. Cambridge, MA: MIT Press, 1999.

Filter characteristics

- The noise sources are filtered by the cavity in front of the constriction.
- In [h] the noise source is at the glottis, so the entire supralaryngeal vocal tract filters the source, just as in a vowel.
- So [h] has formants at the same frequency as a vowel with the same vocal tract shape, but the formants are excited by a noise source instead of voicing.
- The noise source generated at the glottis has lower intensity at low frequencies, so F1 generally has low intensity in [h].



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[h]

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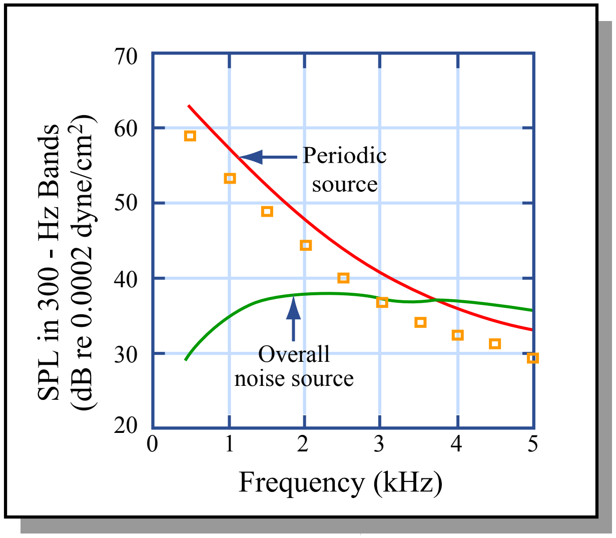

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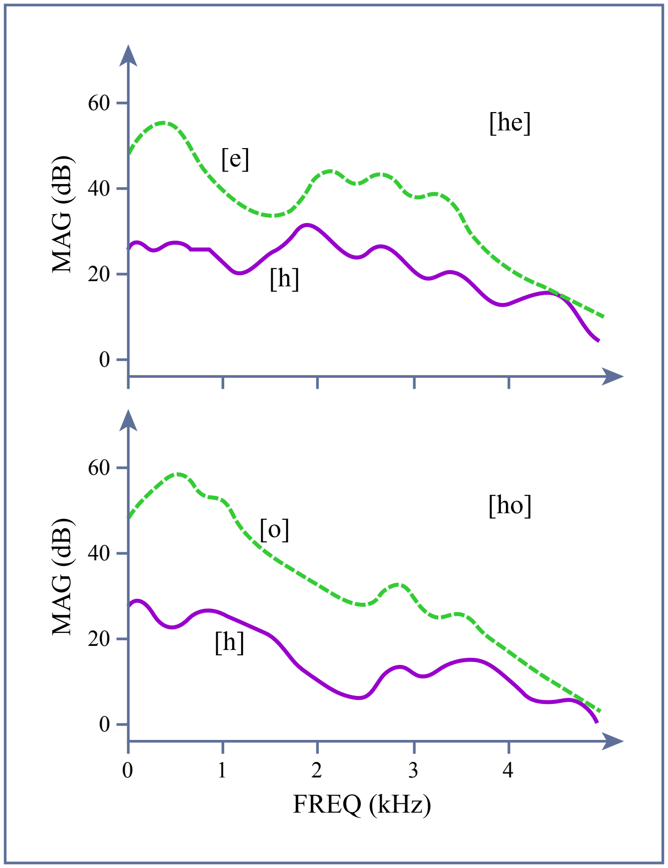


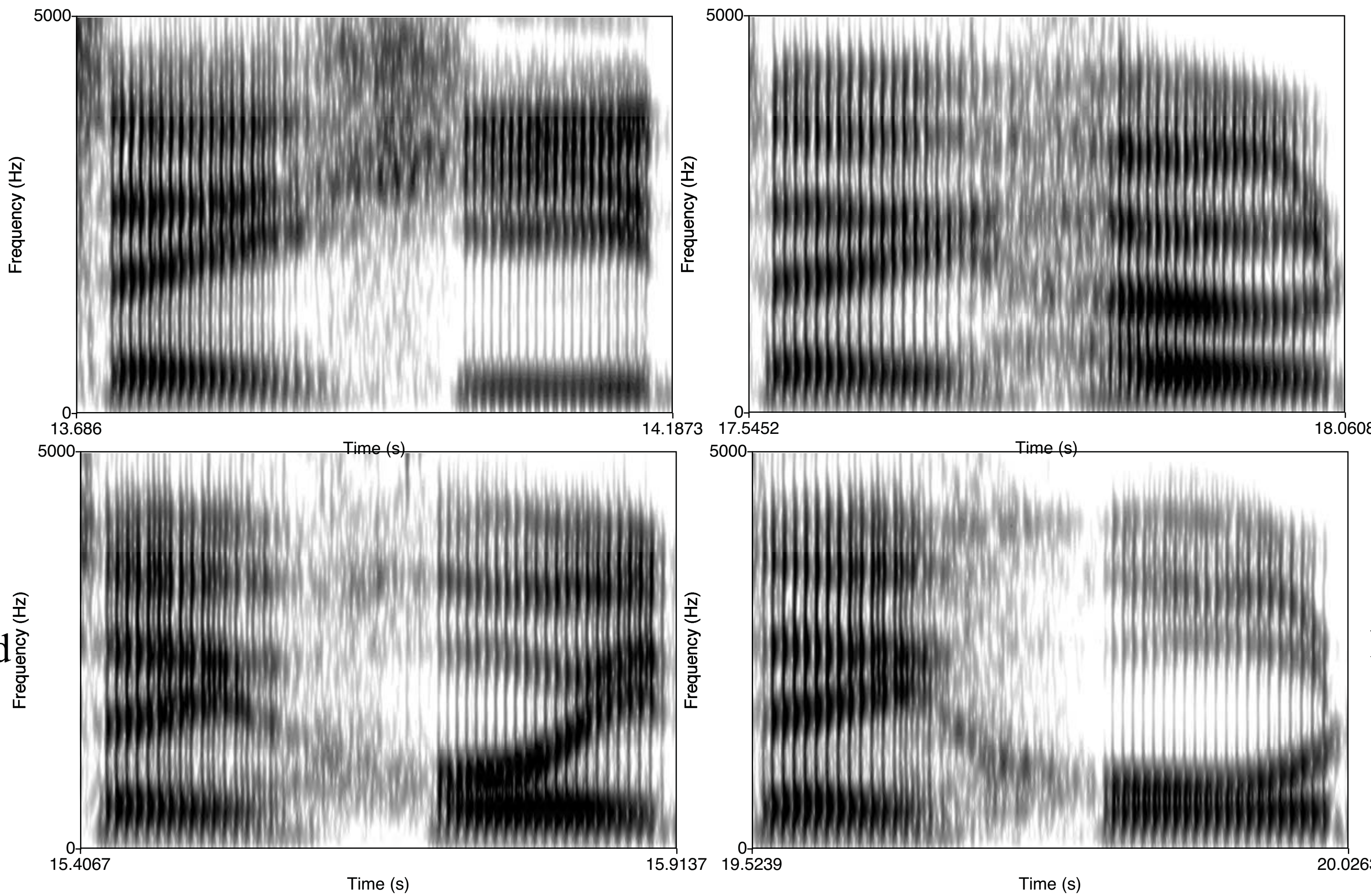
Image by MIT OCW.

Stevens, K. N. *Acoustic Phonetics*. Cambridge, MA: MIT Press, 1999.

[h]

heed

hoed

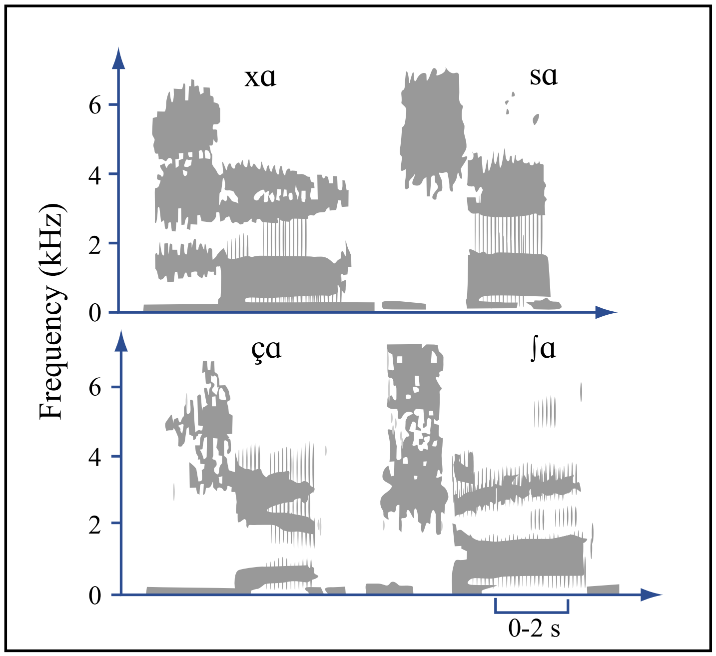


Hoyd

hoard

Filter characteristics

- As the place of articulation shifts forward, the cavity in front of the noise source is progressively smaller.
- A smaller cavity has higher resonances, so other things being equal, the concentration of energy in the fricative spectrum is higher the closer the place of articulation is to the lips.



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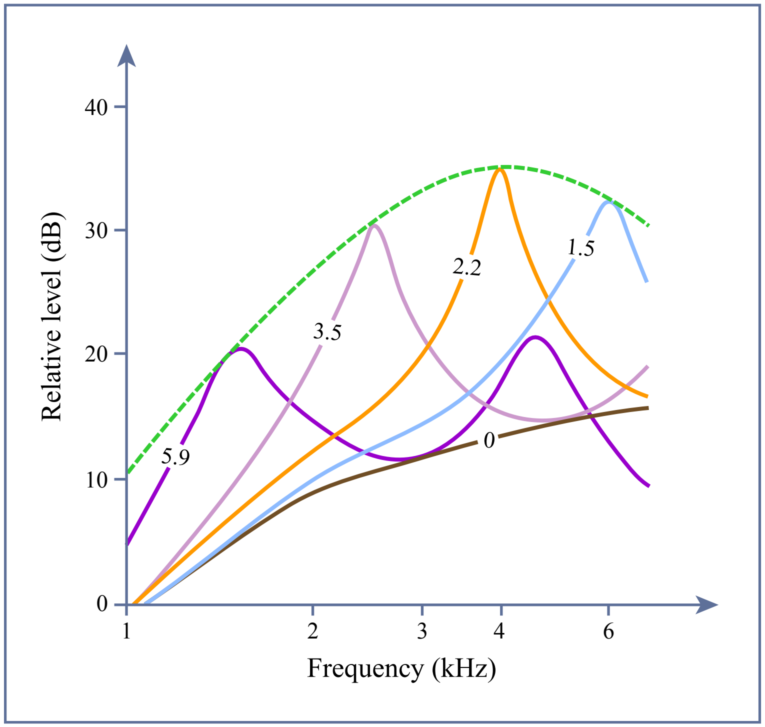
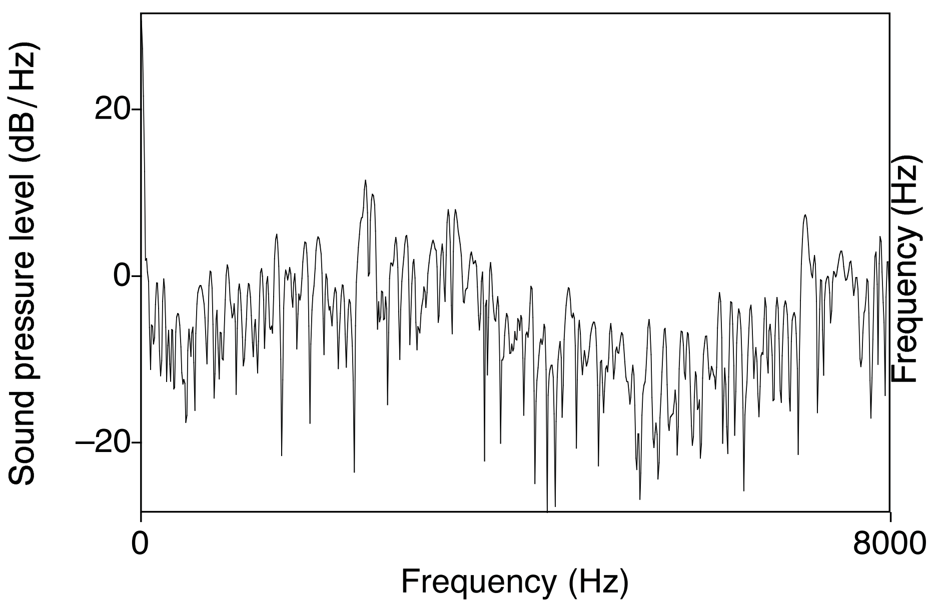
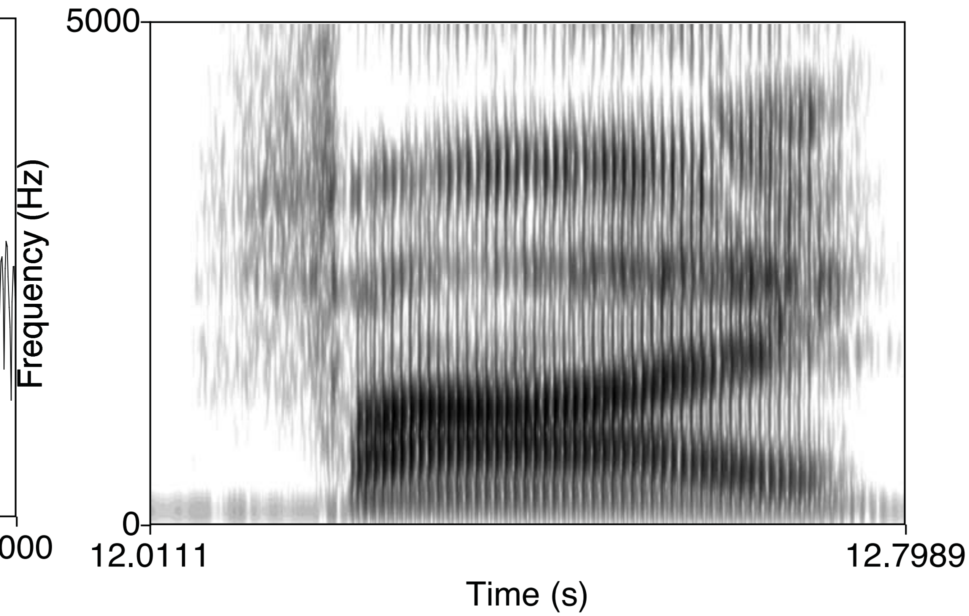


Image by MIT OCW.
Adapted from Stevens, K.N. "On the quantal nature of speech." Journal of Phonetics 17 (1989): 3-46.

Filter characteristics

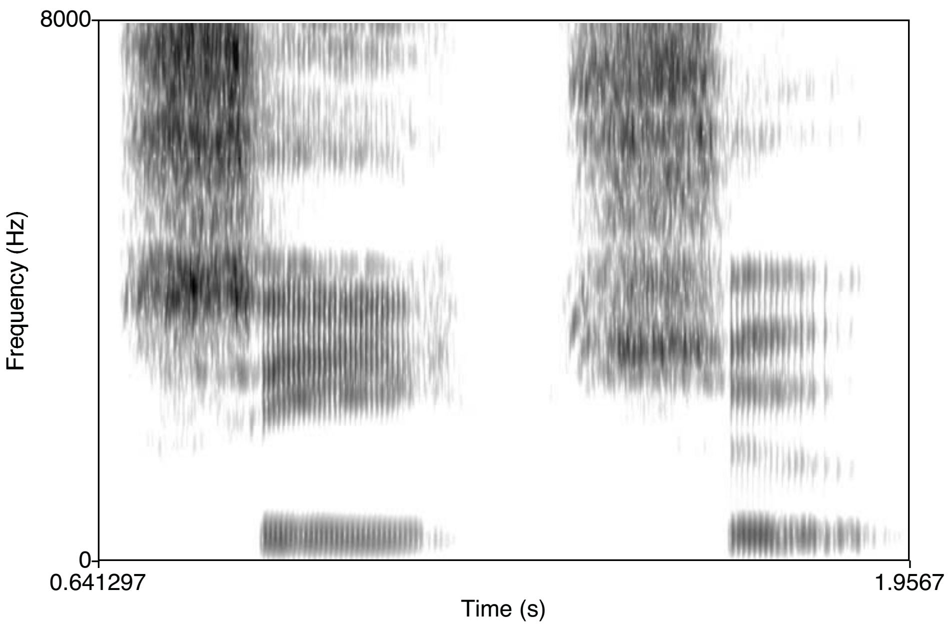
- The front cavity of a labial is so short (first resonance ~10 kHz) that it has little effect on the fricative spectrum, resulting in fricative noise spread over a wide range of frequencies with a broad low-frequency peak.
- This picture can be complicated by acoustic coupling with back cavity.



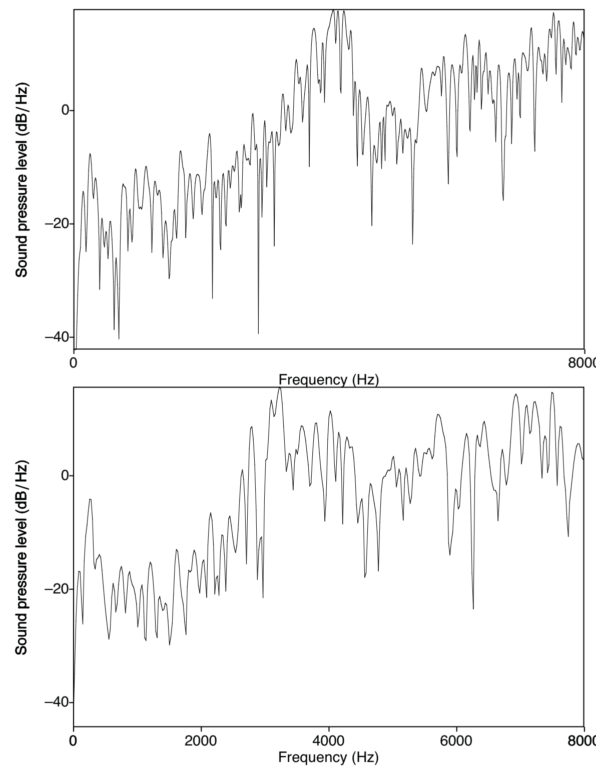


Filter characteristics

- Lip rounding lowers the resonant frequencies of the front cavity, just as in vowels.



si su

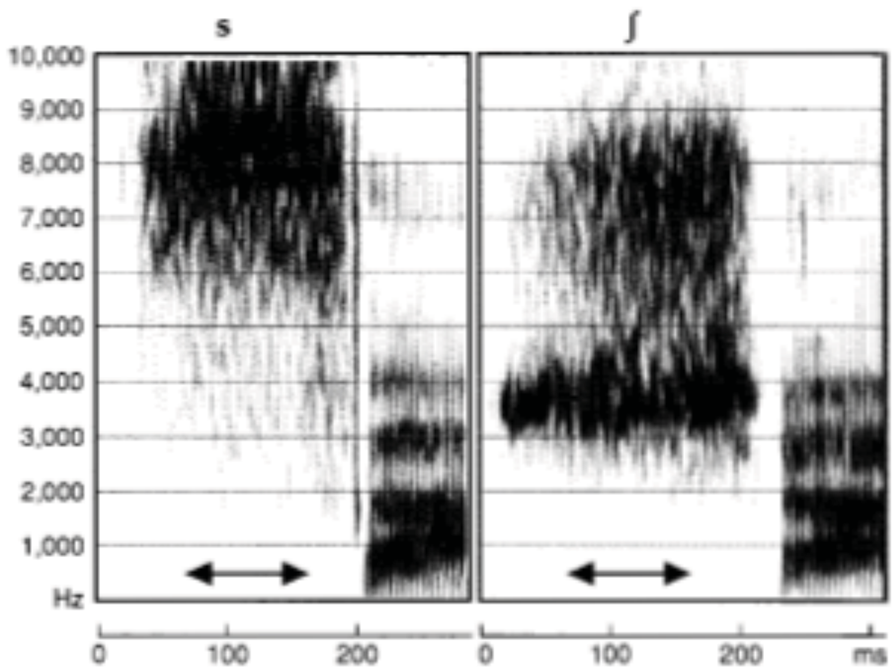


si

su

Filter characteristics

- In coronals, the presence or absence of a sublingual cavity has a significant effect on the size of the front cavity.



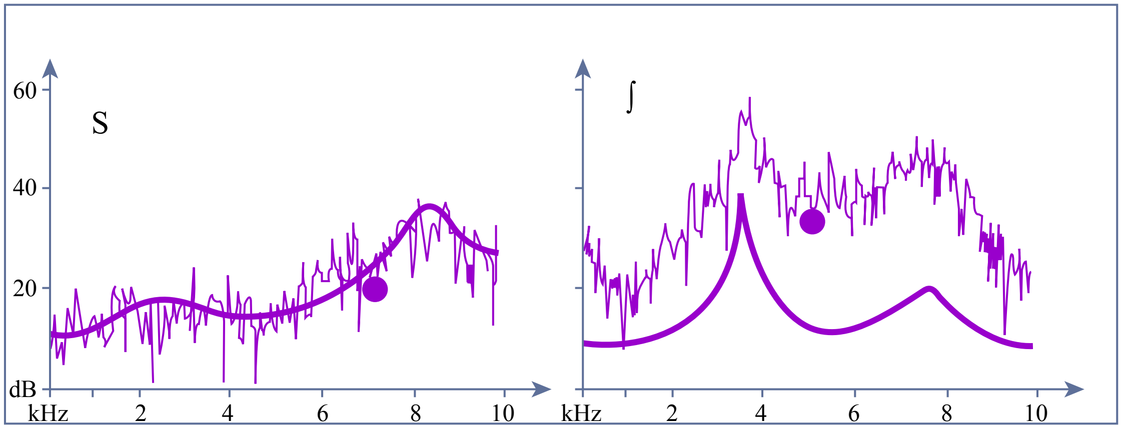
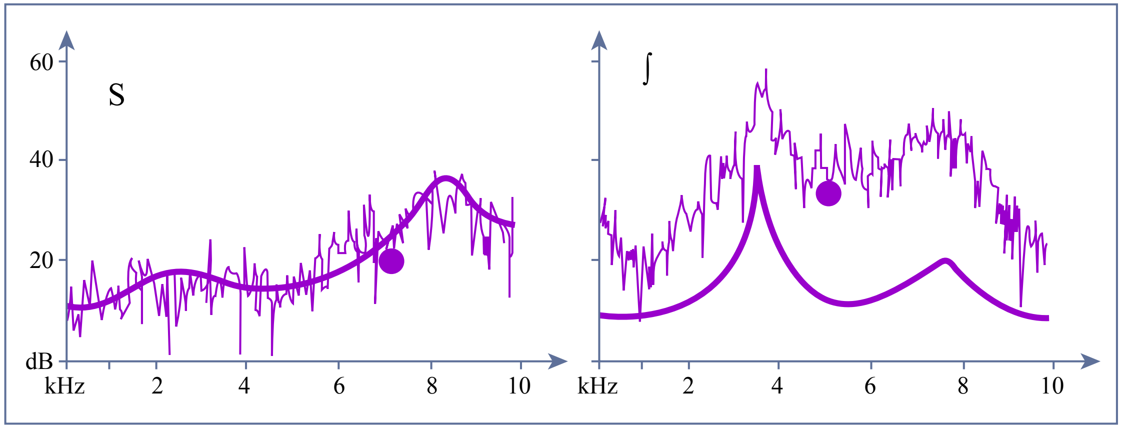


Image by MIT OCW.

Lip rounding/protrusion as an enhancement of sibilant contrasts

- Postalveolar fricatives in English and French are produced with lip-rounding/protrusion (Ladefoged & Maddieson 1996:148), as are retroflex fricatives in Polish (Puppel et al 1977:157).
- This realization can be analyzed as enhancing the perceptual distinctiveness of the contrast with sibilants with smaller front cavities (e.g. anterior sibilants)
  - English, French: [s], Polish [s̪, ɕ]
- [ʃ] has larger front cavity than [s] - [ʃ] has posterior constriction, sub-lingual cavity - and thus has lower spectral peaks.
- Lip rounding further lowers the resonant frequencies of the front cavity, increasing this difference.



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Source-filter analysis of stops

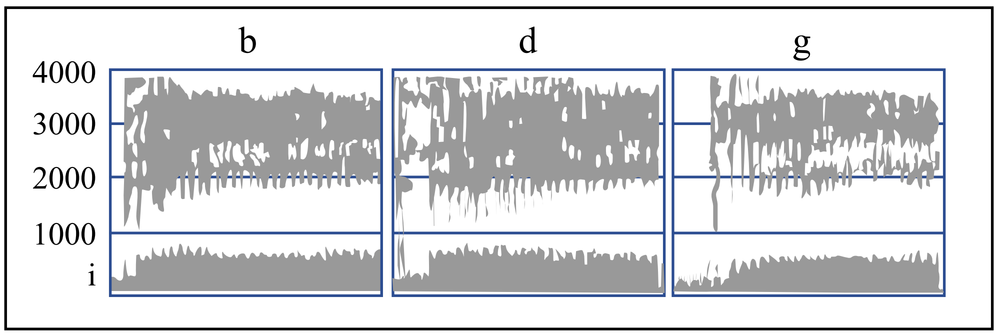
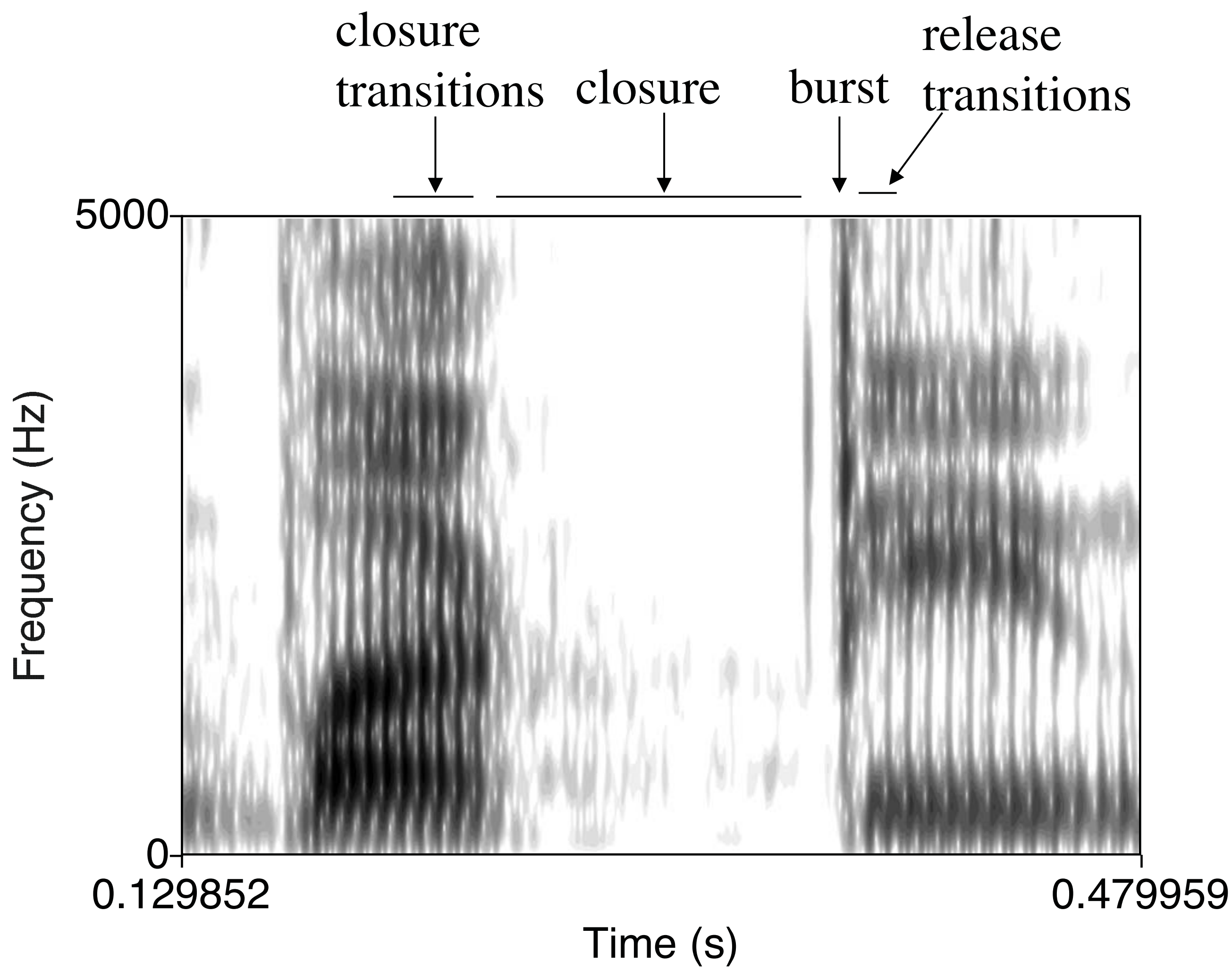


Image by MIT OCW.

Stops

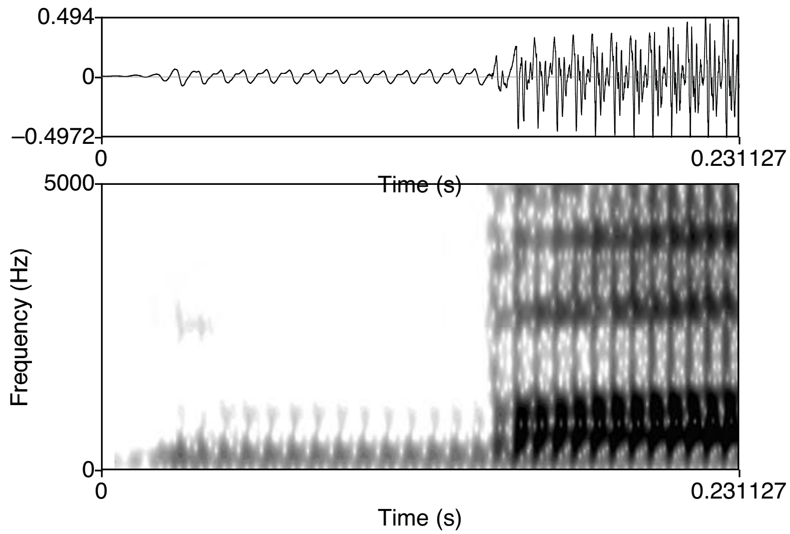
- Stops are complicated in that they involve a series of rapid changes in acoustic properties, but each component can be analyzed in similar terms to vowels and fricatives.
- A stop can consist of four phases: implosion (closure) transitions - closure - burst - release transitions

Components of a stop



Closure

- Only source of sound is voicing, propagated through the walls of the vocal tract.
- The walls of the vocal tract resonate at low frequencies, so mainly low-frequency sound is transmitted (‘voice bar’).



bal

Burst

- Consists of a transient, due to abrupt increase in pressure at release, followed by a short period of frication as air flows at high velocity through the narrow (but widening) constriction.
- Transient source is an impulse (flat spectrum) filtered by the front cavity.
- The frication is essentially the same as a fricative made at the same place of articulation.
- Alveolars have high frequency, high intensity bursts.
- Velar bursts are concentrated at the frequency of F2 and/or F3 at release.
- Labial bursts are of low intensity, with energy over a wide range of freqeuncies, with a broad, low-frequency peak.

Release transitions

- As the constriction becomes more open, frication ceases.
- The source at this time is at the glottis - either voicing or aspiration noise. This source excites the entire vocal tract as in a vowel (or [h]).
- The shape of the vocal tract, and thus the formants, during this phase are basically determined by the location of the stop constriction and the quality of adjacent vowels.
- The formants move rapidly as the articulators move from the position of the stop to the position for the vowel. The formant movements are usually called 'formant transitions'.

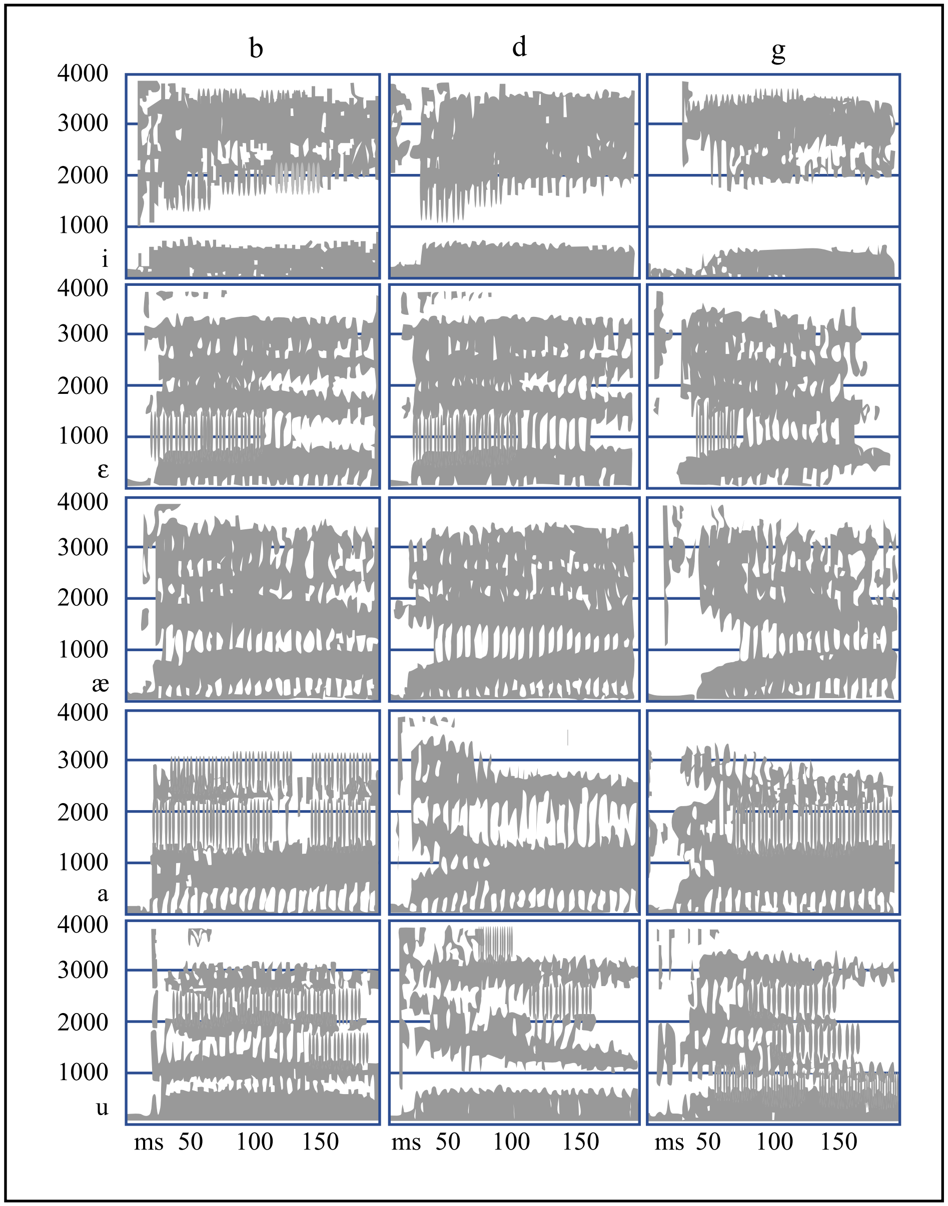


Image by MIT OCW.

Adapted from Ladefoged, Peter. *Phonetic Data Analysis*. Malden, MA: Blackwell, 2003.

Release transitions

- In alveolar stops the formant transitions due to release of the tongue tip constriction are probably very rapid (Manuel and Stevens 1995), so the observed formant transitions appear to be due to tongue body movements.
- The tongue body is generally relatively front to facilitate placement of the tongue tip//blade, thus there is a relatively high F2 at release (~1800-2000 Hz) and high F3.
- Labial stops involve a constriction at the lips. The tongue position is determined by adjacent vowels, so the exact formant frequencies at release depend on these vowel qualities.
- The labial constriction always lowers formants, so F2 and F3 are generally lower at release of a labial than in the following vowel.

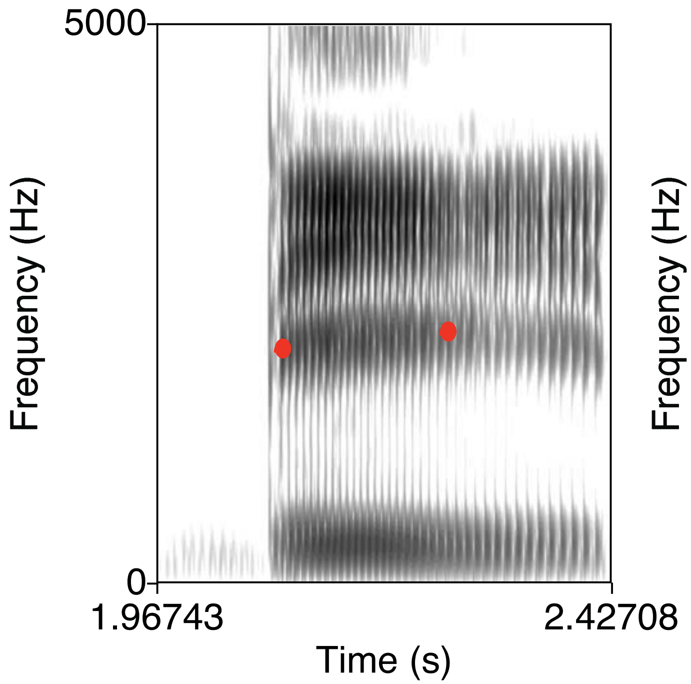
Release transitions

- Velar stops involve a dorsal constriction, but the exact location of this constriction depends on the neighbouring vowels.
- So the formant transitions of velars vary substantially, approximately tracking F2 of the adjacent vowel.
- F2 and F3 are often said to converge at velar closure. Under what conditions should this occur?
- Similar transitions are observed into and out of any consonant with a narrow constriction, e.g. fricatives, nasal stops.

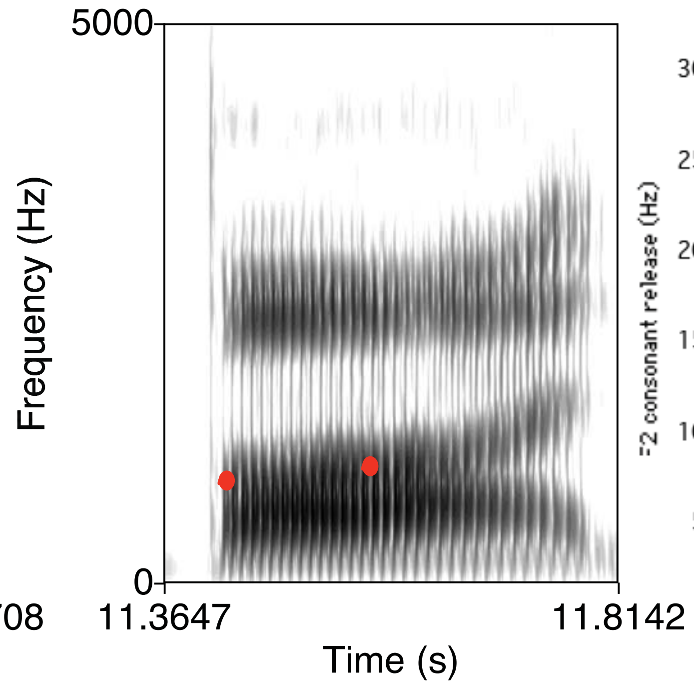
Locus equations

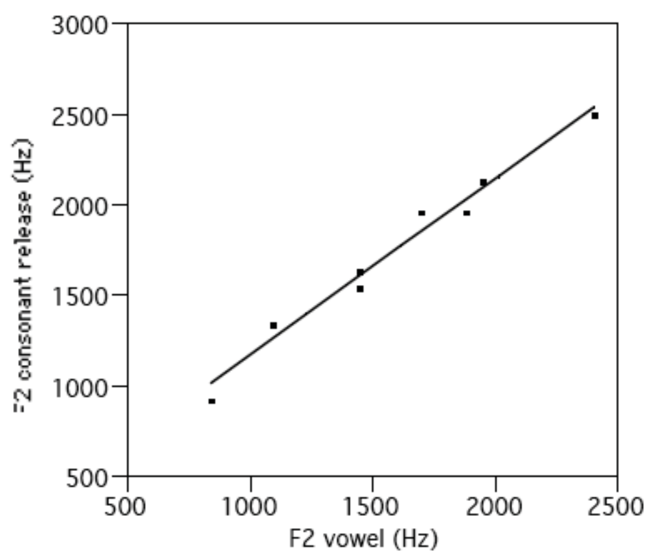
- Typically F2 at the release of a consonant is a linear function of F2 at the midpoint of the adjacent vowel (Lindblom 1963, Klatt 1987, etc).
- The slope and intercept of this function depend on the consonant.

bid



bɔd





Locus equations

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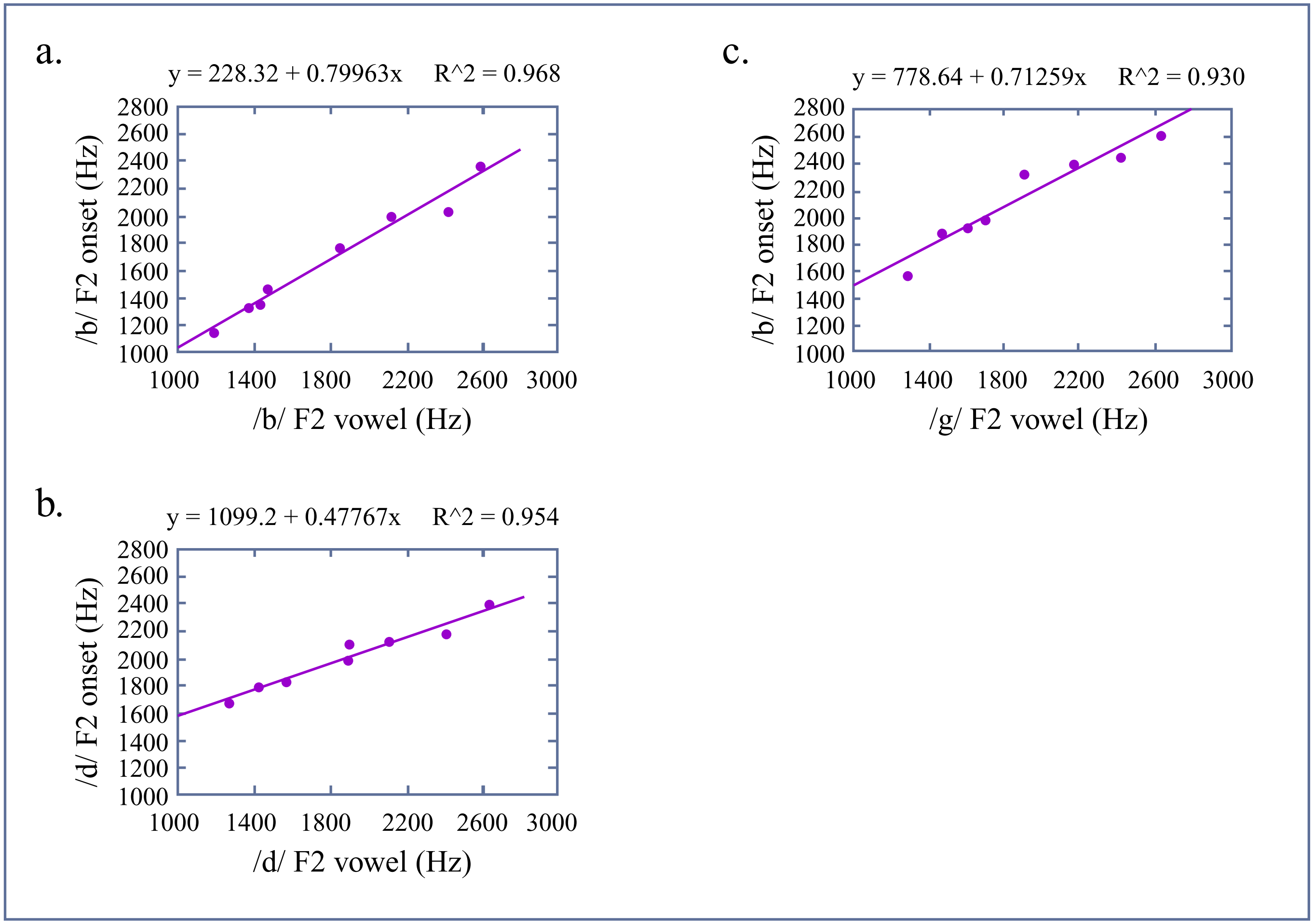

Fowler (1994)

Image by MIT OCW.

Adpated from Fowler, C. A. "Invariants, specifiers, cues: An investigation of locus equations as information for place of articulation." *Perception and Psychophysics* 55, no. 6 (1994): 597-610.

Affricates

- The frication portion of the release of the stop is prolonged to form a full-fledged fricative.
- The fricative portion of an affricate is distinguished from a regular fricative by its shorter duration, and perhaps by the rapid increase in intensity at its onset (short rise time).