L105/205 – Phonetics Handout 11
Scarborough Nov. 3, 2005

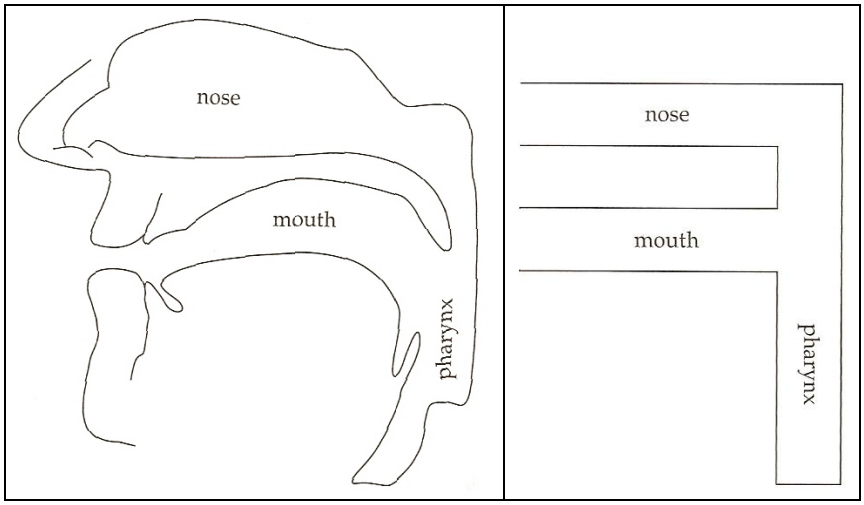
reading: Johnson Ch. 9 (today); Pickett Ch. 5 (Tues.)

Source-filter Analysis of Consonants:
Nasals and Laterals

1. Both nasals and laterals have voicing as their source. They differ from vowels, though, in that the vocal tract configuration that filters them is even more complex, with not only tubes that are coupled with one another end to end, but also with tubes that branch.

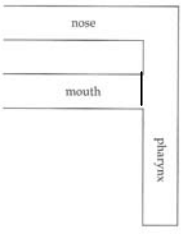
Nasals

2. In nasal consonants (and vowels), the velum is lowered so that the pathway from the pharynx to the nasal passages is open. Air can flow from the lungs out through the nostrils.
   - In nasal obstruents, the mouth cavity is closed off by a complete constriction in the vocal tract (e.g., at the lips, the alveolar ridge, the velum, etc.).
   - In nasal or nasalized vowels, both the mouth and the nasal cavities open to the outside.



(from Johnson, 2003)

3. A uvular nasal [ɴ] can be modeled as a tube closed at the glottis and open at the nostrils. (The oral cavity is blocked off by the closure produced by the velum and the tongue dorsum.)

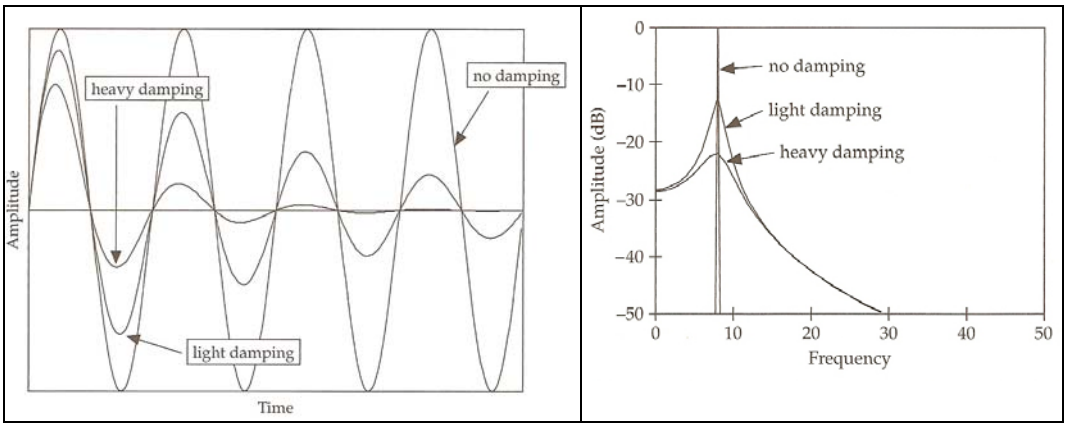


glottis to uvula: 9cm + uvula to nares: 12.5cm = 21.5cm tube

F1 = c/4L = 35,000/(4*21.5) = 407 Hz
F2 = 3c/4L = 1221 Hz
F3 = 5c/4L = 2035 Hz

- Note the resonances are lower in frequency and closer together (about 800Hz apart) than in a neutral vowel.

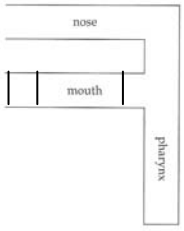
- The resonances are also weaker (i.e., the peaks are lower in amplitude).
  - The walls of the vocal tract are soft and absorb some of the sound energy produced by the glottis. Thus, sound waves are slightly <u>damped</u>. The greater the vocal tract surface area, the greater the damping. (So waves are more damped in the longer pharynx + nasal tube.)



(from Johnson, 2003)

    - Damping also increases spectral bandwidth. Since the energy in the wave is distributed over a wider range of frequency components, the spectral peak is also lower in amplitude.
  - The nasal passages actually also have small side cavities like sinuses, further increasing the surface area.
  - The nasal passages are constricted, both at the opening to the nasal cavity and at the opening to the outside. So less sound can reach the outside.

4. Nasal consonants made with an oral constriction further forward than the uvula add a side cavity (namely, the oral cavity) onto the pharyngeal-nasal tube.
   - The further front the constriction, the longer the side cavity.



5. The side cavity is a tube open at one end. But the cavity is not open to the atmosphere (i.e., at the mouth end), so the resonating frequency components are not transmitted out of the vocal tract. Rather, they are "absorbed" by the side cavity.
   - These frequencies are <u>anti-resonances</u> or anti-formants (sometimes called zeros). These frequencies are cancelled, so they show up in the spectrum as valleys rather than peaks.

     e.g., F1' = c/4L = 35,000/(4*8) = 1100 Hz The mouth cavity in [m] is about 8cm.
     F2' = 3c/4L = 3300 Hz

Nasal/nasalized vowels

6. Nasalized vowels have two resonant systems operating at once: the pharynx + mouth cavity and the nasal cavity.
   - The coupled nasal cavity contributes both formants and anti-formants (since it is nearly closed, relative to the much larger opening of the oral cavity), which combine with the formants of the oral tract.
   - The frequencies of these components depend on the position of the lips and tongue (for the formants) and the size of the velo-pharyngeal port – i.e., the degree of nasality (for the anti-formants)

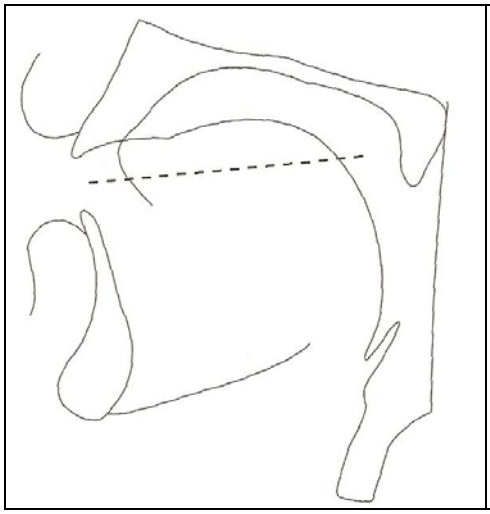
     The anti-formant frequency gets higher as the degree of nasality increases, so as nasality increases, it is more likely to interfere with the oral F1, reducing its amplitude or even canceling it.

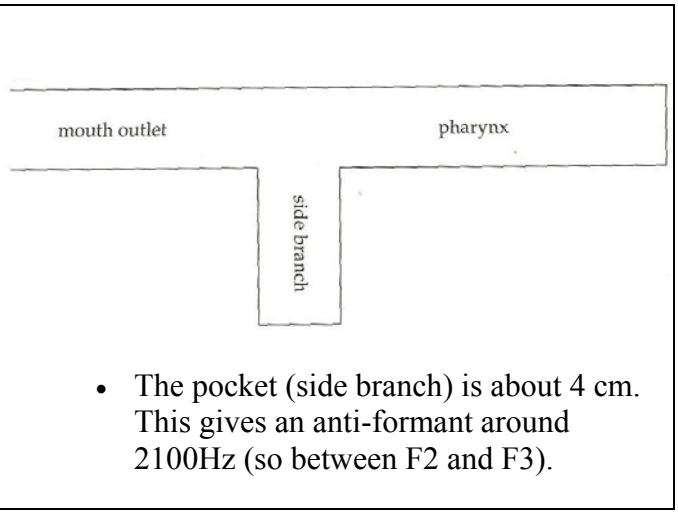
     (All the nasal formants are also lowered by the constriction at the nares.)

   - Due to all of these interacting formants and anti-formants, the acoustic consequences for nasal vowels are much more difficult to model and predict than for oral vowels.

Laterals

7. Laterals, like nasals, laterals have a side cavity that introduces an anti-formant in the output spectrum.
   - The side cavity is the pocket of air on top of the tongue. The main cavity curves around one or both sides of the tongue.





- The pocket (side branch) is about 4 cm. This gives an anti-formant around 2100Hz (so between F2 and F3).

(from Johnson, 2003)

Laterals look somewhat like nasals in a spectrogram, too. Formants are broader and lighter. But the formants are further apart than they would be for a nasal.

1. Summary of acoustic characteristics of consonants

Voicing

voiced	pulses from vocal cord vibration; energy in voicing bar
voiceless	noise only (glottal or supraglottal) or silence

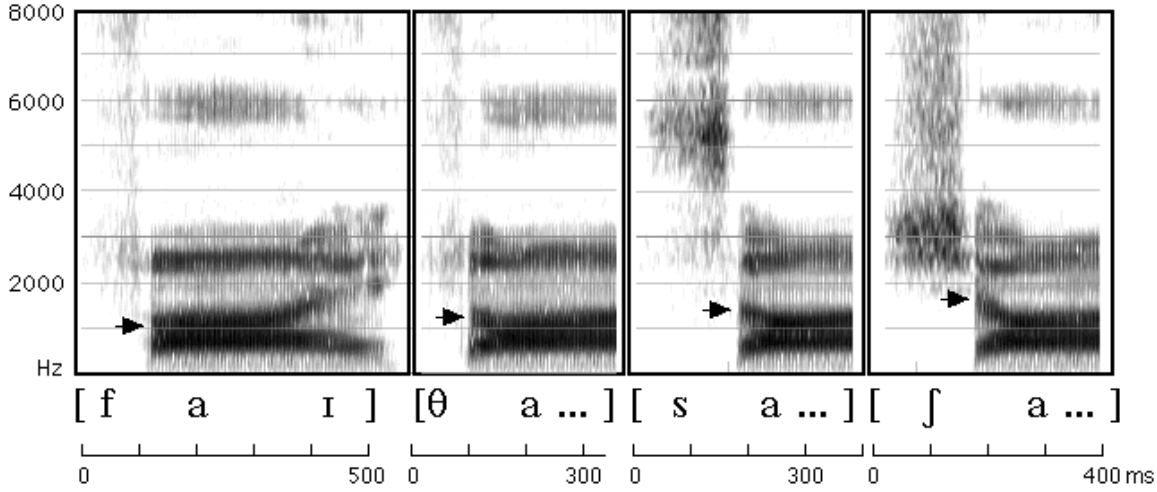
Manner of articulation

stops	voiceless:	silent closure; strong release burst; if aspirated, formants may be seen in noise; generally shorter closure than voiced
	voiced:	possible voice bar during closure; weaker release burst; no aspiration
fricatives	voiceless:	noise only; sibilants much stronger; generally longer than voiced
	voiced:	voiced formant structure plus weaker noise above formants; non-sibilants may have no noise at all (approximants)
nasals		strong resonance about 200-400Hz; anti-formant around/above F2 (so F2 may not be visible); often discontinuity between nasal and adjacent vowel; nasalized vowels show F2 with low amplitude and wide bandwidth
liquids		vowel-like formant sturcuture with special F3: /r/ has a lowered F3 /l/ has raised F3 and weak F2 velarized (dark) /l/ has high but weak F3 and low F2
glides		look like the corresponding vowels, but with lower F1 (due to greater constriction) and more gradual formant transitions: /w/ has a low F2 and weak F3 /j/ has high F2 and strong F3

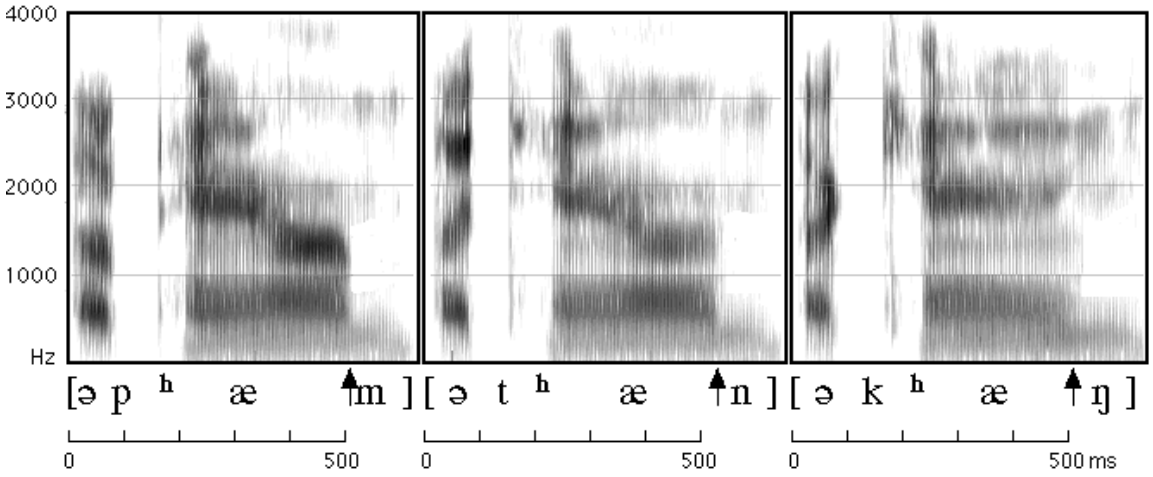
Place of articulation

labial	lack of a front cavity filter means output looks like source: weak, diffuse spectrum with stronger low frequencies; constriction at lips lowers all frequencies
coronal	small front cavity means high frequencies (anterior higher than non-anterior); stop burst is strongest at high frequencies (F4 or above); bursts are generally intense; locus of F2 near 1800Hz
velar	F2 and F3 similar in frequency, so transitions converge (“velar pinch”); often have a double burst

2. Sample spectrograms of American English consonants (from Ladefoged, 2001)
   - voiceless fricatives (showing formant transitions)



   - nasals and voiceless stops (showing formant transitions for both)



   - liquids and glides