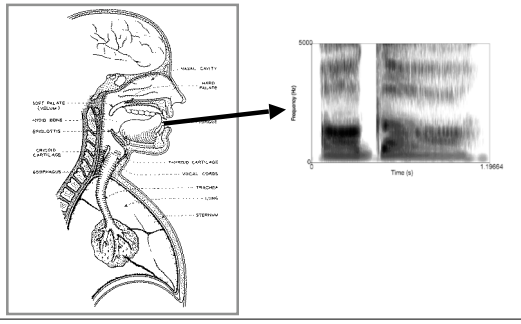
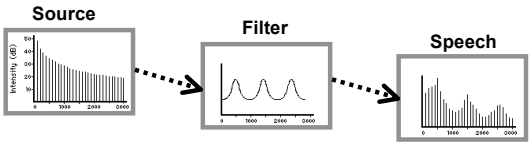
The Acoustics of Speech Production: Consonants



Source-Filter Theory of Speech Production



Speech production can be divided into two independent parts

- Sources of sound (i.e., signals) such as the larynx
- Filters that modify the source (i.e., systems) such as the vocal tract

Consonants

All three sources are used

- Frication
- Aspiration
- Voicing

Articulations change resonances of the vocal tract

- Resonances of the vocal tract are called *formants*
- Moving the tongue, lips and jaw change the shape of the vocal tract
- Changing the shape of the vocal tract changes the *formant frequencies*

Consonants are created by coordinating changes in the sources with changes in the filter (i.e., formant frequencies)

Consonants Vs. Vowels

Vowels	Consonants
• Slow changes in articulators	• Rapid changes in articulators
• Produced by with a relatively open vocal tract	• Produced by making constrictions in the vocal tract
• Only the voicing source is used	• Coordination of all three sources (frication, aspiration, voicing)

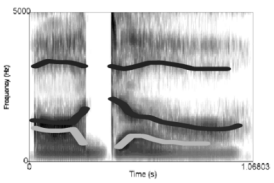
Formant Frequencies

The First Formant (F1)

- Affected by the size of the constriction
- Cue for manner
- Unrelated to place

The second and third formants (F2 and F3)

- Affected by place of articulation



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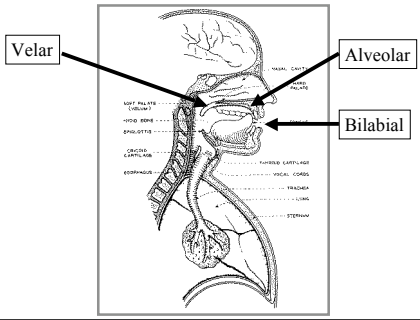
Place of Articulation



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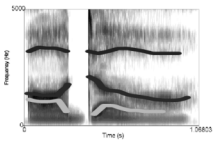

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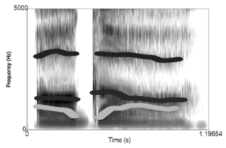

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Place of Articulation

Bilabials (e.g., /b/, /p/, /m/) -- Low Frequencies

- Lower F2
- Lower F3

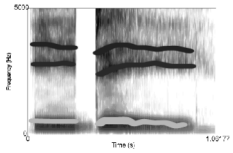
Alveolars (e.g., /d/, /n/, /s/) -- High Frequencies

- Higher F2
- Higher F3

Velars (e.g., /g/, /k/) -- Middle Frequencies

- Higher F2
- Lower F3

Place of Articulation Vs. Different Vowels



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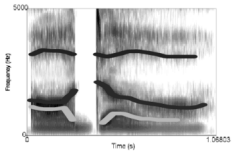

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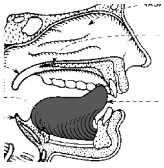
Stops (e.g., /b/,/p/,/d/,/t/,/k/,/g/)

Step 1: Complete closure of the vocal tract

- Blocks flow of air through the oral cavity
  - Impedes vocal fold vibration
- Flesh absorbs most of the sound that the vocal folds manage to produce
- During voiced stops, only a **voice bar** can be produced during the closure



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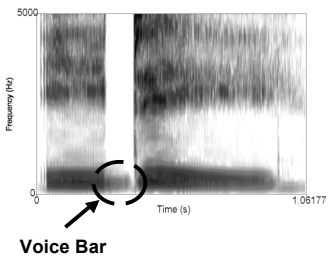

Stops (e.g., /b/,/p/,/d/,/t/,/k/,/g/)

Step 2: Release of the closure

- Air rushes out through opening
- When only partially open, frication energy (I.e., noise due to turbulence) is produced.
  - Seen as a ***burst*** on a spectrogram

Stops (e.g., /b/,/p/,/d/,/t/,/k/,/g/)

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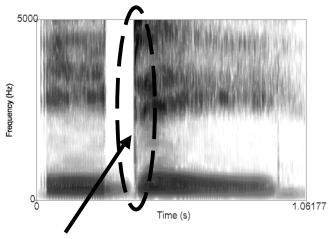

Burst

Stops (e.g., /b/,/p/,/d/,/t/,/k/,/g/)

Step 3: Onset of voicing

- Air pressure is released, so vocal folds can vibrate again
- Articulators move into position for next phoneme
  - Movement of transitions change resonant frequencies, which are seen as ***formant transitions***

Stops (e.g., /b/,/p/,/d/,/t/,/k/,/g/)

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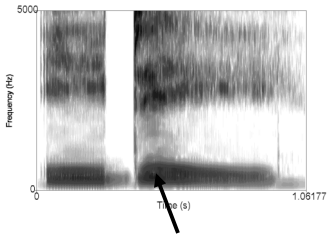

Voicing

Stop Consonant Voicing

Voiced Consonants	**Unvoiced Consonants**
• Voicing starts less than about 30 ms after release	• Voicing starts more than about 50 ms after release

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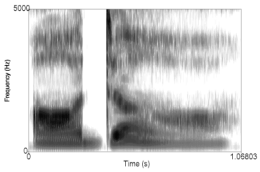
• Voicing can occur during closure	• Voicing cannot occur during closure

Stop Consonant Voicing



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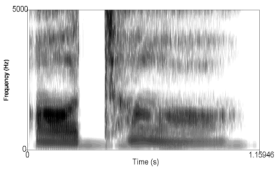

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Stop Consonant Voicing

Voiced Consonants

- Voicing starts less than about 30 ms after release
- Voicing can occur during closure

Unvoiced Consonants

- Voicing starts more than about 50 ms after release
- Voicing cannot occur during closure

Duration between release (i.e. burst) and start of voicing is called *Voice Onset Time* (VOT).

Nasals (e.g., /m/, /n/)

Similar to voiced stops, except air also flows through nasal cavity

- Uvula flap controls airflow through nasal cavity
- Airflow allows voicing to continue during closure

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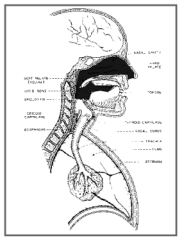

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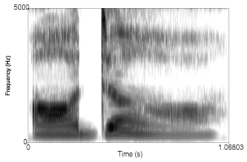
Resonances of the oral and nasal cavities interact

- Hard to see on spectrograms

Nasals (e.g., /m/, /n/)



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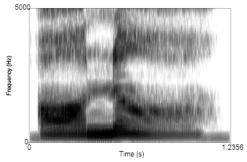

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Fricatives (e.g., /s/,/z/,/f/,/v/)

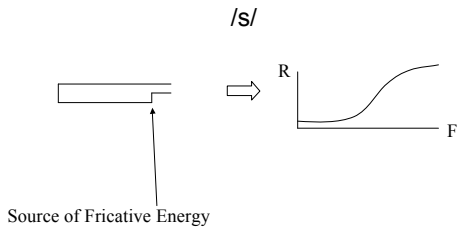
Created by forcing air through a small constriction

- Noise is produced due to *turbulence*

Filtering of the vocal tract depends on where the fricative is produced

- Fricatives produced toward the mouth have a flatter frequency response than those produced further back
- Fricatives produced toward the mouth have a higher center frequency than those produced further back

Acoustic tube models of fricatives



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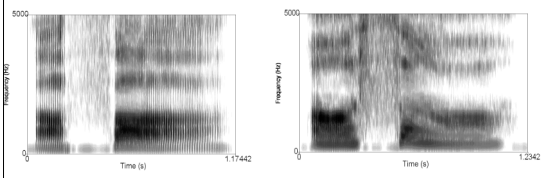

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Voiced Fricatives (e.g., /z/,/v/)

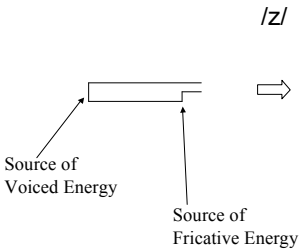
Vocal folds can vibrate at the same time that fricative energy is produced

- Creates a voice bar during the fricative

Vocal fold vibration reduces airflow

- Reduces the amplitude of the fricative energy

Acoustic tube models of voiced fricatives



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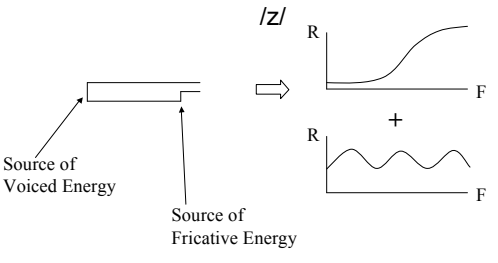
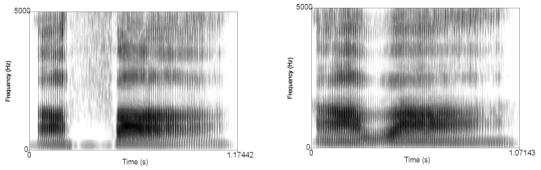


Voiced Vs. Voiceless Fricatives



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Acoustics of Fricatives

- Frequency
  - Front of vocal tract - higher frequencies because of shorter tube
  - Back of vocal tract - lower frequencies because of longer tube
- Bandwidth
  - Front of vocal tract - broader bandwidth
  - Back of vocal tract - more formant structure

Acoustics of bursts in stop consonants

- Burst - just a short fricative
  - Acoustics of burst can be explained just like fricatives
  - /b/-/p/: broad burst
  - /d/-/t/: high-frequency burst
  - /g/-/k/: mid-frequency burst

Approximants (e.g., /l/,/w/,/r/)

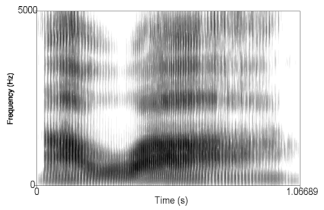
More open constriction than for fricatives

- Free flow of air produces no turbulence
- Voicing continues during consonant

Similar to vowels

- Approximants have lower F1 than for vowels
- Approximants tend to have more formant movement than vowels

Approximants



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Summary

Consonants involve rapid changes in the sources and the filter.

Place of articulation affects F2 and F3

Stops, Fricatives, and Approximants differ in the degree of constriction of the vocal cavity

Voiced and Voiceless consonants differ in the timing of articulations and the vibration of the vocal folds