

# **Introduction to the Acoustics of the Human Voice**

MUSC 2350: Acoustics and Psychoacoustics of Music

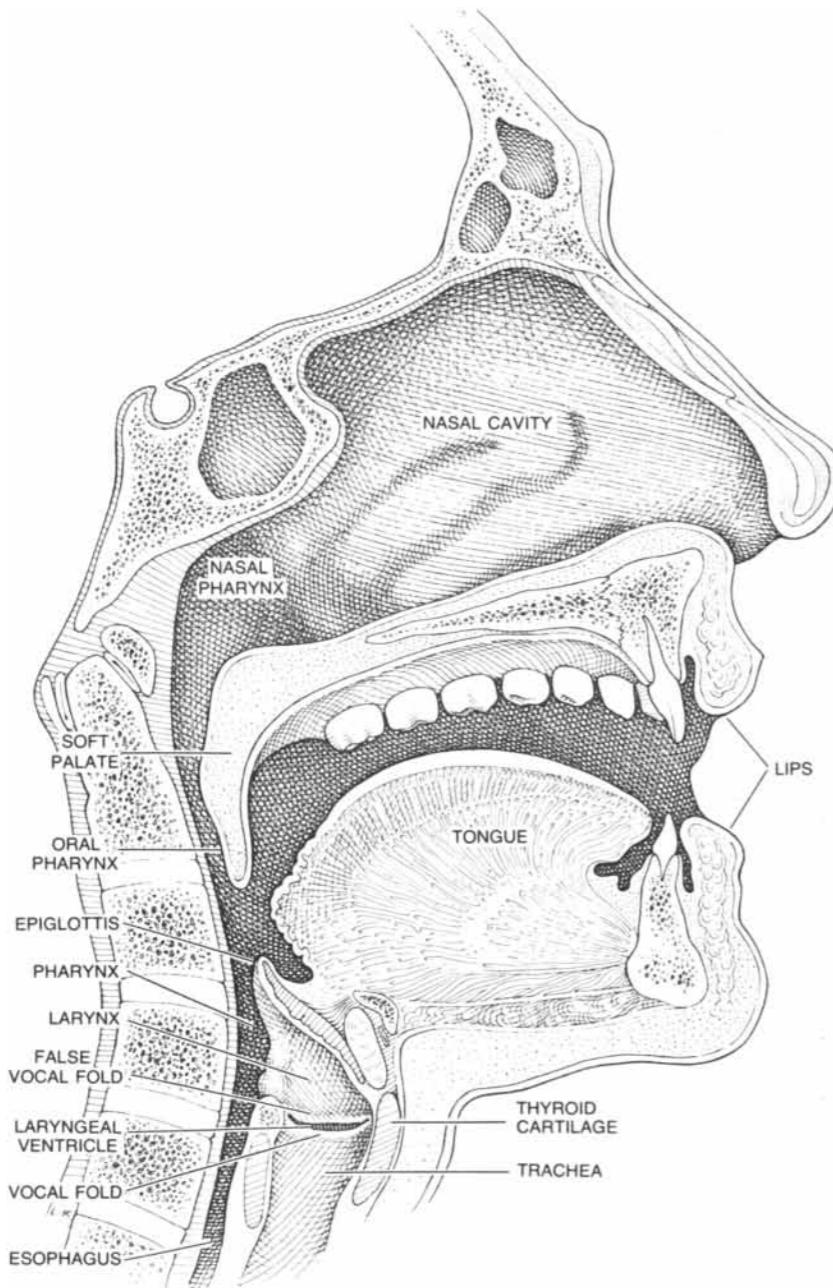
# **Class Outline**

- ▶ **Vocal Physiology**
- ▶ **Source-Filter Model**
- ▶ **Speech Sounds**
- ▶ **Singing**

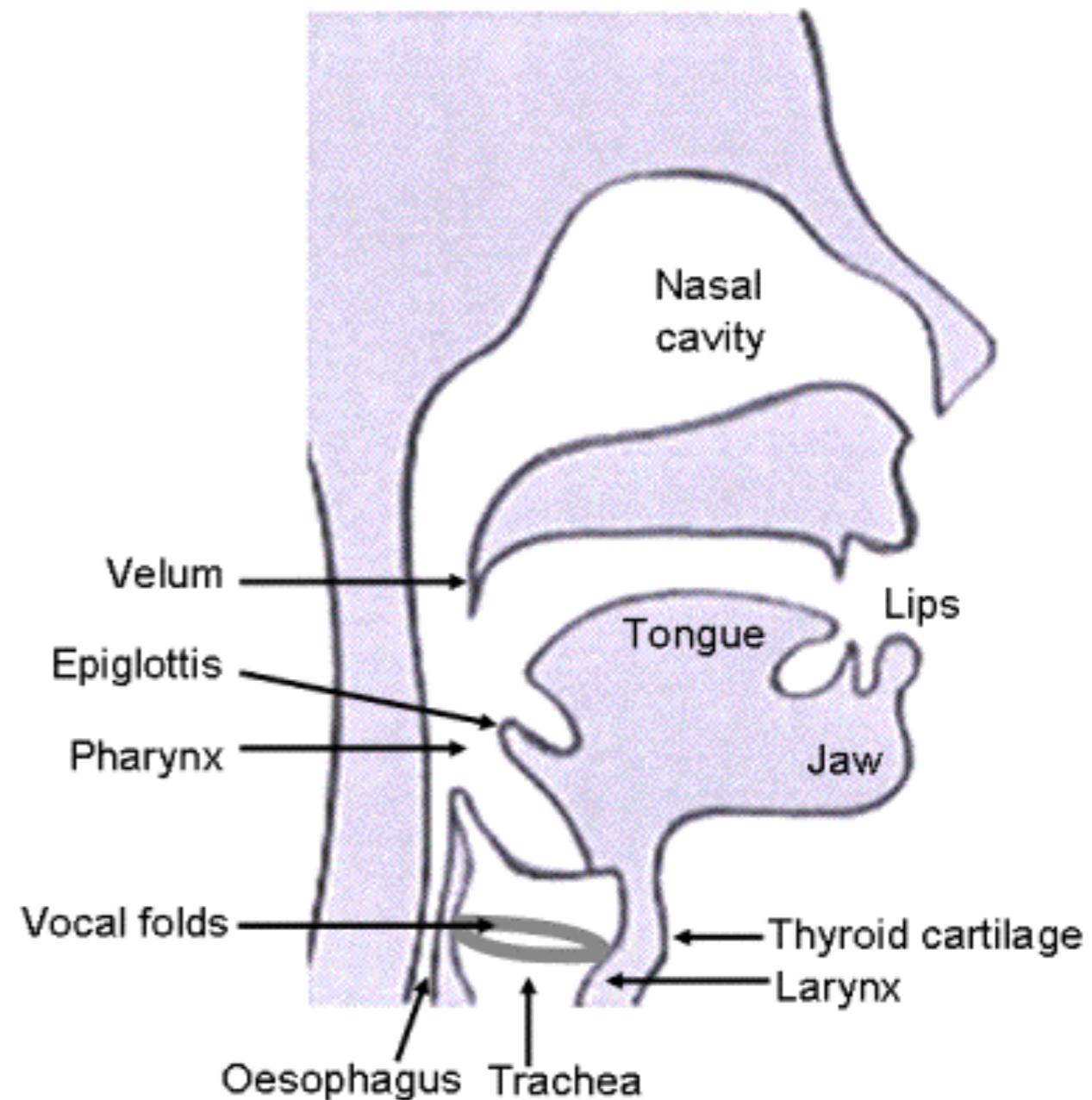
# Vocal Physiology

# Vocal Physiology

Vocal tract: Larynx, pharynx, and mouth



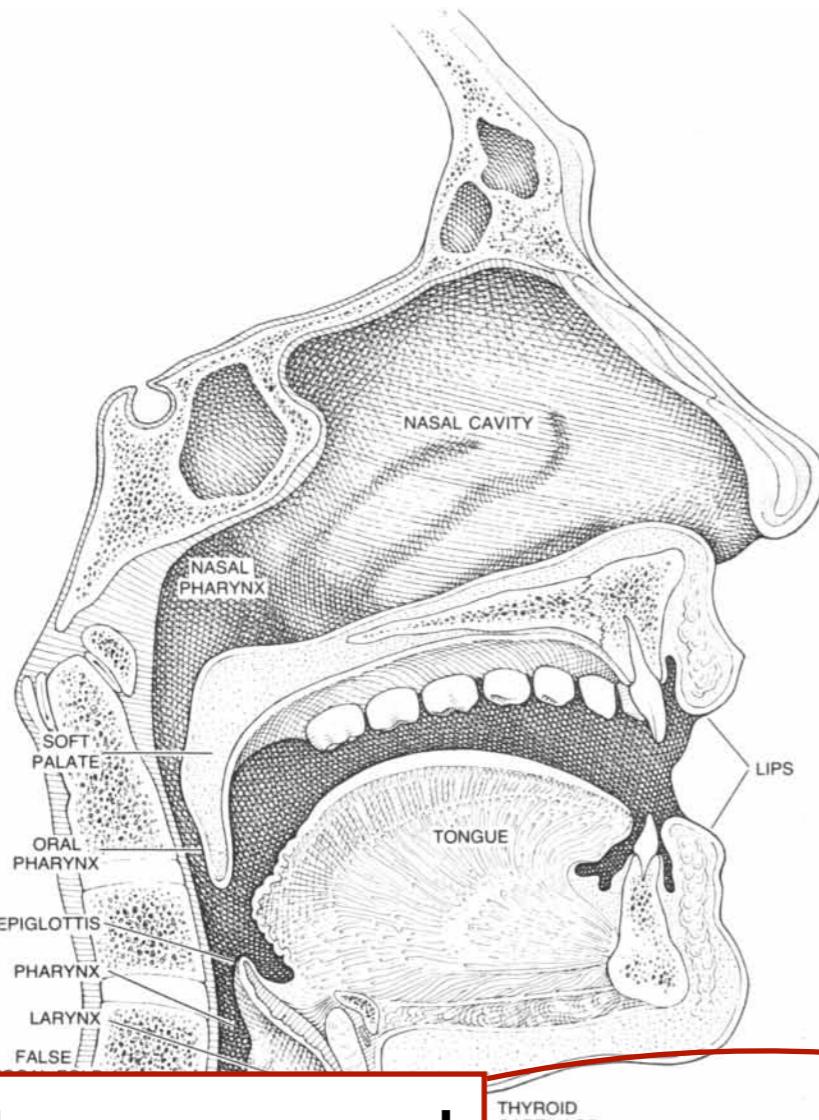
Sundberg (1977)



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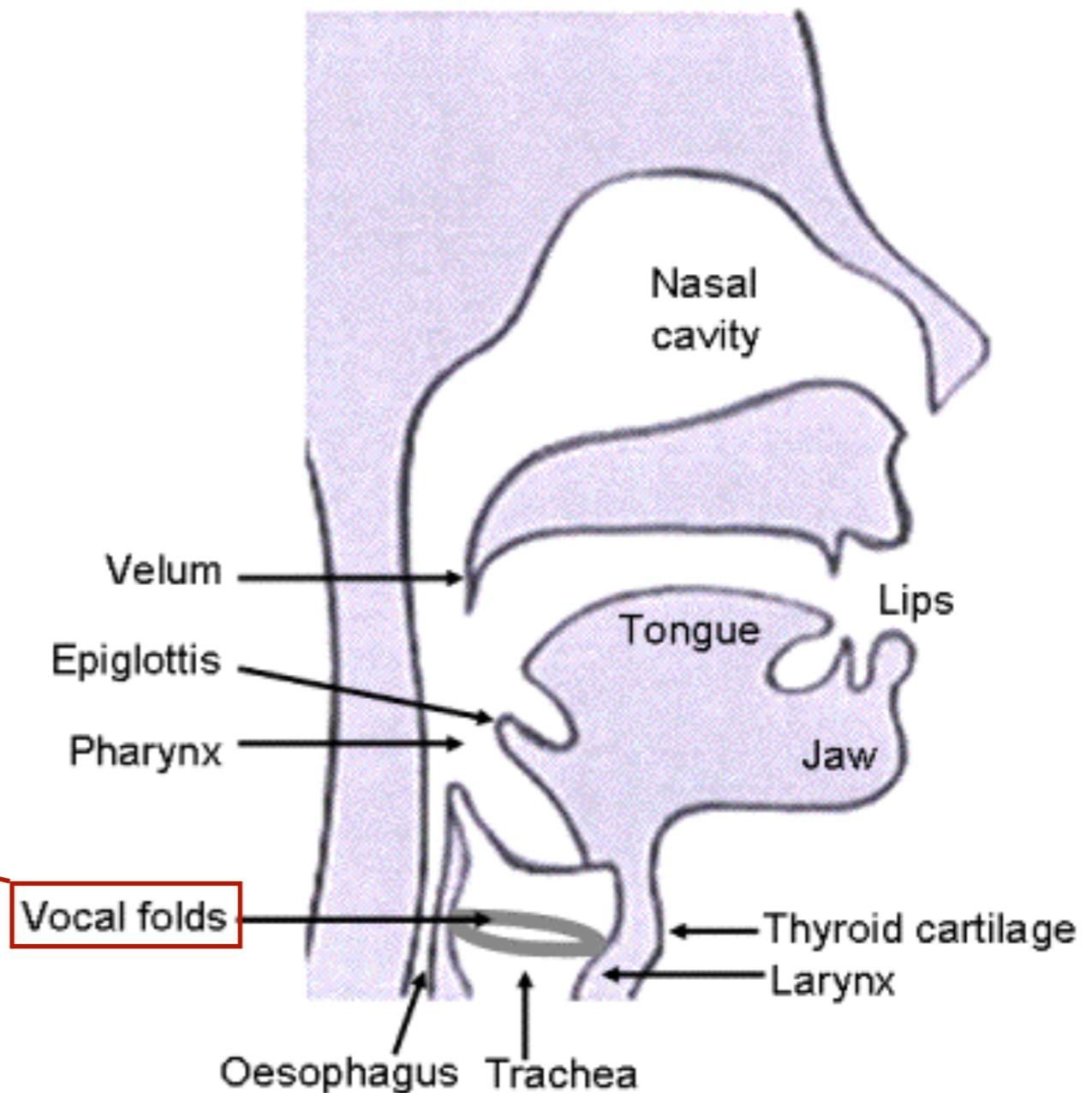
# Vocal Physiology

Vocal tract: Larynx, pharynx, and mouth



Produce sound  
Protect airways

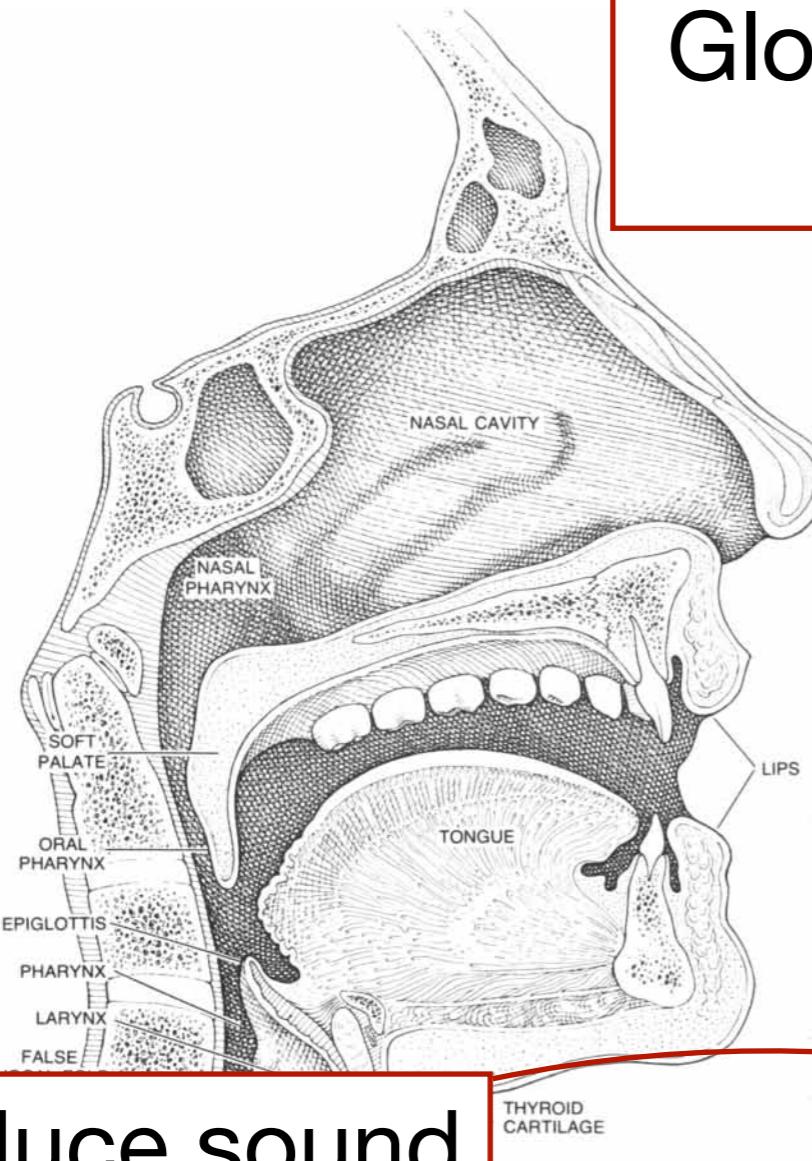
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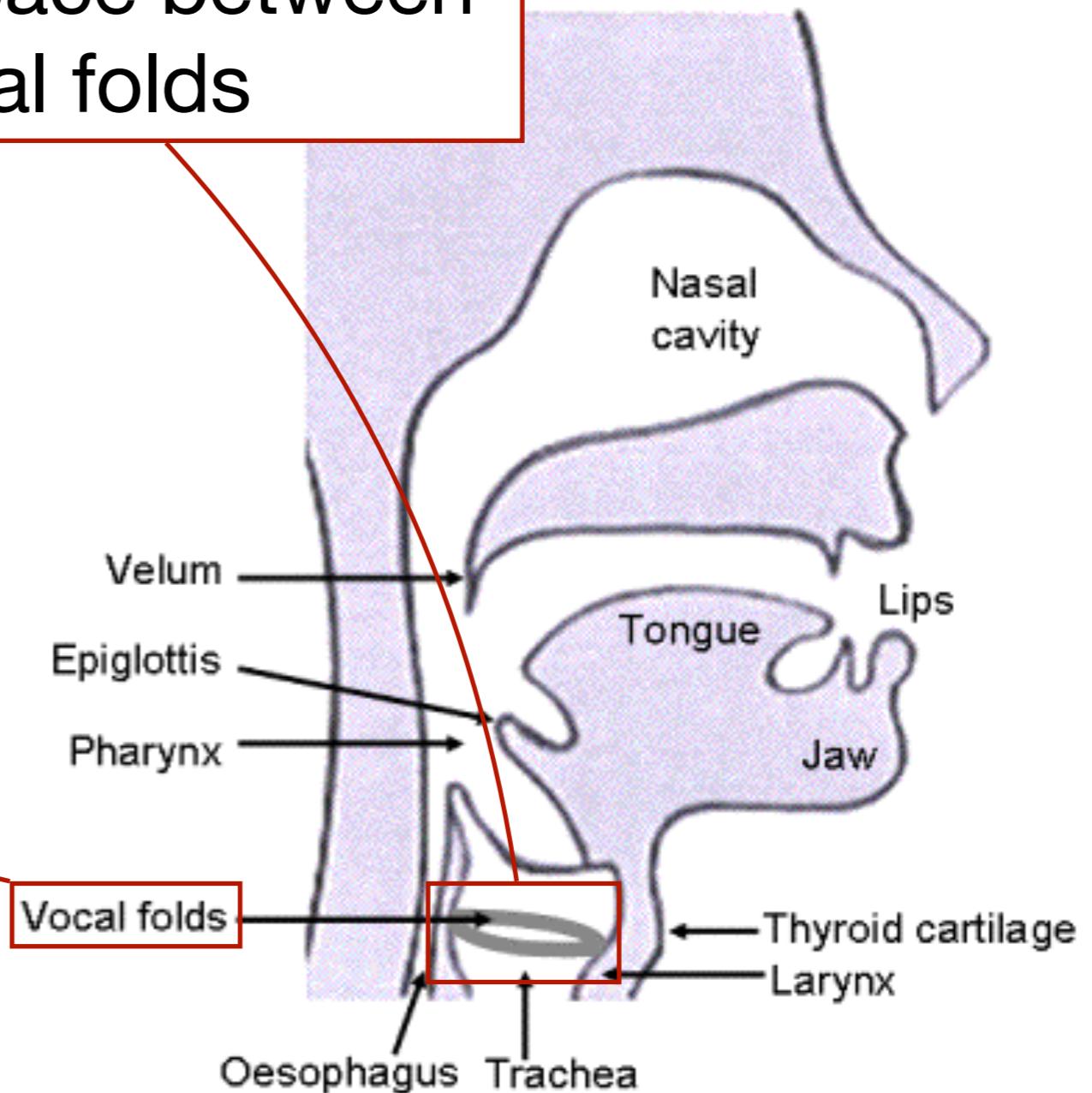
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# Vocal Physiology

Vocal tract: Larynx, pharynx, and mouth



Glottis: space between  
vocal folds



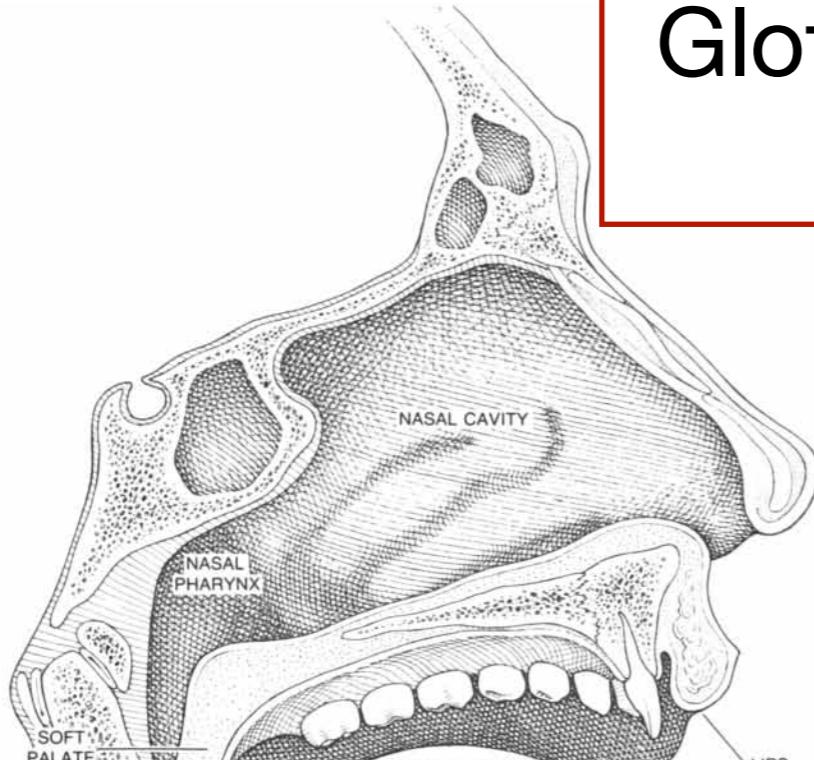
Produce sound  
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Sundberg (1977)

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# Vocal Physiology

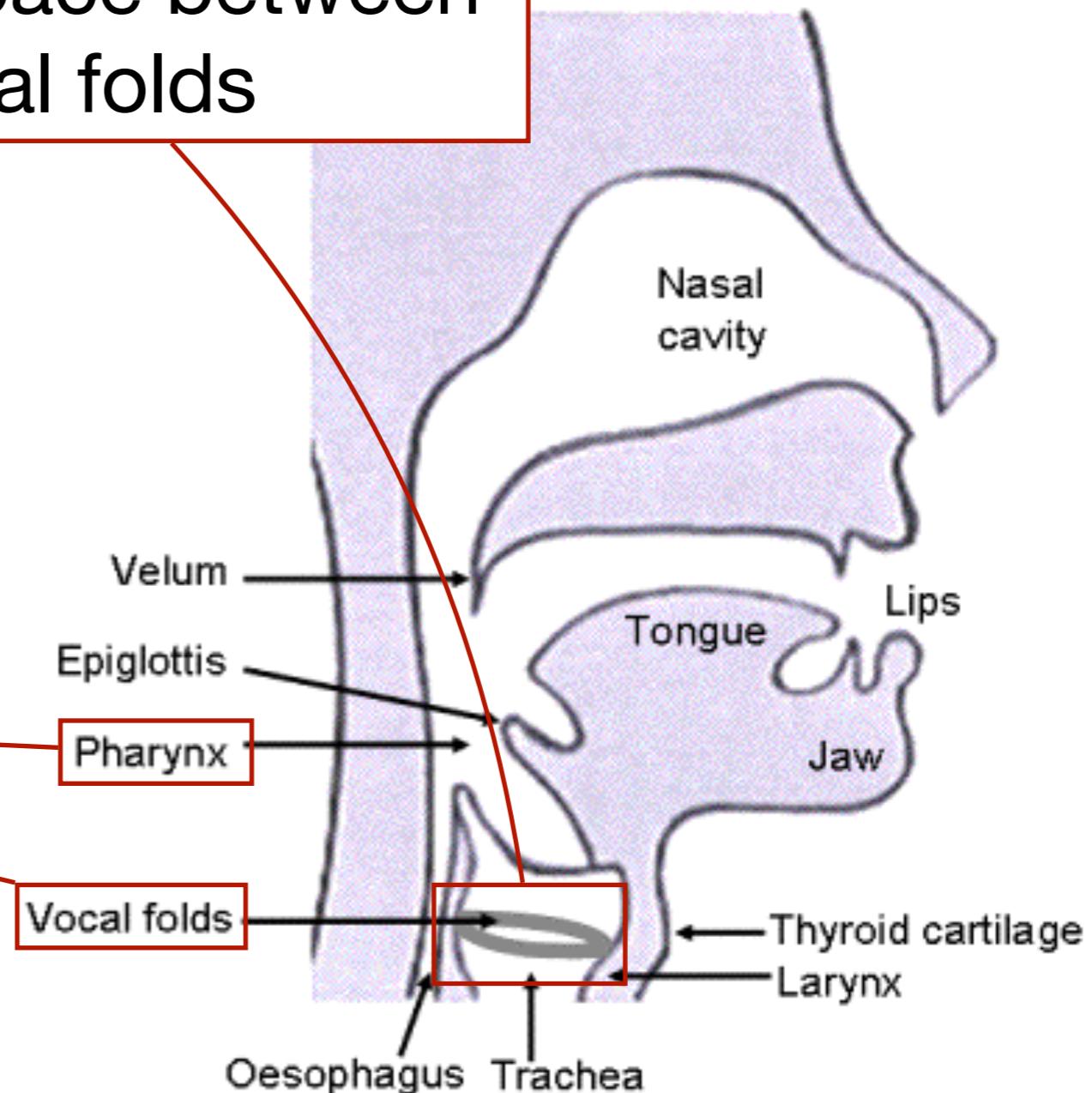
Vocal tract: Larynx, pharynx, and mouth



Glottis: space between  
vocal folds

Cavity between mouth  
and oesophagus

Produce sound  
Protect airways

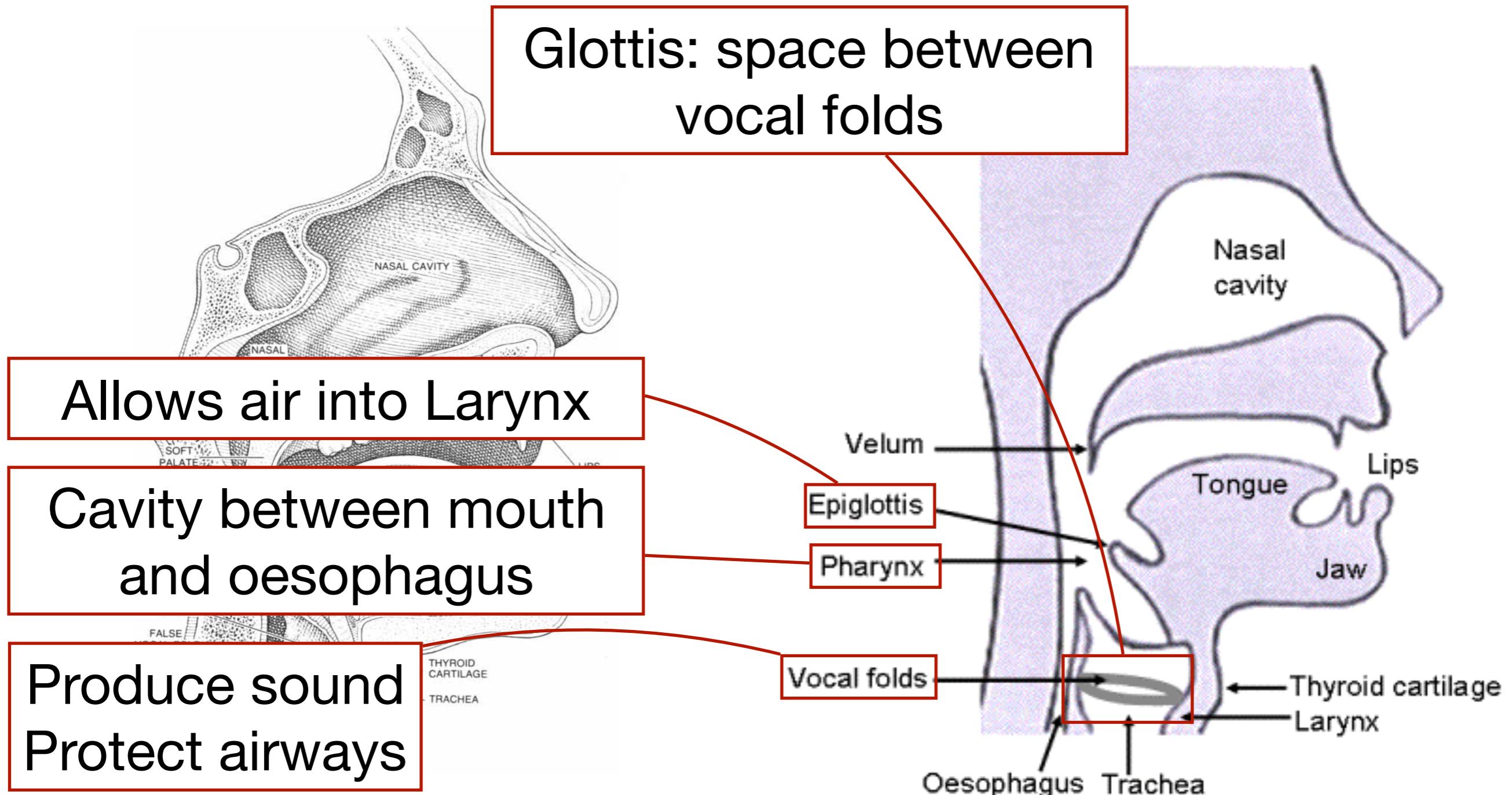


Sundberg (1977)

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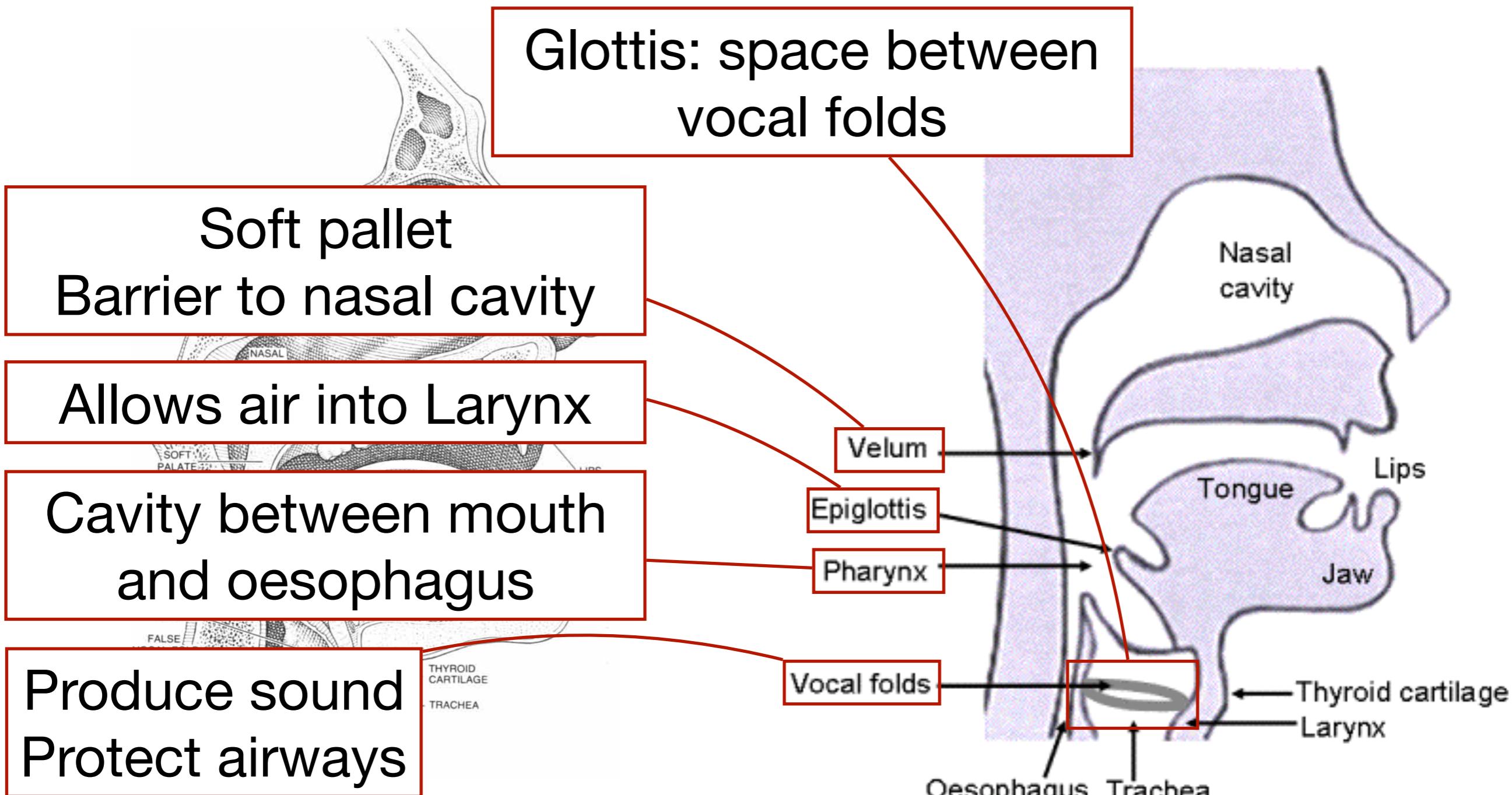
# Vocal Physiology

Vocal tract: Larynx, pharynx, and mouth



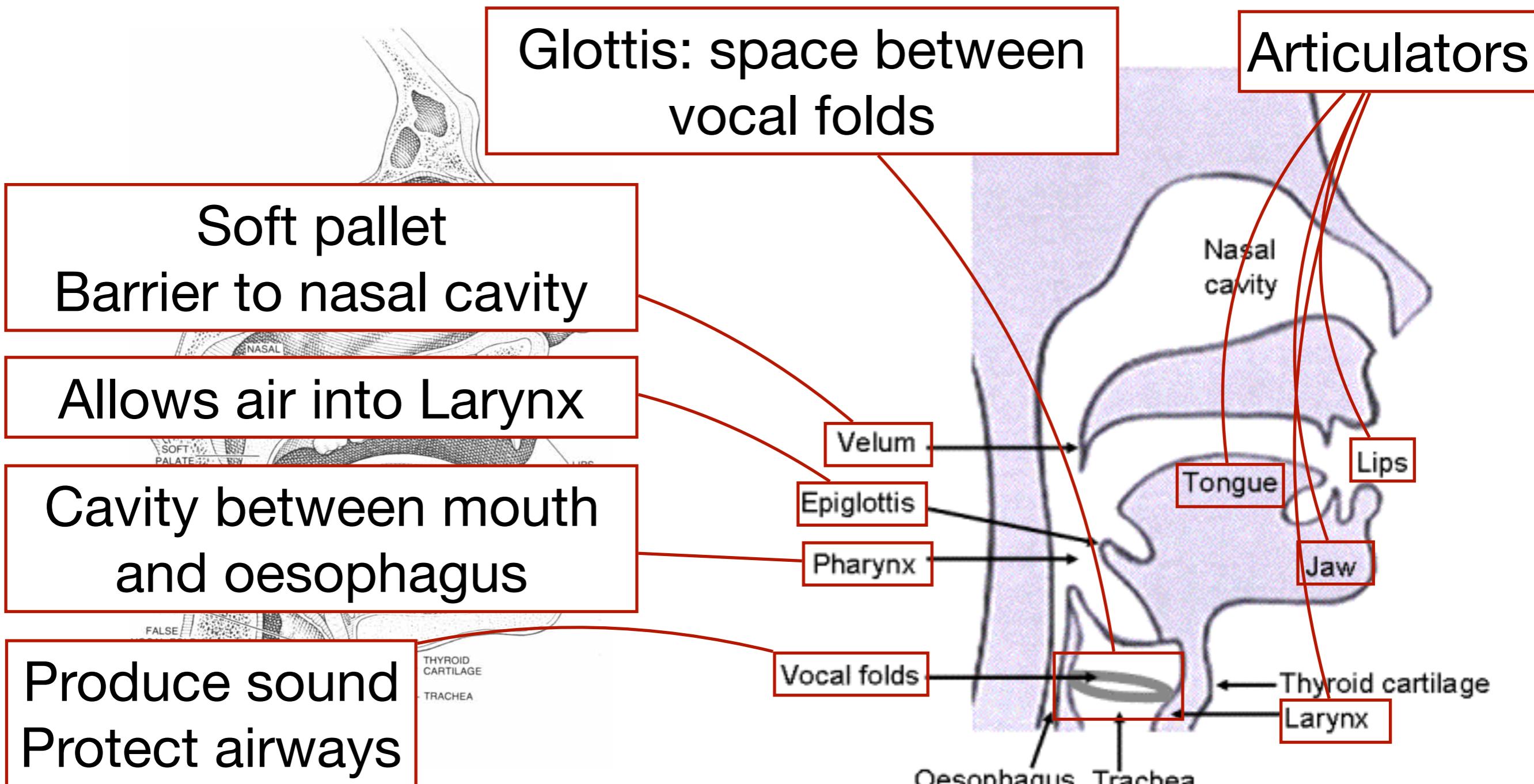
# Vocal Physiology

Vocal tract: Larynx, pharynx, and mouth



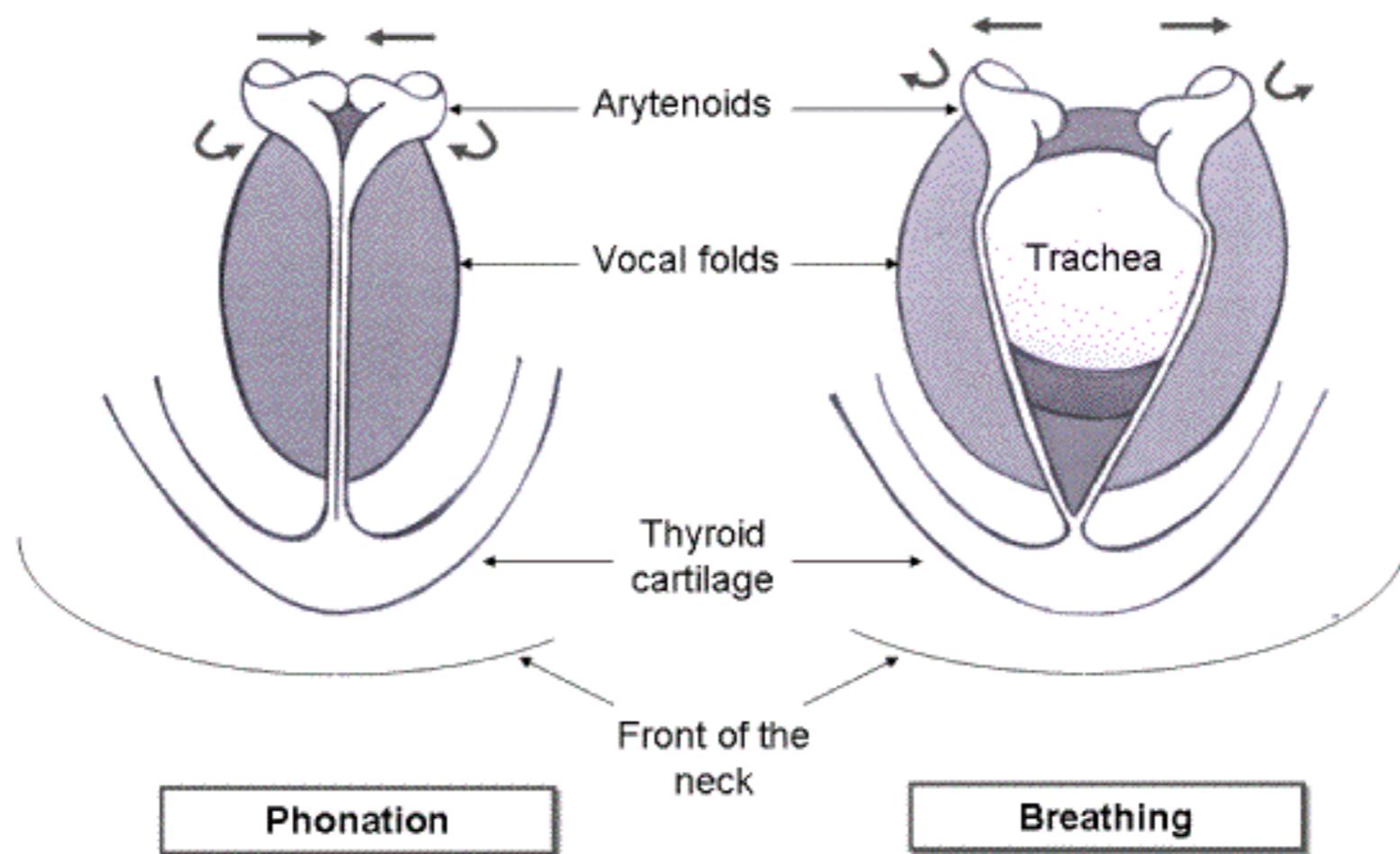
# Vocal Physiology

Vocal tract: Larynx, pharynx, and mouth



# Vocal Physiology

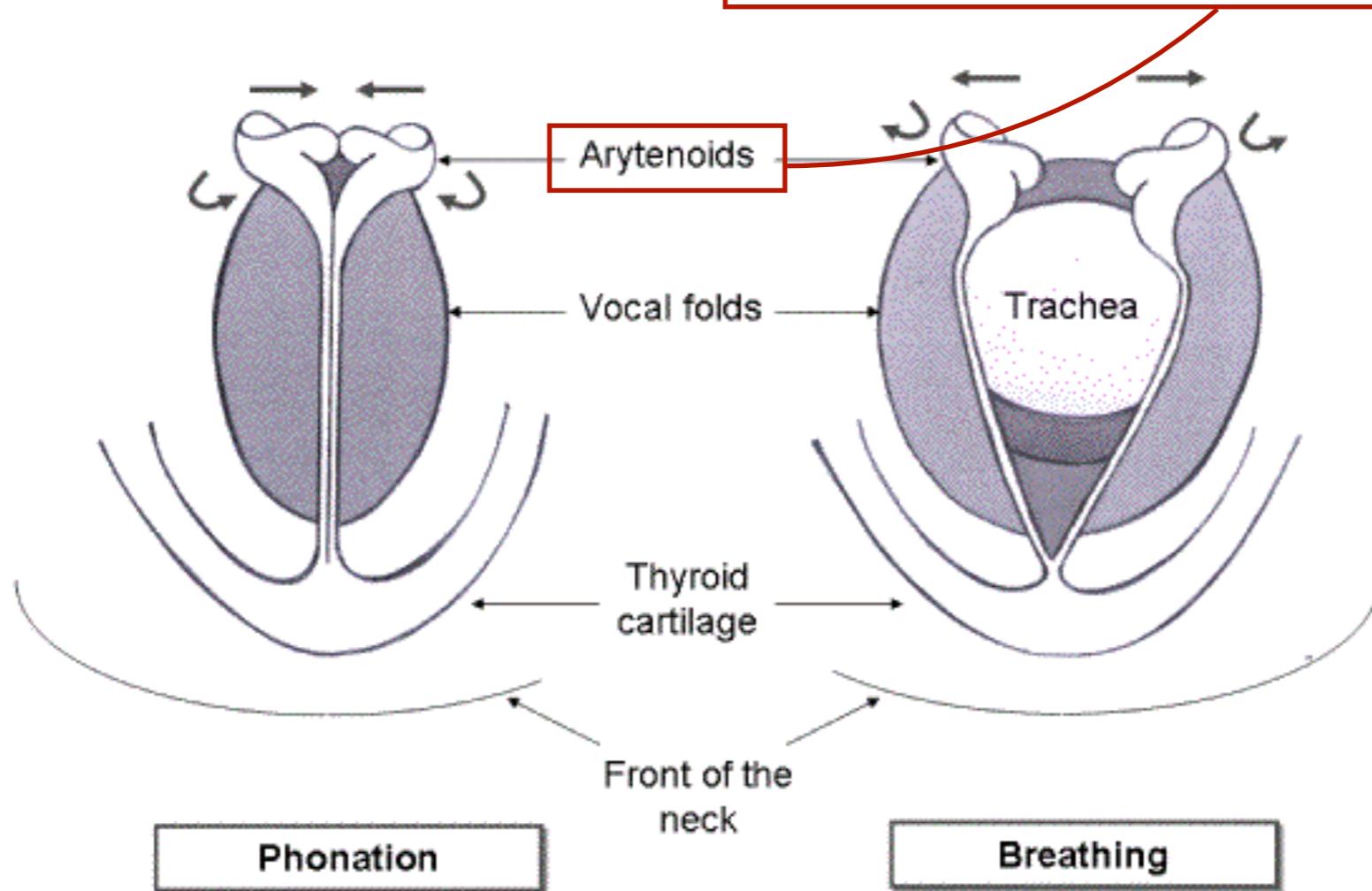
## Vocal folds (top view)



# Vocal Physiology

Vocal folds (top view)

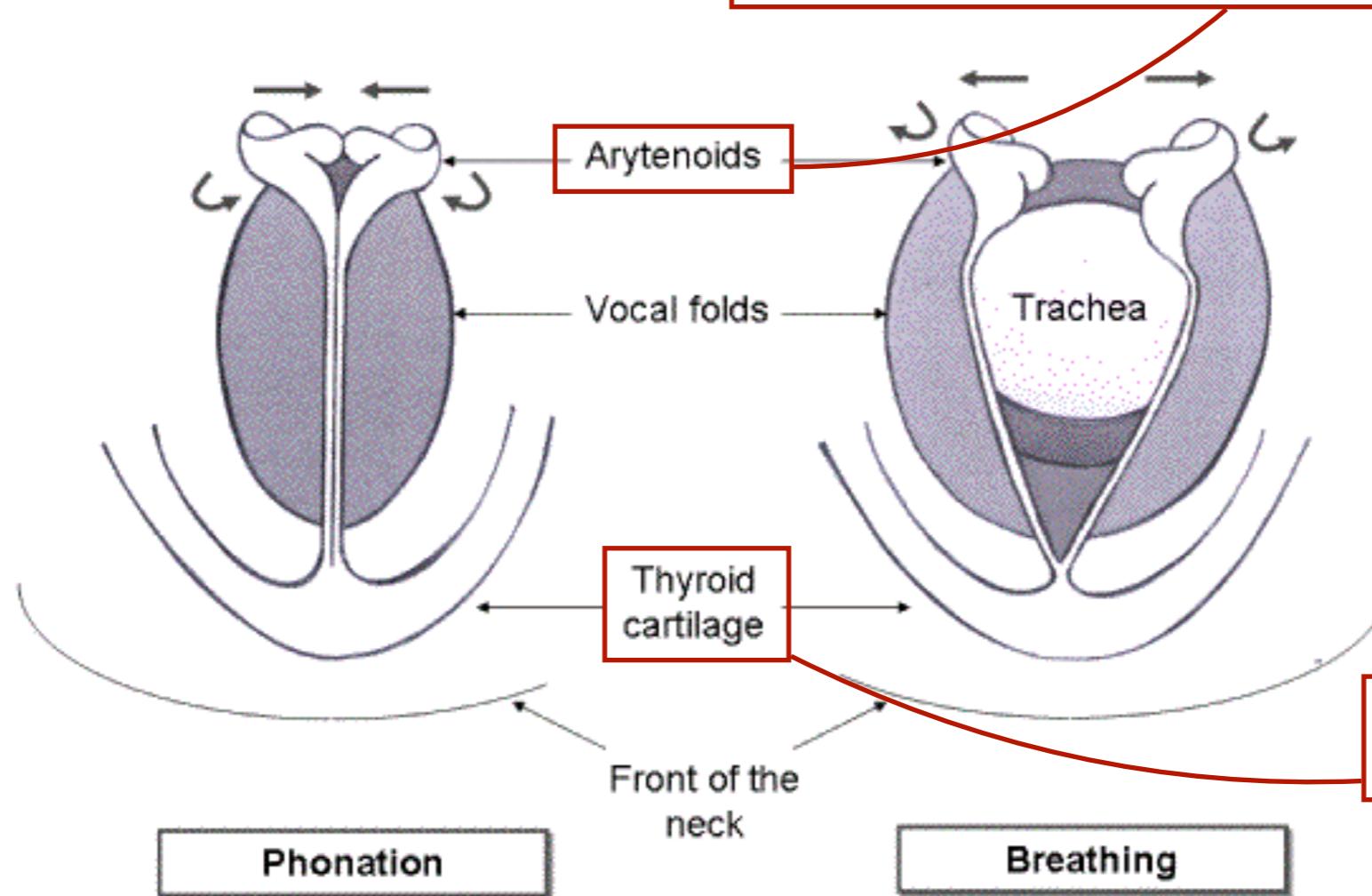
Open vocal folds for breathing  
Close vocal folds for phonation



# Vocal Physiology

Vocal folds (top view)

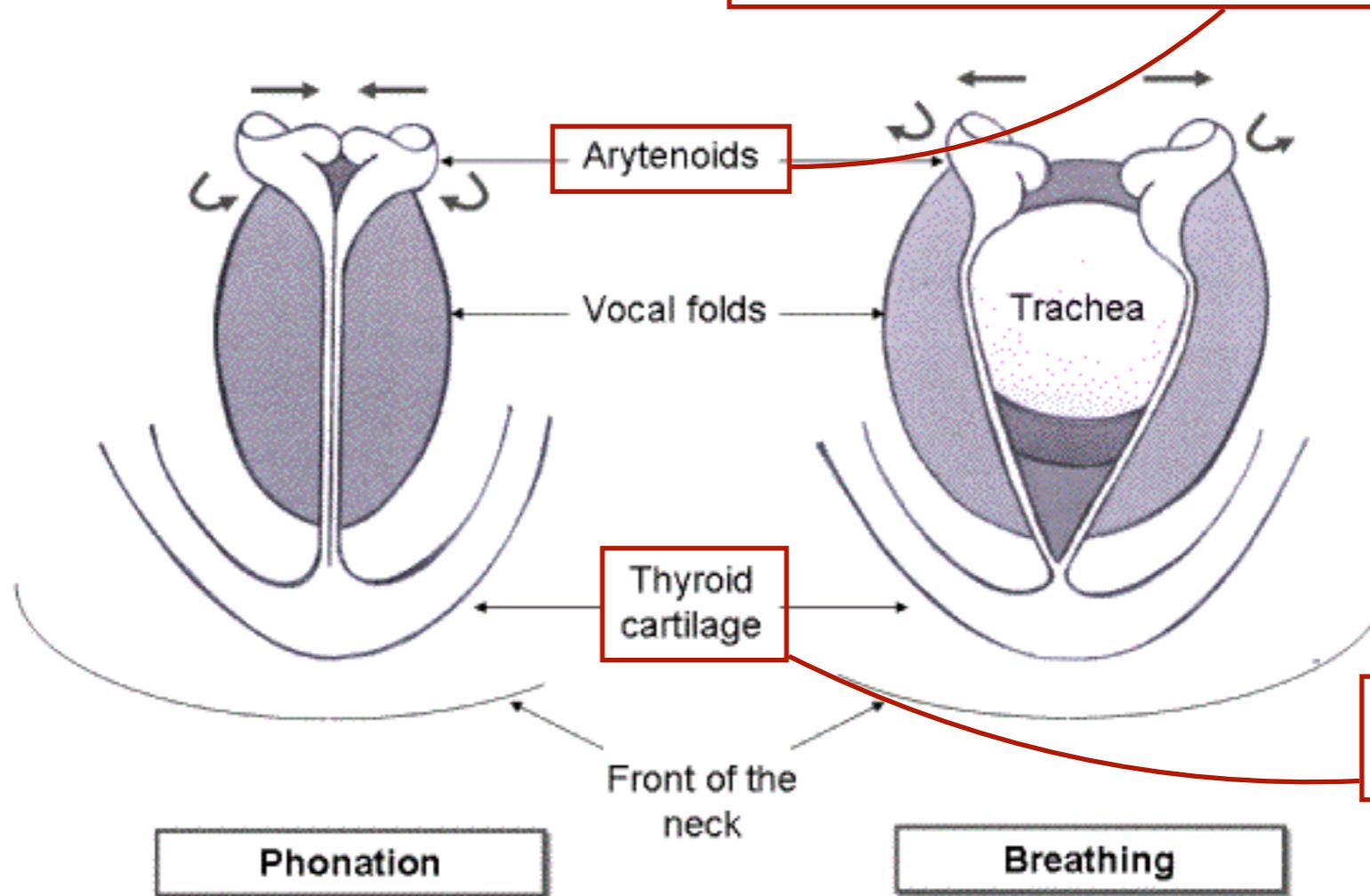
Open vocal folds for breathing  
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# Vocal Physiology

Vocal folds (top view)

Open vocal folds for breathing  
Close vocal folds for phonation

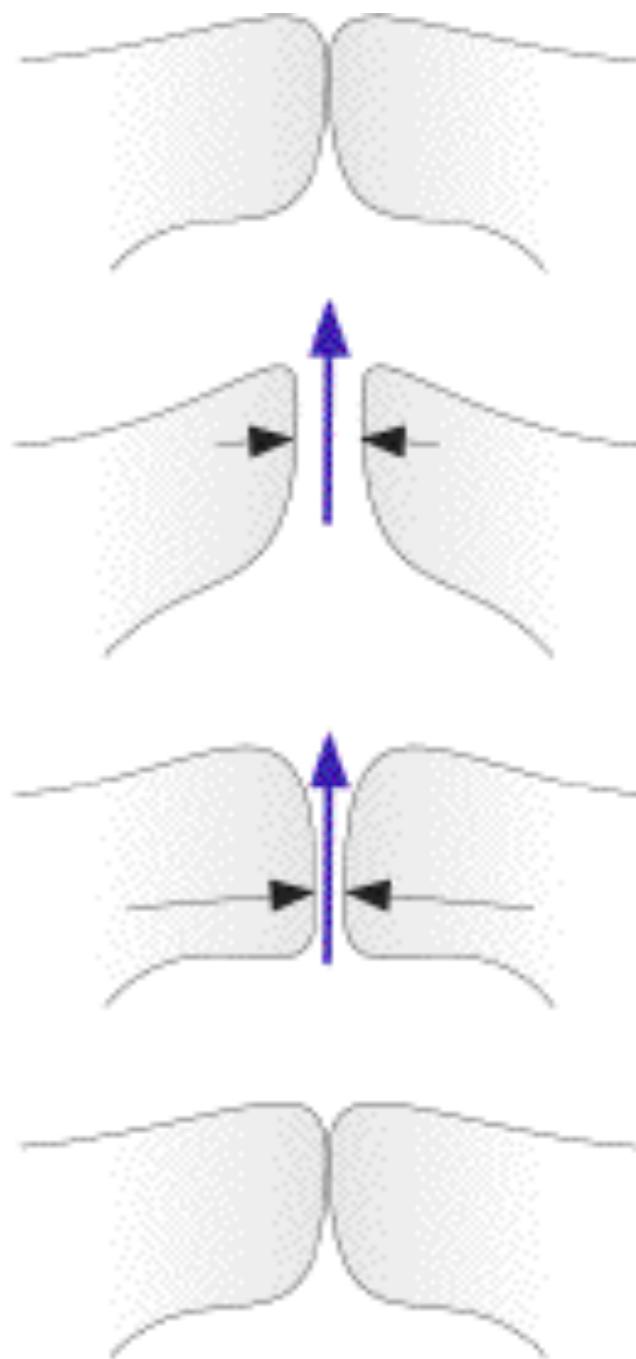


Adam's apple

Opening/closing of vocal folds for sound production is not muscular

# Vocal Physiology

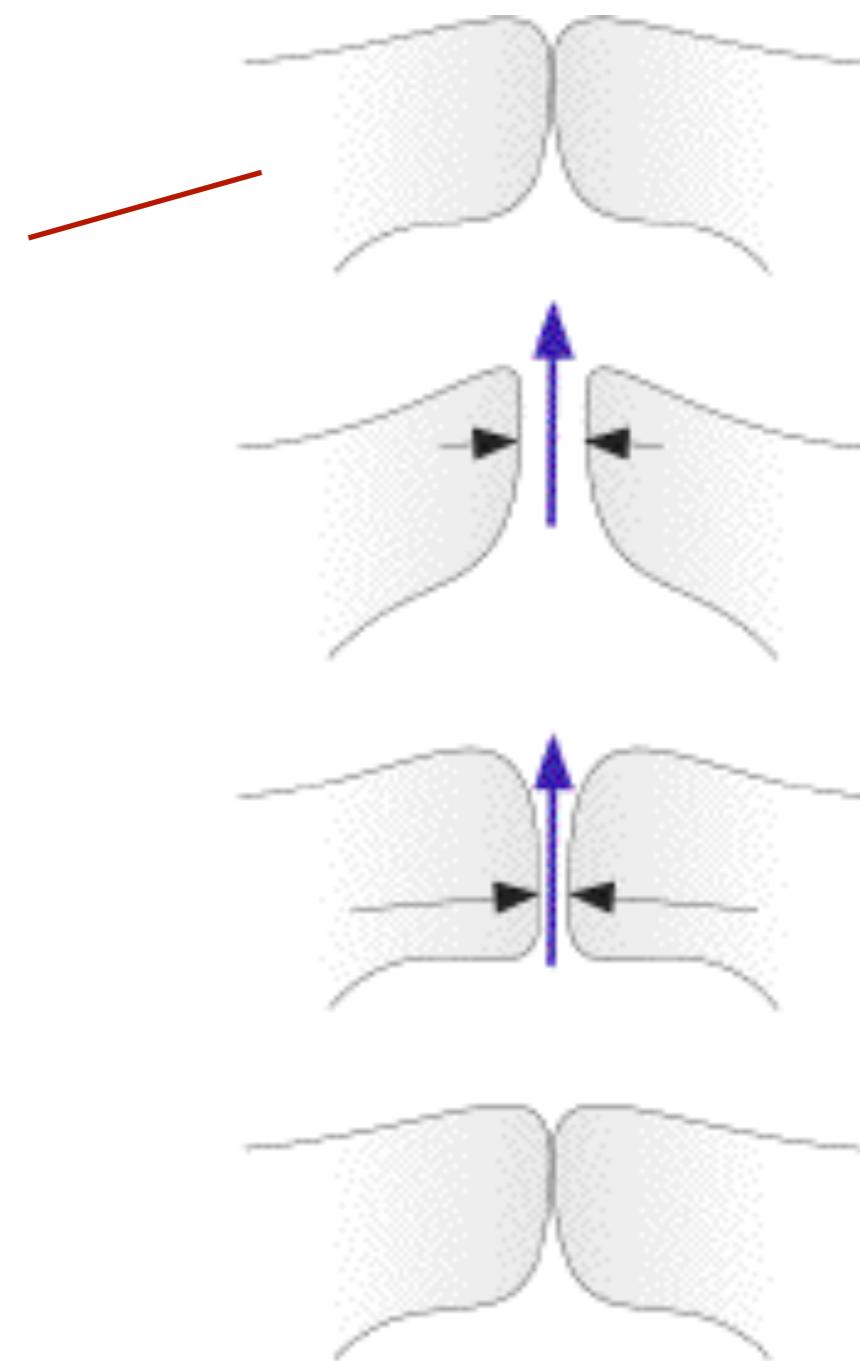
Vocal folds (side view): phonation



# Vocal Physiology

Vocal folds (side view): phonation

Pressure acting below the vocal folds tends to force them upwards and apart

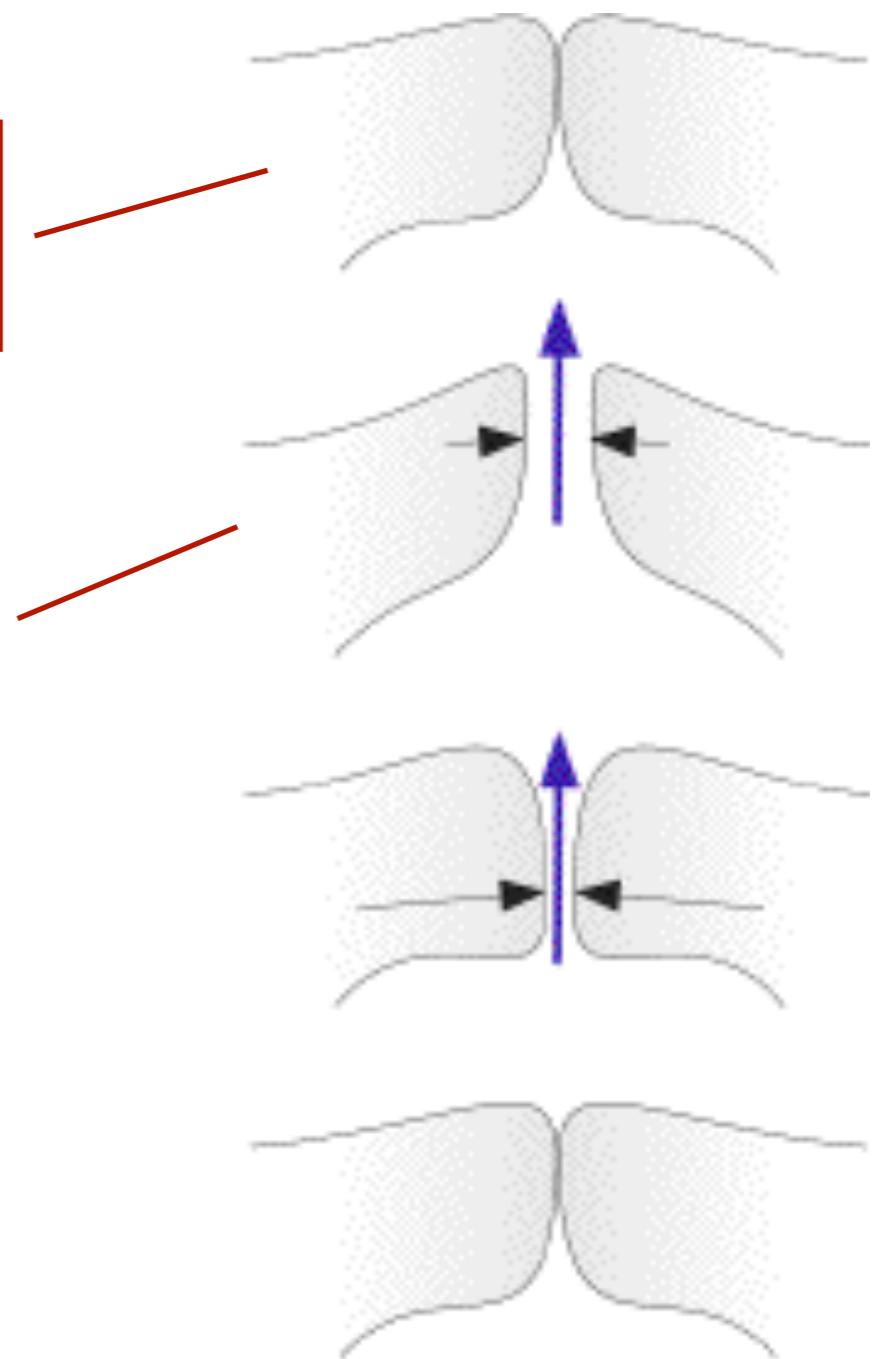


# Vocal Physiology

Vocal folds (side view): phonation

Pressure acting below the vocal folds tends to force them upwards and apart

Pressure difference is also responsible for accelerating air through the glottis for producing the high-speed air flow



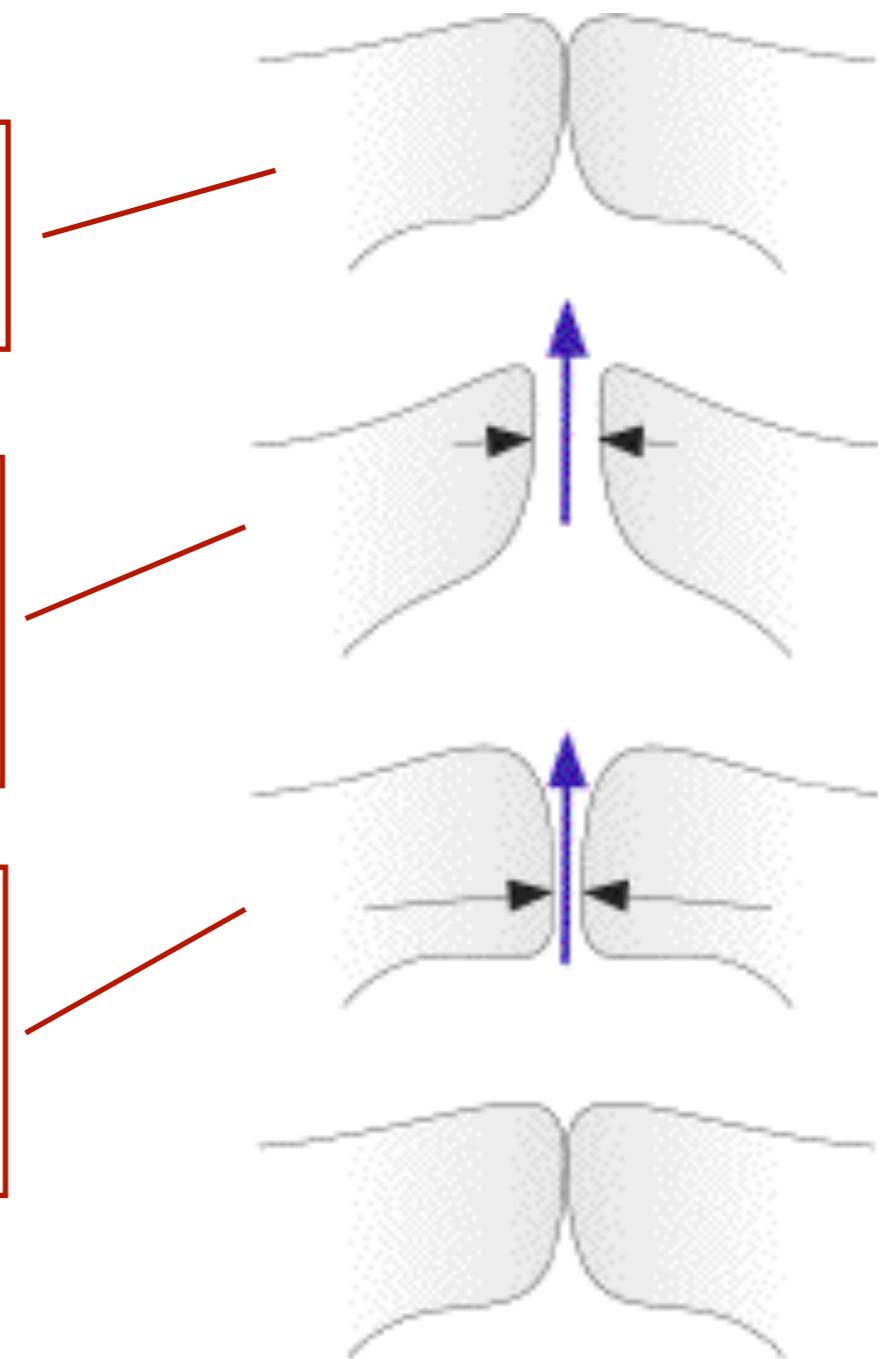
# Vocal Physiology

Vocal folds (side view): phonation

Pressure acting below the vocal folds tends to force them upwards and apart

Pressure difference is also responsible for accelerating air through the glottis for producing the high-speed air flow

Rapid air flow through the glottis creates a suction, which draws the folds back together



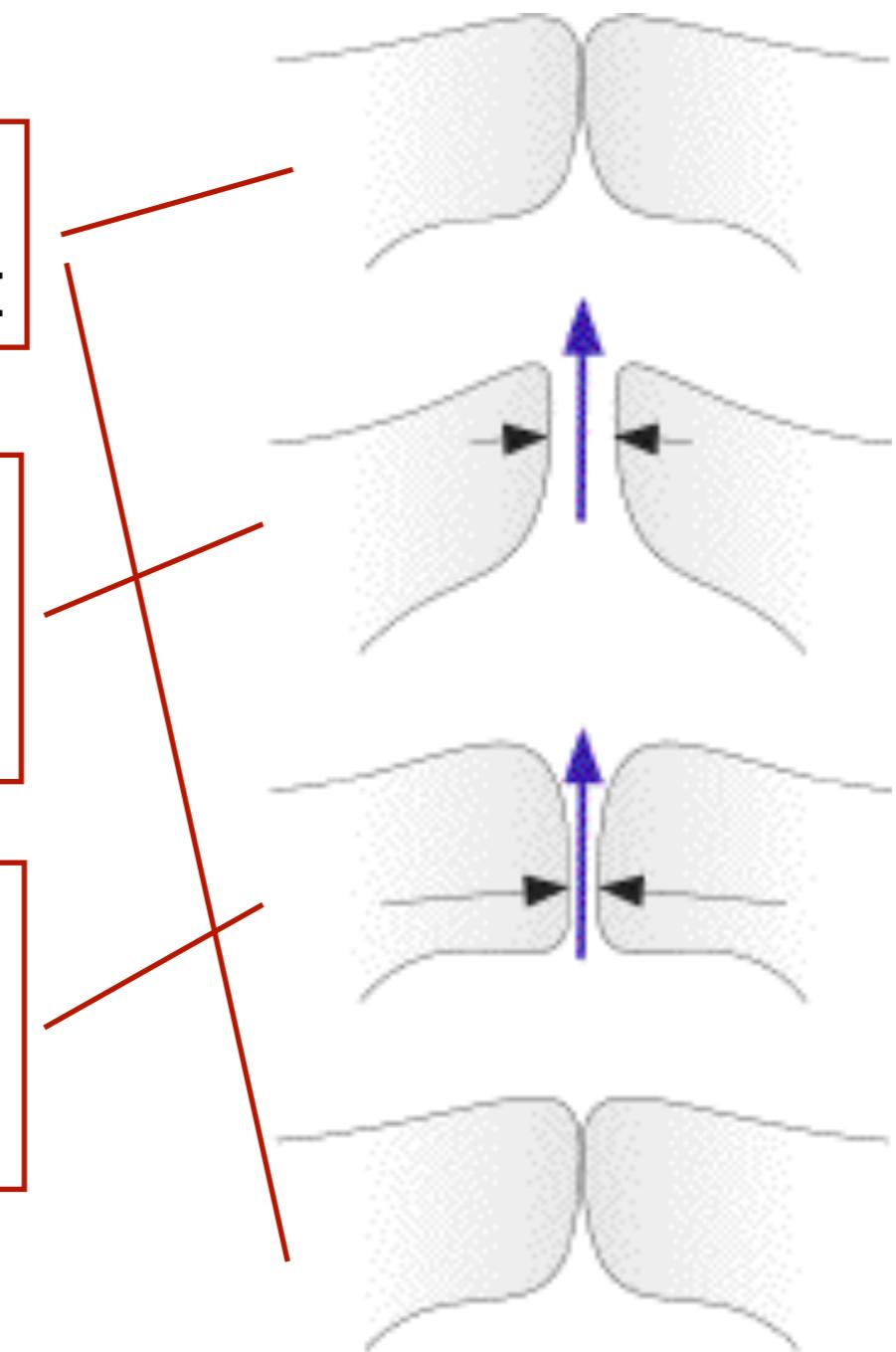
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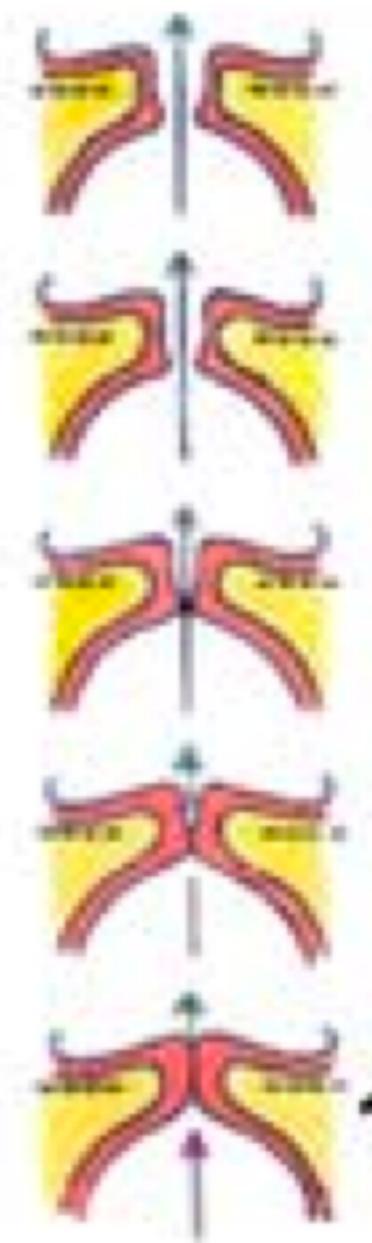
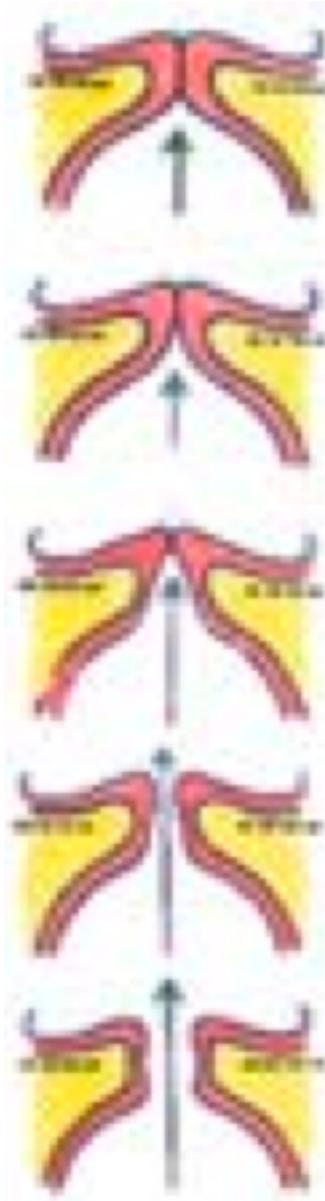
Rapid air flow through the glottis creates a suction, which draws the folds back together



# Vocal Physiology

Vocal folds (side view): phonation

The vertical vocal folds do not open and close simultaneously



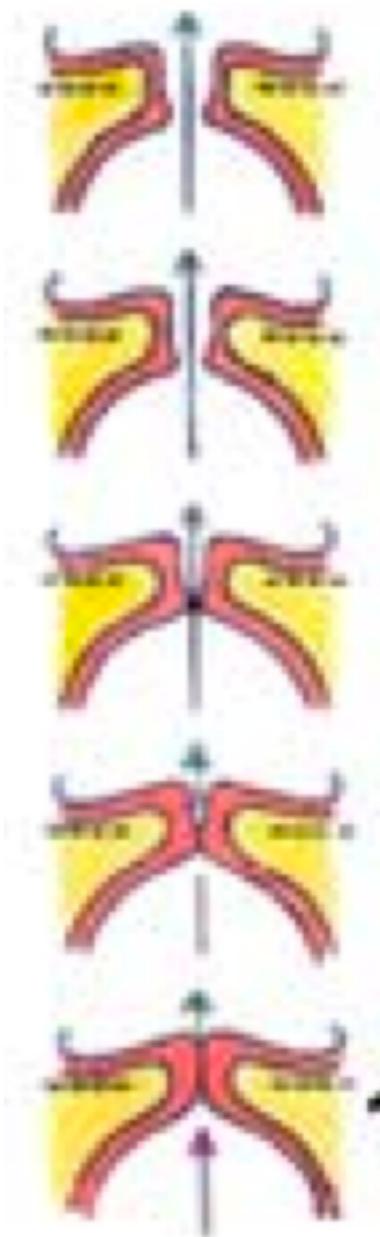
# Vocal Physiology

Vocal folds (side view): phonation

The vertical vocal folds do not open and close simultaneously



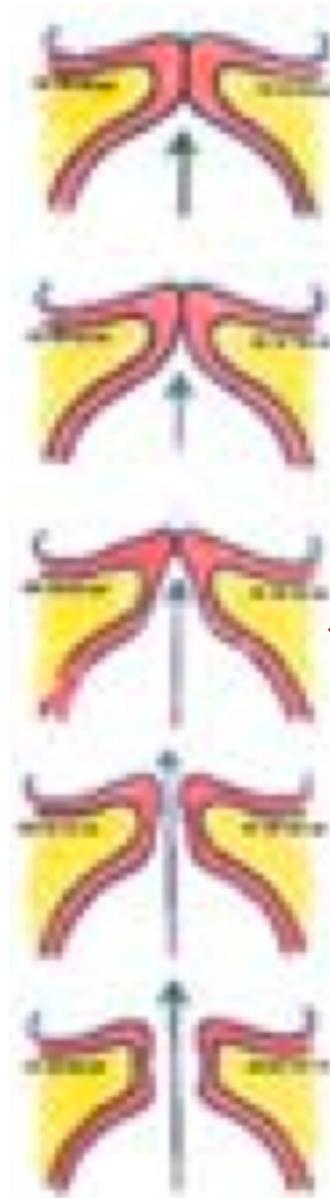
Air pressure closes vocal folds



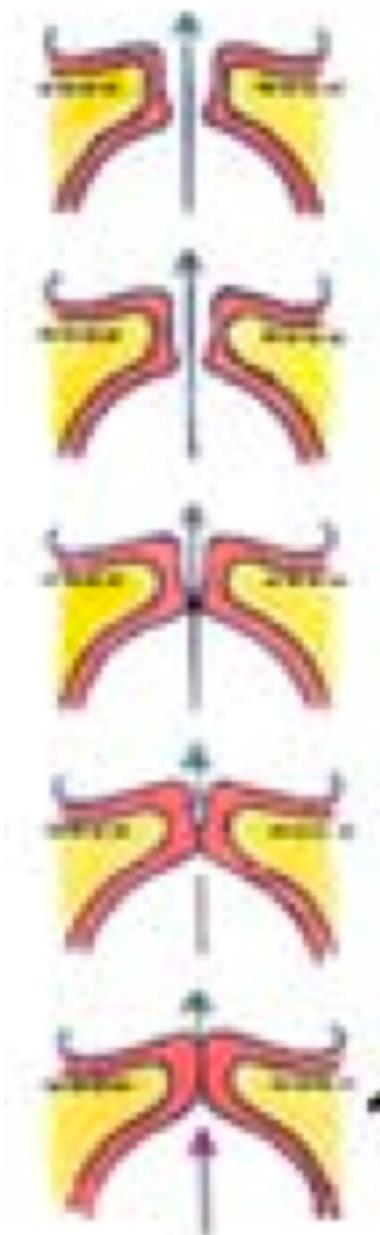
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Vocal folds (side view): phonation

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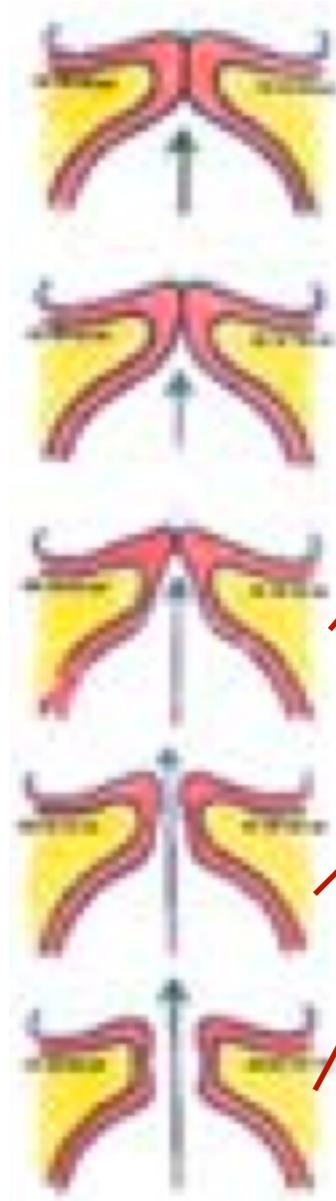
- Air pressure closes vocal folds
- Air pressure opens bottom of vocal folds



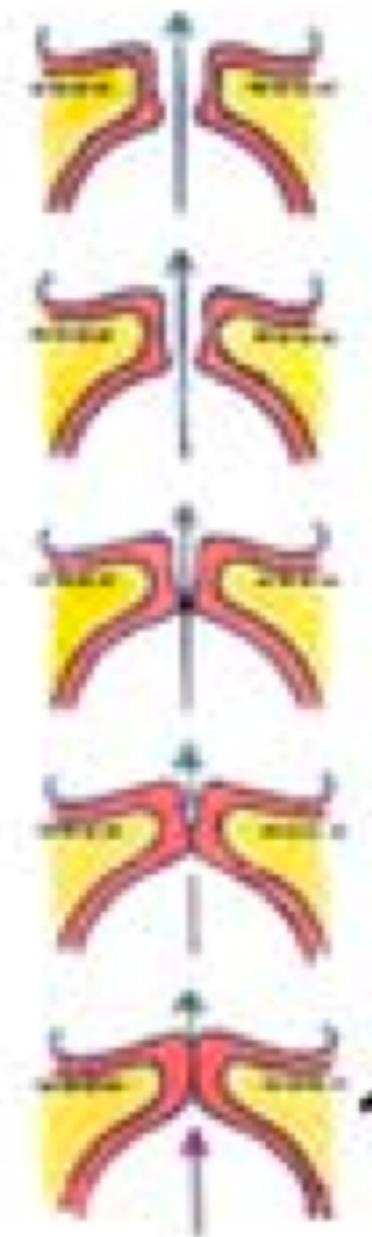
# Vocal Physiology

Vocal folds (side view): phonation

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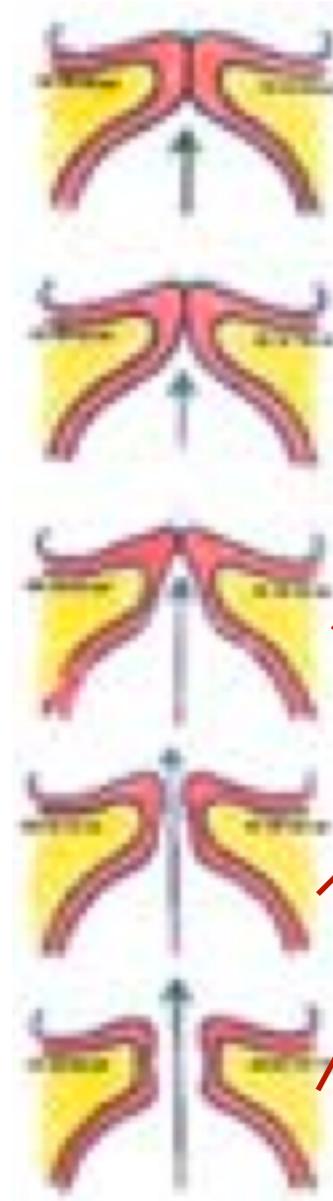
- Air pressure closes vocal folds
- Air pressure opens bottom of vocal folds
- Air pressure opens top of vocal folds



# Vocal Physiology

Vocal folds (side view): phonation

The vertical vocal folds do not open and close simultaneously

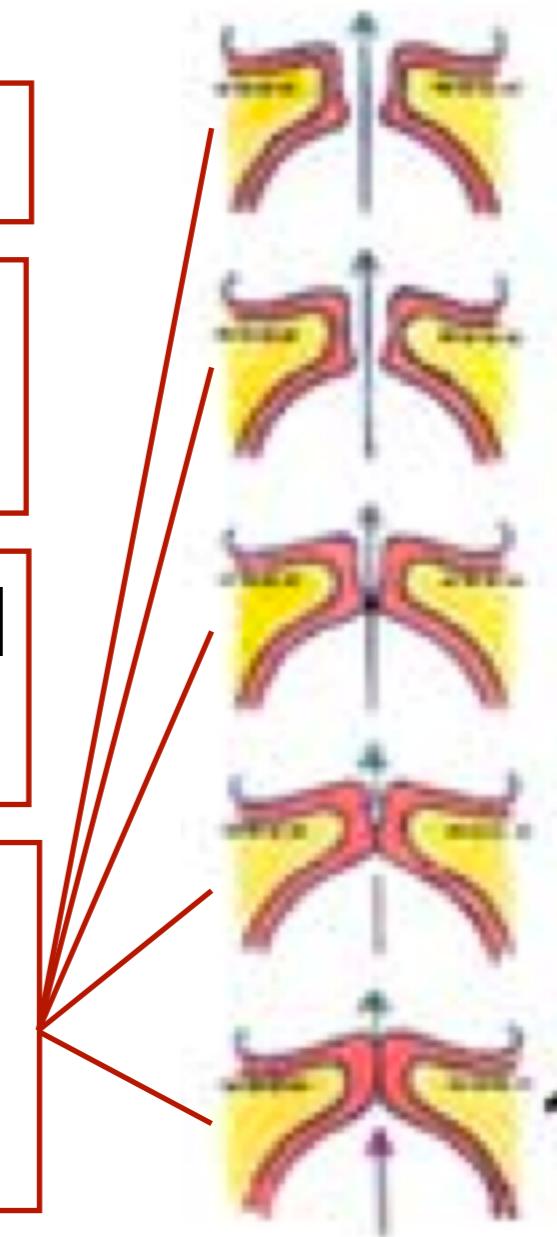


Air pressure closes vocal folds

Air pressure opens bottom of  
vocal folds

Air pressure opens top of vocal  
folds

Low pressure beneath air  
pressure produces a Bernoulli  
effect, closing the vocal folds



# Vocal Physiology

## Phonation

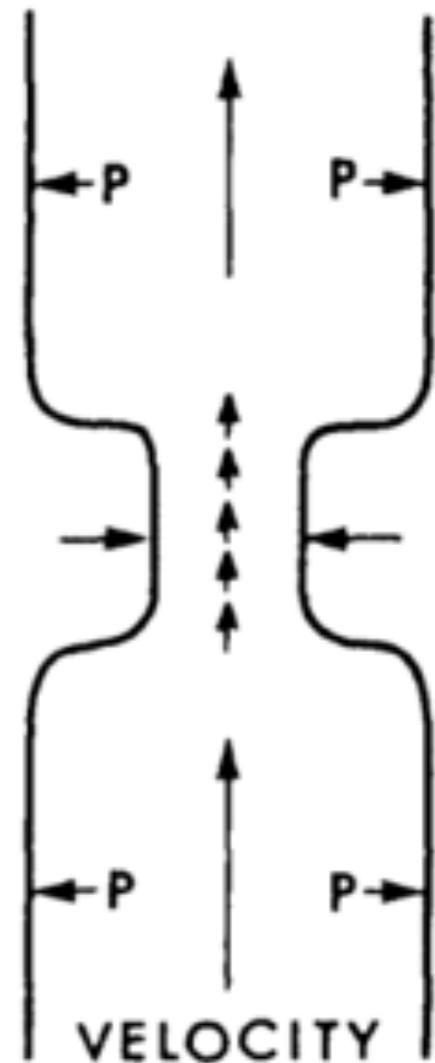
Air pressure opens the folds

Bernoulli force plus elasticity of vocal folds bring them back together

*Not musculature*

Bernoulli force occurs in systems where increases in speed correspond to decreases in pressure

e.g., *reed instruments, wings of an airplane*

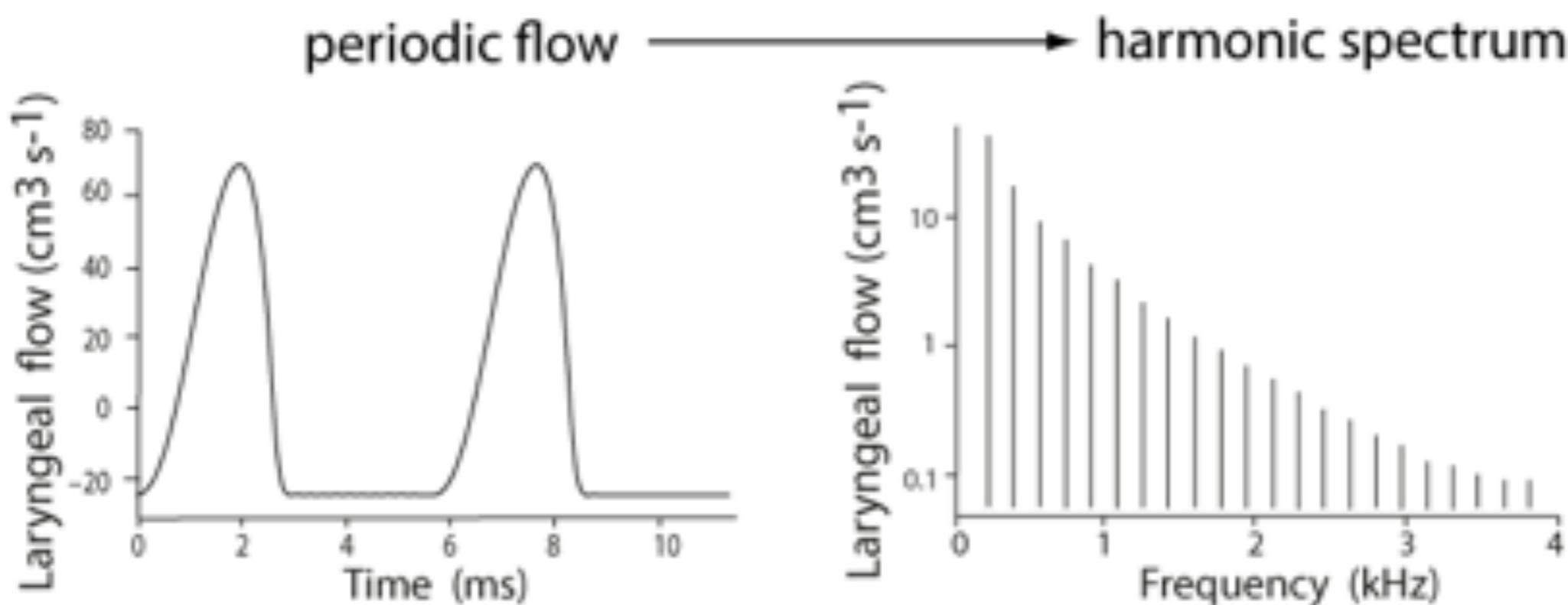


# Vocal Physiology

## Phonation

Phonation produces the voice source

The voice source is a complex tone with a fundamental frequency corresponding to the phonation frequency



# Vocal Physiology

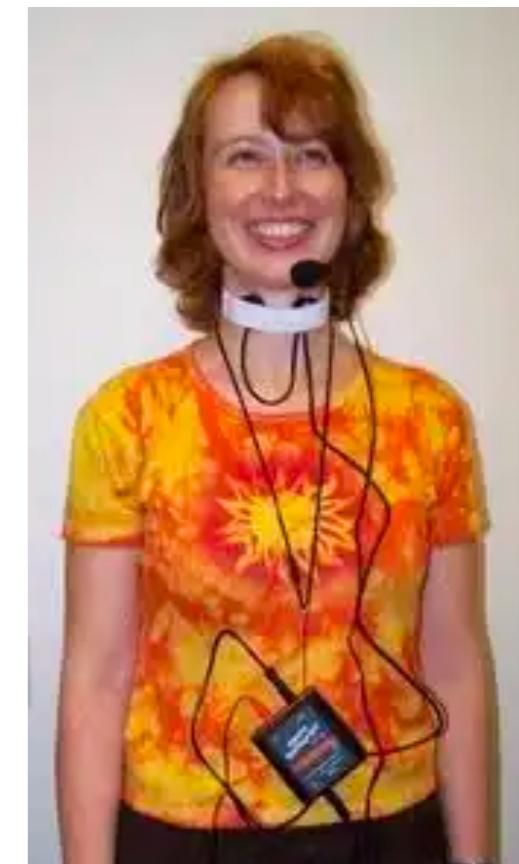
Measuring vocal fold activity



**Stroboscope**



**Laryngal Electromyography  
(EMG)**



**Electroglottography  
(EGG)**

# Vocal Physiology

## Articulators

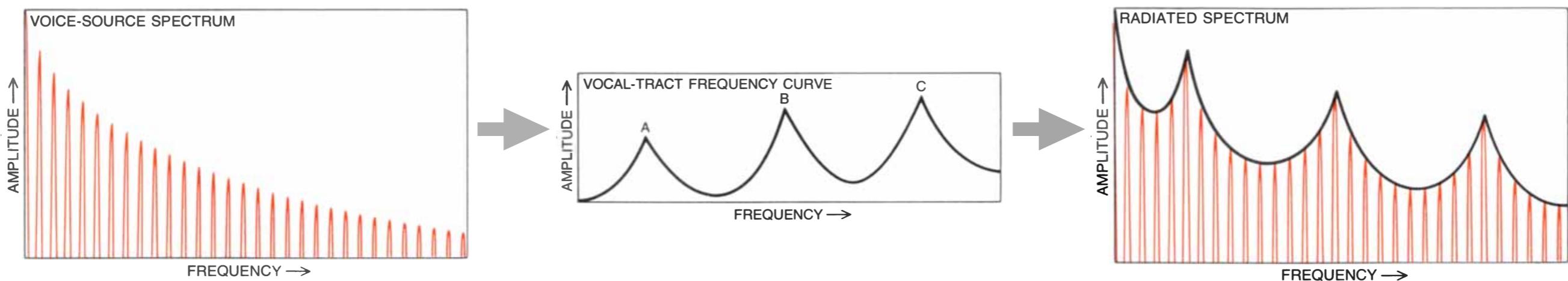
Larynx

Jaw

Tongue

Lips

Shape the spectrum of the voice source



# Vocal Physiology

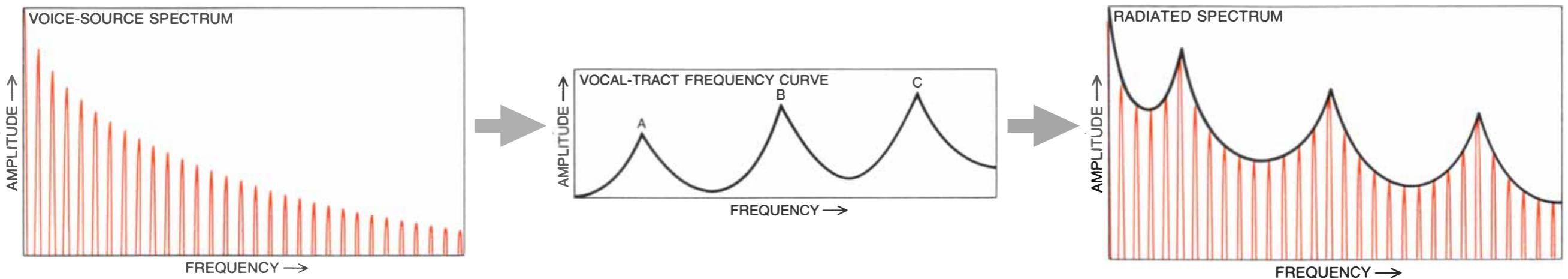
## Key Terms

- ▶ **Vocal folds**
- ▶ **Glottis**
- ▶ **Phonation**
- ▶ **Bernoulli force**
- ▶ **Voice Source**
- ▶ **Articulators**
- ▶ **Larynx**

# **Source-Filter Model**

# Source-Filter Model

## Big Picture

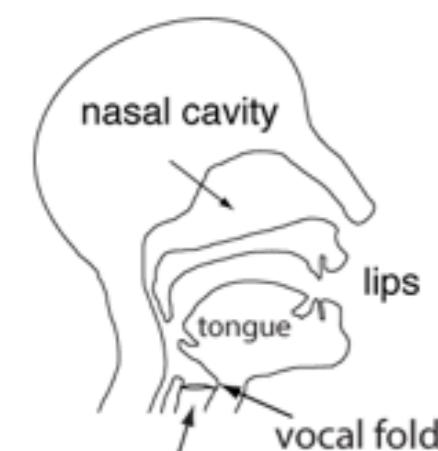


**Vocal source  
(glottis)**

**Vocal tract articulators  
(resonator)**

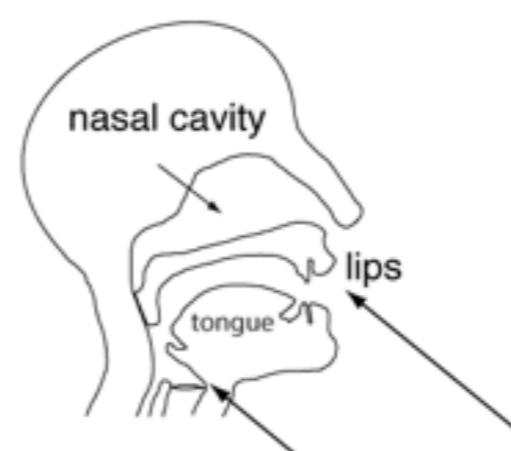
**Output sound**

**Source**



steady airflow from lungs via  
trachea provides energy source

**Filter**

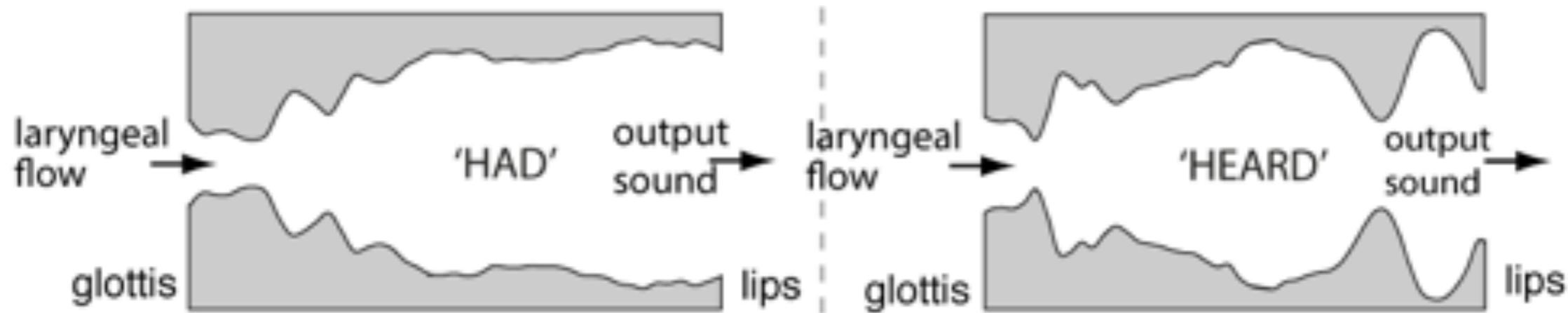


region from the vocal folds to the lips  
defines the vocal tract

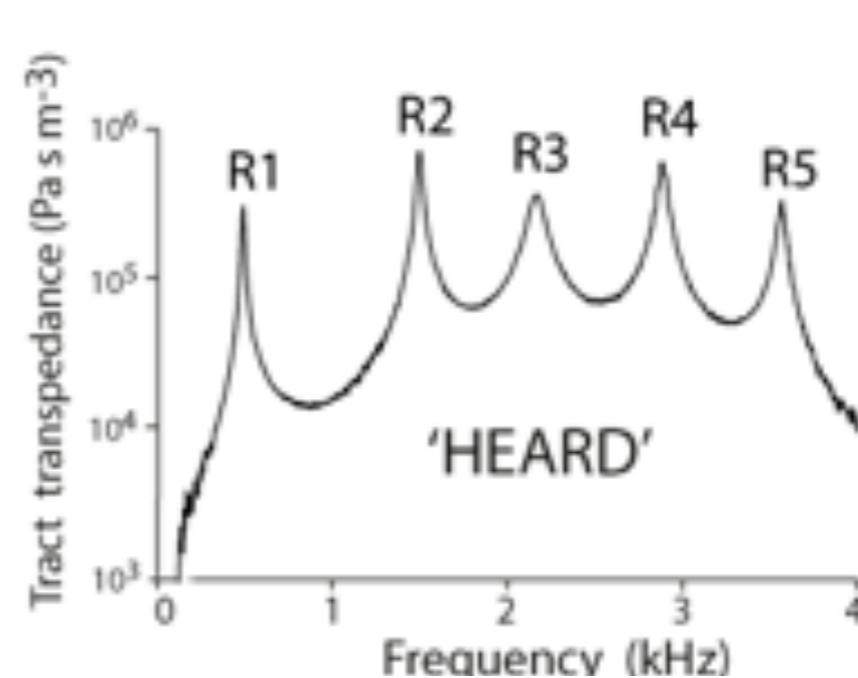
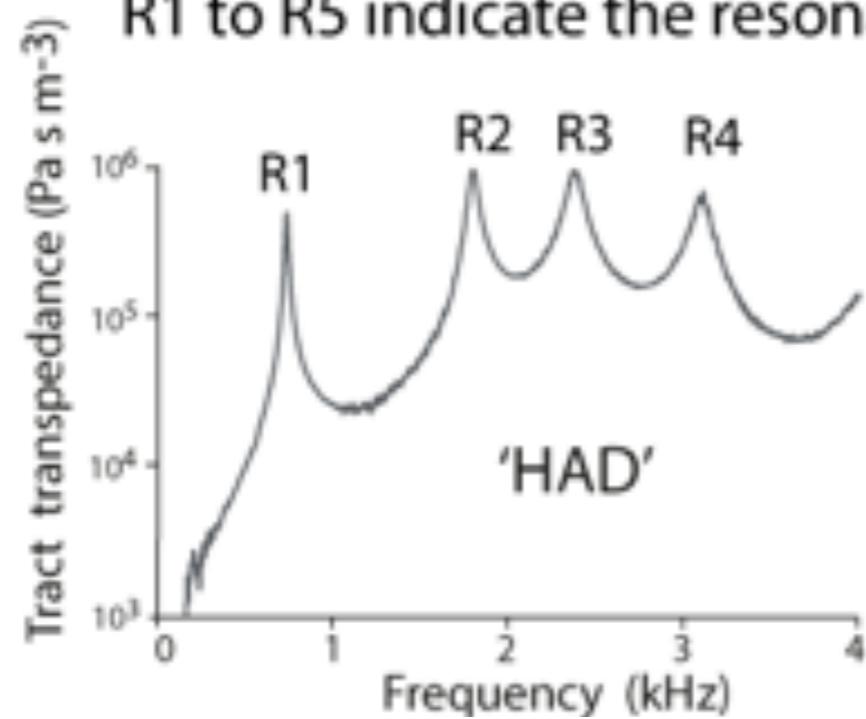
Sundberg (1977)  
[newt.phys.unsw.edu.au](http://newt.phys.unsw.edu.au)

# Source-Filter Model

## Filter

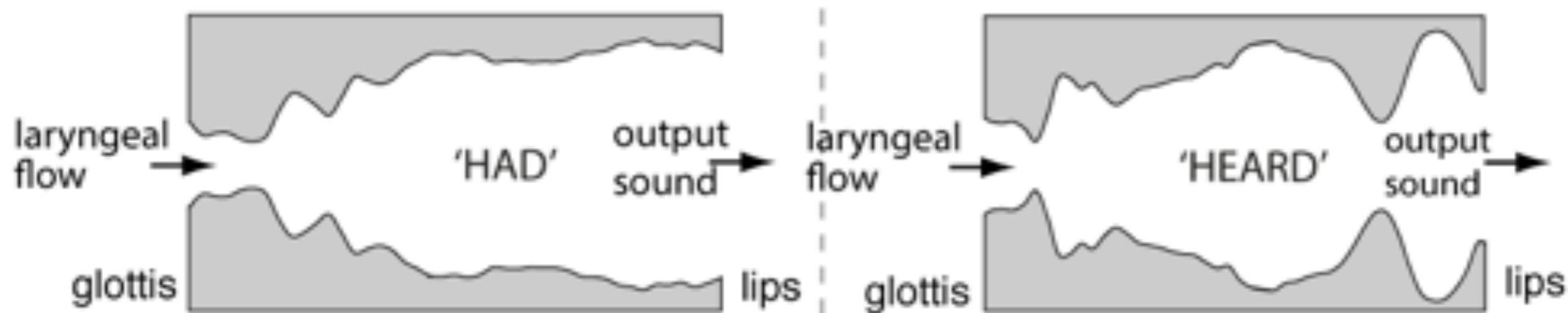


The 2 vocal tract models have the measured transpedances shown below.  
R1 to R5 indicate the resonances of the tract

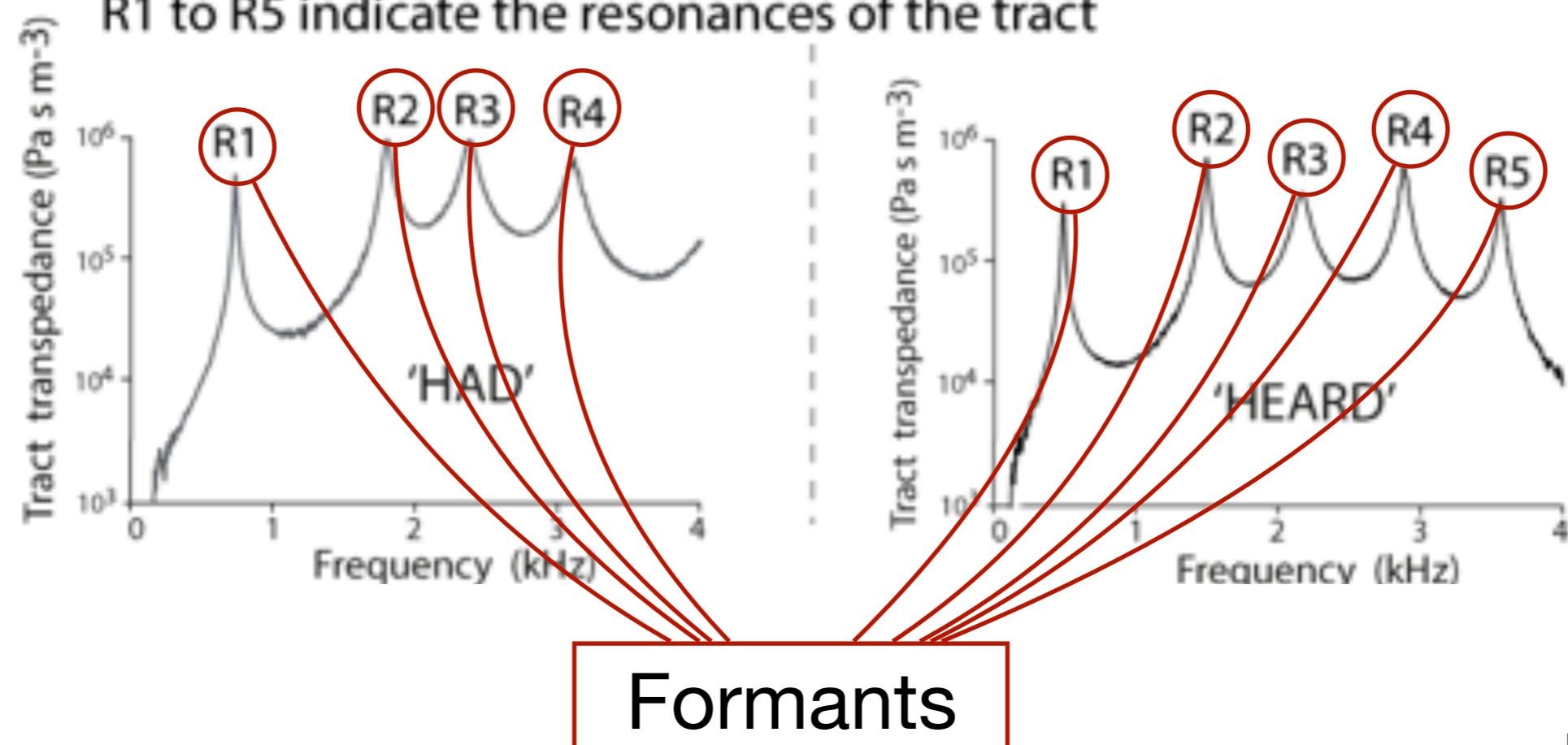


# Source-Filter Model

## Filter



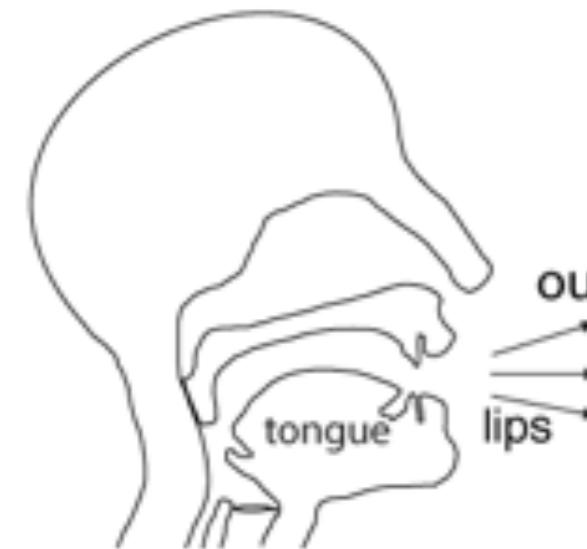
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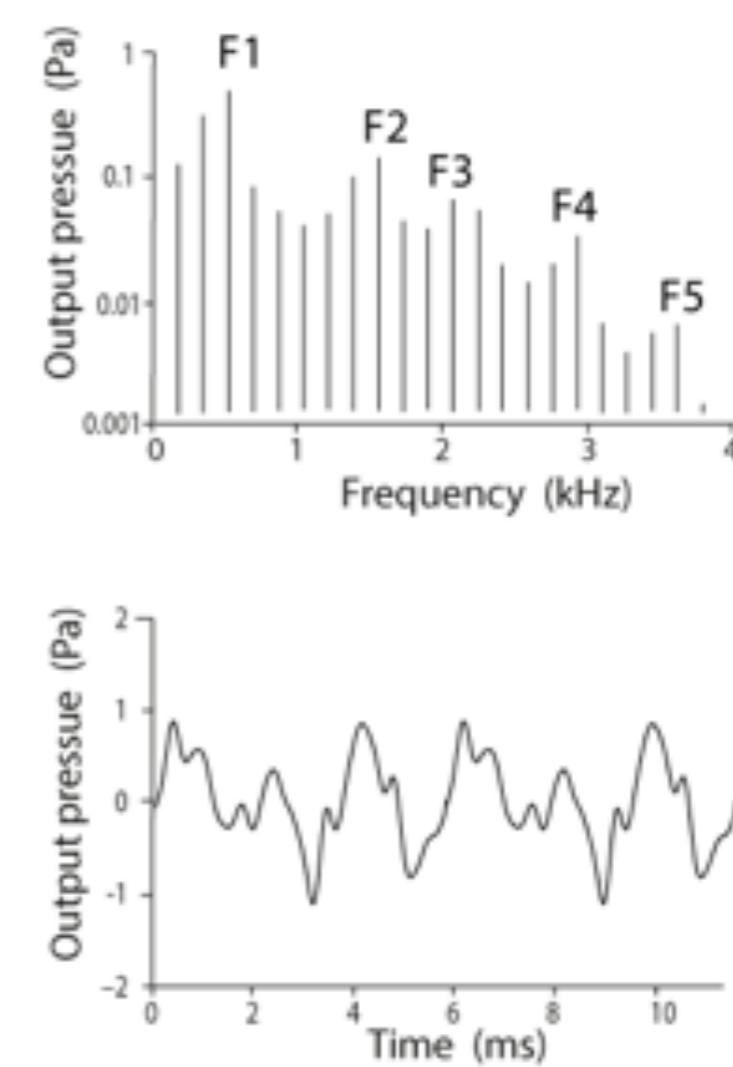
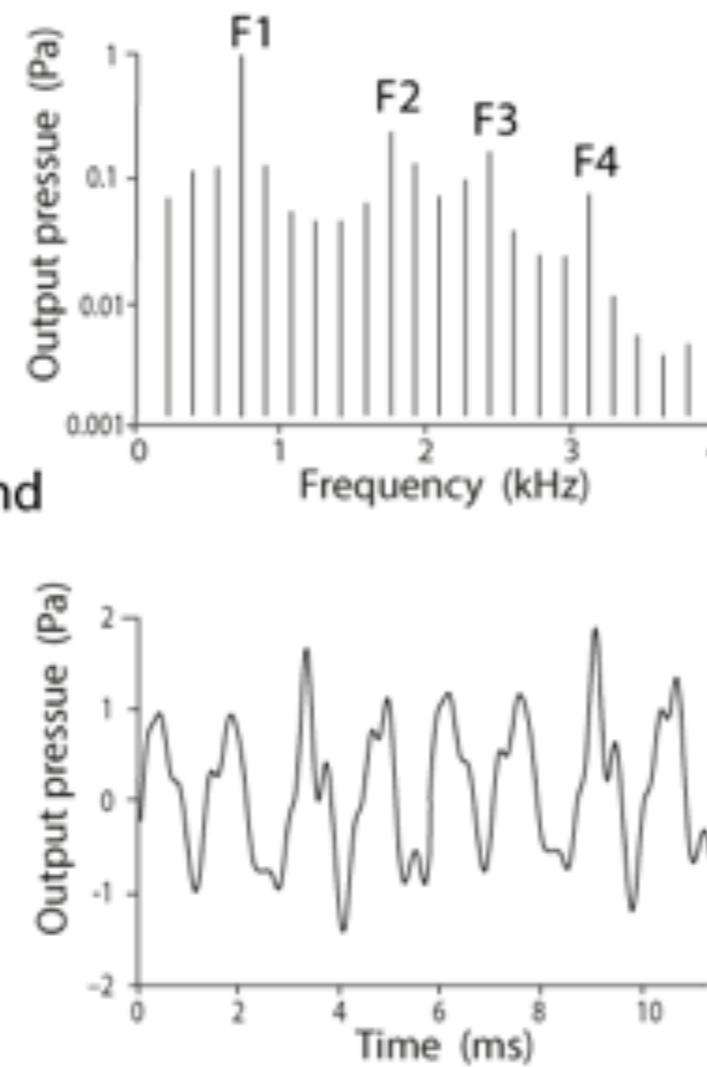
# Source-Filter Model

## Output Sound

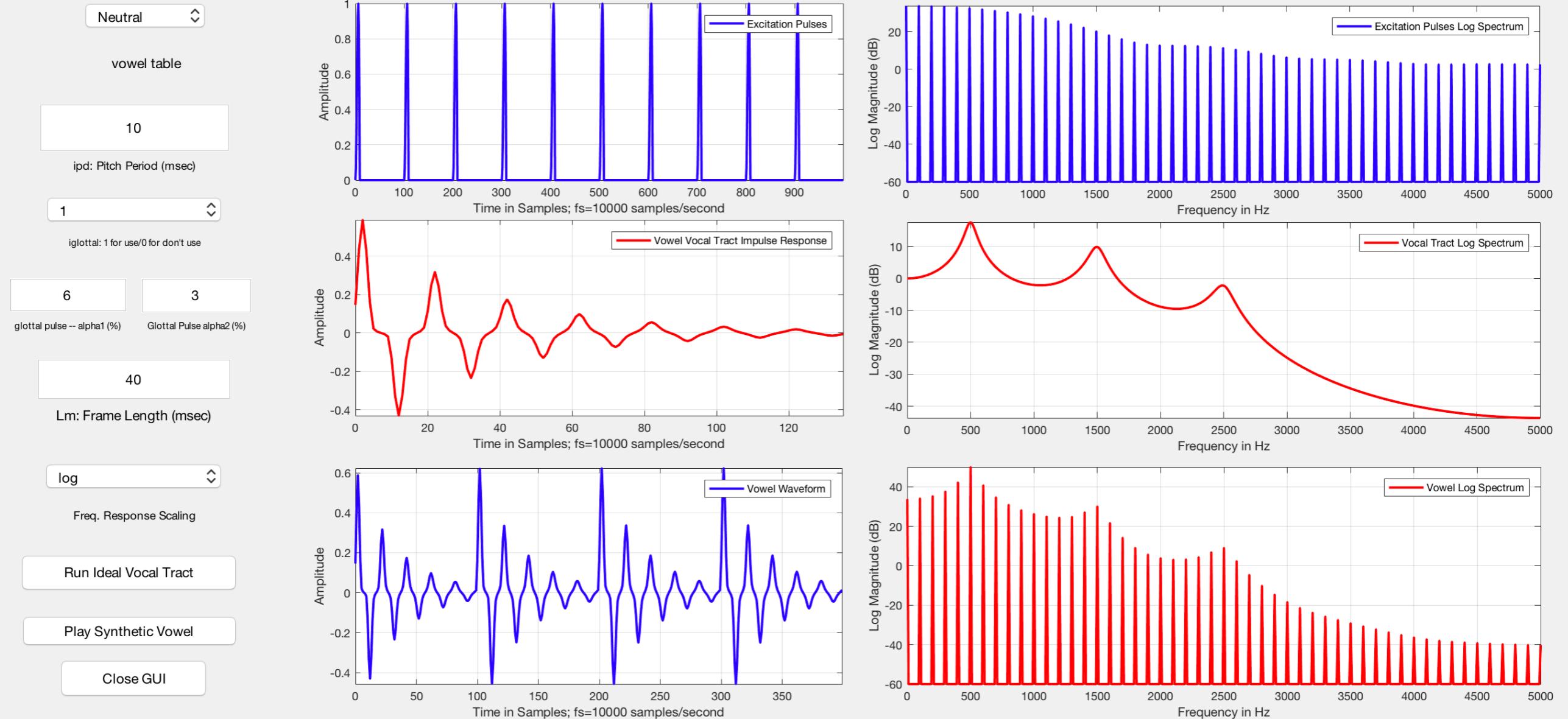
### OUTPUT SOUND



In a linear system the output sounds are the product of the source function and the filter function and will have the pressure spectra and waveforms shown below



## Ideal Vocal Tract -- Vowel:Ne, ipd:100, L:400, fs:10000, eps: 0.001



# Source-Filter Model

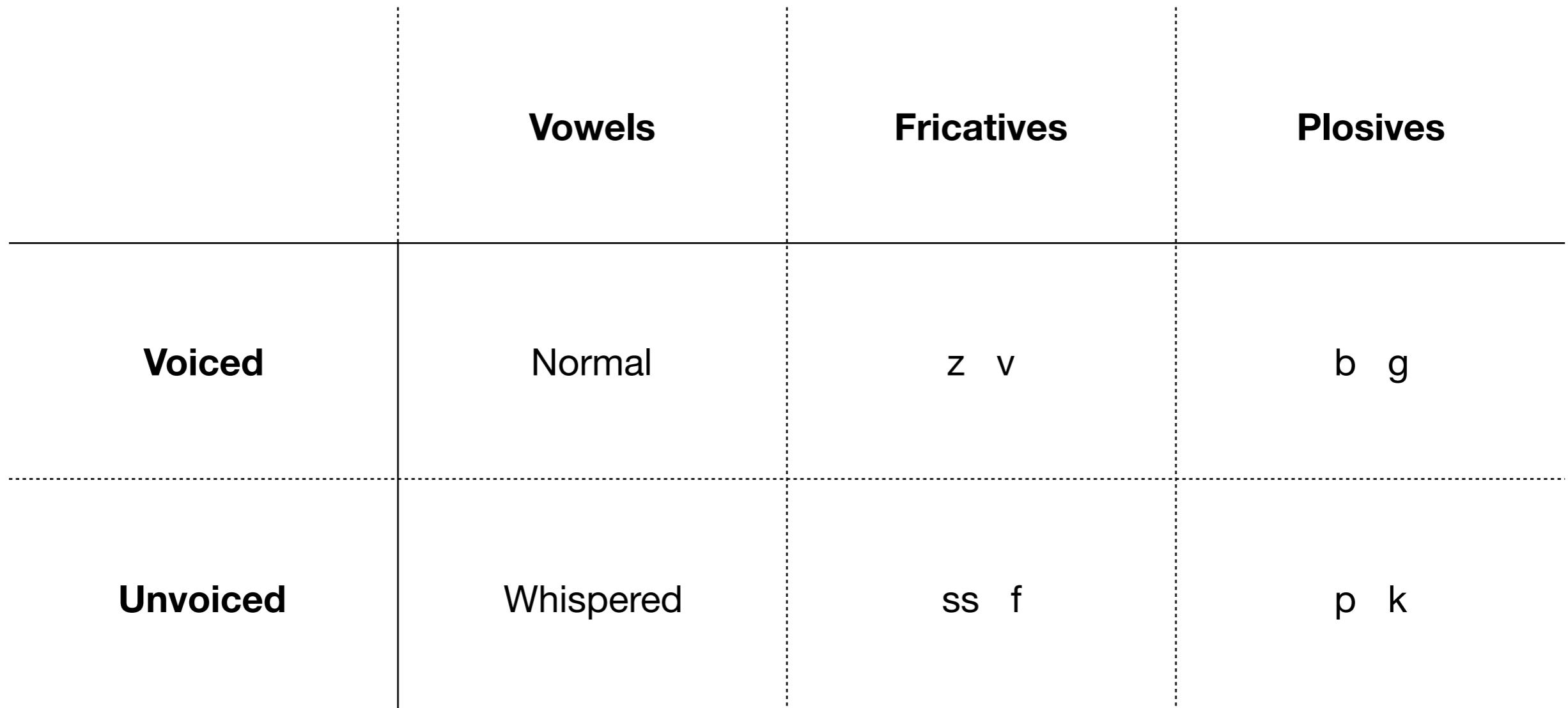
## Key Terms

- ▶ **Source**
- ▶ **Filter**
- ▶ **Resonator**
- ▶ **Formants**

# **Speech Sounds**

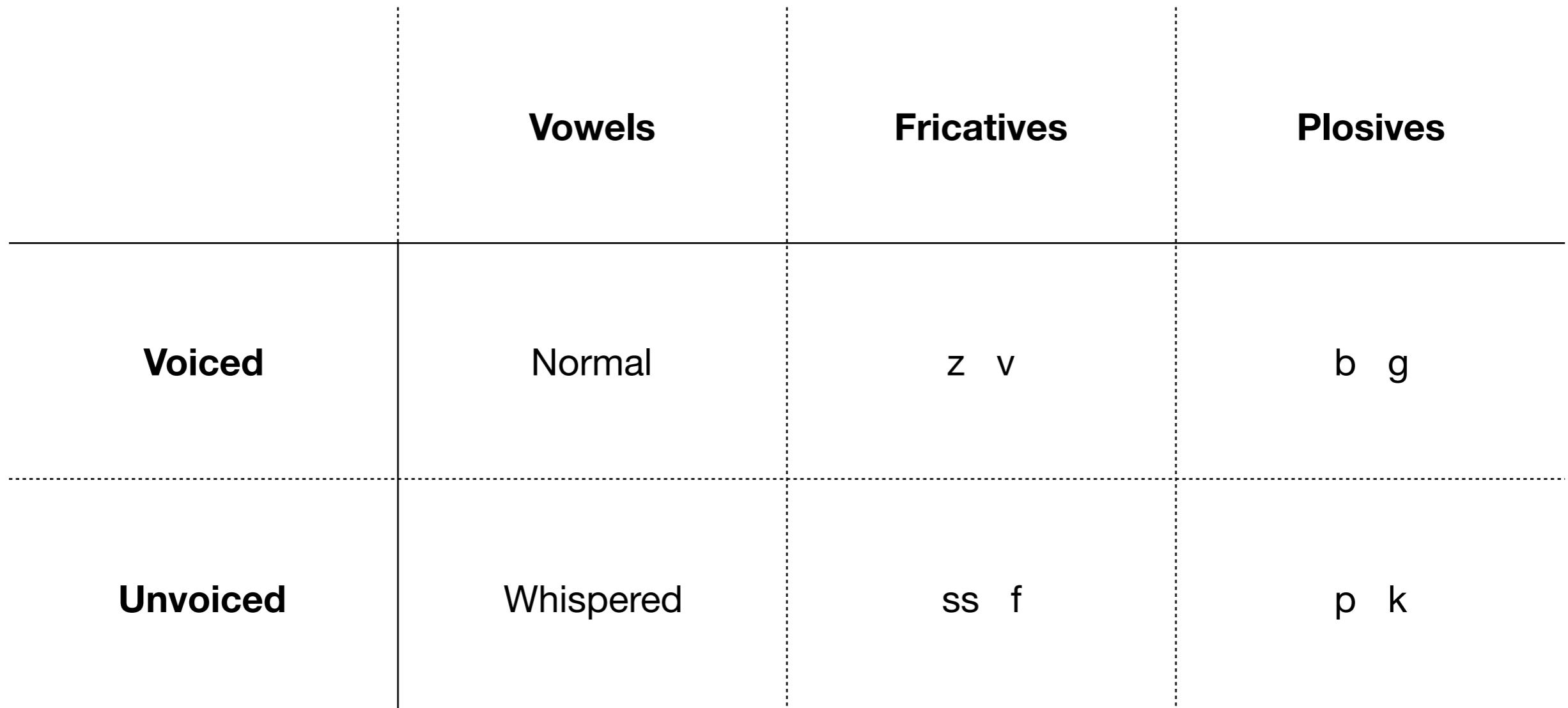
# Speech Sounds

## Types of Sounds



# Speech Sounds

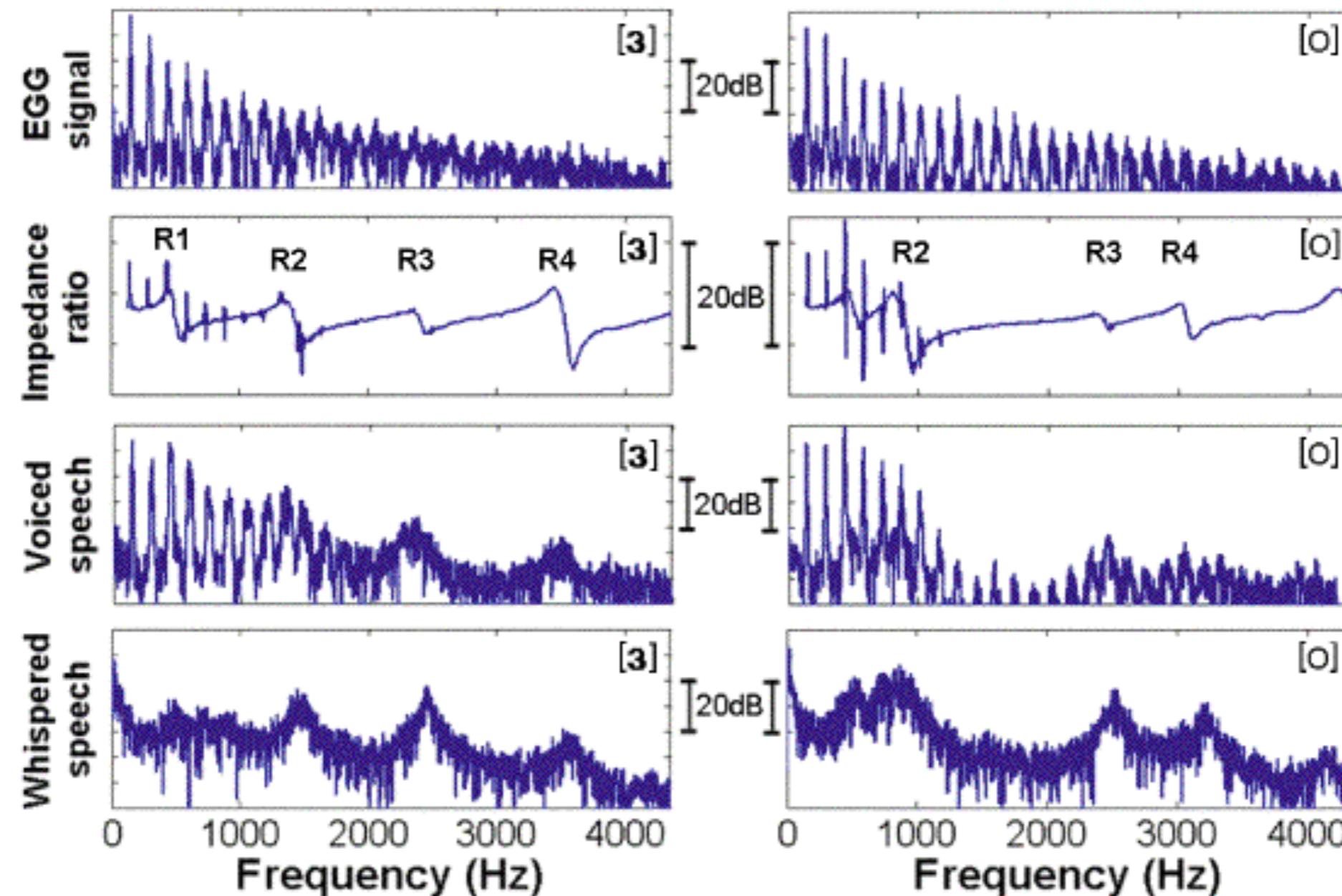
## Types of Sounds



**Voiced sentence: We were away a year, Roy**

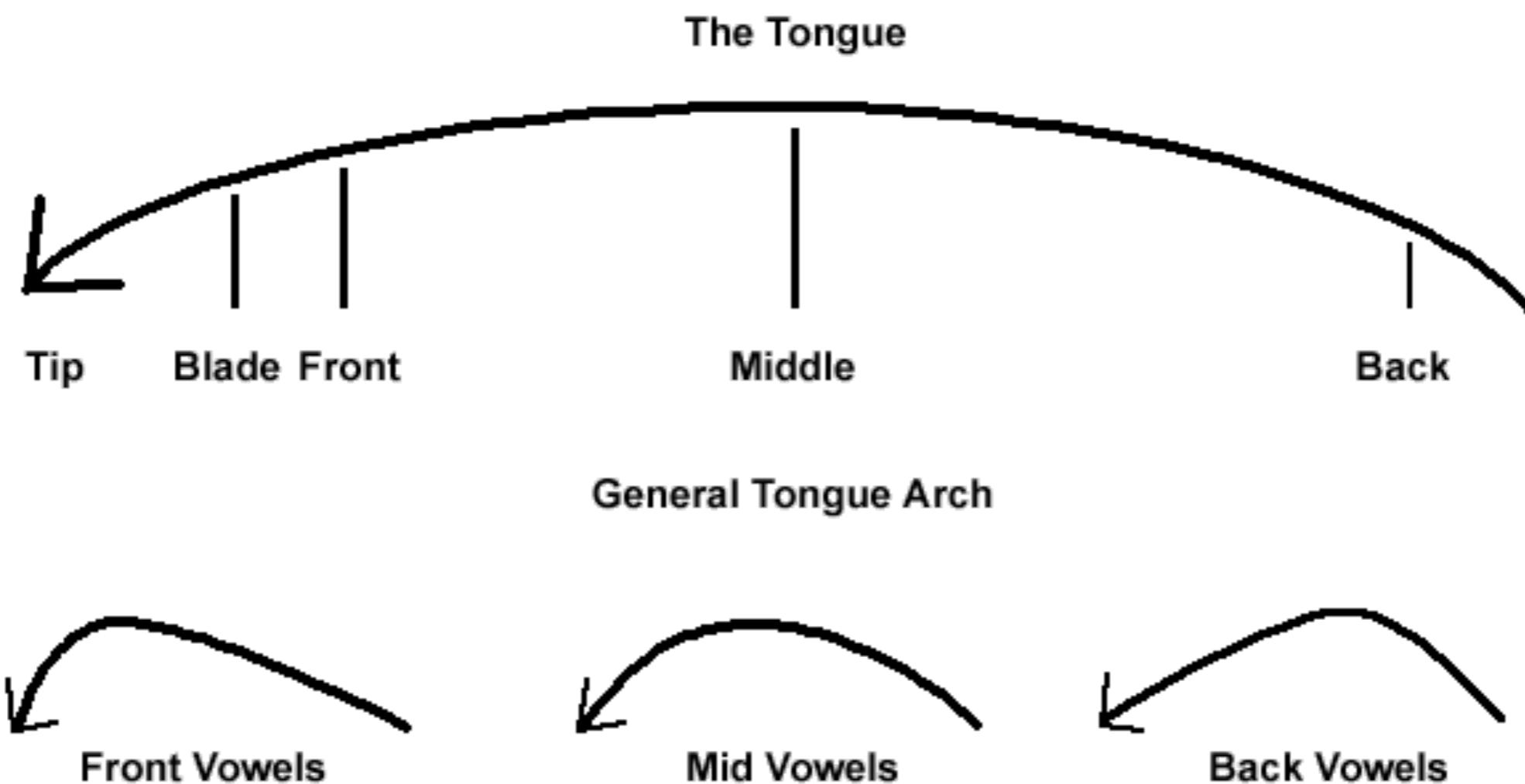
# Speech Sounds

## Types of Sounds



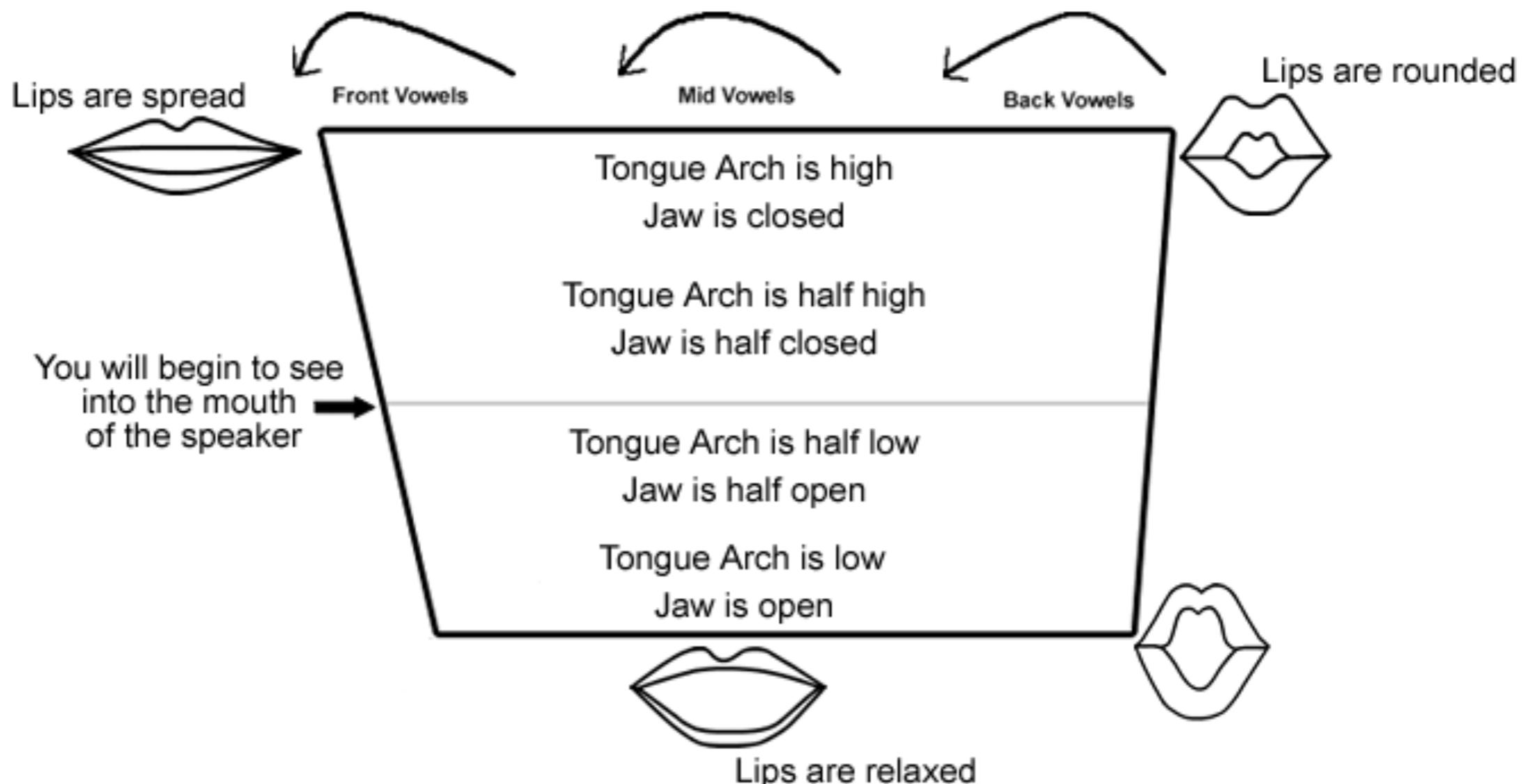
# Speech Sounds

## Tongue Positions



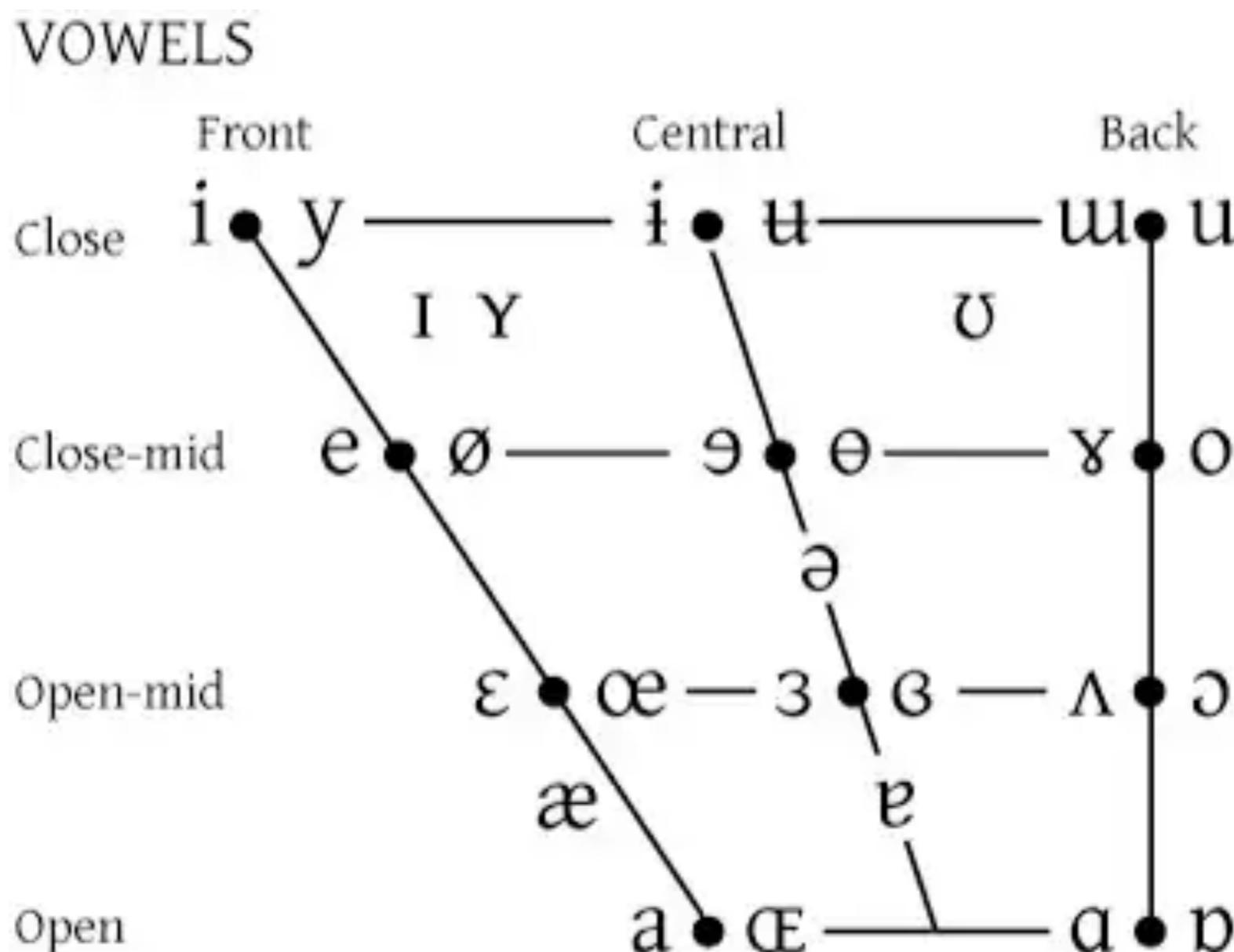
# Speech Sounds

## Vowel Chart



# Speech Sounds

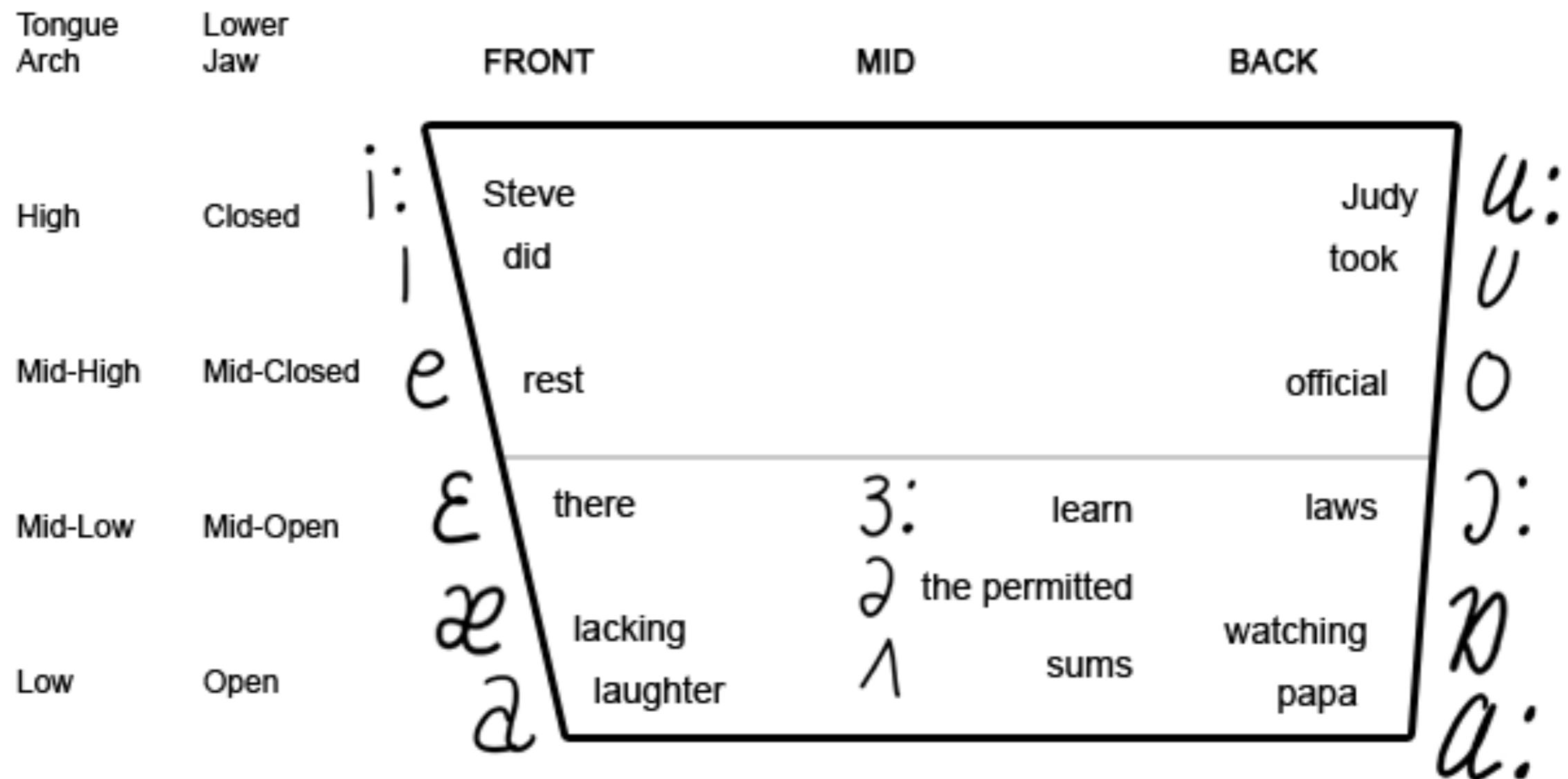
## Vowel Chart



Where symbols appear in pairs, the one to the right represents a rounded vowel

# Speech Sounds

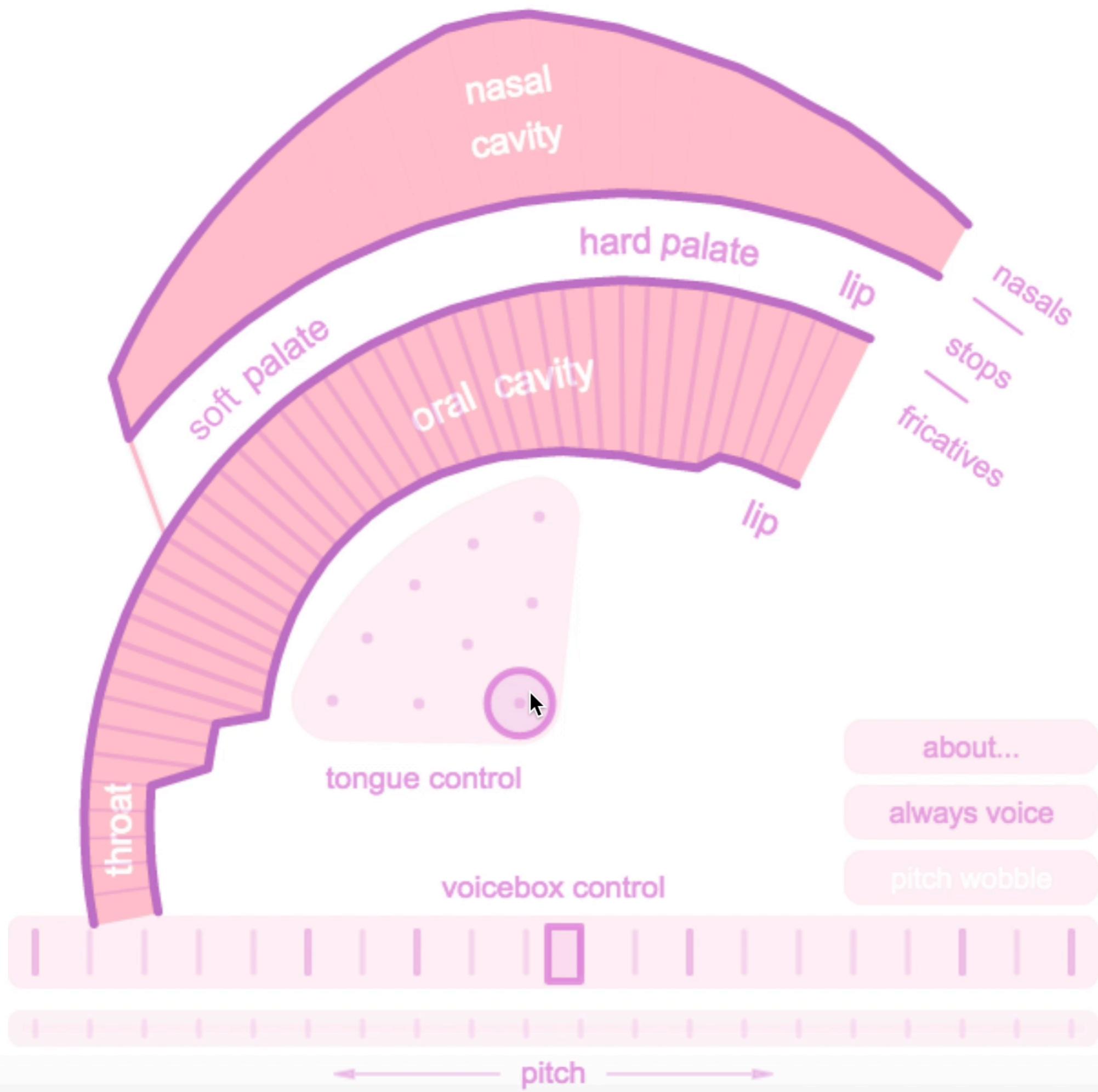
## Vowel Chart

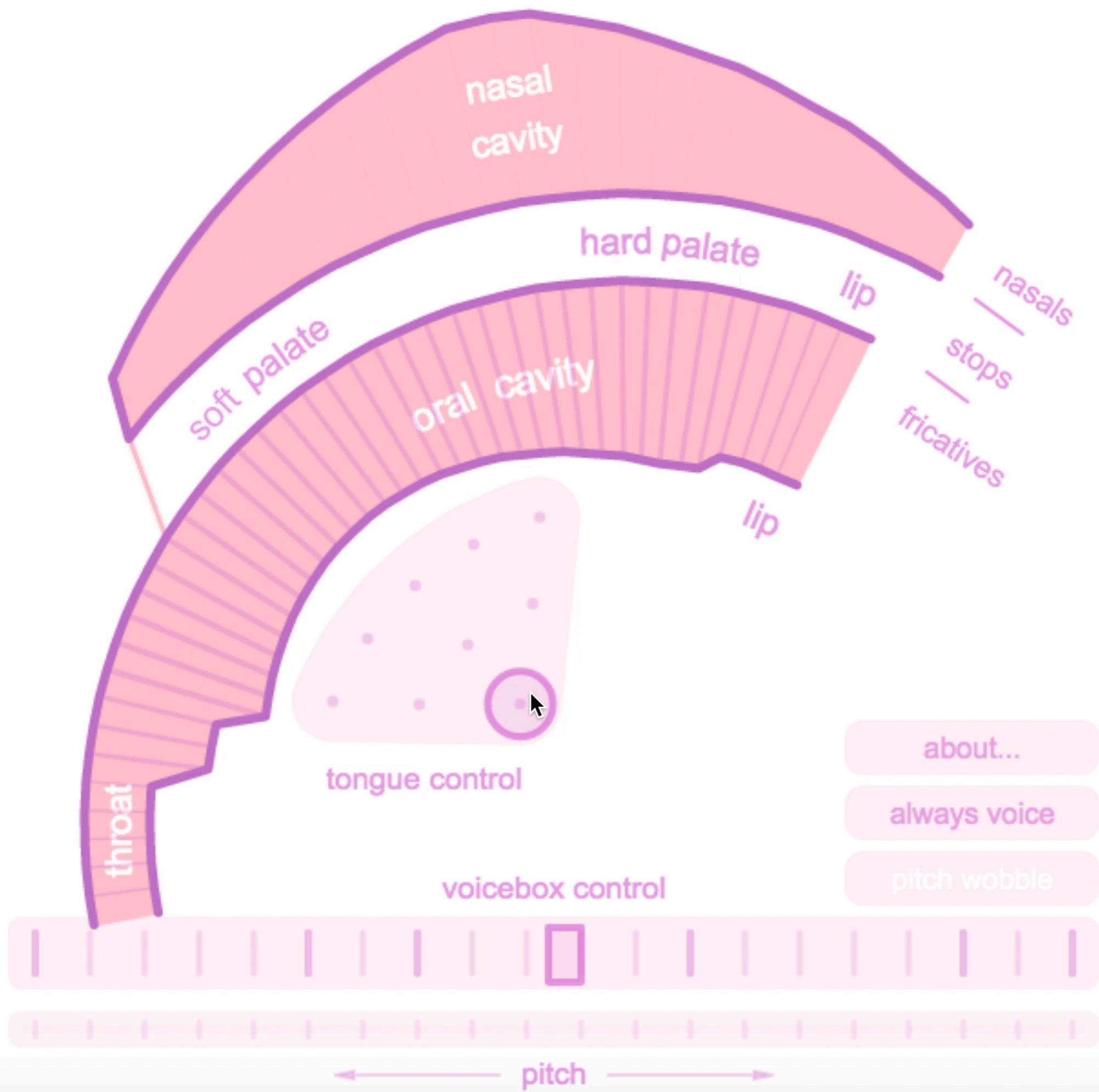


# Pink Trombone

bare-handed speech synthesis

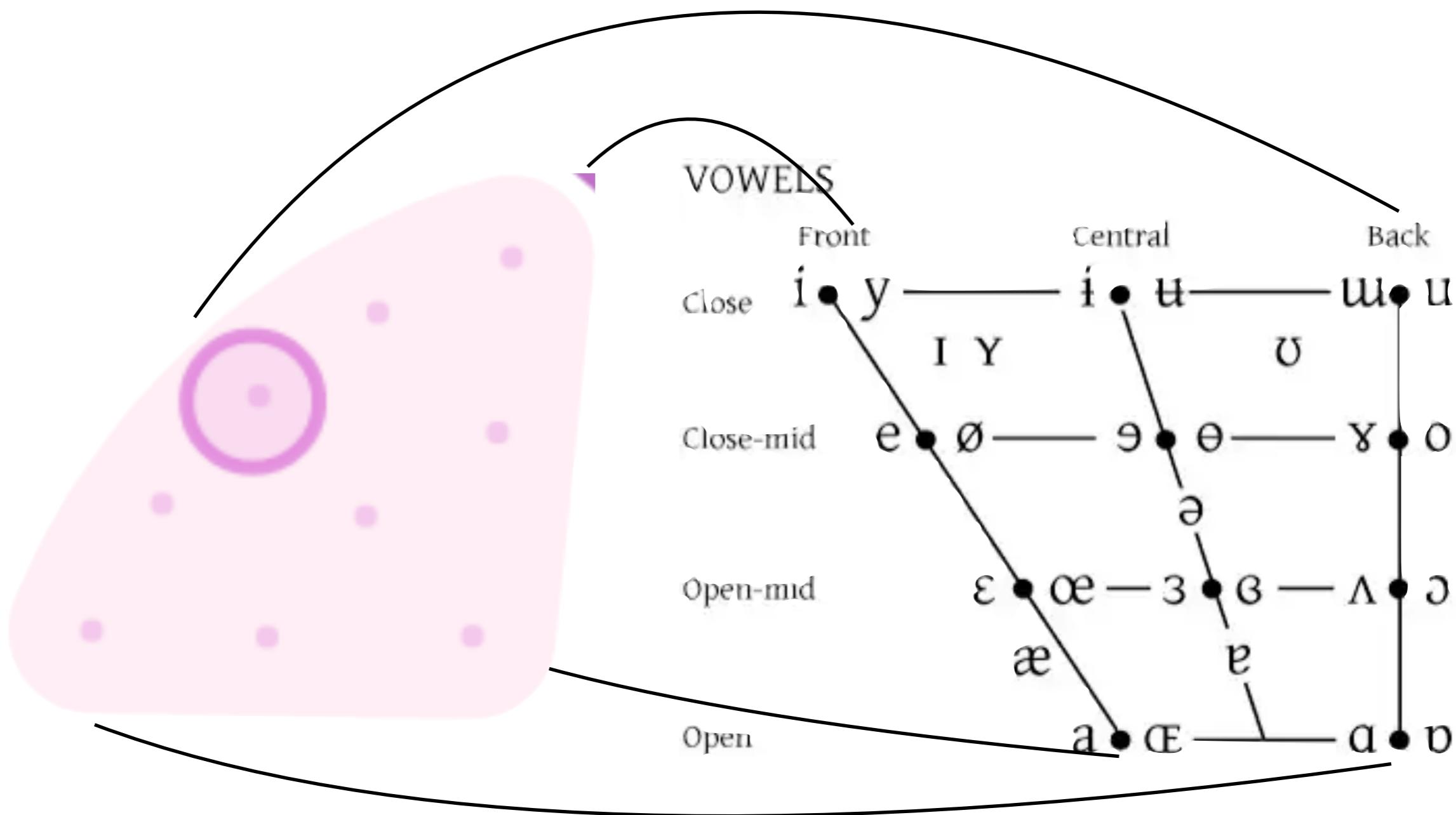


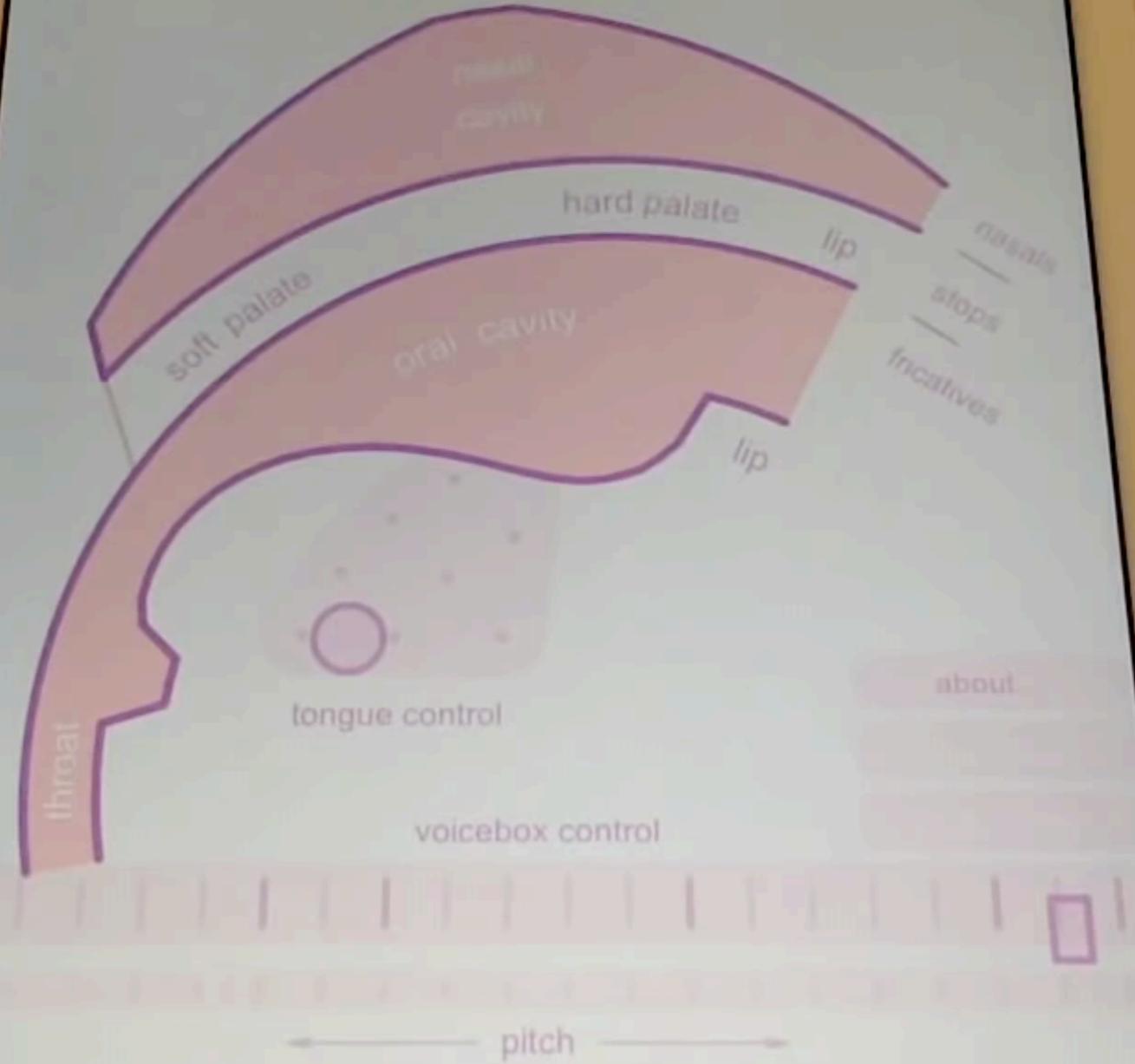


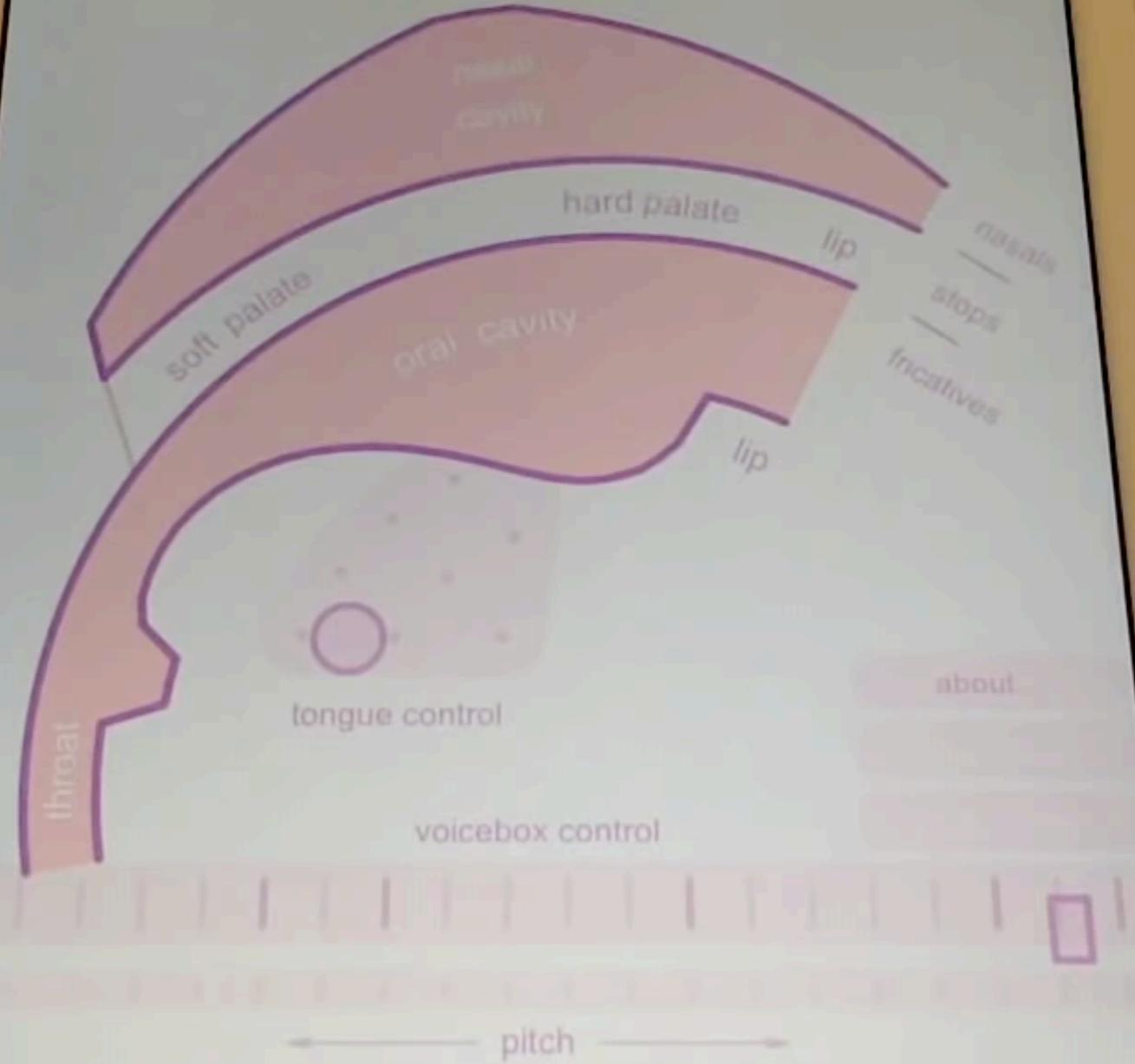


# Speech Sounds

Pink Trombone vs. vowel chart

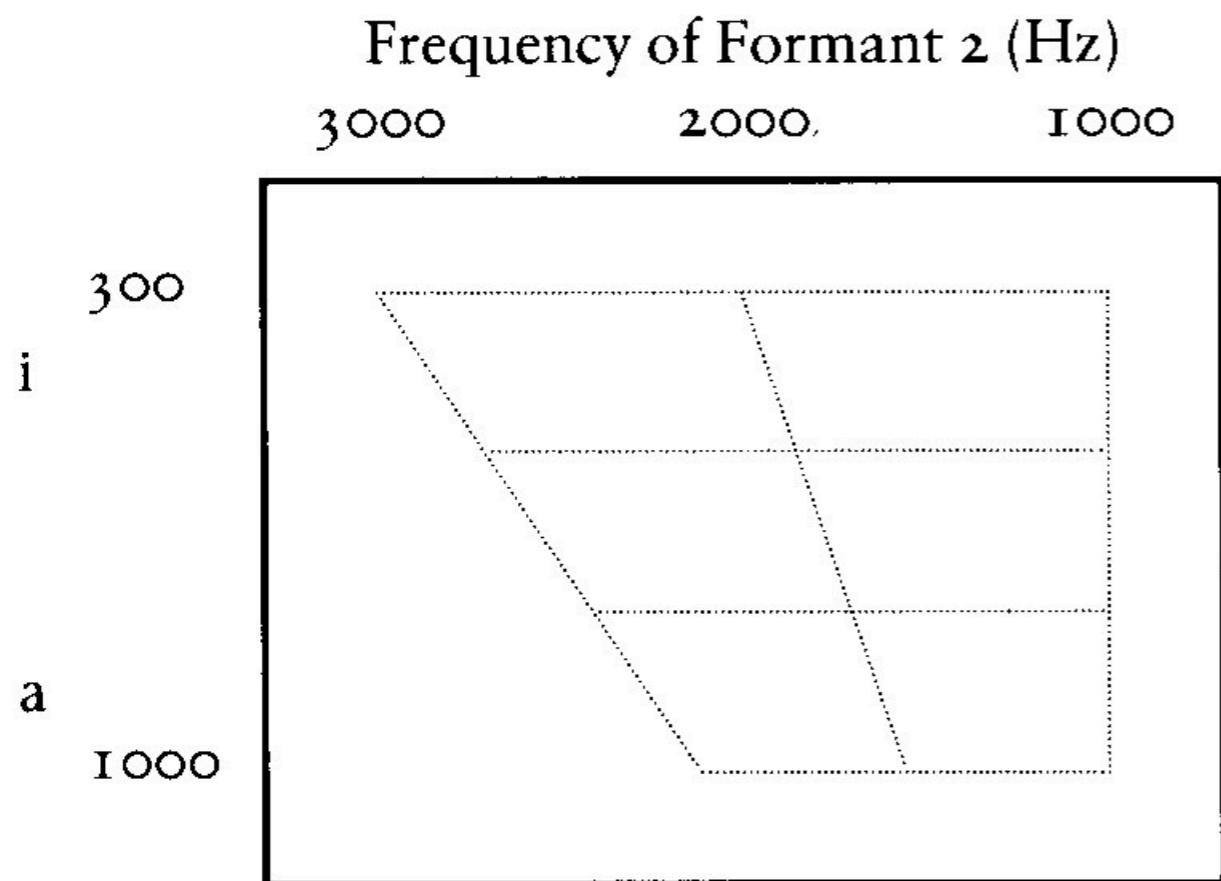




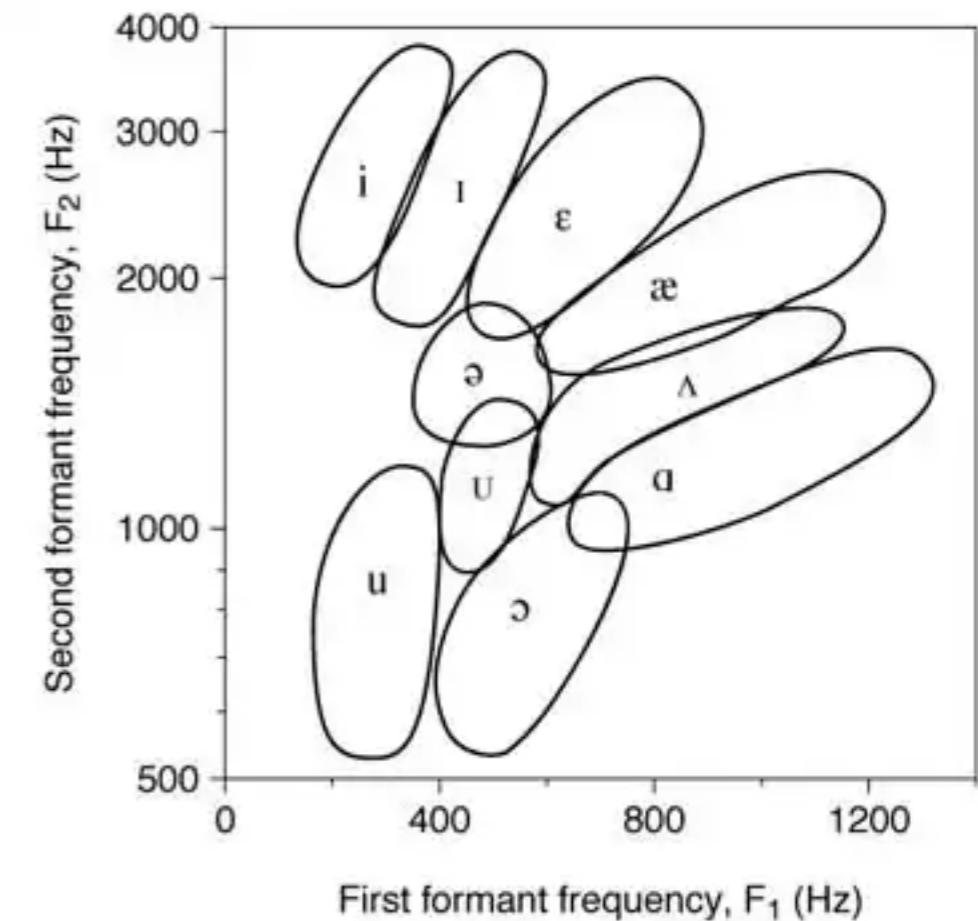


# Speech Sounds

## Vowel Chart and Formants



Frequency of Formant 1 (Hz)



19.3

5.1

1.3

323

65

1

## Spectrogram Controls

Log scale

Full color

Speed

Show labels

Number of ticks

[about](#)

19.3

5.1

1.3

323

65

1

## Spectrogram Controls

Log scale

Full color

Speed

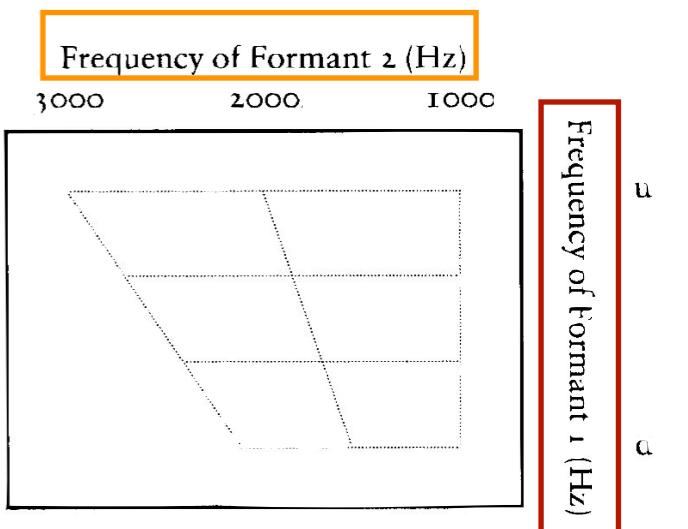
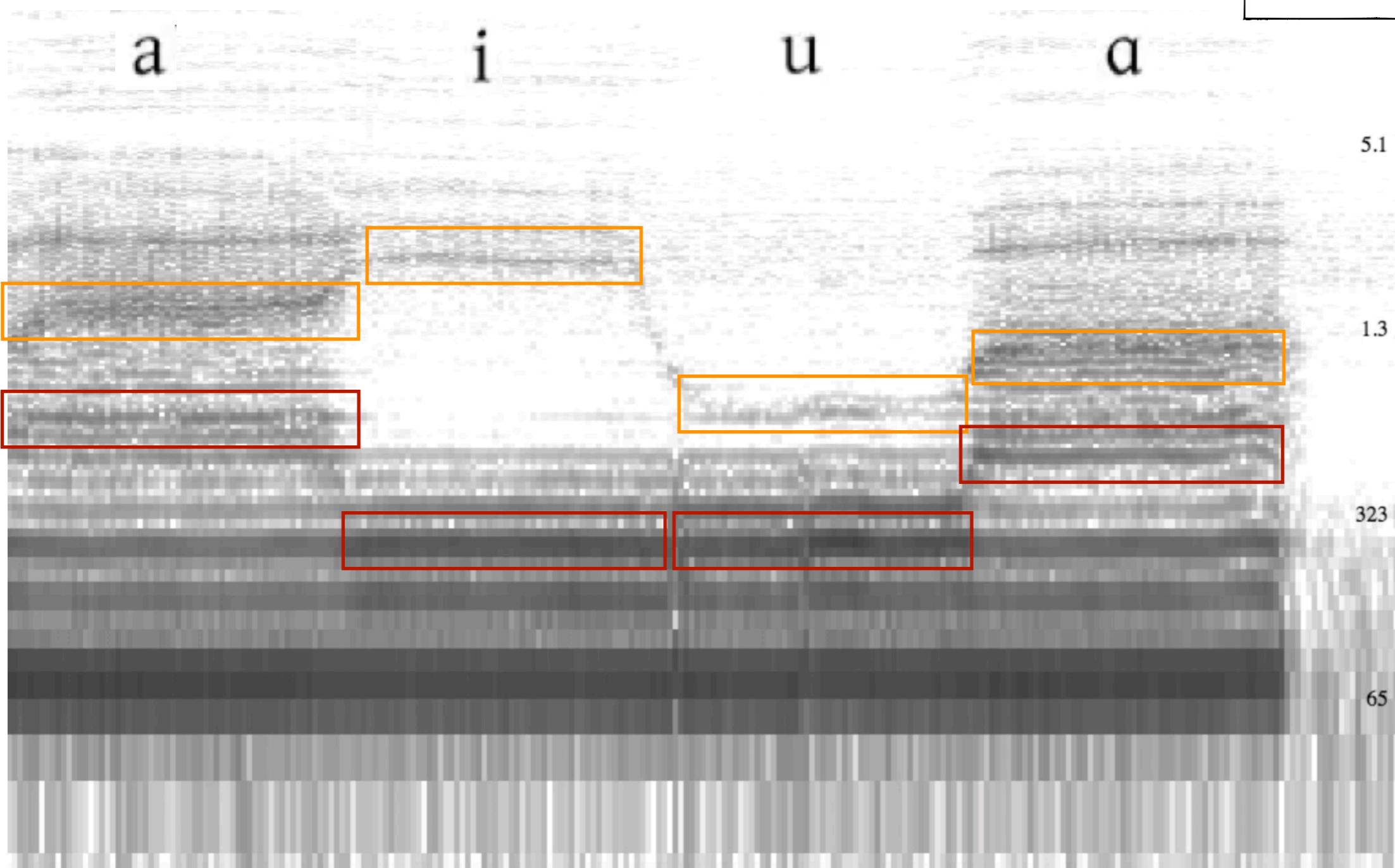
Show labels

Number of ticks

[about](#)

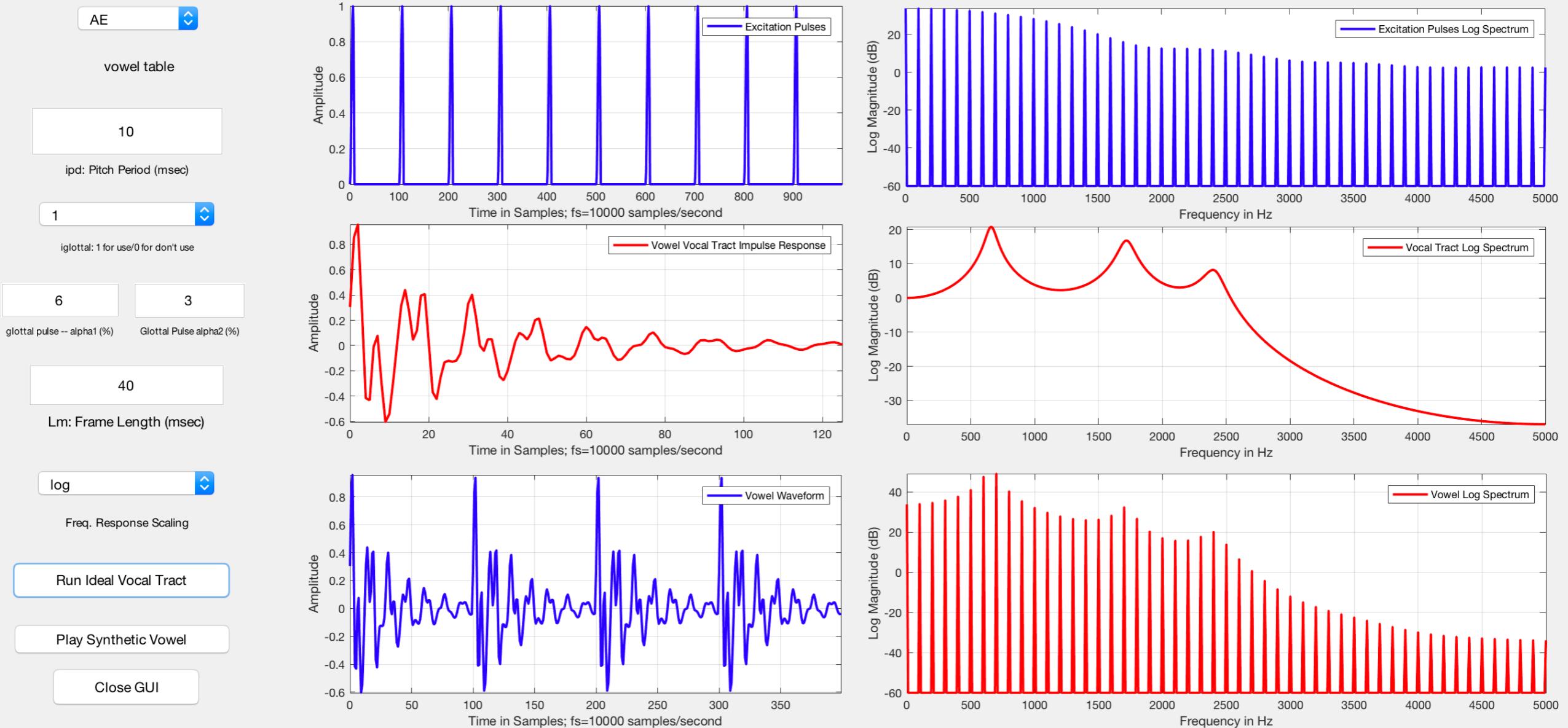
# Speech Sounds

## Vowels



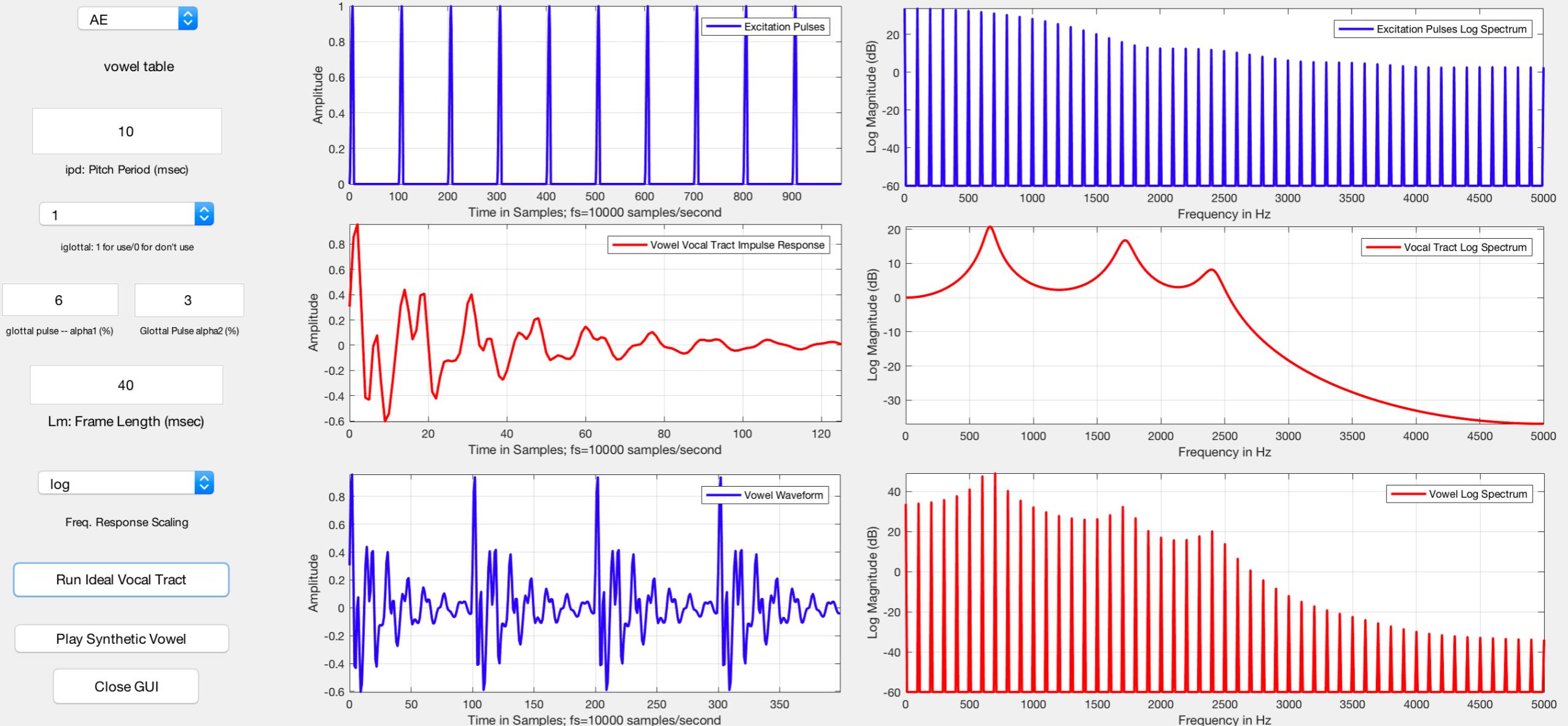
## ideal\_vocal\_tract\_GUI

Ideal Vocal Tract -- Vowel:AE, ipd:100, L:400, fs:10000, eps: 0.001



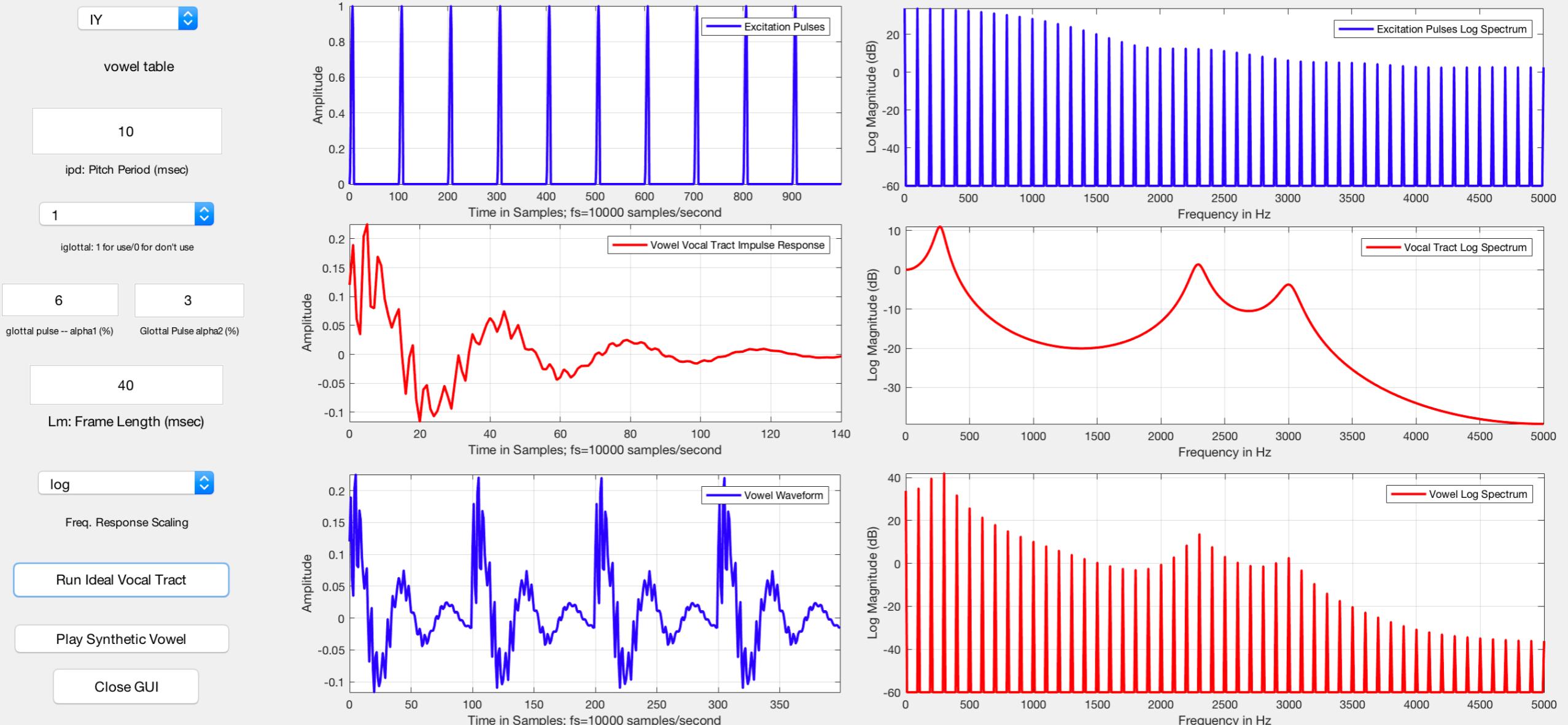
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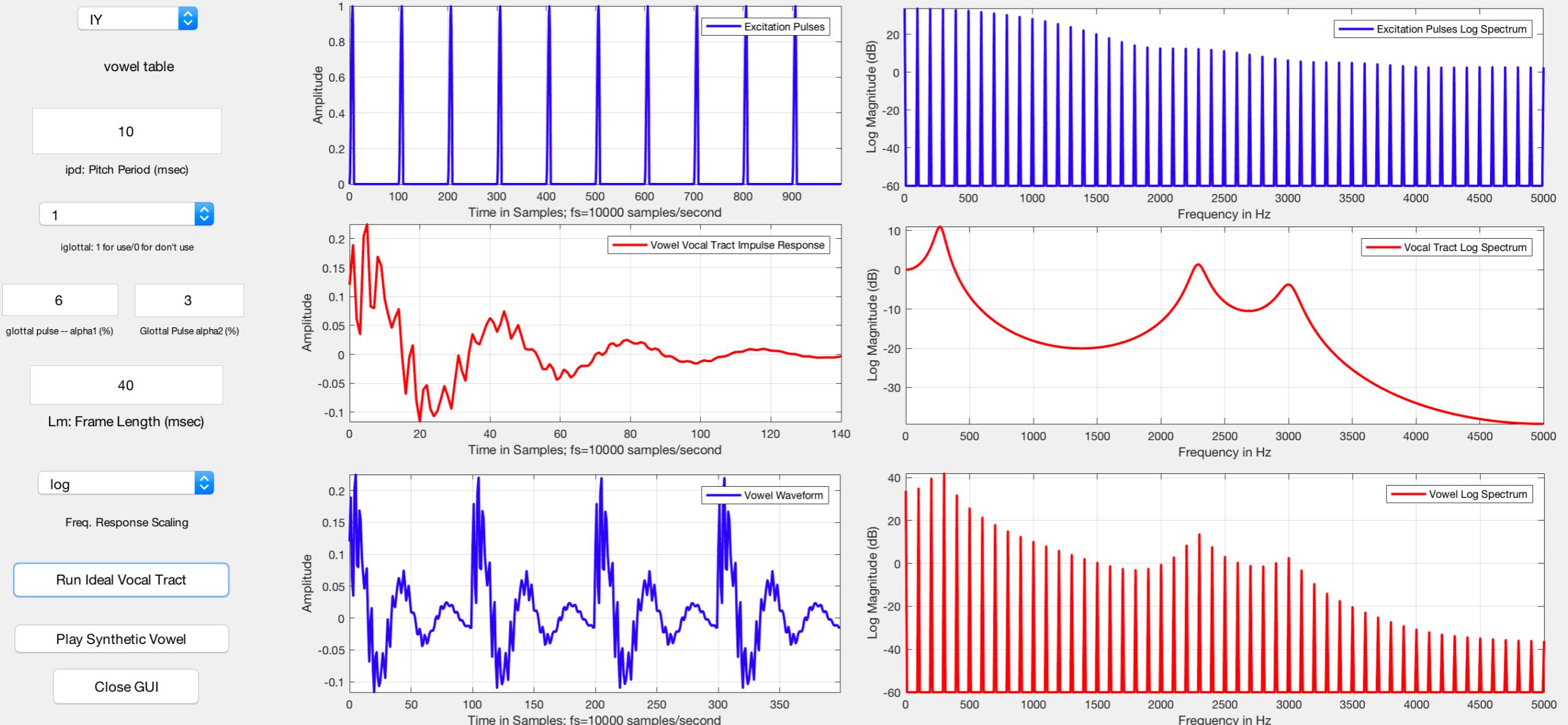
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Ideal Vocal Tract -- Vowel:IY, ipd:100, L:400, fs:10000, eps: 0.001



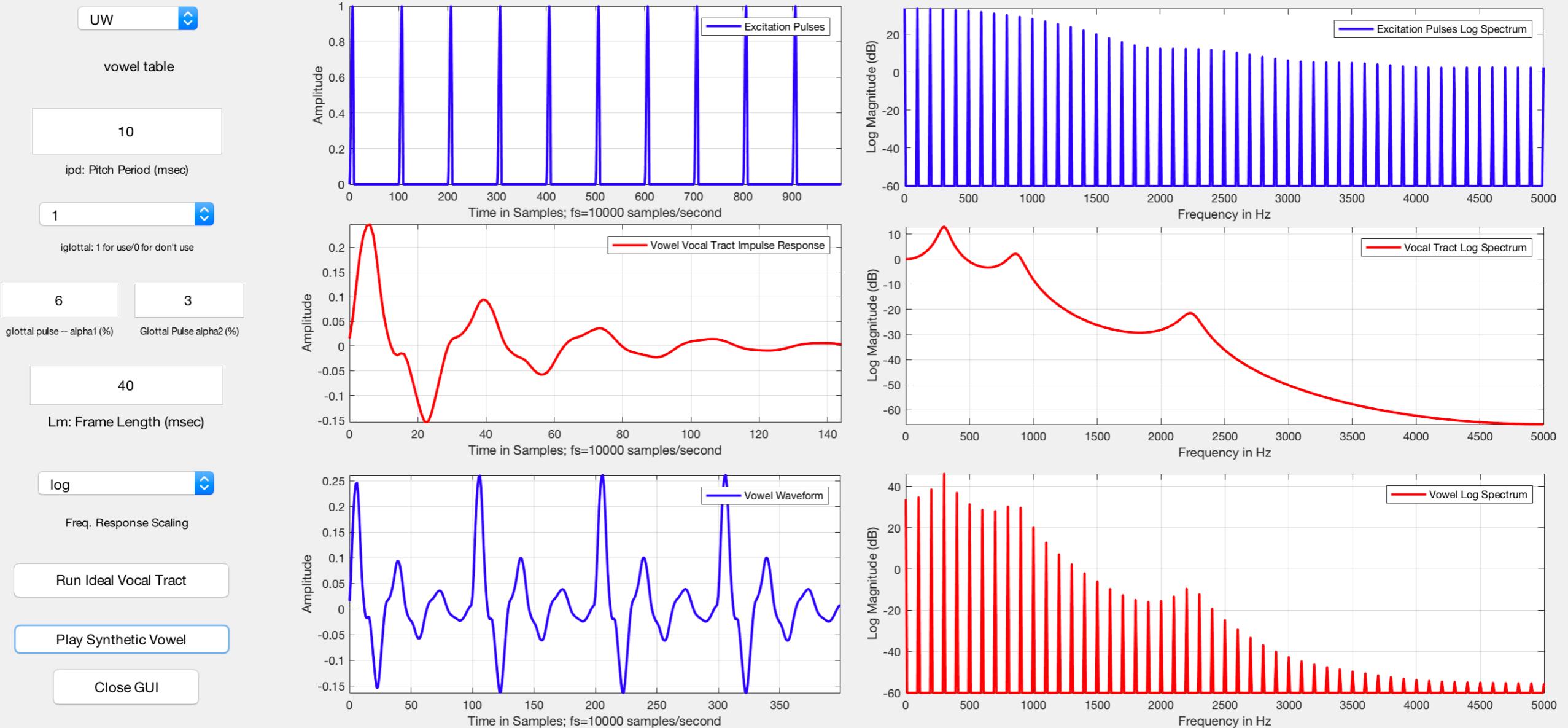
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Ideal Vocal Tract -- Vowel:IY, ipd:100, L:400, fs:10000, eps: 0.001



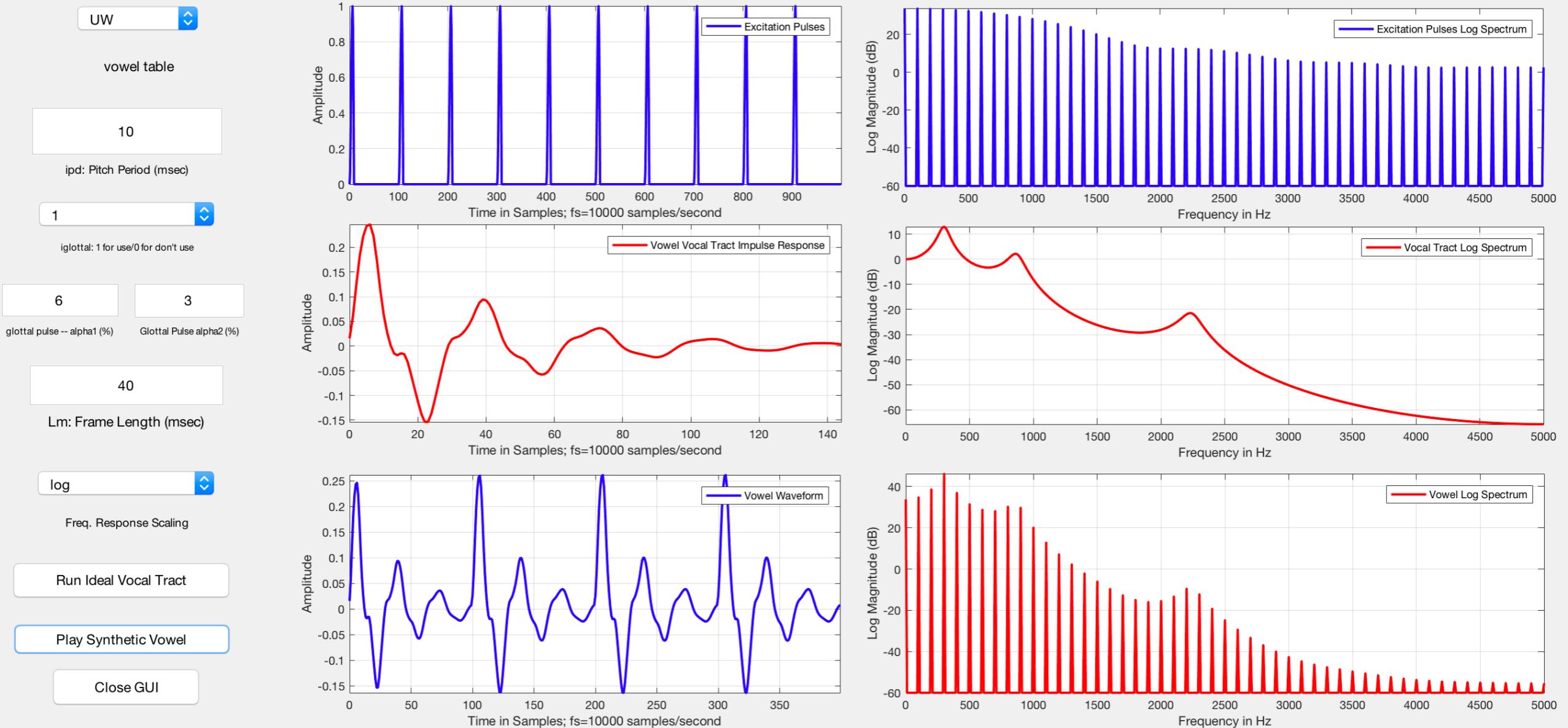
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Ideal Vocal Tract -- Vowel:UW, ipd:100, L:400, fs:10000, eps: 0.001



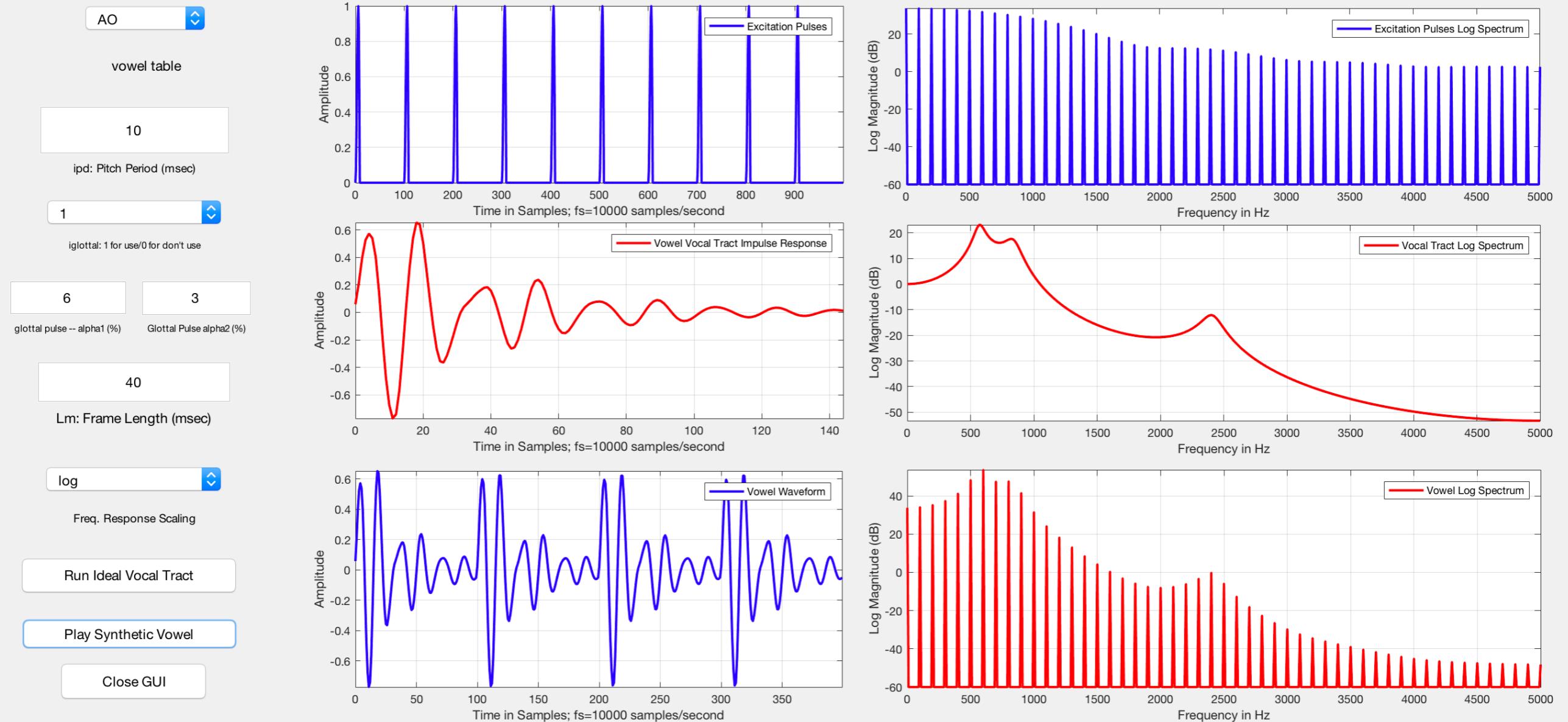
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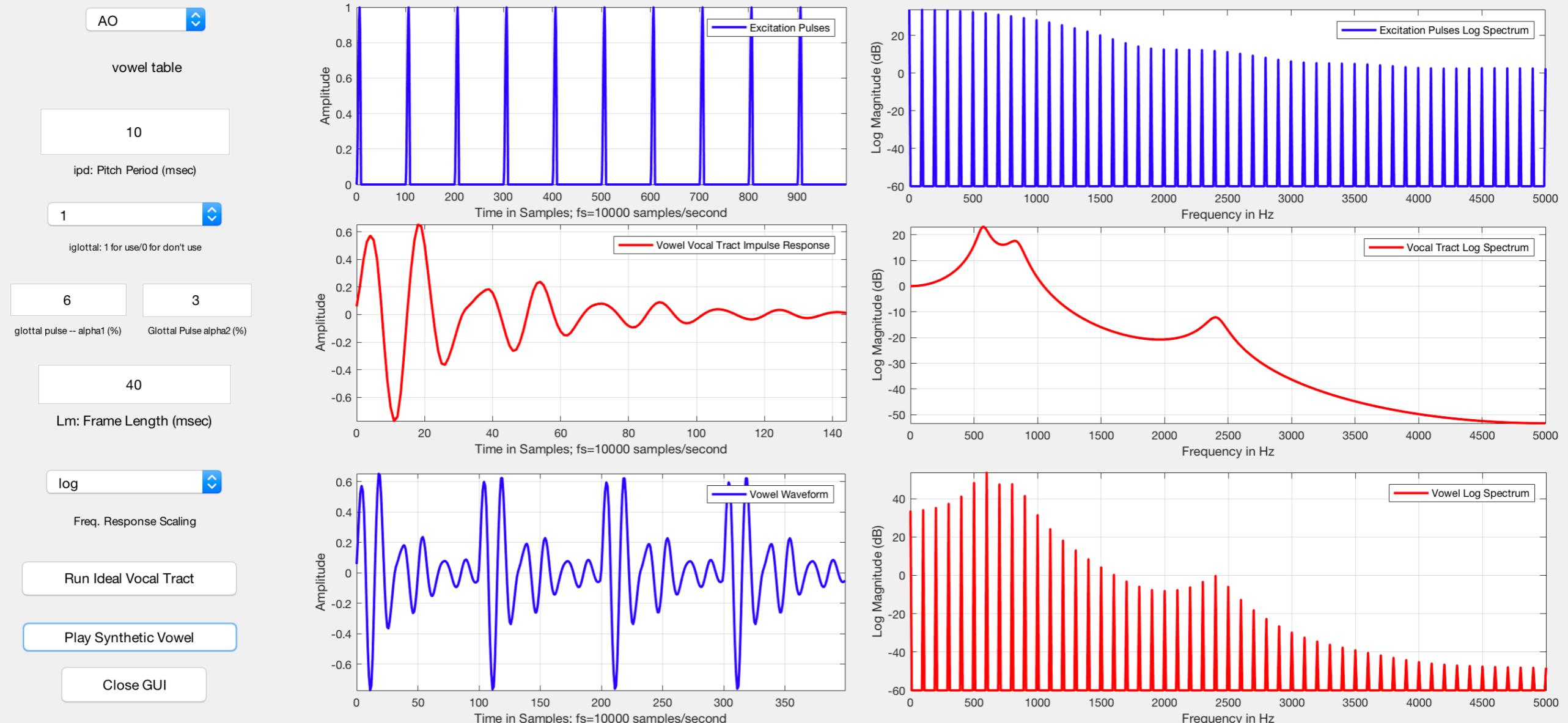
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Ideal Vocal Tract -- Vowel:AO, ipd:100, L:400, fs:10000, eps: 0.001



## ideal\_vocal\_tract\_GUI

Ideal Vocal Tract -- Vowel:AO, ipd:100, L:400, fs:10000, eps: 0.001



# Speech Sounds

## Key Terms

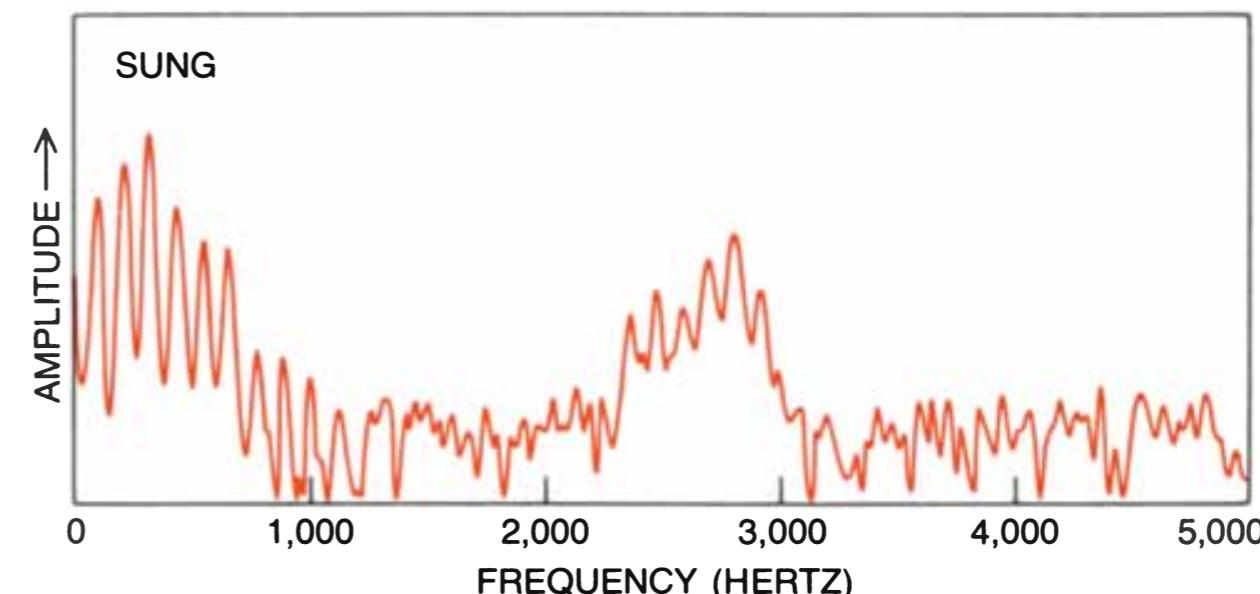
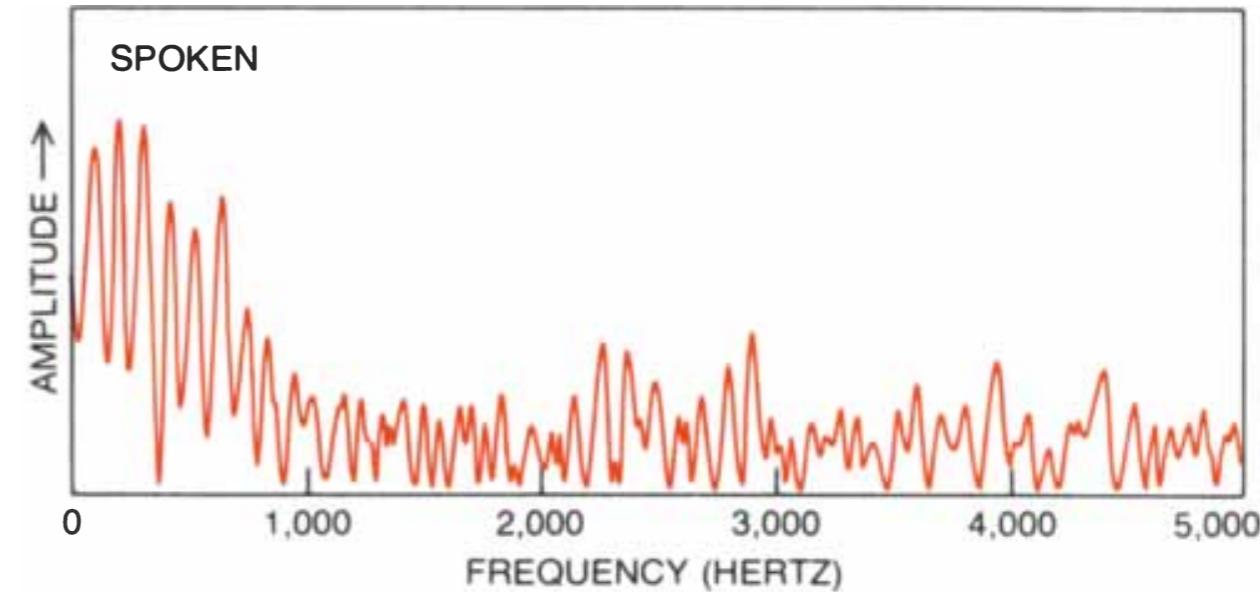
- ▶ **Voiced**
- ▶ **Unvoiced**
- ▶ **Fricatives**
- ▶ **Plosives**
- ▶ **Vowel Chart**

# **Singing**

# Singing

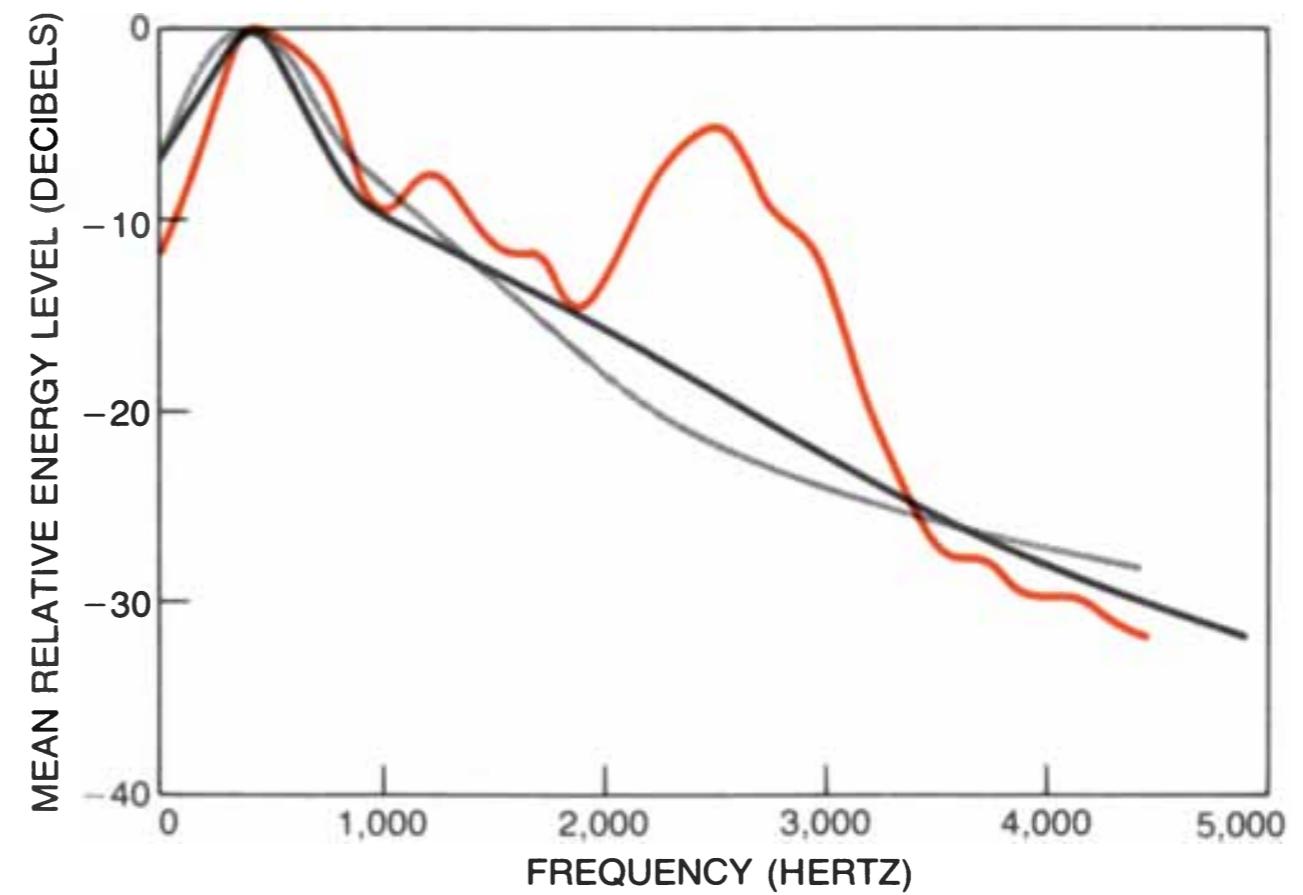
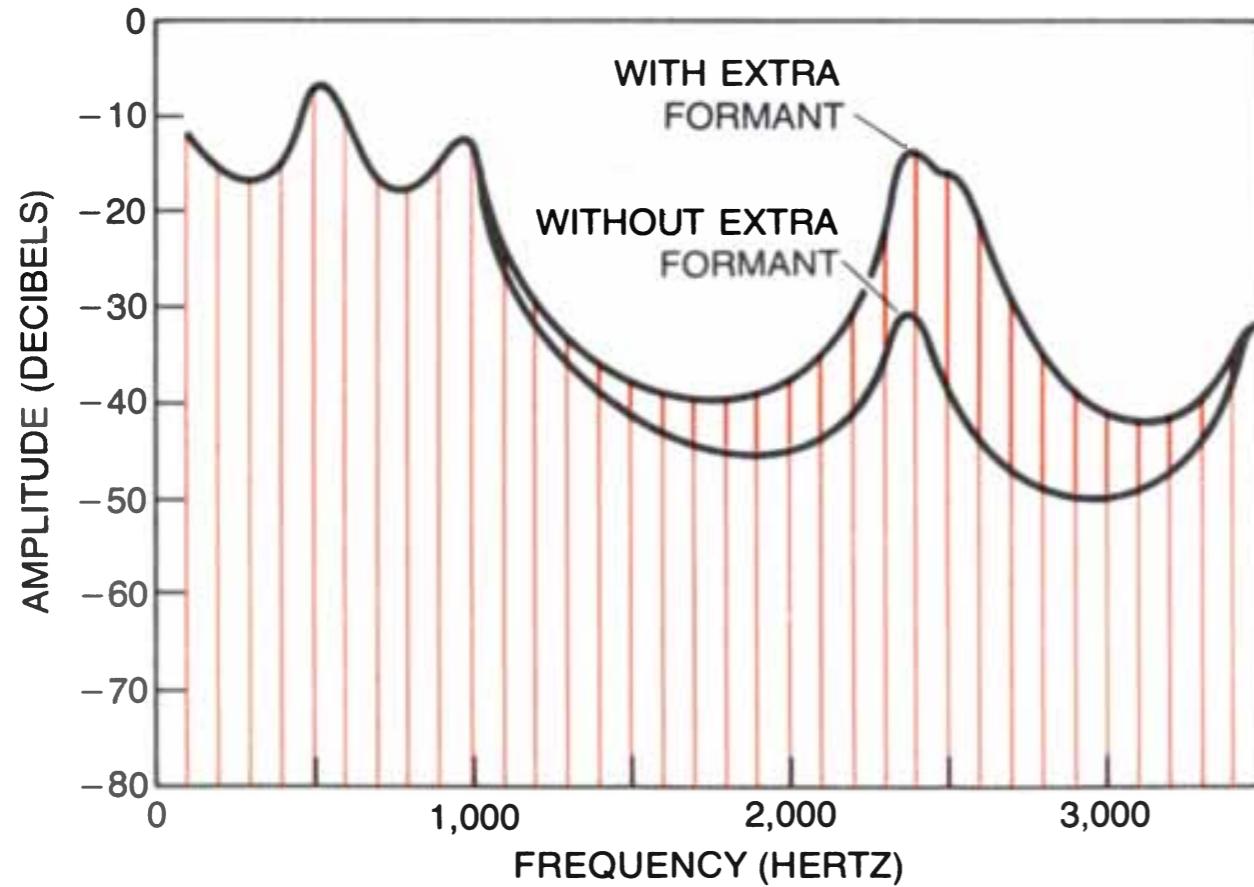
## Singing versus Speech

- ▶ **F0 Range**
  - ▶ **Speech: 100–400 Hz**
  - ▶ **Singing: 60–1500 Hz**
- ▶ **Spectral Energy**
  - ▶ **Boost between 2 and 3 kHz in singing**



# Singing

## Singer's Formant



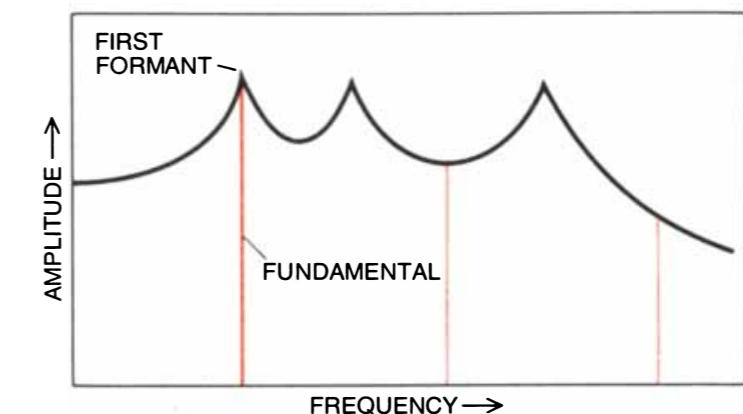
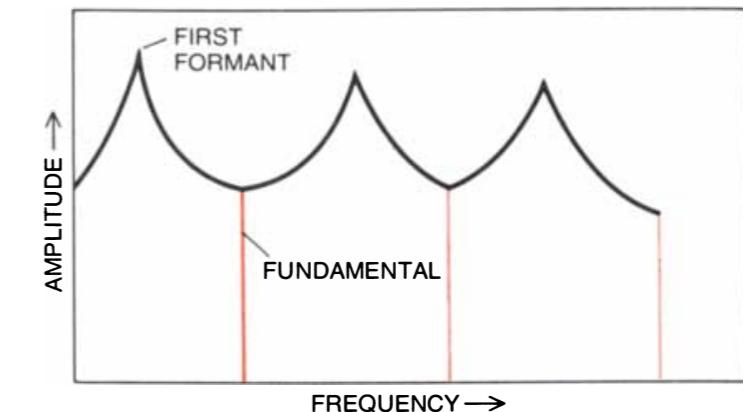
**Amplitude boost between the 3rd and 4th formants  
Allows singers to project over orchestra**

# Singing

## Mouth/Jaw Opening



**Singers tend to open mouth wider as they sing higher pitches**



**Wider jaw opening raises the pitch of the 1st formant**

# Cantor Digitalis – LIMSI-CNRS

[License](#)[Help](#)

## 1 Control Type

Vocalic Rectangle  
(for graphic tablet)

Vocalic Axis  
(for graphic tablet)

Demo  
(for mouse and keyboard)

## 2 Vertical Control

Vocal Effort

## 3 Voice Type

Noisy Soprano

Child 1

Soprano

Child 2

Noisy Alto

Baby

Alto

Extreme Voice 1

Tenor

Extreme Voice 2

Bass

Extreme Voice 3

Bulgarian Style (Woman)

[Advanced Settings](#)



## Options

[Pedagogic Voice Factory](#)

[Manual Tuning](#)

[Send Data](#)

## Accuracy Correction

Contact Correction  
(On)

Trajectory Correction  
(On)

[Advanced Setting](#)

[Demo Mapping](#)

## Audio Setup

Sound On / Off



Reverb Level

0 1 2 3 4

[Reverb \(advanced\)](#)

[Audio Status](#)

[Quick Record](#)

Control without tablet

Control the vocal source with your mouse: Control  
 - Horizontal position: pitch  
 - Vertical position: vocal effort

100% □ m X ▶ +

# Cantor Digitalis — LIMSI-CNRS

License Help

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Tenor	Extreme Voice 2
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Bulgarian Style (Woman)	
Advanced Settings	

**Options**

Pedagogic Voice Factory      Manual Tuning      Send Data

**Audio Setup**

Sound On / Off      Reverb Level (0-4)      Reverb (advanced)      Audio Status      Quick Record

**Accuracy Correction**

Contact Correction (On)      Trajectory Correction (On)      Advanced Setting      Demo Mapping

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Advanced Settings



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(On)Trajectory Correction  
(On)

Advanced Setting

Demo Mapping

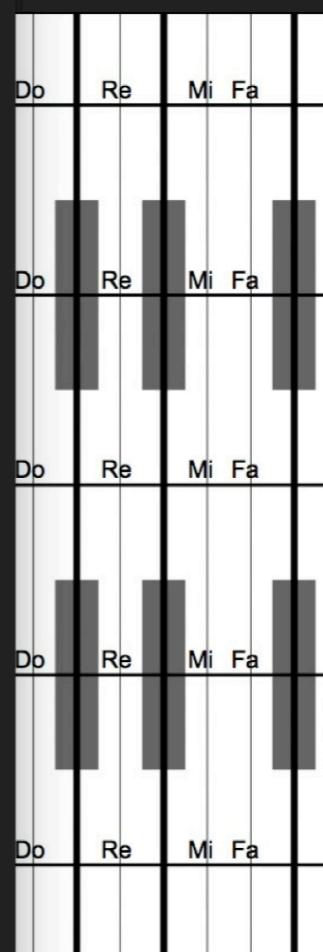
board:  
/a/, /e/, /u/, /i/, /o/, /y/

Change the size of the control window:

- Horizontal size:



Default Size



# Cantor Digitalis – LIMSI-CNRS

License

Help

## 1 Control Type

Vocalic Rectangle  
(for graphic tablet)Vocalic Axis  
(for graphic tablet)Demo  
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Contact Correction  
(On)Trajectory Correction  
(On)

Advanced Setting

Demo Mapping

### Audio Setup

Sound On / Off



Reverb Level

0 1 2 3 4

Reverb (advanced)

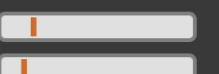
Audio Status

Quick Record

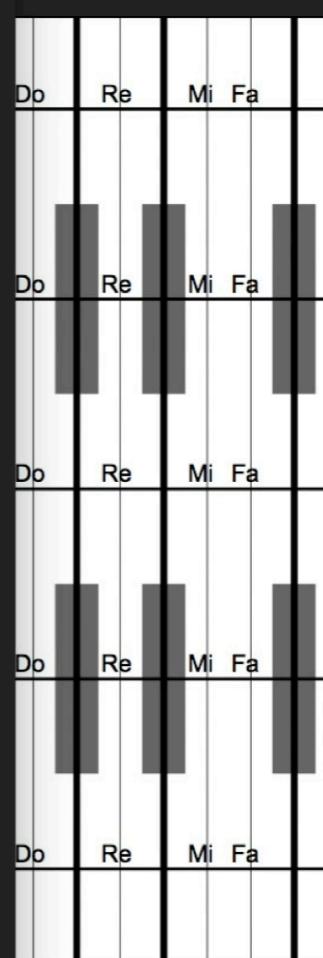
board:  
/a/, /e/, /u/, /i/, /o/, /y/

Change the size of the control window:

- Horizontal size:

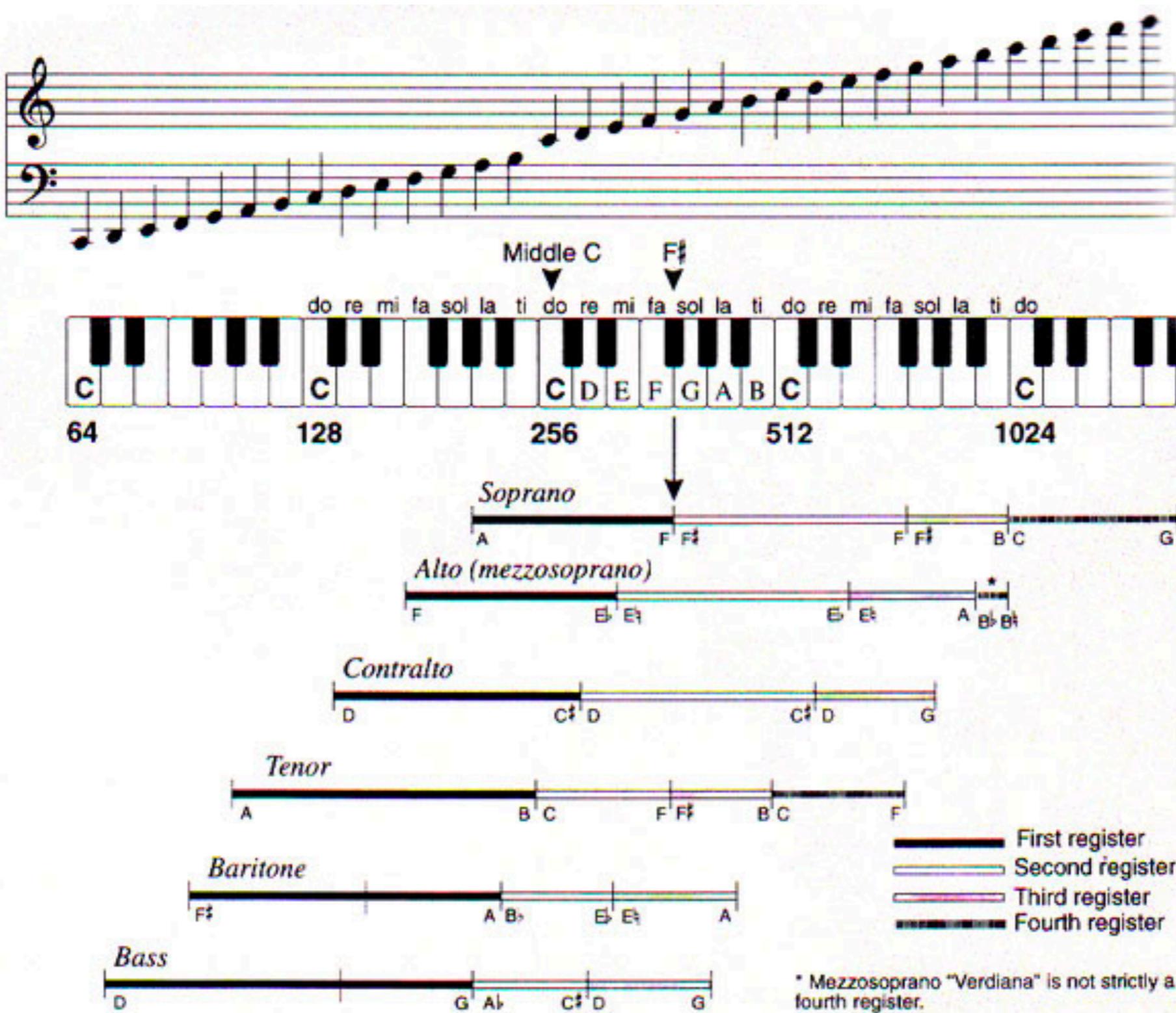


Default Size



# Singing

## Registers



# Singing

## Mechanisms

<b>Mechanism 0 (M0)</b>	<b>Creak/Vocal Fry: Vibration is not periodic</b>
<b>Mechanism 1 (M1)</b>	<b>Chest: (Almost) all of vocal folds vibrate, low-medium pitches</b>
<b>Mechanism 2 (M2)</b>	<b>Head/Falsetto: 2/3 length of vocal folds, opening is longer than closing, medium-high pitches</b>
<b>Mechanism 3 (M3)</b>	<b>Flageolet/Whistle: little studied</b>





# Singing

## Terms to Remember

- ▶ **Singer's Formant**
- ▶ **Mechanism/Register**

# Software

- ▶ **Ideal Vocal Track Model (MATLAB)**
  - <https://www.mathworks.com/matlabcentral/fileexchange/45317-ideal-vocal-tract>
- ▶ **Pink Trombone (Online, JavaScript)**
  - <https://dood.al/pinktrombone/>
- ▶ **Boris Mus' Spectrogram (Online)**
  - <https://borismus.github.io/spectrogram/>
- ▶ **Cantor Digitalis (MAX)**
  - <https://cantordigitalis.limsi.fr/>

# Additional Resources

- ▶ Chen, C. J. (2017). *Elements of human voice*. World Scientific.
- ▶ Sundberg, J. (1977). The acoustics of the singing voice. *Scientific American*.
- ▶ Sundberg, J. (1989). *The science of the singing voice*. Northern Illinois University Press

# Additional Resources

- ▶ **National Center for Voice and Speech**  
<http://www.ncvs.org/>
- ▶ **Speech, Hearing and Phonetic Sciences,  
University College London**  
<http://www.phon.ucl.ac.uk/courses/spsci/expphon/index.php>
- ▶ **Voice Acoustics, University of New South Wales**  
<https://newt.phys.unsw.edu.au/jw/voice.html>  
<http://www.animations.physics.unsw.edu.au/jw/voice.html>
- ▶ **Voice Foundation**  
<http://voicefoundation.org/>