

# Acoustic Phonetics

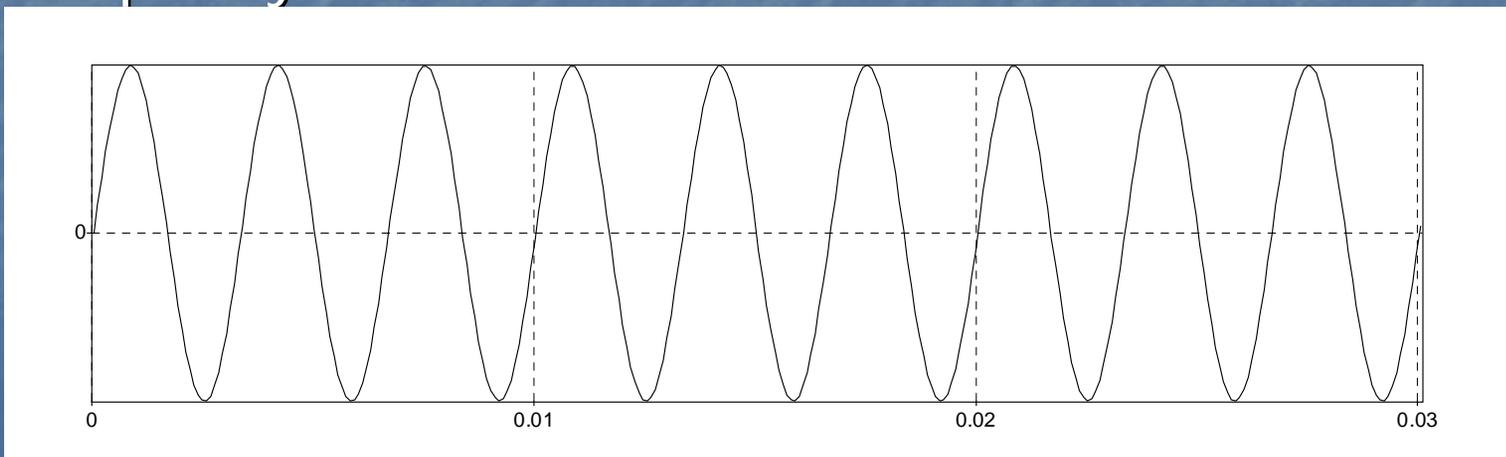
## Chapter 8

# 1. Sound waves

Vocal folds:

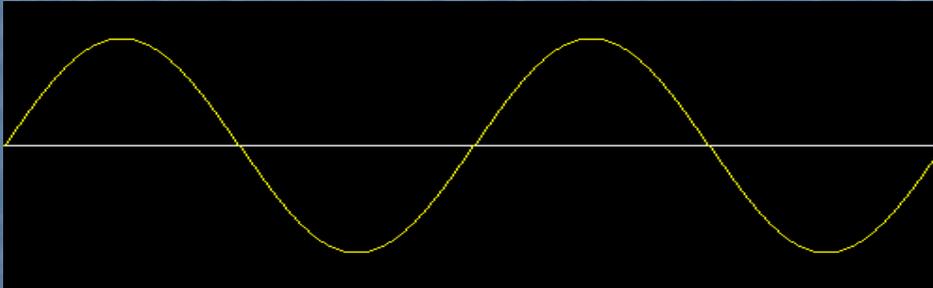


Frequency: 300 Hz 



# 1.1 Sound waves: The parts of waves

We will be considering the parts of a wave with the wave represented as a transverse wave as in the following diagram:



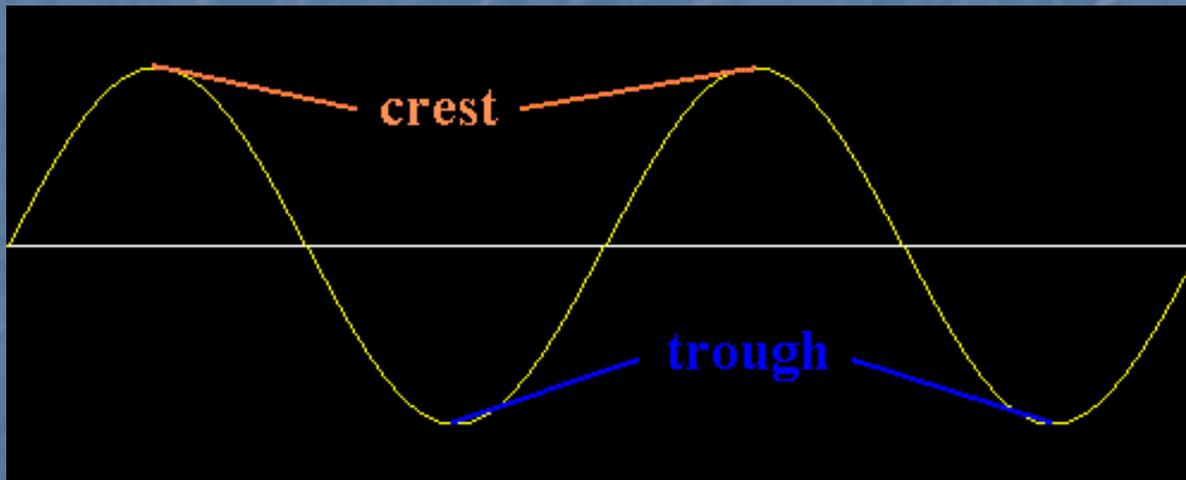
In the above diagram the white line represents the position of the medium when no wave is present. This medium could be imagined as a rope fixed at one end a few feet above the ground and held by you at the other end.

The yellow line represents the position of the medium as a wave travels through it. We simply say that the yellow line is the wave. If we consider the rope mentioned before, this wave could be created by vertically shaking the end of the rope.

Often, when several waves are traveling along a medium as shown above, the continuous group of waves is called a wave train.

## 1.2 Sound waves: What is crest and trough?

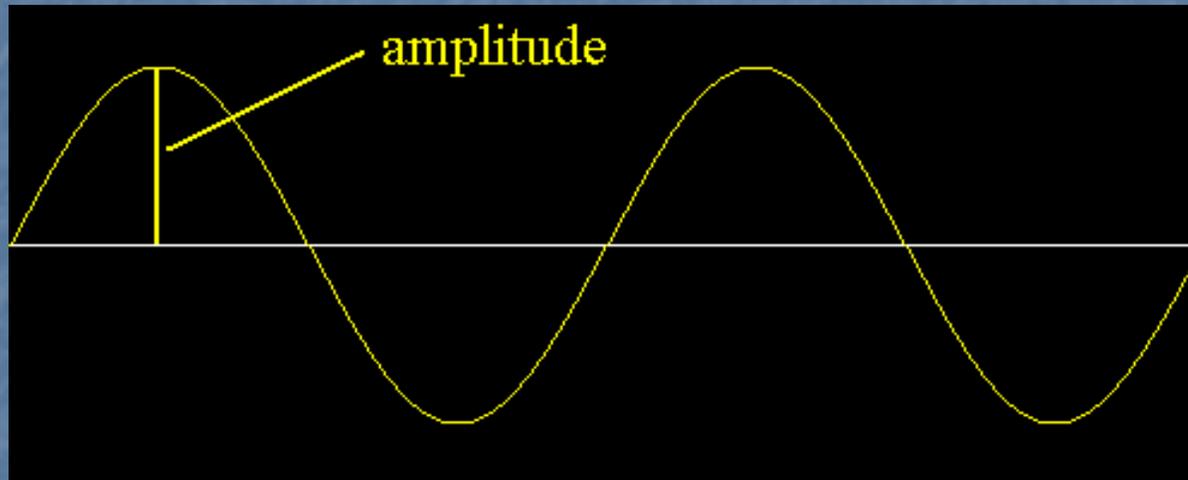
The section of the wave that rises above the undisturbed position is called the **crest**. That section which lies below the undisturbed position is called the **trough**. These sections are labeled in the following diagram:



## 1.3 Sound waves: What is amplitude?

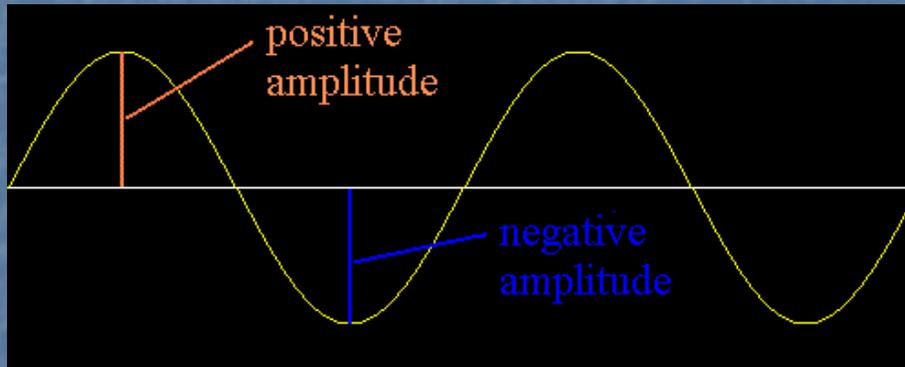
The term **amplitude** can have slightly different meanings depending upon the context of the situation.

Its **most general definition** is that the amplitude is **the maximum positive displacement from the undisturbed position of the medium to the top of a crest**. This is shown in the following diagram:

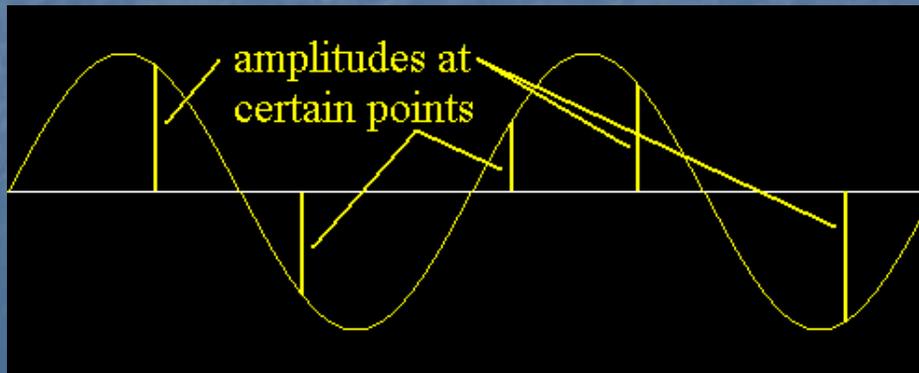


## 1.4 What is positive & negative amplitude?

The displacements of **positive** and **negative** amplitudes are shown in the following diagram:

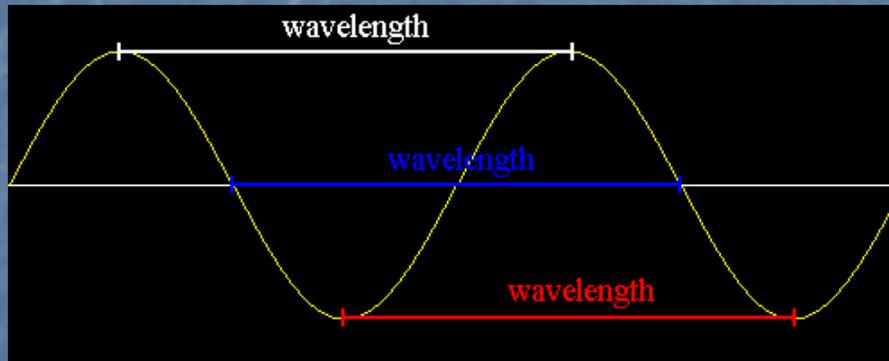


Sometimes it is necessary to discuss an **amplitude at a certain point** along the wave. Several of these amplitudes are shown in the following diagram:

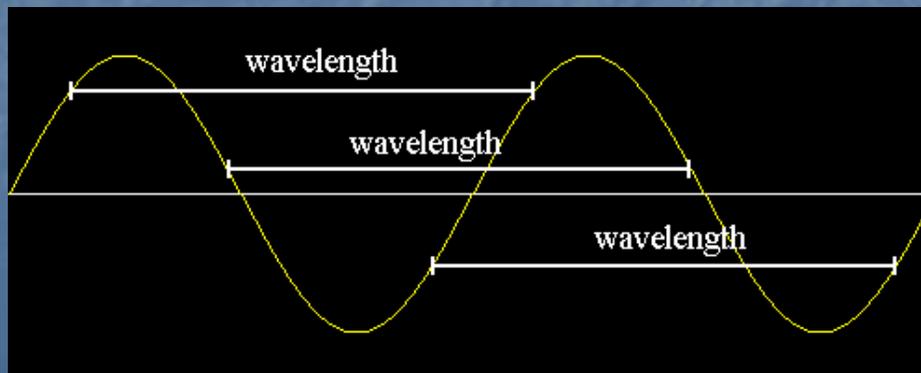


## 1.5 Sound waves: What is wavelength?

The wavelength of a wave is the distance between any two adjacent corresponding locations on the wave train. This distance is usually measured in one of three ways: crest to next crest, **trough to next trough**, or **from the start of a wave cycle to the next starting point**.



Actually, the a wavelength exists between any point on a wave and the corresponding point on the next wave in the wave train. A few of such distances are shown below:

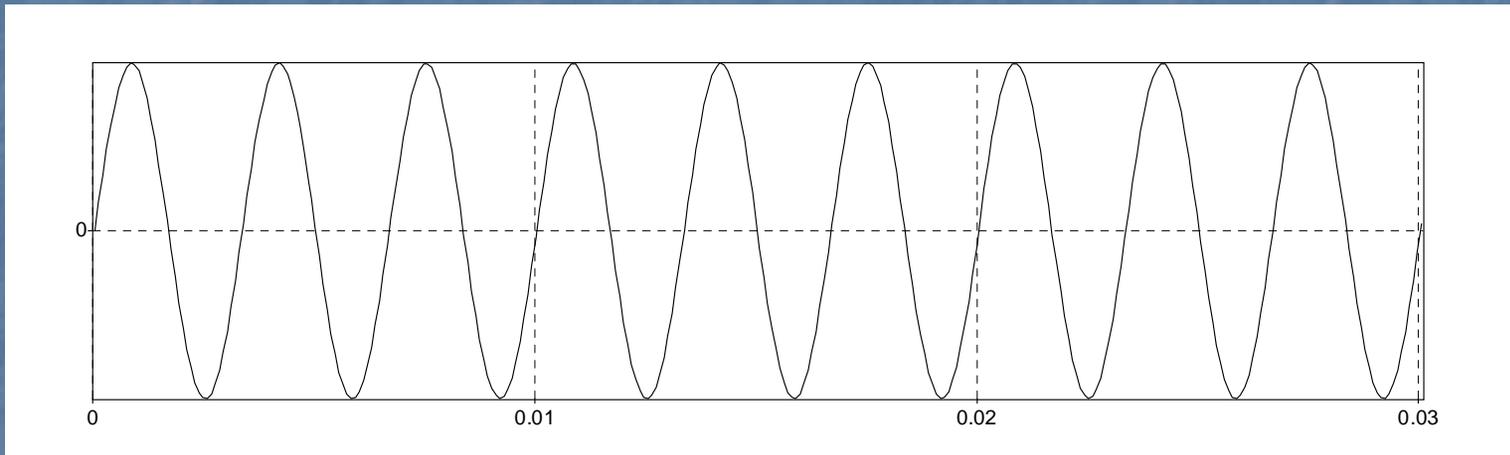


## 2.1 What is frequency?

1. Frequency refers to **how many waves are made per time interval**. This is usually described as **how many waves are made per second**, or as **cycles per second**.
2. If **ten waves are made per second**, then the **frequency** is said to be **ten cycles per second**, written as **10 cps**.
3. Usually, we use the **unit Hertz** to state **frequency**. A frequency of **10 cps** is noted as a frequency of **10 Hertz**. So, one cycle per second is one Hertz, as in:  
$$1 \text{ cps} = 1 \text{ Hertz} \quad \text{or it is abbreviated this way:}$$
$$1 \text{ cps} = 1 \text{ Hz}$$
  
$$120 \text{ cps} = 120 \text{ Hz}$$
$$350 \text{ cps} = 350 \text{ Hz}$$

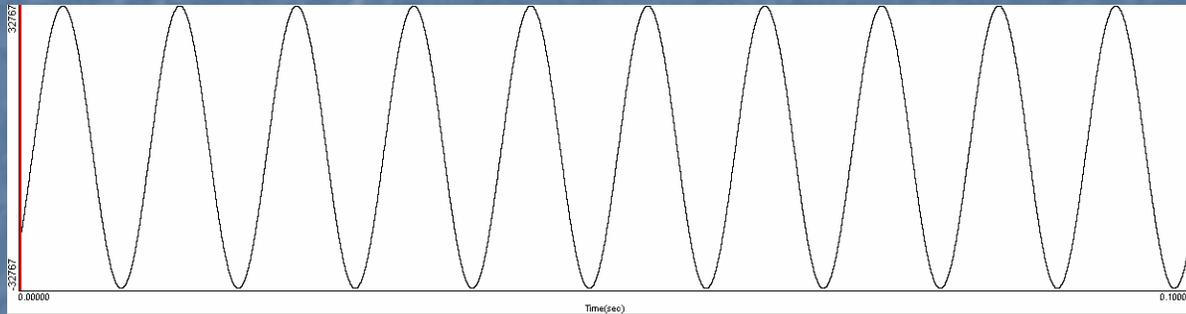
## 2.2. Sound waves and the frequency

Frequency: The number of **complete repetitions** (cycles) of variations in air pressure occurring **in a second**. The unit of frequency measurement is the **hertz (Hz)**.

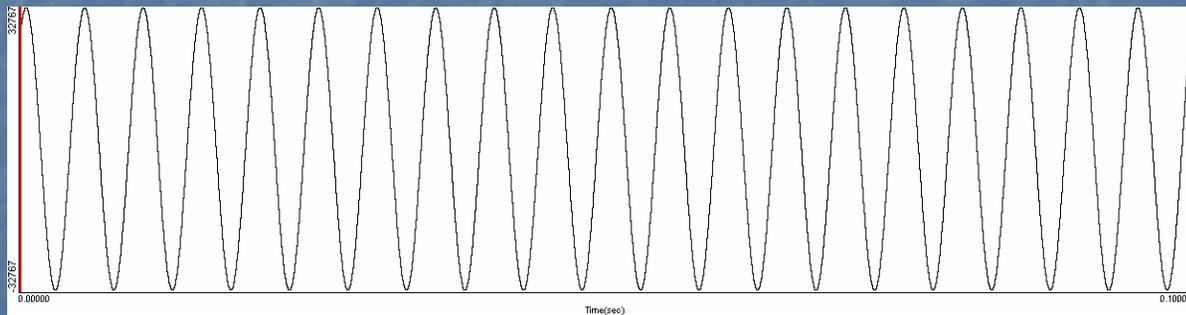


## 2.3 Sound waves with different frequencies?

100 Hz



200 Hz

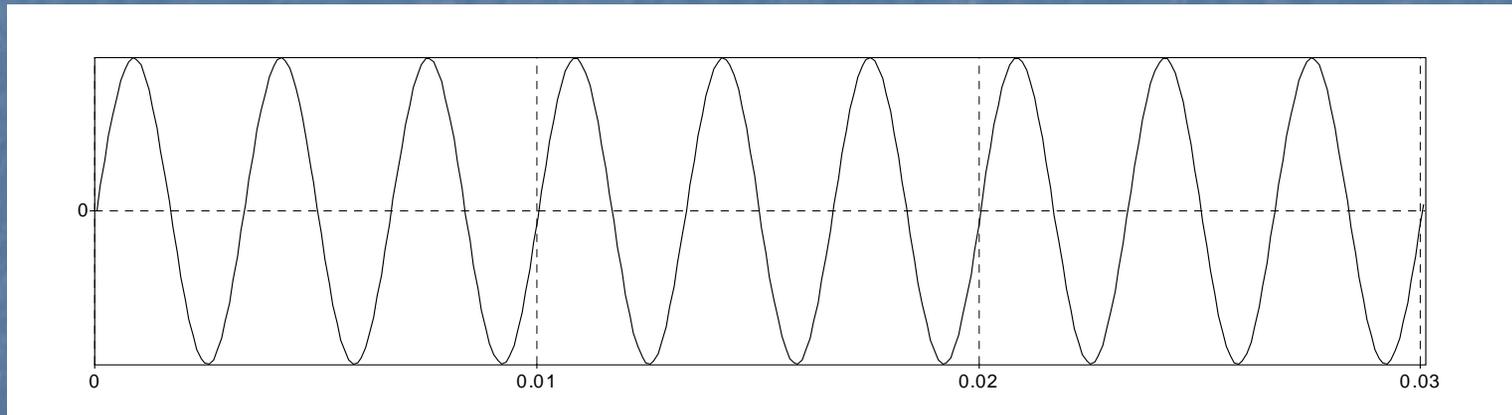


0

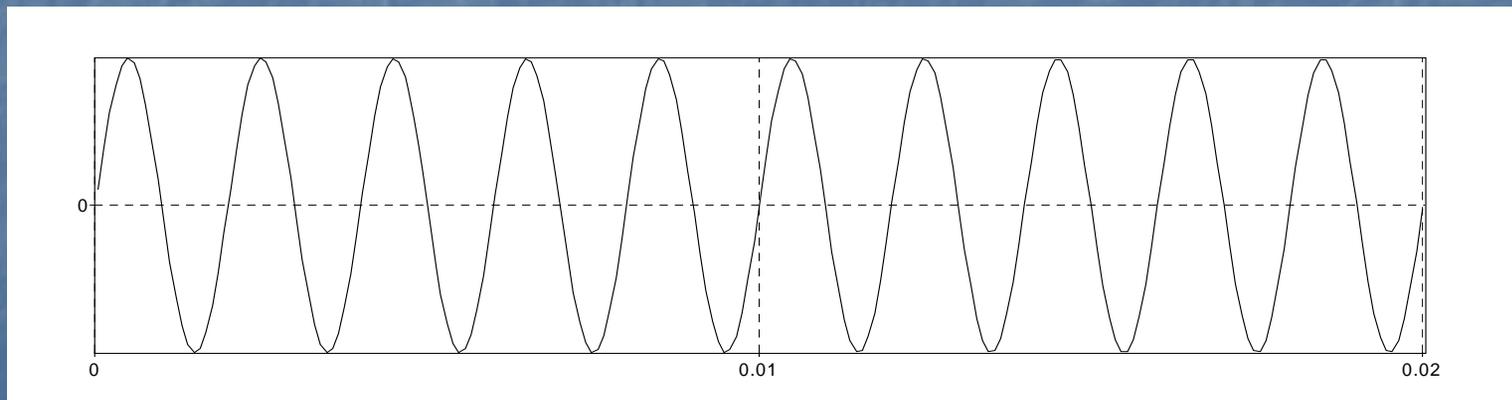
0.1 second

## 2.4. Frequencies and sound waves

Frequency: 300 Hz 

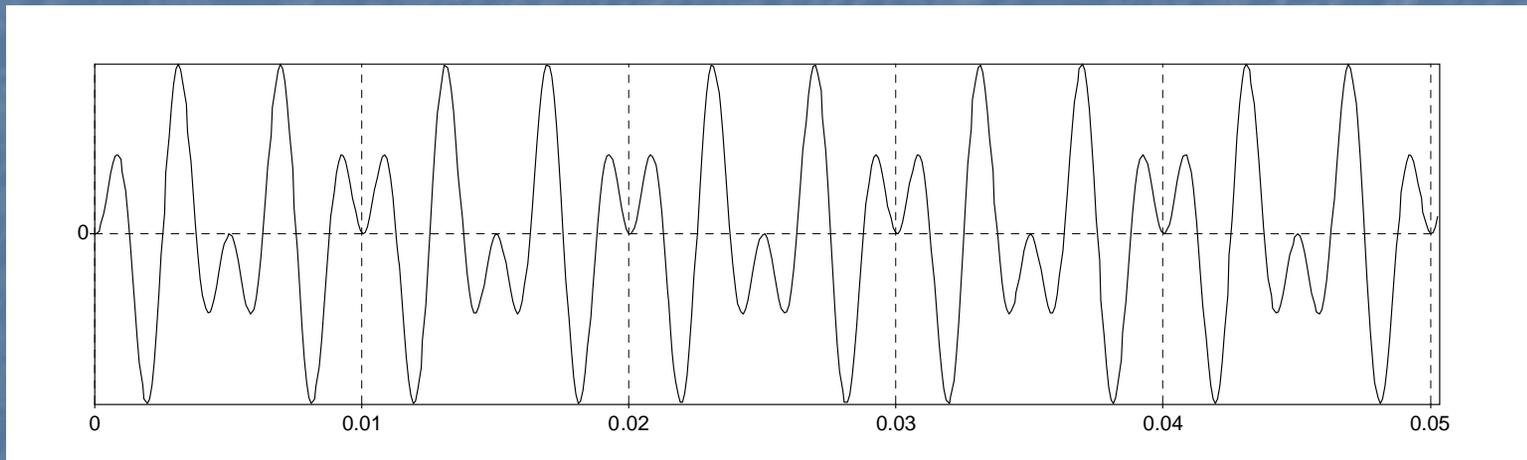


Frequency: 500 Hz 



## 2.5 High & low frequencies and sound waves

Frequency: 350 Hz 



Try to listen to the following sounds:

10000, 11000, 12000, 13000, 14000, 15000,



16000, 17000, 18000, 19000, 20000, 100, 20, 10, 8, 6, 5



## 2.6 More varieties of frequencies

16 Hz



32 Hz



64 Hz



100 Hz



160 Hz



200 Hz



250 Hz



320 Hz



400 Hz



450 Hz



1000 Hz



1600 Hz



2000 Hz



4000 Hz



5000 Hz



8000 Hz



12000 Hz



16000 Hz



20000 Hz



900 Hz + 1100 Hz

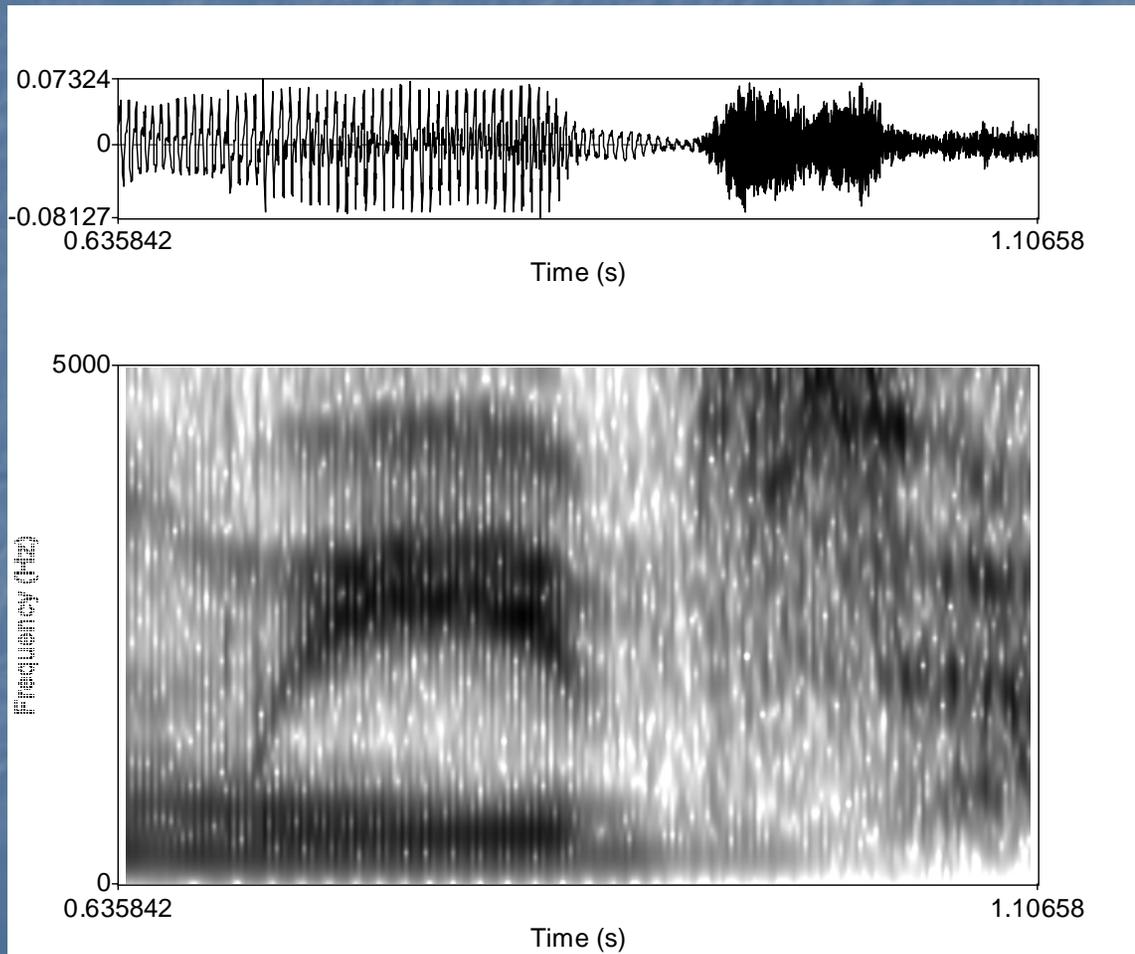


300 Hz + 2000 Hz



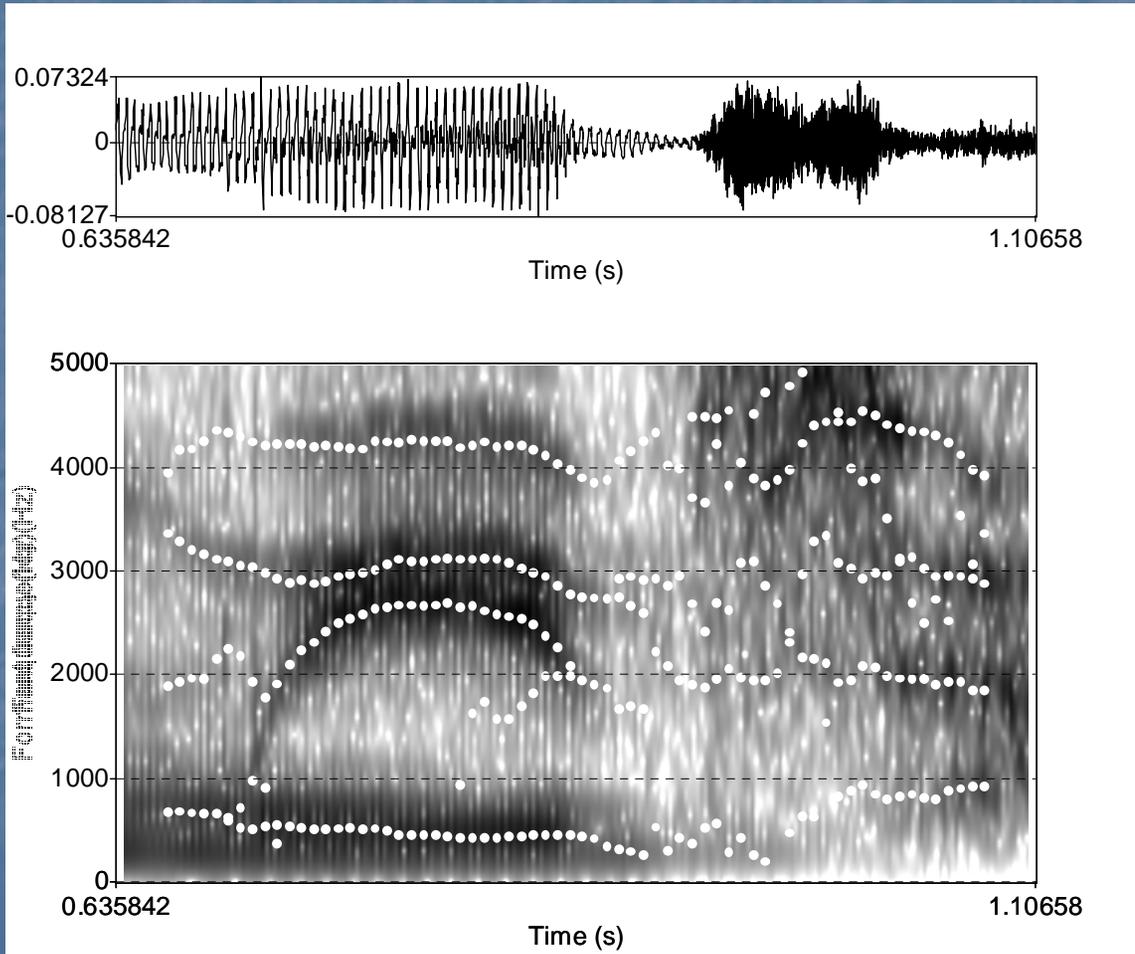
# 3. Formants

Formants 1-4: leaves (Amanda)



# 3.1 Formants with lines

Formants 1-4: leaves (Amanda) 



## 3.2 Formants of different vowels

See [CBCAP](#)

## 3.2 The relationship between F1 and F2

Formant 1: reflecting the “high” or “low” of the vowel in the oral tract

Formant 2: reflecting the “backness” of the vowel in the oral tract

Try to use praat to figure out the relationship described above.

See also [CBCAP](#)

## 3.3 The Assignment

Try to examine the articulation positions and sounds.

1. Draw the matrix to represent space of oral tract  
Make sure that the X and Y axes  
(with X axis = 3000 Hz and Y axis = 1500 Hz)
2. Try to produce different vowels by yourself
3. Try to collect the acoustic info of the first and second formants by means of any speech analyzer (e.g., PRAAT)
4. Try to locate each vowel according to the sets of formant values from speech analyzers

# 4 Formants of consonants

See [CBCAP](#)

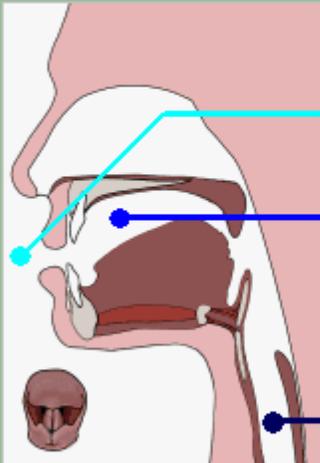
1. Aerodynamic effects
2. Degree of constriction
3. Place of articulation
4. Voicing
5. Nasalization

# 4.1 Aerodynamic effects

See [CBCAP](#)

**Consonant Acoustics: Aerodynamic effects 1**

During speech, the lung pressure (below the **glottis**) is higher than **atmospheric pressure**. The difference in pressures is very small - only 10 cm H<sub>2</sub>O out of 1030 cm H<sub>2</sub>O. This causes air to flow out of the lungs, through the vocal tract and out of the mouth (unless something blocks the flow of air).



The diagram shows a sagittal cross-section of the human vocal tract. Three horizontal lines indicate pressure levels: a cyan line at the top (atmospheric pressure), a blue line in the oral and pharyngeal cavities (supraglottal pressure), and a dark blue line at the bottom (subglottal pressure). To the right of the diagram are three vertical bars of corresponding colors, each labeled with a pressure value and 'ATMOSPHERIC PRESSURE'.

Location	Pressure (cm H <sub>2</sub> O)
Outside the vocal tract (Atmospheric)	1030
Supraglottal cavities (Oral and pharyngeal)	1030
Subglottal (During speech)	1040

**1030 cm H<sub>2</sub>O**  
ATMOSPHERIC PRESSURE

The atmospheric pressure outside the vocal tract is about 1030 cm H<sub>2</sub>O.

**1030 cm H<sub>2</sub>O**  
ATMOSPHERIC PRESSURE

Here, the supraglottal pressure in the oral and pharyngeal cavities is about 1030 cm H<sub>2</sub>O.

**1040 cm H<sub>2</sub>O**  
ATMOSPHERIC PRESSURE

The subglottal pressure during speech is about 1040 cm H<sub>2</sub>O, slightly above the atmospheric pressure indicated by the grey line.

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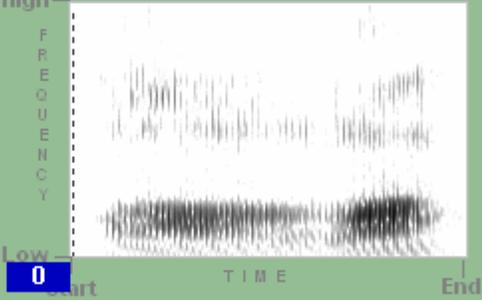
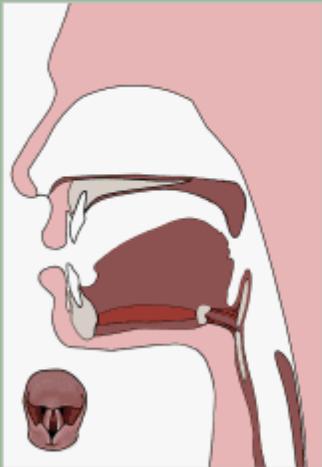
**Help**

← →

# 4.2.1 Degree of constriction

See [CBCAP](#)

**Consonant Acoustics: Degree of Constriction 1**  
Play this animation of tongue movement during a consonant. What is the manner of articulation of this consonant? Look at the [spectrogram](#). The period of change during the production of the consonant contains 3 events worth noting - the transitions before and after the consonant, and the [formant pattern](#) corresponding to the highest position of the tongue.



High  
FREQUENCY  
Low

0  
Start TIME End

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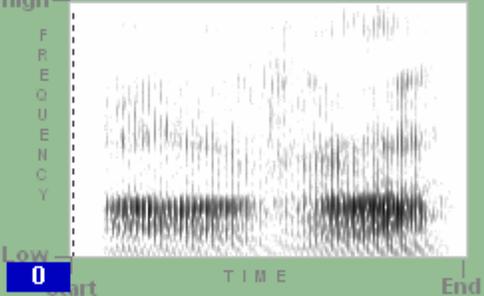
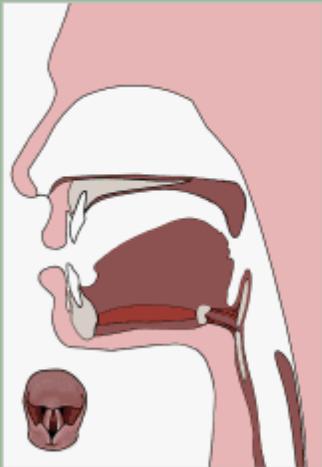


## 4.2.2 Degree of constriction

See [CBCAP](#)

**Consonant Acoustics: Degree of Constriction 2**

In this consonant, the tongue moves towards the roof of the **oral cavity**, making a constriction narrow enough to cause **turbulence** in the air flowing through the vocal tract. What portion of the spectrogram corresponds to the period of turbulence? Compare these **formant transitions** to the transitions of the consonant on the previous screen. What differences do you see?



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Low

0 Start TIME End

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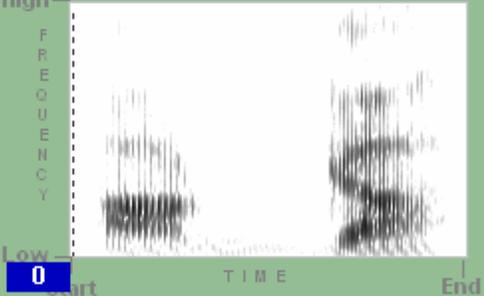
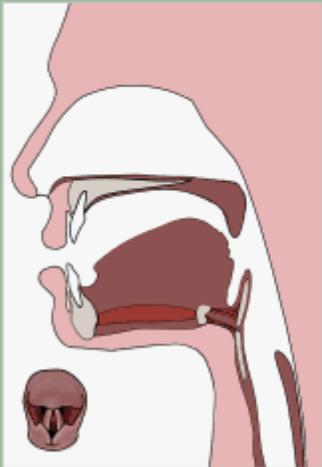
Navigation icons: left arrow, play button, right arrow, and two document icons with arrows.

## 4.2.3 Degree of constriction

See [CBCAP](#)

**Consonant Acoustics: Degree of Constriction 3**

Here, the tongue touches the **palate**, creating a **stop**. Look at the spectrogram. What part of the spectrogram corresponds to the **period** during which the tongue touches the palate? What does the tongue do before touching? What part of the spectrogram is that? What does the tongue do after touching the palate? What part of the spectrogram is that?



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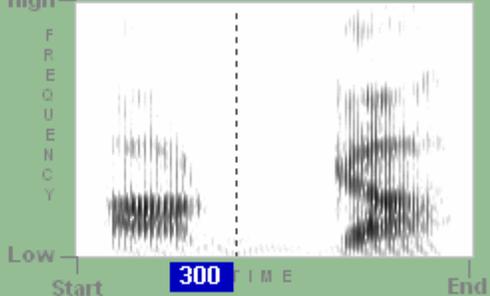
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# 4.3 Place of articulation

See [CBCAP](#)

**Consonant Acoustics: Place of articulation 14**  
This animation shows the articulation of a velar stop /g/ together with a spectrogram. How do the formant frequencies change as the articulation of the consonant begins? How do the formant frequencies change as the articulation of the consonant ends? Compare these formant frequency changes with the ones you observed on the spectrograms of /k/ and /ŋ/.



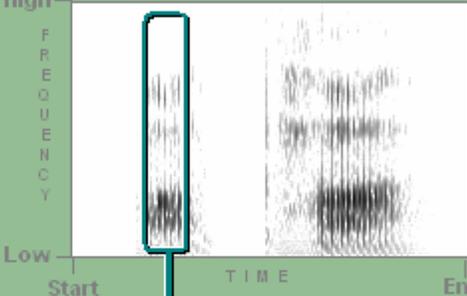
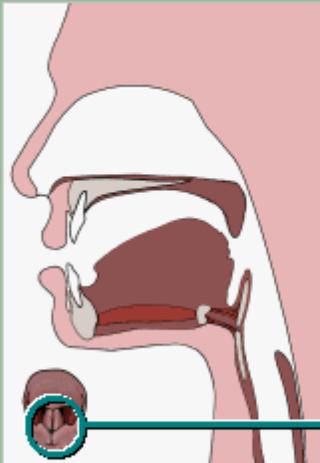
The spectrogram displays frequency on the vertical axis, ranging from 'Low' to 'High'. The horizontal axis represents 'TIME', with markers for 'Start', '300', and 'End'. A vertical dashed line is positioned at the 300 mark. The spectrogram shows a series of horizontal lines representing formants. At the 'Start' of the articulation, the formants are relatively stable. As the articulation begins, there is a noticeable shift in the frequencies of the lower formants. At the 'End' of the articulation, the formants return to their initial frequencies.

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# 4.4.1 Voicing

See CBCAP

**Consonant Acoustics: Voicing 6**  
In voiceless aspirated stops, such as /p<sup>h</sup>/, the timing of vocal fold gestures with respect to articulatory gestures is different from the timing in voiceless unaspirated stops, such as /p/. In aspirated stops, the vocal fold **adduction** occurs after the articulatory release, not at the same time.



Before the consonant articulation begins, the vocal folds are adducted for voicing.

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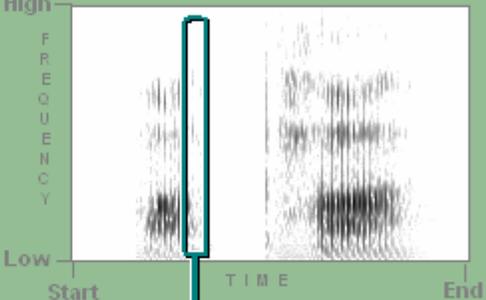
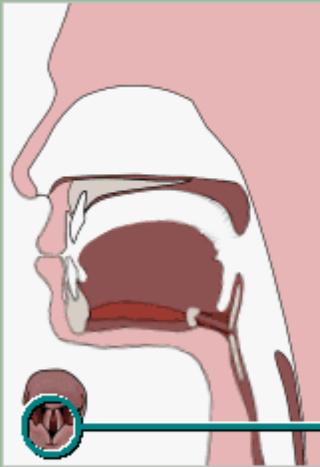
Navigation arrows

## 4.4.2 Voicing

See CBCAP

**Consonant Acoustics: Voicing 6**

In voiceless aspirated stops, such as /p<sup>h</sup>/, the timing of vocal fold gestures with respect to articulatory gestures is different from the timing in voiceless unaspirated stops, such as /p/. In aspirated stops, the vocal fold **adduction** occurs after the articulatory release, not at the same time.



As the articulators close, the vocal folds abduct and voicing stops.

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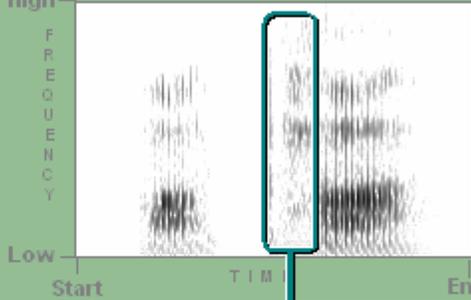
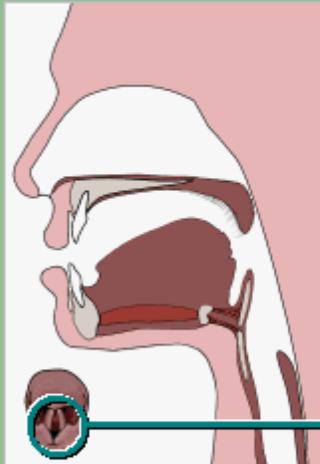
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# 4.4.4 Voicing

See CBCAP

**Consonant Acoustics: Voicing 6**  
In voiceless aspirated stops, such as /p<sup>h</sup>/, the timing of vocal fold gestures with respect to articulatory gestures is different from the timing in voiceless unaspirated stops, such as /p/. In aspirated stops, the vocal fold **adduction** occurs after the articulatory release, not at the same time.



High  
F  
R  
E  
Q  
U  
E  
N  
C  
Y  
Low

Start T I M E End

After the release of the articulatory closure, the vocal folds remain abducted. Aspiration results from turbulent airflow through the glottis.

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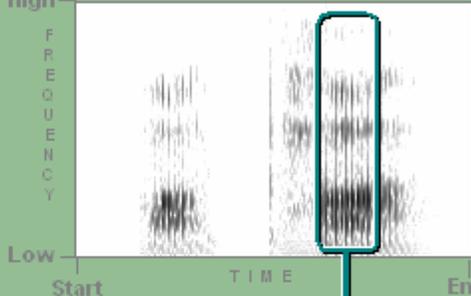
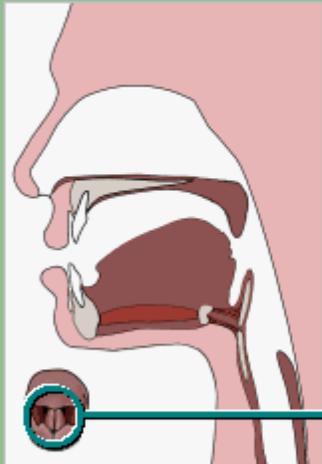
Navigation arrows

## 4.4.5 Voicing

See CBCAP

**Consonant Acoustics: Voicing 6**

In voiceless aspirated stops, such as /p<sup>h</sup>/, the timing of vocal fold gestures with respect to articulatory gestures is different from the timing in voiceless unaspirated stops, such as /p/. In aspirated stops, the vocal fold **adduction** occurs after the articulatory release, not at the same time.



High  
F  
R  
E  
Q  
U  
E  
N  
C  
Y  
Low

Start TIME End

The vocal folds adduct again well after the release of the articulatory closure. Voicing begins again.

**Reread Notes**

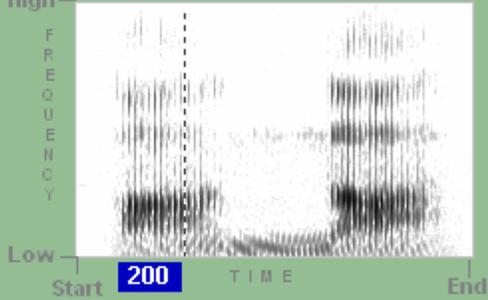
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Navigation arrows

# 4.5.1 Nasalization

See [CBCAP](#)

**Consonant Acoustics: Nasalization 6**  
Here is an animation of a voiced alveolar nasal stop /**n**/. Can you identify the nasal murmur and the **nasal formant**? What other acoustic differences between this nasal stop and the voiced alveolar oral stop /**d**/ can you see?



High  
F  
R  
E  
Q  
U  
E  
N  
C  
Y  
Low

Start **200** TIME End

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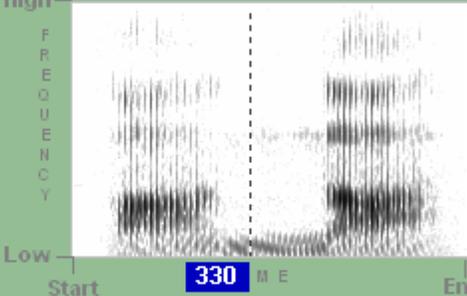
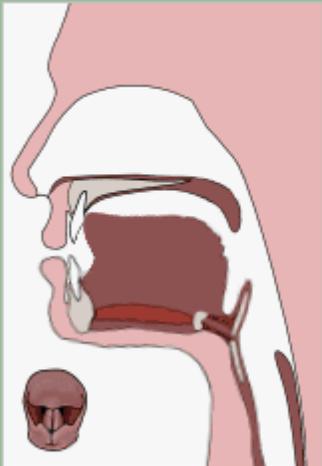
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## 4.5.2 Nasalization

See [CBCAP](#)

**Consonant Acoustics: Nasalization 6**

Here is an animation of a voiced alveolar nasal stop /**n**/. Can you identify the nasal murmur and the **nasal formant**? What other acoustic differences between this nasal stop and the voiced alveolar oral stop /**d**/ can you see?



High  
FREQUENCY  
Low

Start 330 ME End

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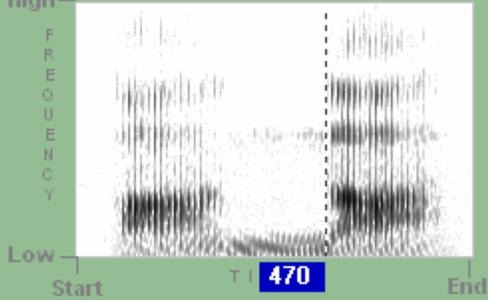
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# 4.5 Nasalization

See [CBCAP](#)

**Consonant Acoustics: Nasalization 6**  
Here is an animation of a voiced alveolar nasal stop /n/. Can you identify the nasal murmur and the nasal formant? What other acoustic differences between this nasal stop and the voiced alveolar oral stop /d/ can you see?



High  
FREQUENCY  
Low

Start T 470 End

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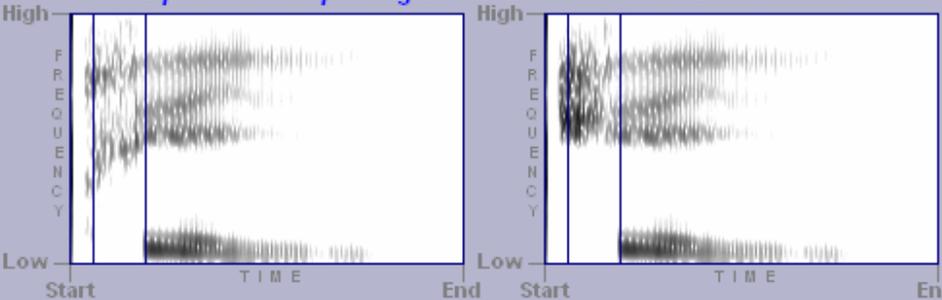


# 4.6 Summary and conclusion

See [CBCAP](#)

**Speech Perception: What is an acoustic cue? 3**  
Many other pairs of words have relatively small acoustic differences. It is possible to investigate many of the acoustic cues which differentiate speech sounds by performing experiments using synthetic speech. Combine various portions of these words; which portions affect the consonants that you hear?

*Click a piece of the spectrogram to move it to the blank frame...*



High  
F  
R  
E  
Q  
U  
E  
N  
C  
Y  
Low

Start TIME End Start TIME End

High  
F  
R  
E  
Q  
U  
E  
N  
C  
Y  
Low

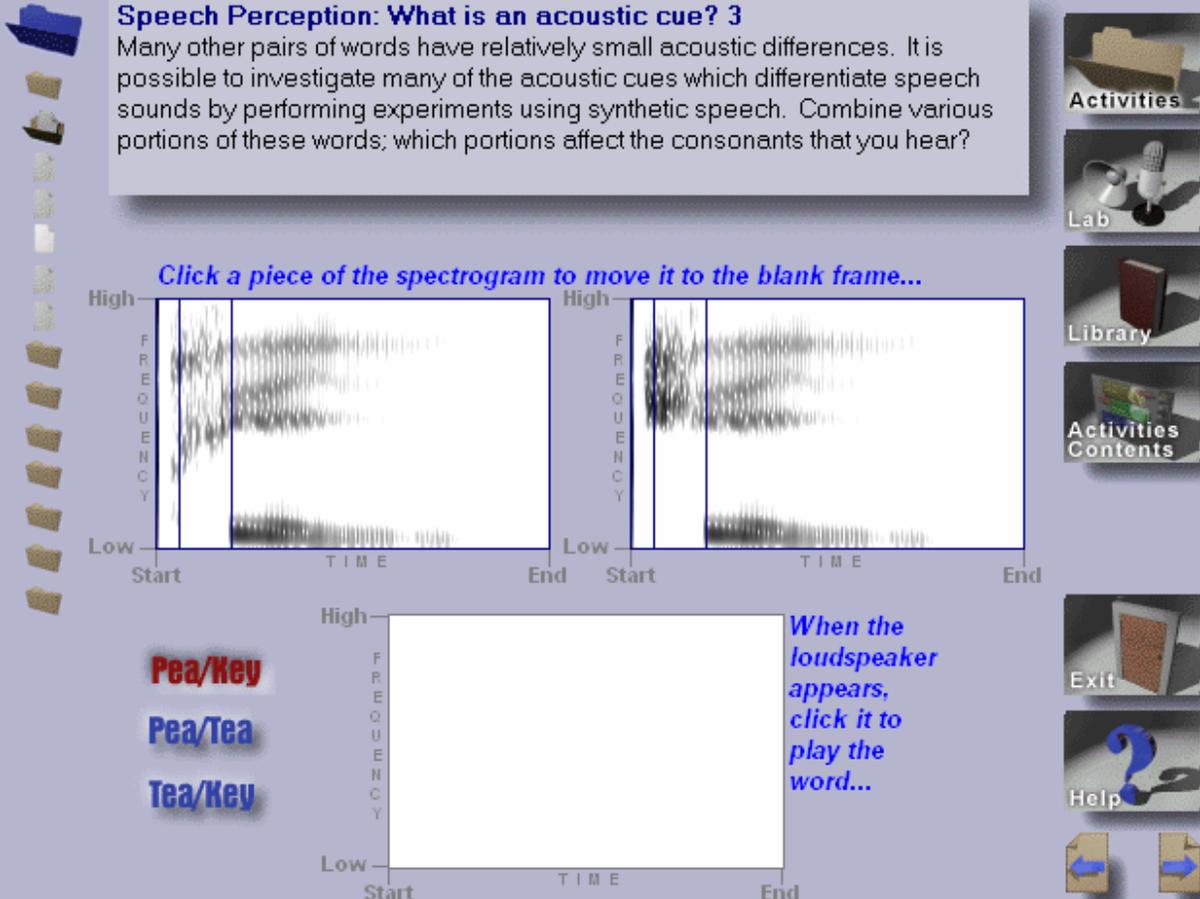
Start TIME End

**Pea/Key**  
**Pea/Tea**  
**Tea/Key**

High  
F  
R  
E  
Q  
U  
E  
N  
C  
Y  
Low

Start TIME End

*When the loudspeaker appears, click it to play the word...*



# 4.7 Summary and conclusion

See [CBCAP](#)

**Speech Perception: What is an acoustic cue? 3**  
Many other pairs of words have relatively small acoustic differences. It is possible to investigate many of the acoustic cues which differentiate speech sounds by performing experiments using synthetic speech. Combine various portions of these words; which portions affect the consonants that you hear?

*Click a piece of the spectrogram to move it to the blank frame...*

High F R E Q U E N C Y Low Start TIME End Start TIME End

High F R E Q U E N C Y Low Start TIME End

**Pea/Key**  
**Pea/Tea**  
**Tea/Key**

*When the loudspeaker appears, click it to play the word...*

High F R E Q U E N C Y Low Start TIME End

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# 4.8 Summary and conclusion

See [CBCAP](#)

**Speech Perception: What is an acoustic cue? 3**  
Many other pairs of words have relatively small acoustic differences. It is possible to investigate many of the acoustic cues which differentiate speech sounds by performing experiments using synthetic speech. Combine various portions of these words; which portions affect the consonants that you hear?

*Click a piece of the spectrogram to move it to the blank frame...*

High F R E Q U E N C Y Low Start TIME End Start TIME End

Pea/Key  
Pea/Tea  
Tea/Key

High F R E Q U E N C Y Low Start TIME End

*When the loudspeaker appears, click it to play the word...*

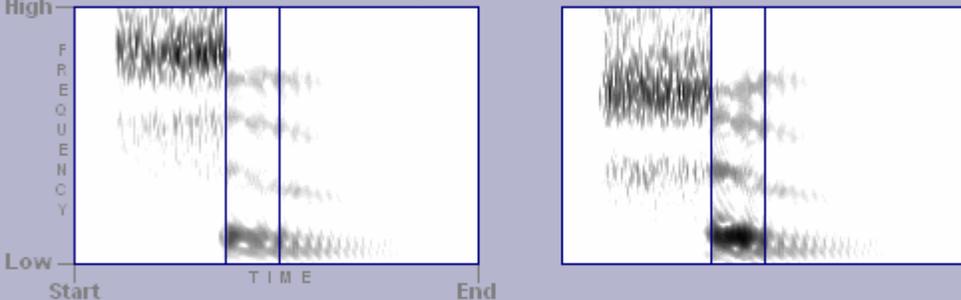
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# 4.9 Summary and conclusion

See [CBCAP](#)

**Speech Perception: What is an acoustic cue? 4**  
Here are spectrograms of two more synthesized words, /su/ "sue" and /ʃu/ "shoe". Exchange various parts of the synthetic words. Which portions affect the consonant at the beginning of the word most? Are these the same portions that affect "pea", "tea", and "key"?

*Click a piece of the spectrogram to move it to the blank frame...*



High  
FREQUENCY  
Low

Start TIME End



*When the loudspeaker appears, click it to play the word...*

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## 4.10 Summary and conclusion

See [CBCAP](#)

**Speech Perception: An identification task 3**  
Here is another example. This is a simple stimulus continuum, in which only one acoustic parameter varies. What do stimuli at the ends of the continuum sound like? What do the intermediate stimuli sound like?

Only the F2 transition varies in this synthetic stimulus continuum.

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# 4.11 Summary and conclusion

See [CBCAP](#)

**Speech Perception: Child and adult acquisition 7**  
English speakers easily identify /t/ and /d/. Mandarin Chinese speakers also easily identify word-final /t/ and /d/ when there is a **burst** after the **stops**. But in fluent speech, when another word immediately follows, there is often no burst after the stops. English speakers have no difficulty discriminating these burstless stops, but Mandarin Chinese speakers do.

**Correct identifications:**

Condition	English (%)	Chinese (%)
[baet]	100	100
[baed]	100	100
[baet']	~75	0
[baed']	~75	0

Navigation icons: Activities, Lab, Library, Activities Contents, Exit, Help, and navigation arrows.

# 4.11 Summary and conclusion

See [CBCAP](#)

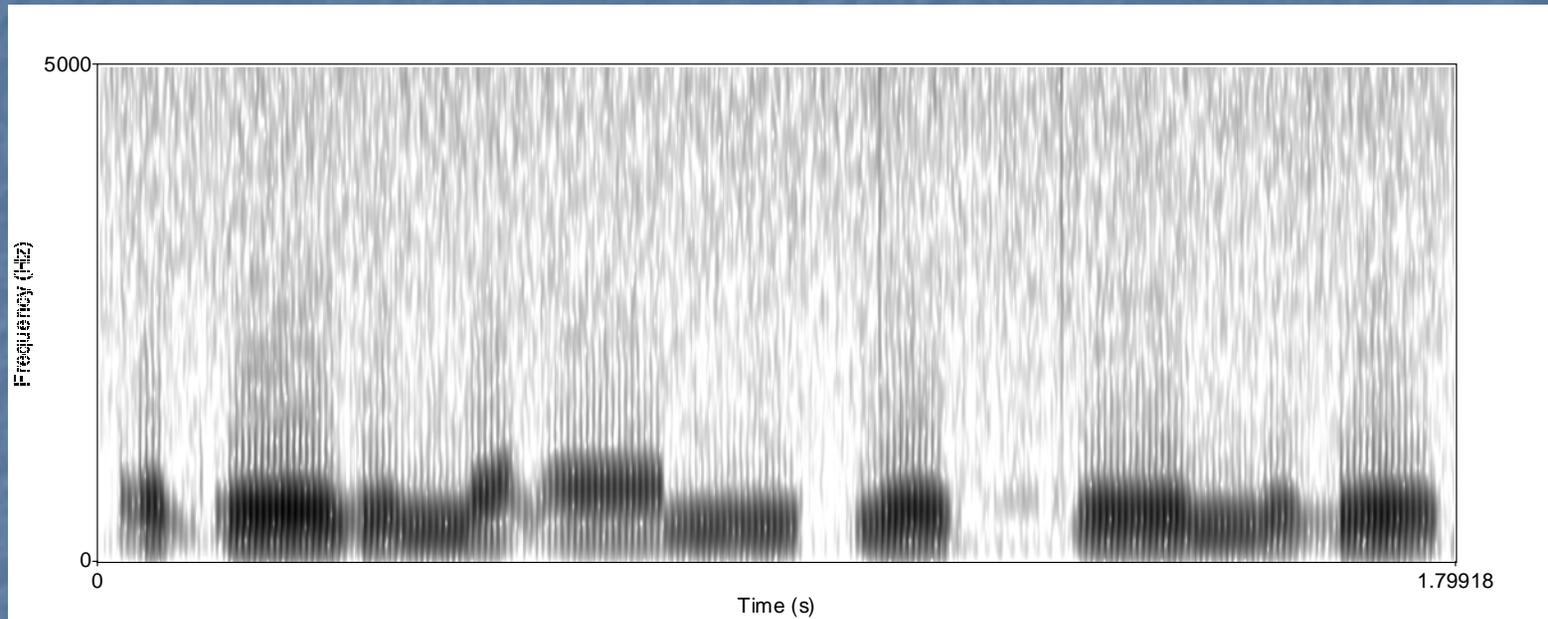
**Speech Perception: Child and adult acquisition 7**  
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**Correct identifications:**

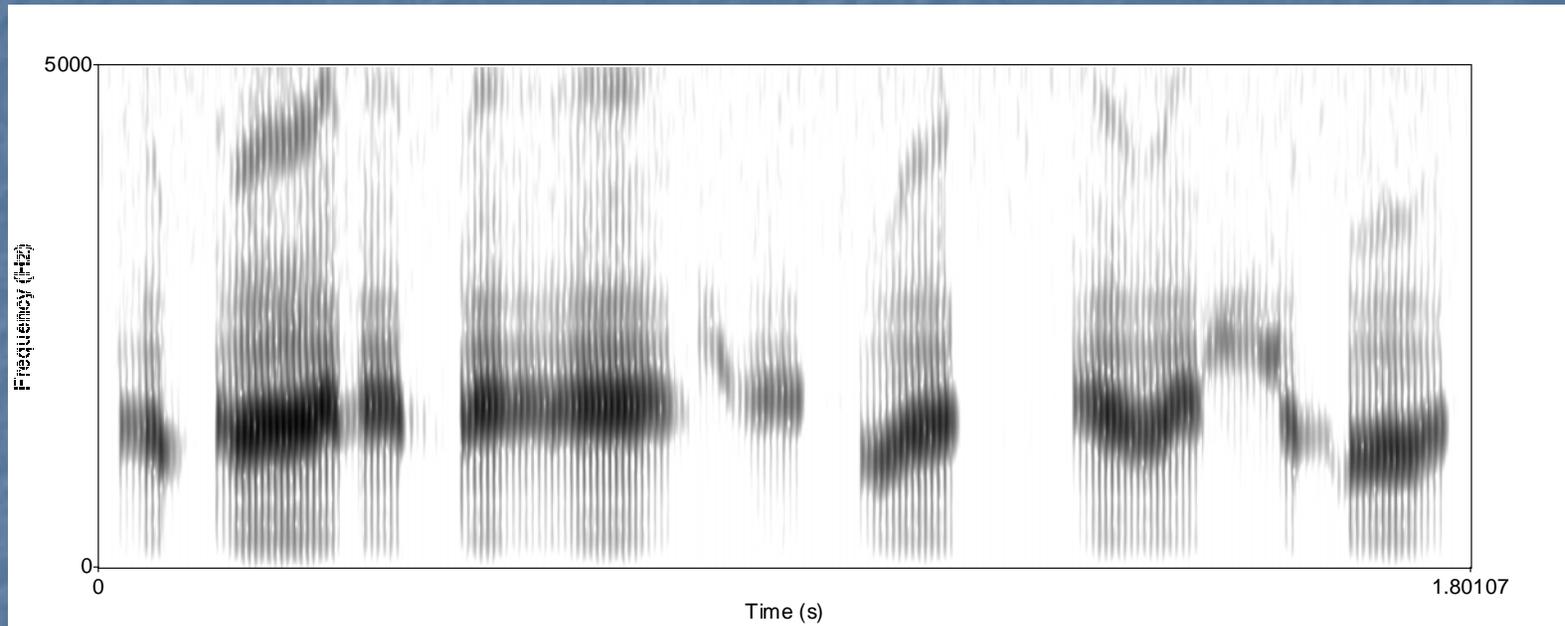
Condition	English (%)	Chinese (%)
[baet]	100	100
[baed]	100	100
[baet']	~75	~50
[baed']	~75	~50

Navigation icons: Activities, Lab, Library, Activities Contents, Exit, Help, and navigation arrows.

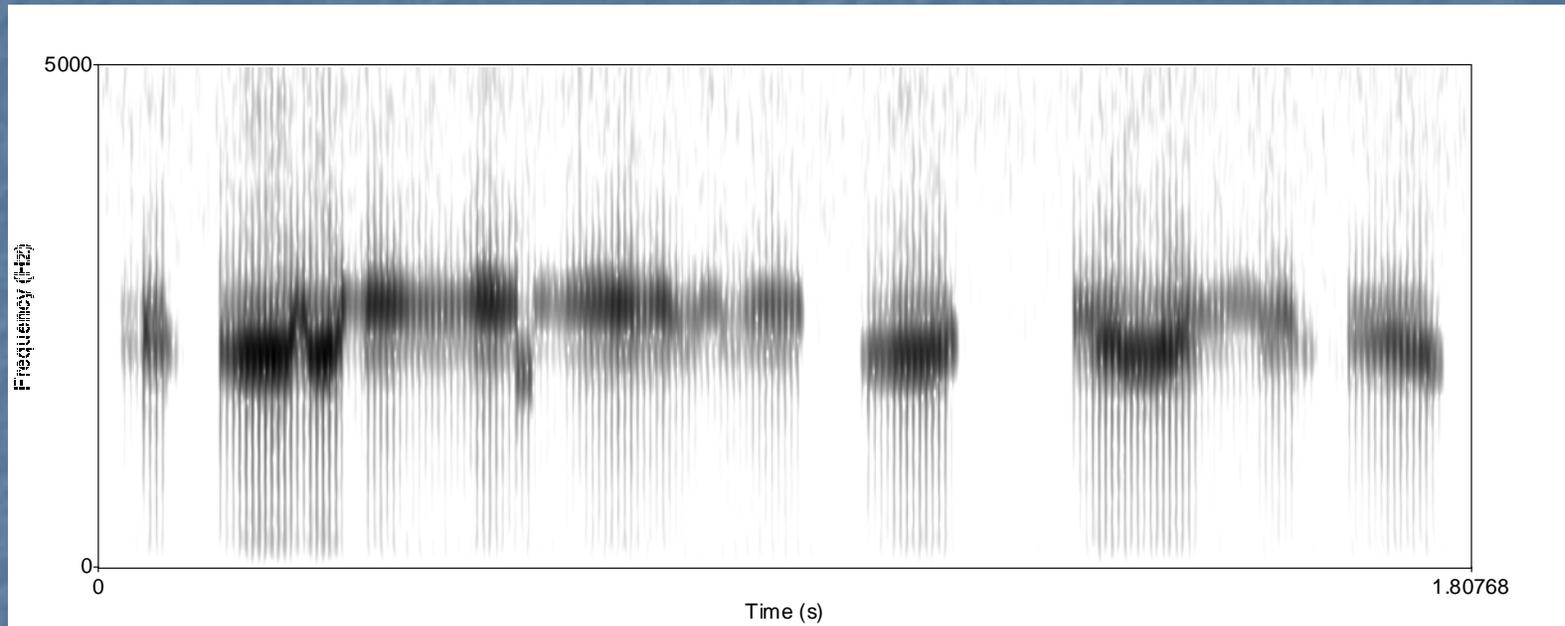
## 4.12 An expression with only the first formants



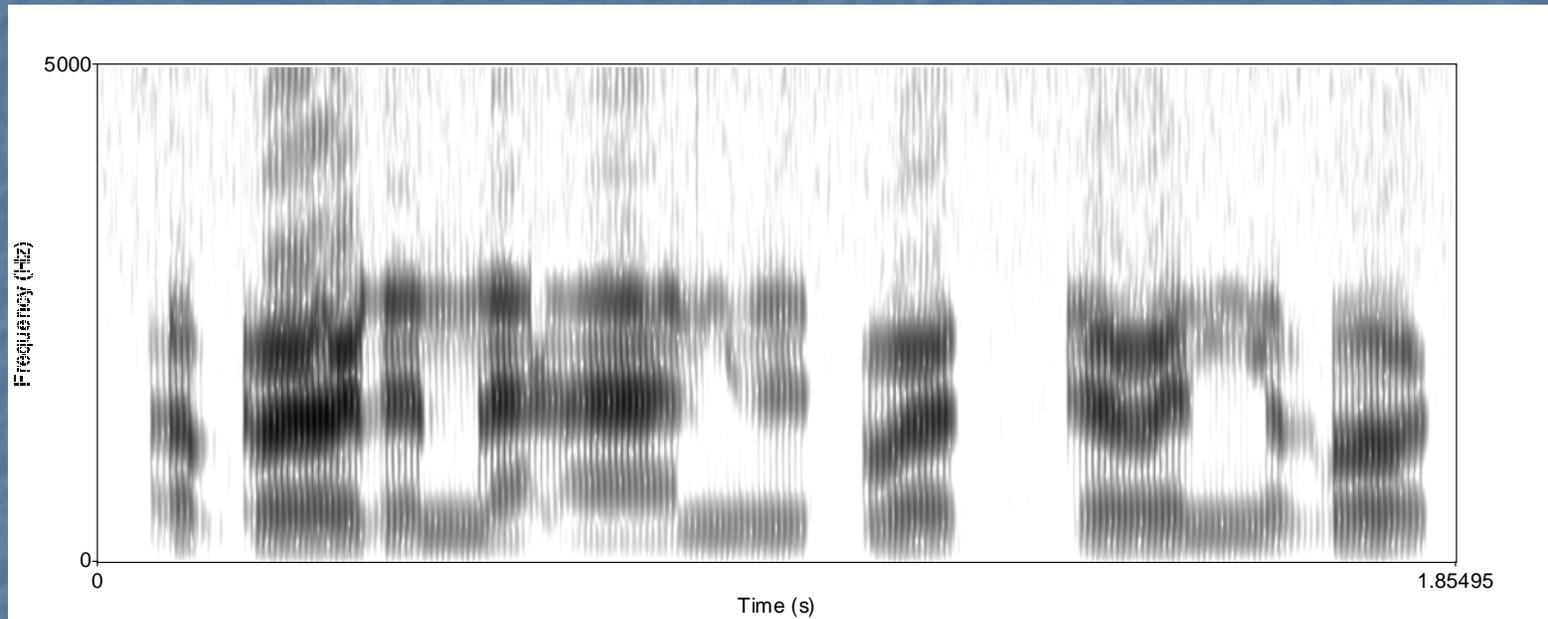
## 4.13 An expression with only the second formants



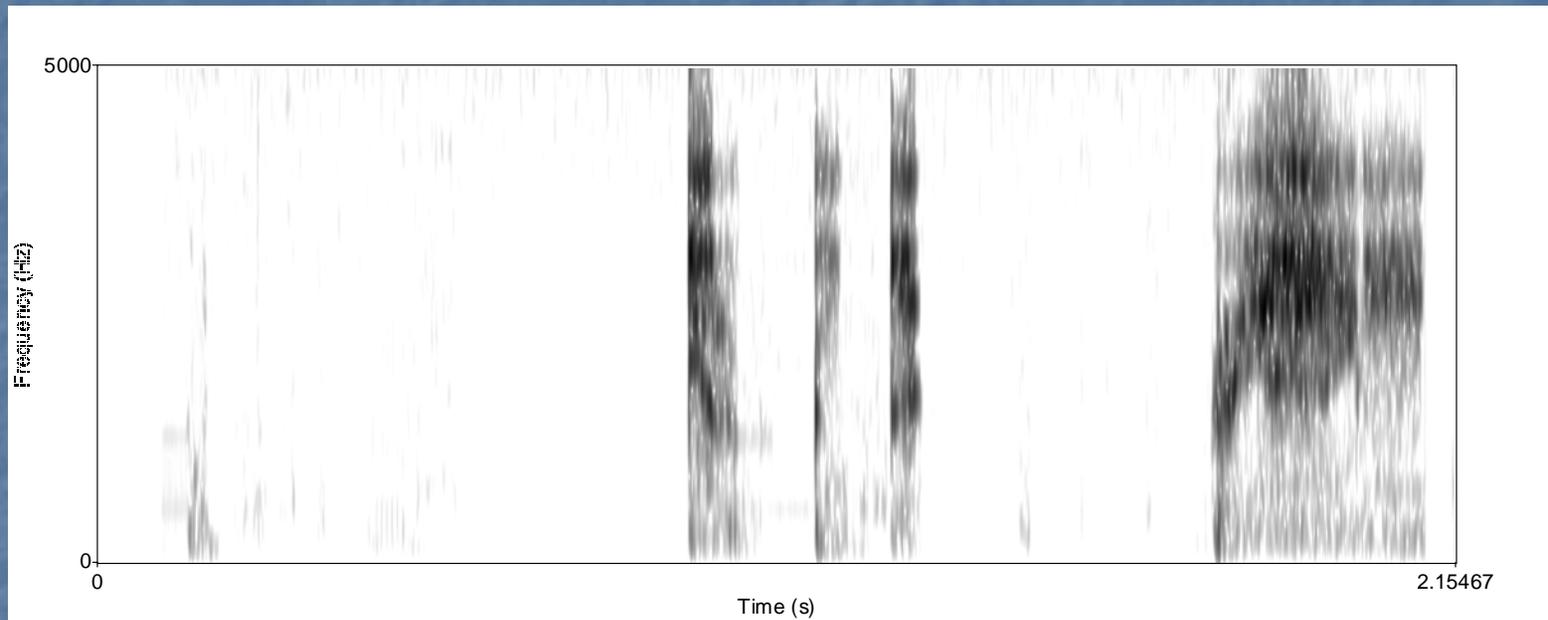
## 4.14 An expression with only the third formants



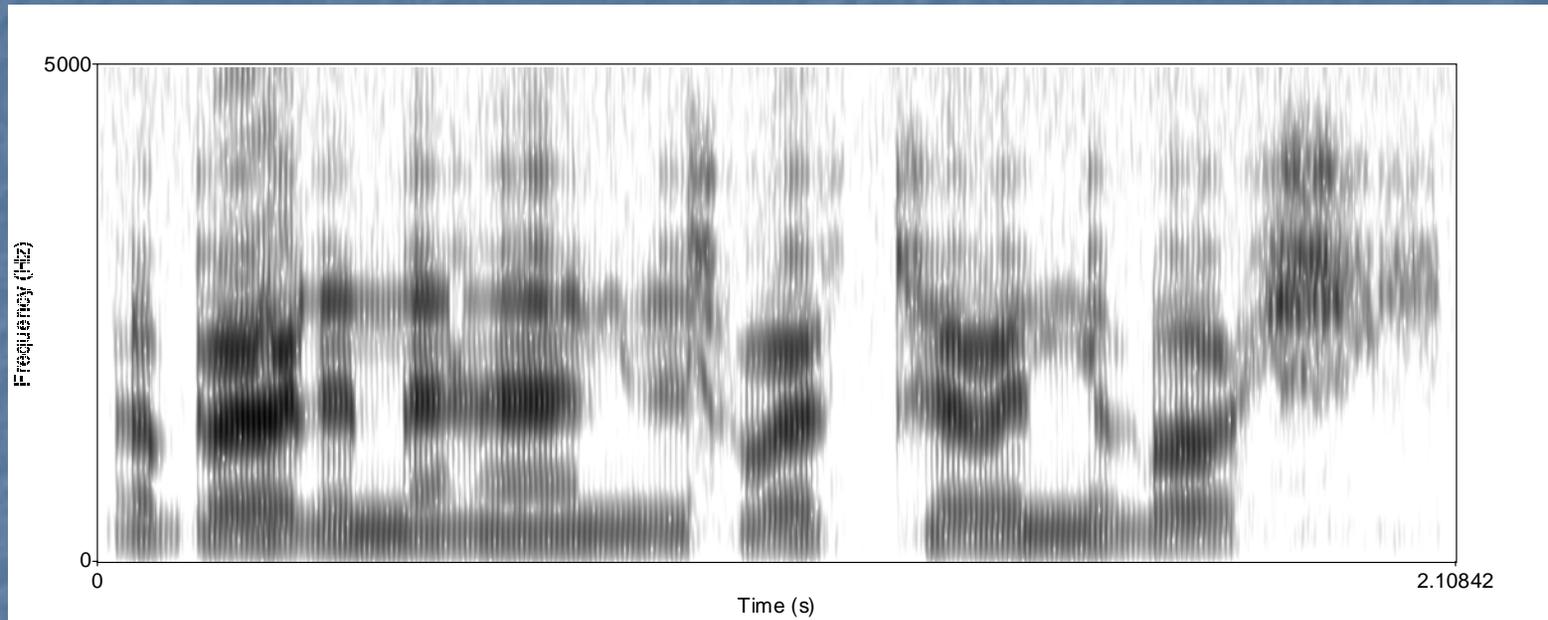
## 4.15 An expression with only the first three formants



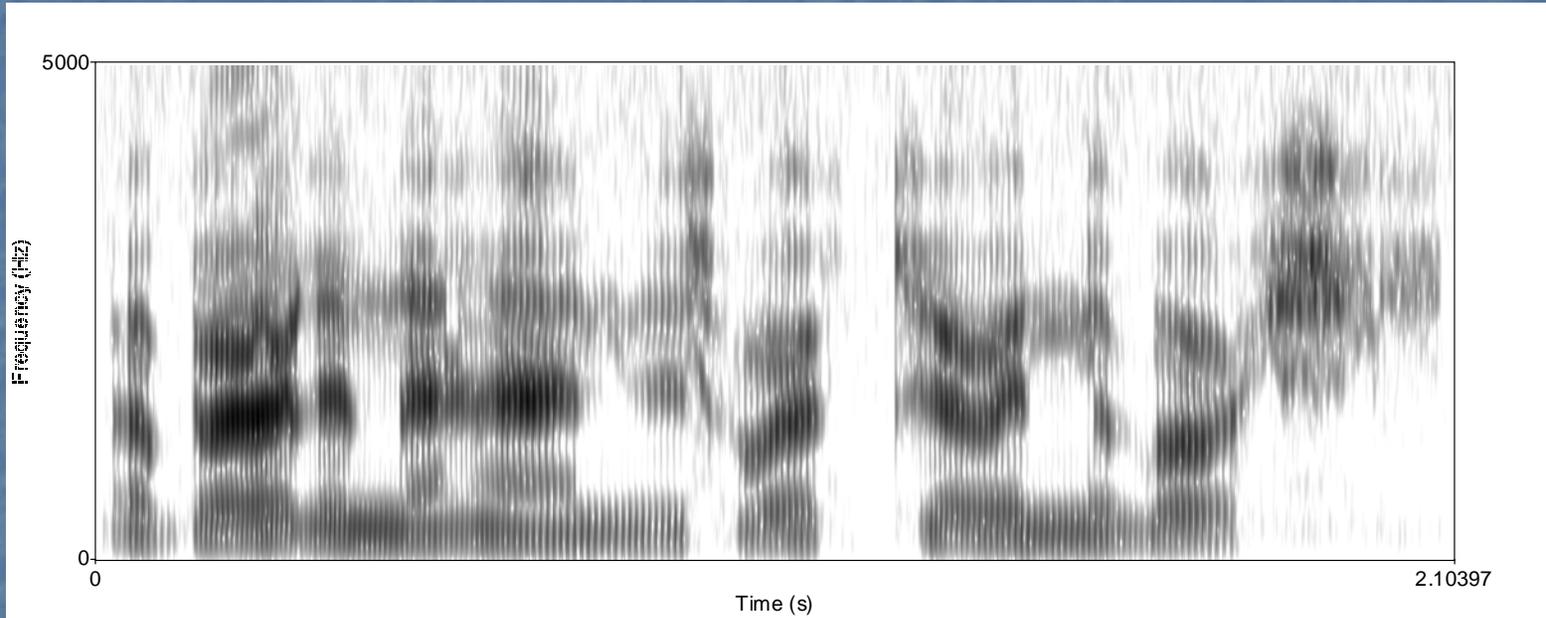
## 4.16 An expression with only the consonants



## 4.17 An expression with everything but F0



# 4.18 An expression with everything



4.19 Try to read the following pairs in PRAAT