



Articulatory Phonetics

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CS-578 Digital Speech Signal Processing
Spring Term 2019-20
University of Crete

[What is Phonetics?]

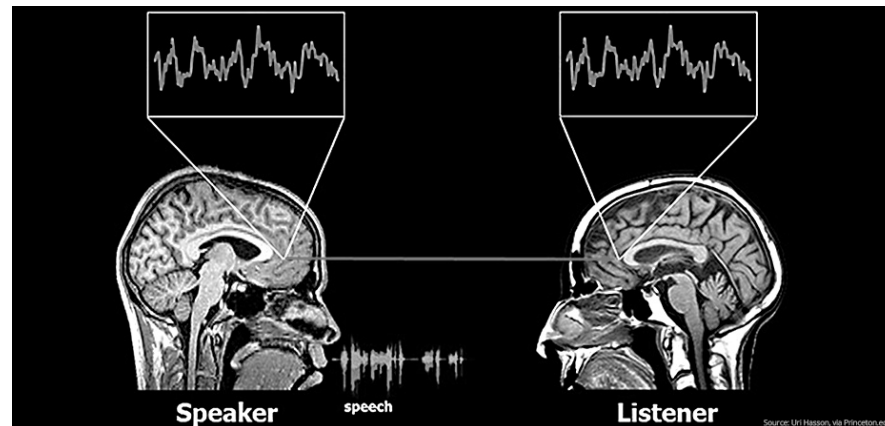
- Phonetics is a branch of Linguistics that systematically studies the sounds of human speech.
 1. How speech sounds are produced → **Production (Articulation)**
 2. How speech sounds are transmitted → **Acoustics**
 3. How speech sounds are received → **Perception**

It is an interdisciplinary subject, **theoretical** as much as **experimental**.

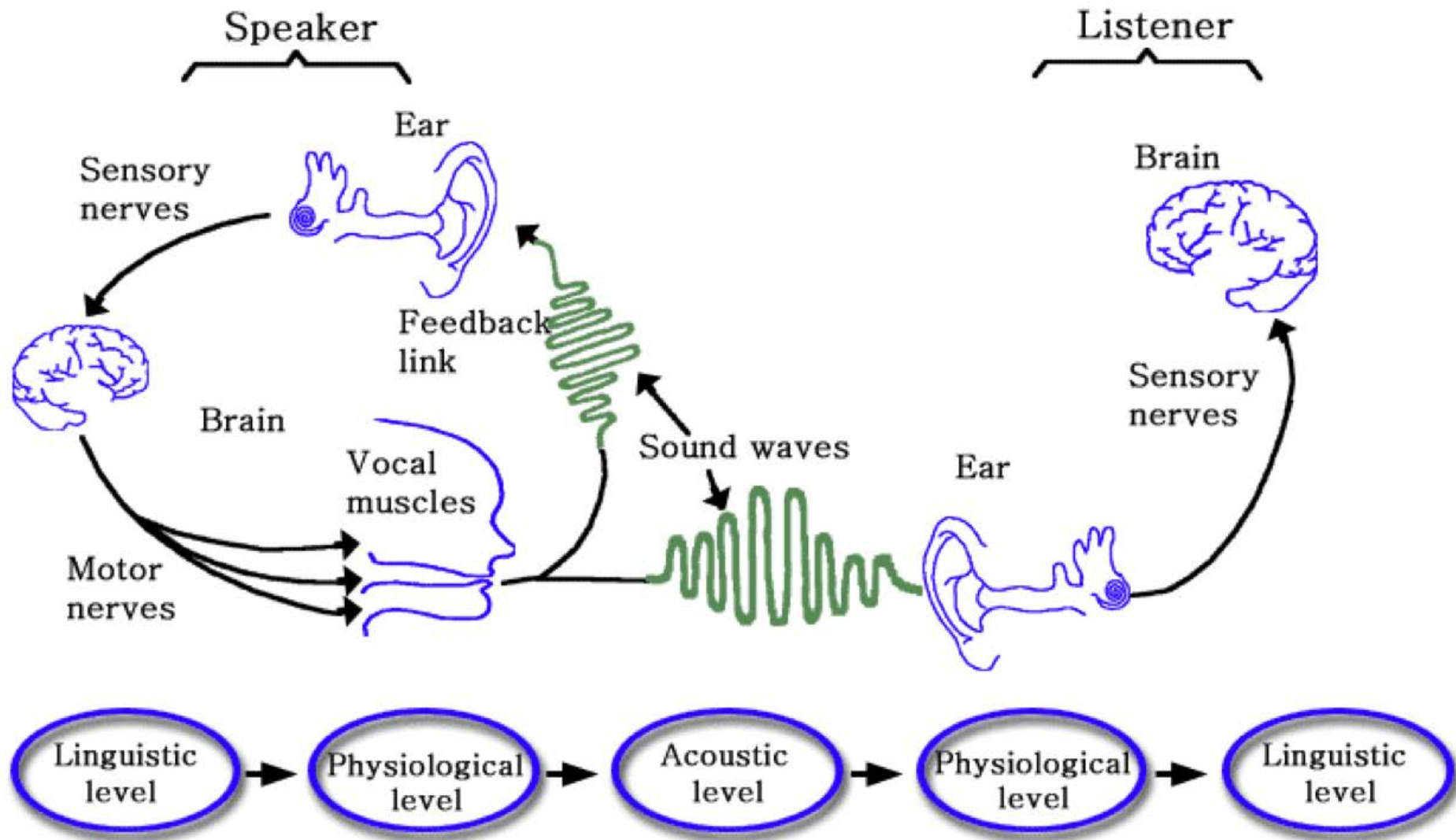


Why do speech engineers need phonetics?

- An engineer working on speech signal processing usually ignores the linguistic background of the speech he analyzes. (Olaszy, 2005)
 - How was the utterance planned in the speaker's brain?
 - How was it produced by the speaker's articulation organs?
 - What sort of contextual influences did it receive?
 - How will the listener decode the message?



The Speech Chain



[Phonetics in Speech Engineering]

Combined knowledge of articulatory gestures
and acoustic properties of speech sounds

Categorization of
sounds

speech
Segmentation



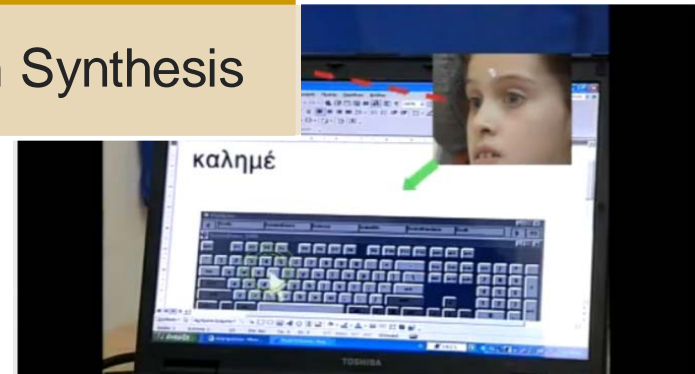
Speech Database Annotation



Algorithms

Speech Recognition

Speech Synthesis



[Phonetics in Speech Engineering]

Speech Disorders

- diagnosis
- treatment



Pronunciation Teaching Tools

- L2
- Foreign languages



Speech Intelligibility Enhancement

- Hearing aids
- Other tools



[A week with a Phonetician...]

■ *Thursday 10:00-12:00*

Articulatory Phonetics

- Speech production
- Sound waves
- Places and manners of articulation
 - Consonants & Vowels
- Waveforms of consonants - VOT
- Suprasegmentals

■ *Friday 10:00-12:00*

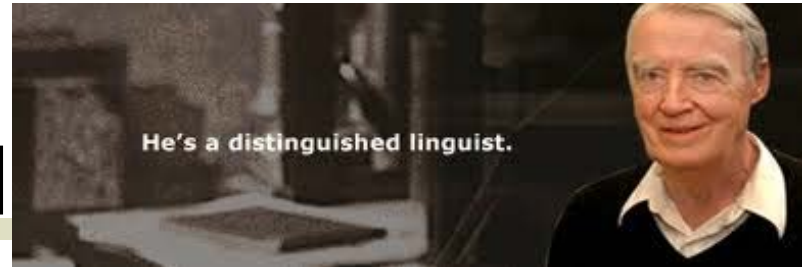
Acoustic Phonetics

- Formants
- Fundamental Frequency
- Acoustics of Vowels
 - Articulatory vs Acoustic charts
- Acoustics of Consonants
 - Formant Transitions
- Individual differences
- Interpreting spectrograms

More Phonetics:

CS-590.74 Introduction to Speech Science & Technology
Next Spring Term

Peter Ladefoged

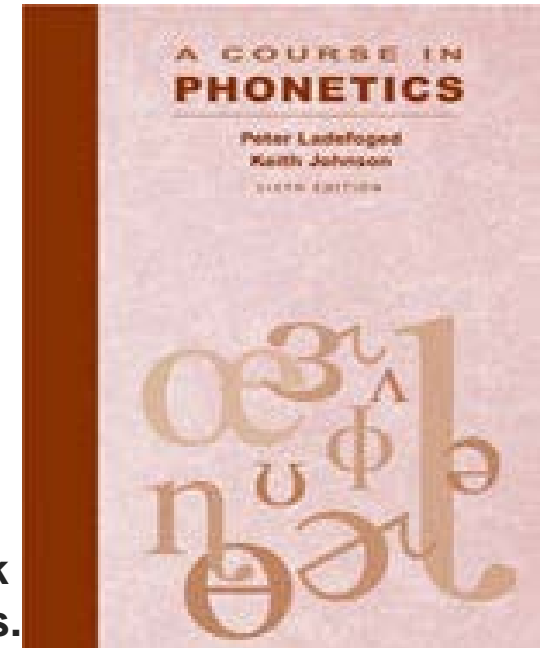


Home Page:

<http://www.linguistics.ucla.edu/people/ladefoged/>

- Professor UCLA (1962-1991)
- Travelled in Europe, Africa, India, China, Australia, etc.
- Interested in listening to and describing every sound used in spoken human language, which he estimated at 900 consonants and 200 vowels (*The Sounds of the World's Languages*).
- He was president of the International Phonetic Association (1986-1991) & the Linguistic Society of America.
- Had a brief career in Hollywood as the chief linguistic consultant on the 1964 film *My Fair Lady*.
- Exemplary teacher

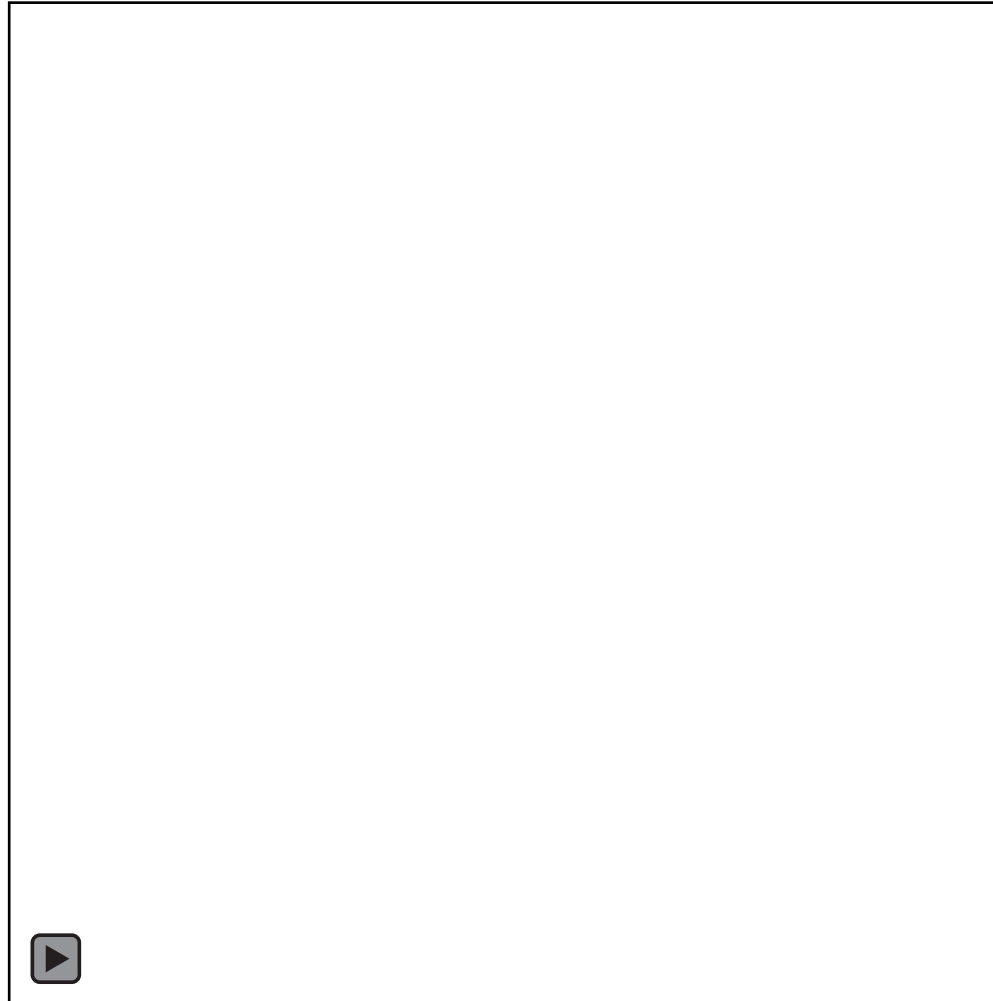
Material from this book was used in the slides.



[Speech Production]

- Most speech sounds result from movements of the tongue and the lips.
- Speech movements are named **articulatory gestures**.
- Making speech gestures audible involves
 - pushing air out of the lungs
 - producing a noise in the throat or mouth
- Tongue and lip movements form the noise coming from the larynx.

[Joy Nash trapped in an MRI machine...]



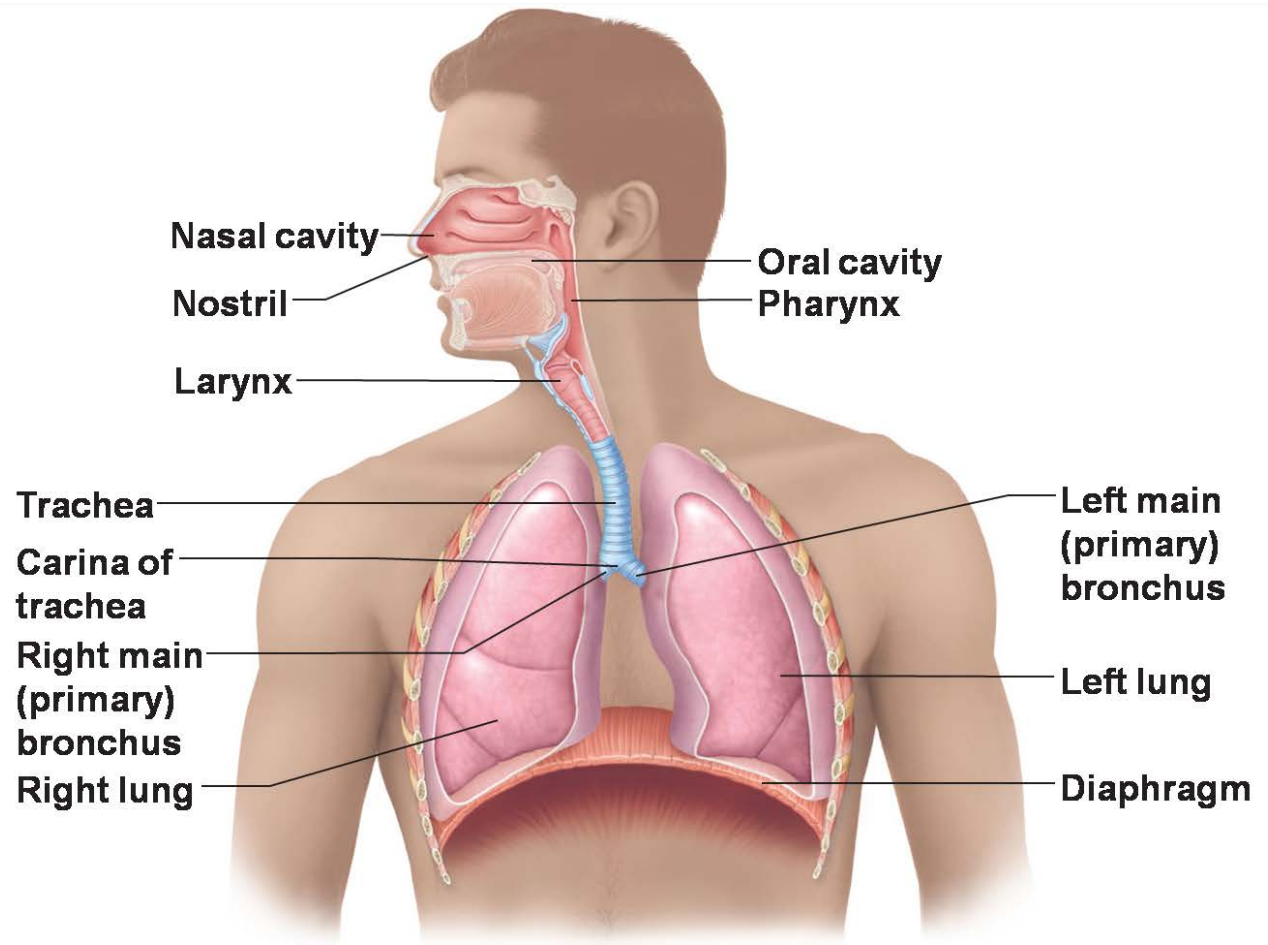
<https://www.youtube.com/watch?v=0-aEN2xHBCc>

[Speech Production]

- The tongue and lips move rapidly from one position to another.
- The actions of the tongue are among the fastest and the most precise physical movements that people make.

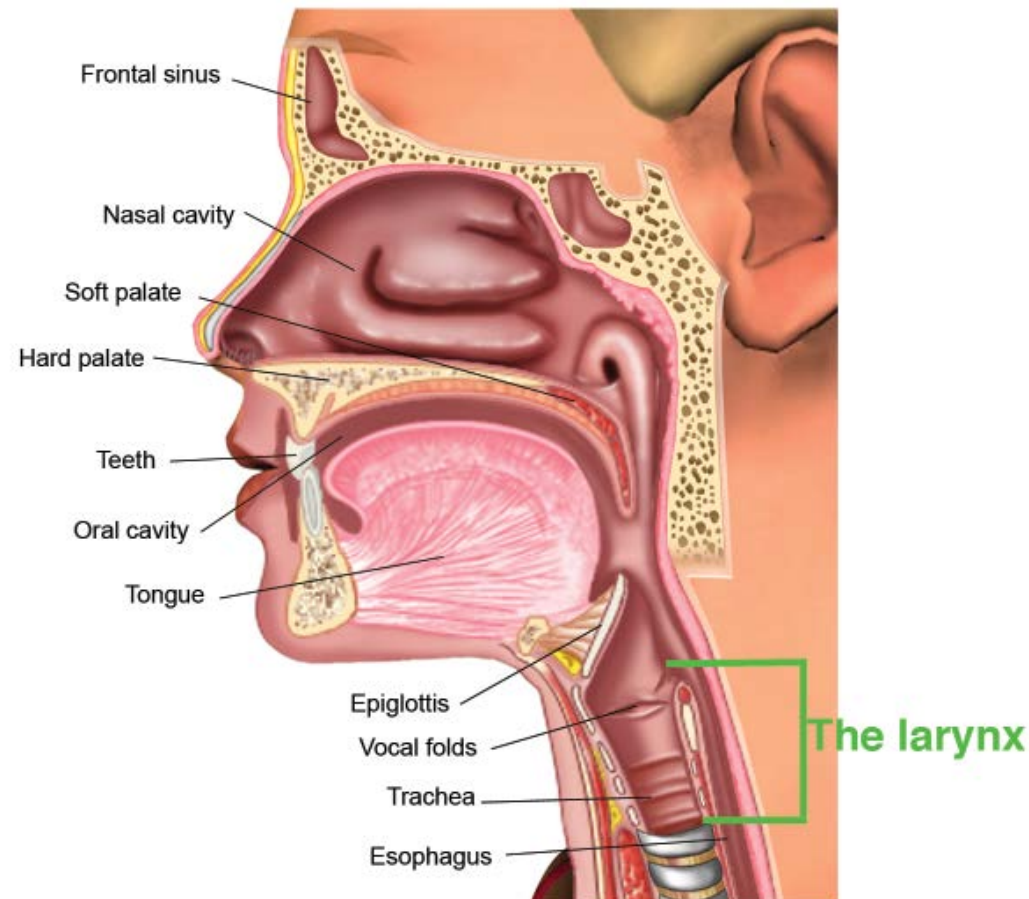
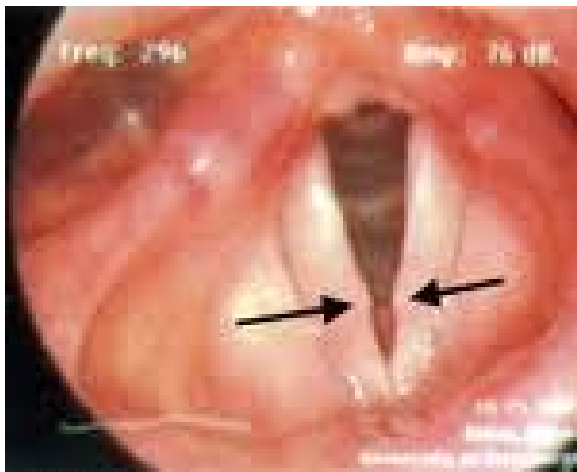
- The basic source of power for speech:
the **respiratory system**
 - Pushing **air** out of the lungs
- **lungs → trachea → larynx → vocal folds**

Try to talk
while
breathing in
instead of out.
What do you
observe?

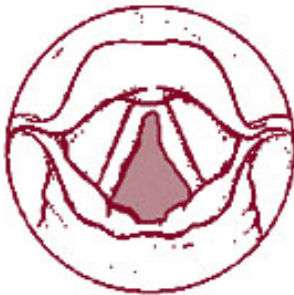


Speech Production - Vocal folds

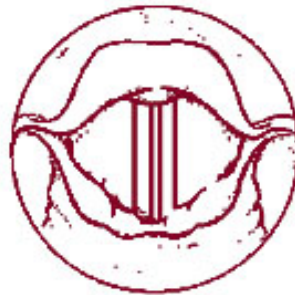
- In the larynx there are two small muscular folds, the **vocal folds**.
- If they are apart, the air has free passage into the pharynx and the mouth.



Speech Production - Vocal folds



Vocal cords
abducted
to breathe



Vocal cords
adducted
to speak

Abducted vocal folds:

- respiration
- Production of **voiceless** sounds

Adducted vocal folds:

- Production of **voiced** sounds (phonation)

Exercise: Voiceless vs voiced sound
[fffffffff vvvvvvv ffffffffff vvvvvvvvvvv]

- Put your fingertips against the larynx.
- Stop up your ears while contrasting.

Speech Production - Vocal folds



- Stroboscopy: female vocal folds vibrating at high and low pitches
Video: <http://www.youtube.com/watch?v=UpOXecWC5Dw>

[Voicing]

- Distinguishing sounds on the basis of voicing:
 - **f**at vs. **v**at
 - **t**high vs. **th**y
 - **s**ue vs. **z**oo
 - **φ**άρος vs. **β**άρος
 - **σ**ώνει vs. **ζ**ώνη

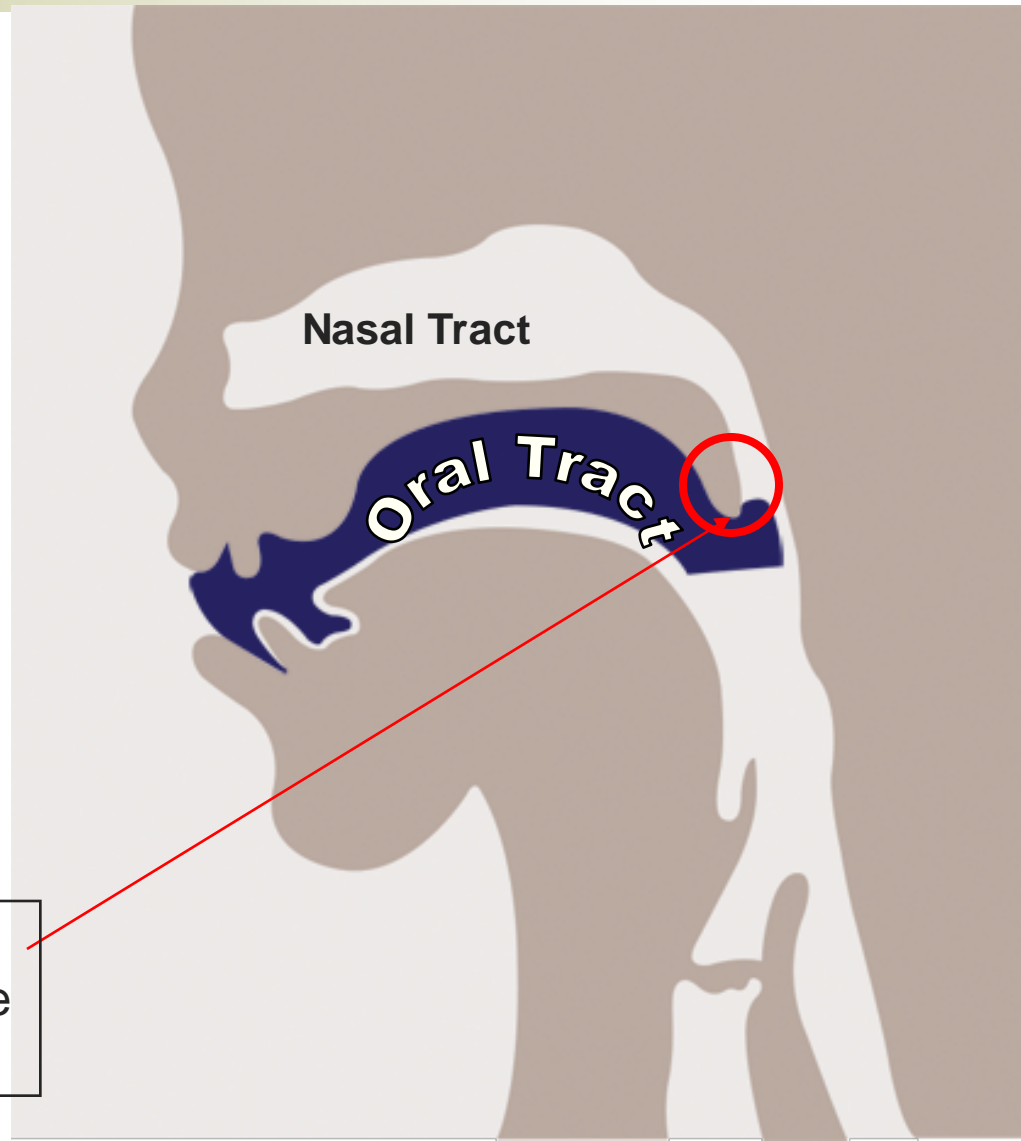
More pairs?

[Vocal Tract]

- Oral Tract
 - mouth
 - pharynx
- Nasal Tract
- Articulators
 - tongue
 - lips

Flap at the back of mouth:

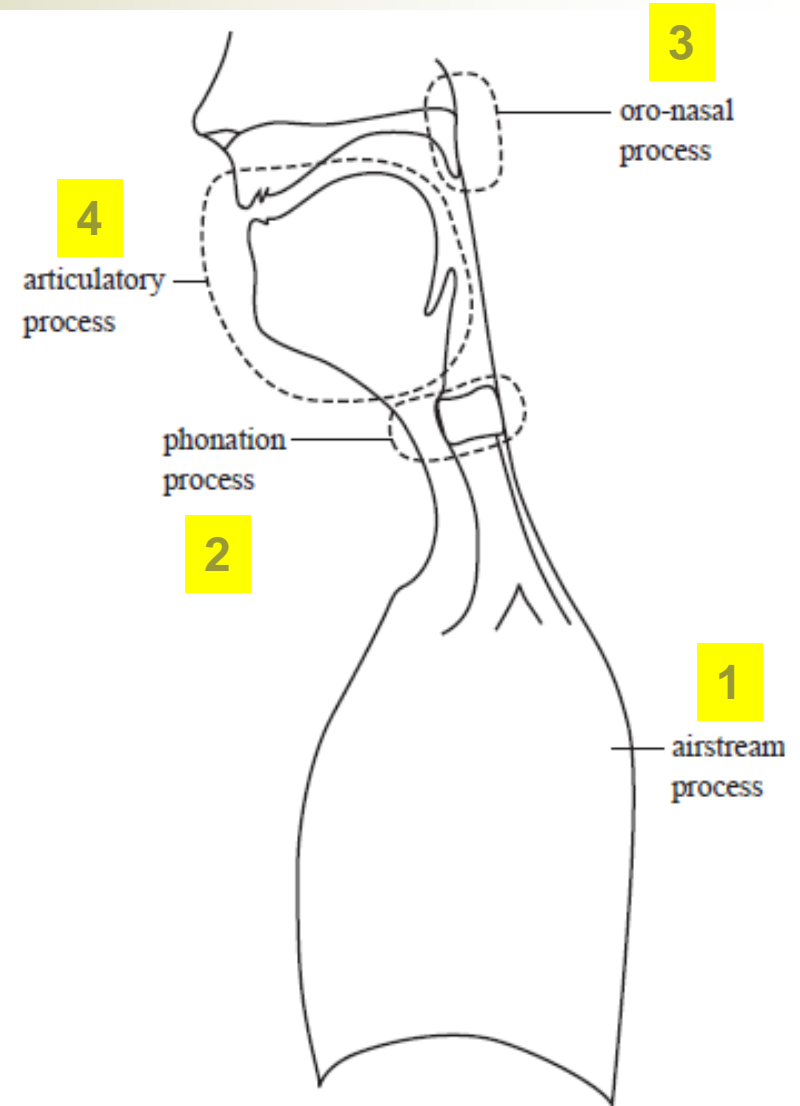
- air goes in and out through the nose
- production of [m] and [n]



Speech Production Mechanism

The four main components of the speech production mechanism:

1. airstream process
2. phonation process
3. oro-nasal process
4. articulatory process

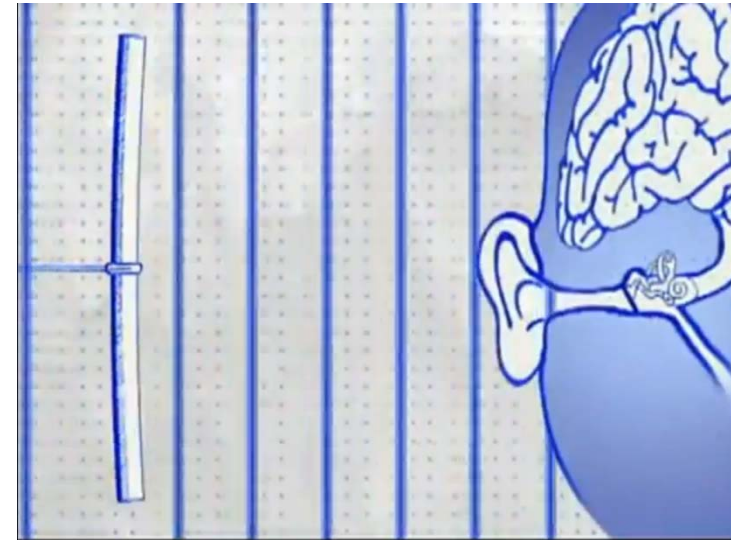


[Sound waves]

- The way in which we hear a sound depends on its **acoustic structure**.

- Speech sounds differ from one another in three ways

1. **pitch/frequency**
2. **loudness**
3. **quality**



- How is sound produced

articulatory movements superimposed on outgoing flow of lung air → small variations in air pressure → **sound wave** → vibrations in listener's eardrum

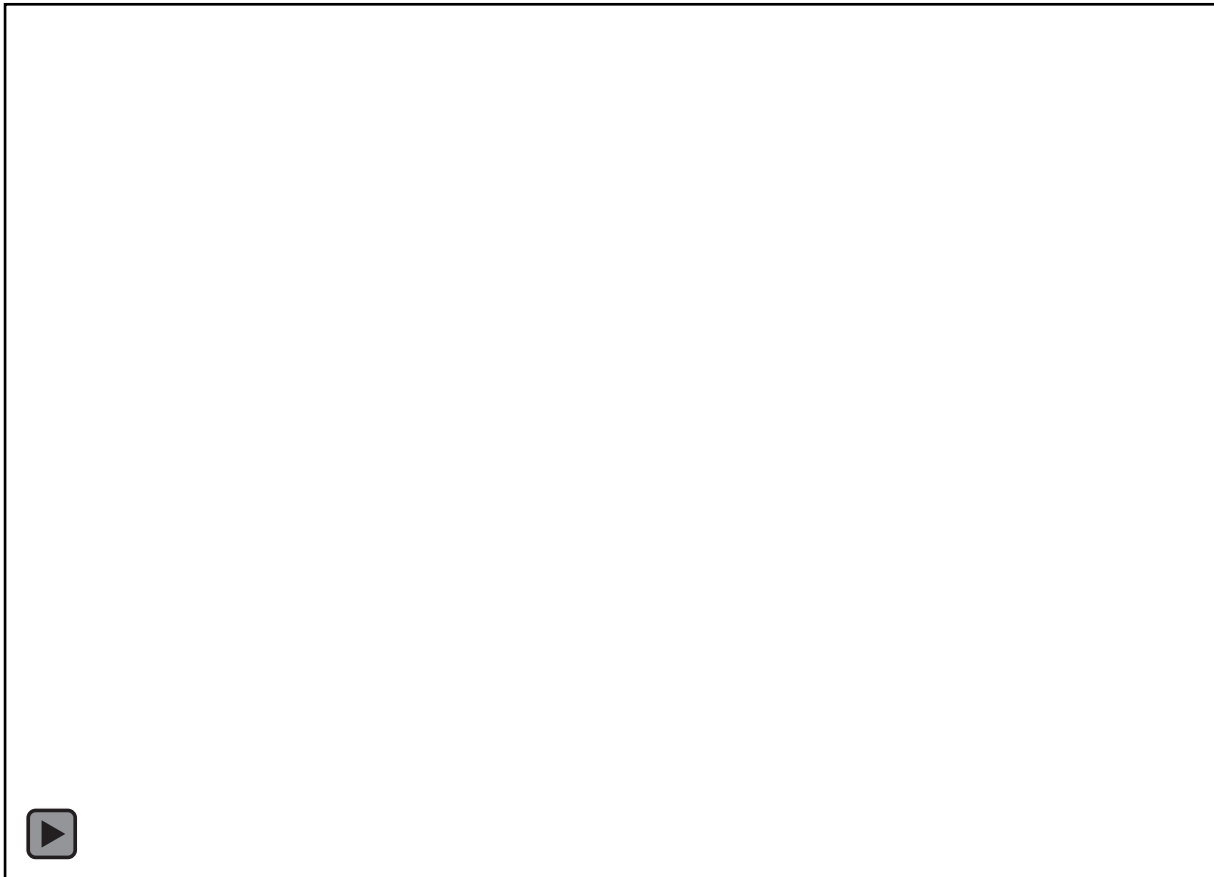
[Sound waves]



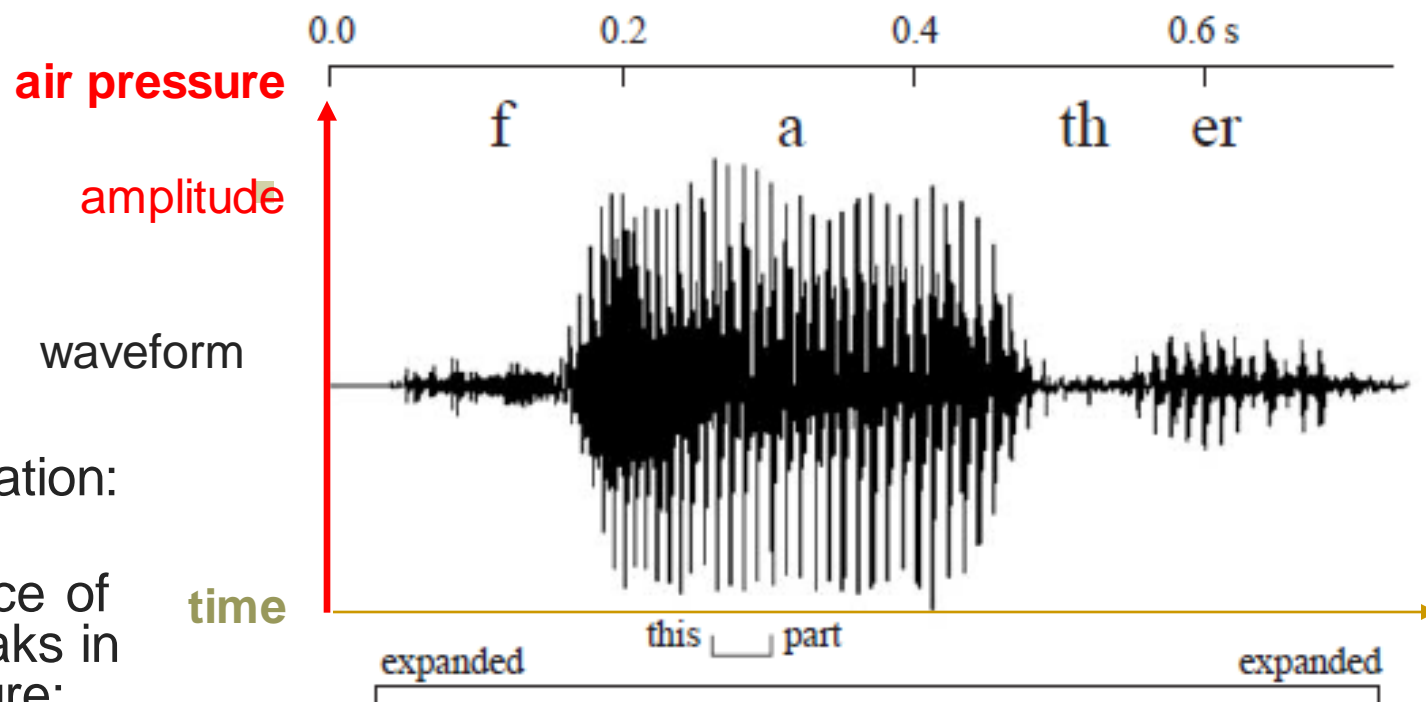
<http://www.youtube.com/watch?v=-rFnzHXX1vk>

[Sound waves]

- Sound, vibration and acoustic characteristics

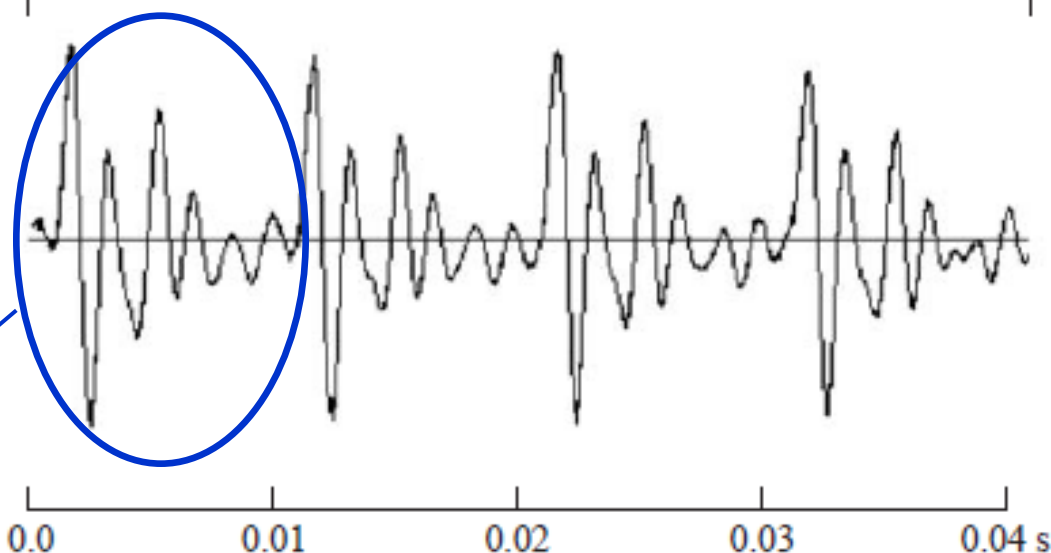


Variations in air pressure



- Word duration: 0,6s
- Recurrence of major peaks in air pressure: 0,01s →
- Vocal folds vibrate 100 times a sec. →
- 1 pulse every 1/100 sec

Variations within each period
→Vocal tract shape
(**vowel quality**)



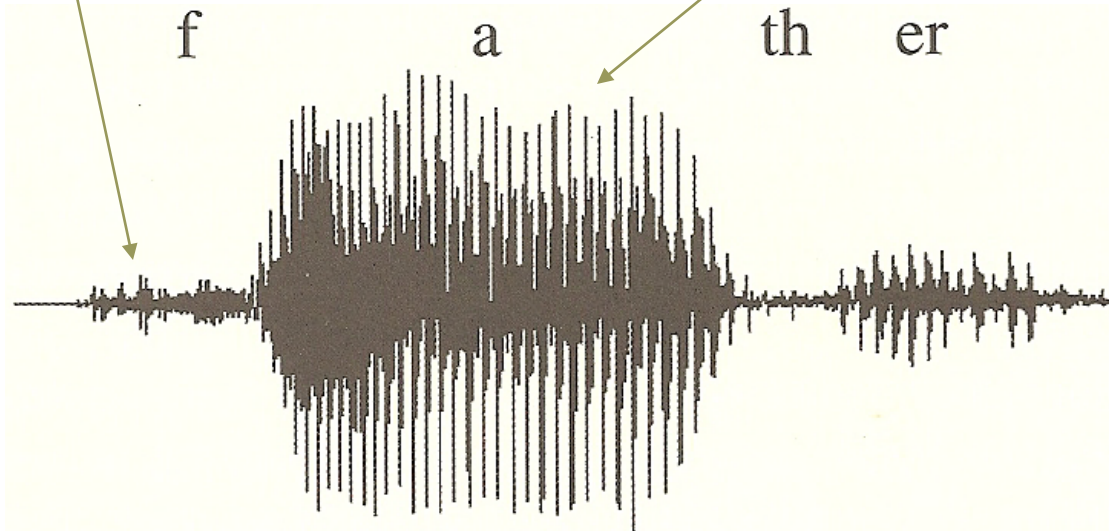
[Sound waves]

CONSONANTS

- smaller amplitude
- irregular vibrations in air pressure
- Vocal folds do not vibrate (voiceless C).

VOWELS

- large regular pulses of air pressure
- Vocal folds vibrate.

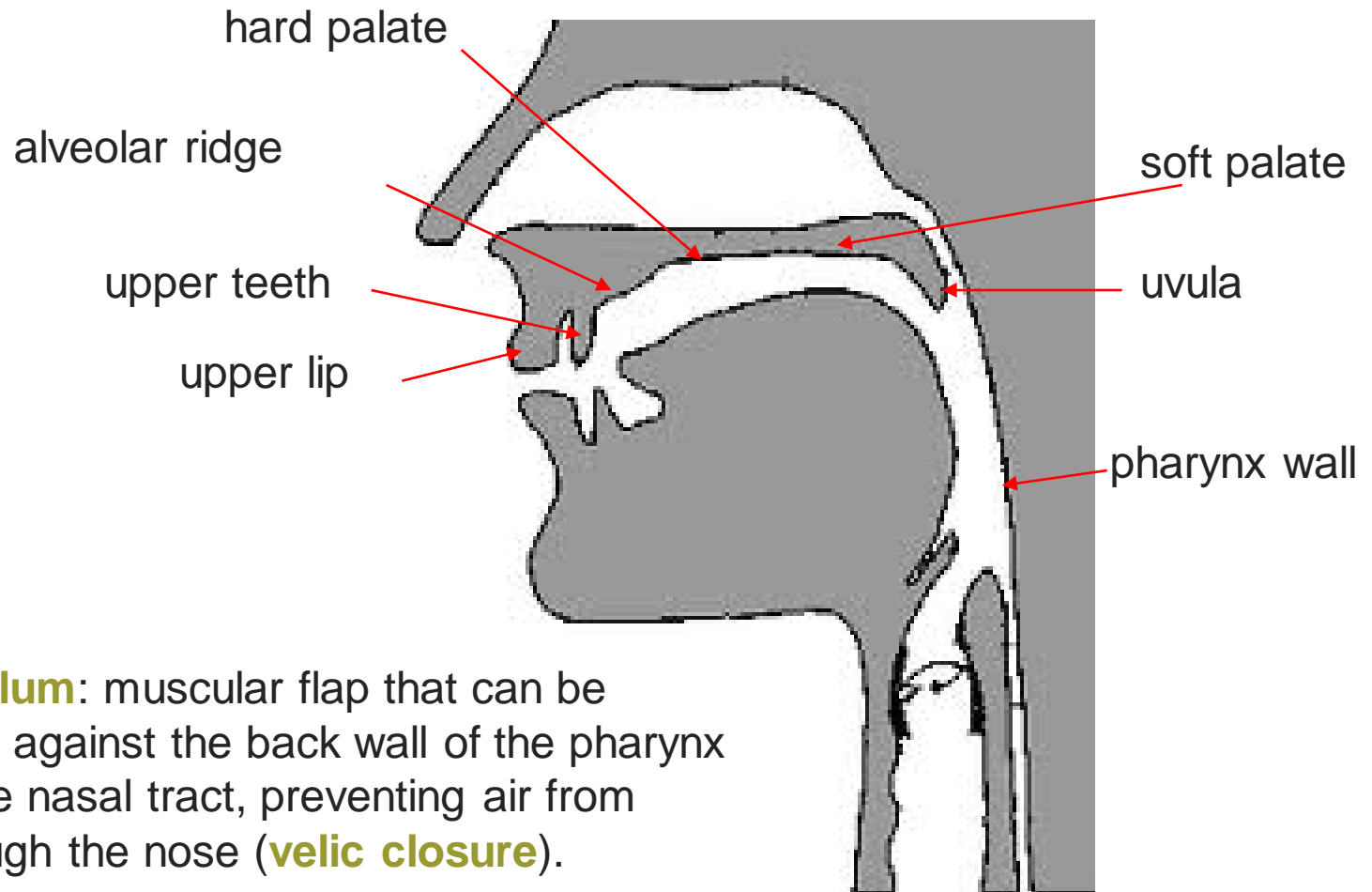


[Places of articulatory gestures]

- Articulators: parts of the vocal tract used to form sounds
- Articulators forming the lower surface of the vocal tract
 - are highly mobile
 - move towards articulators that form the upper surface

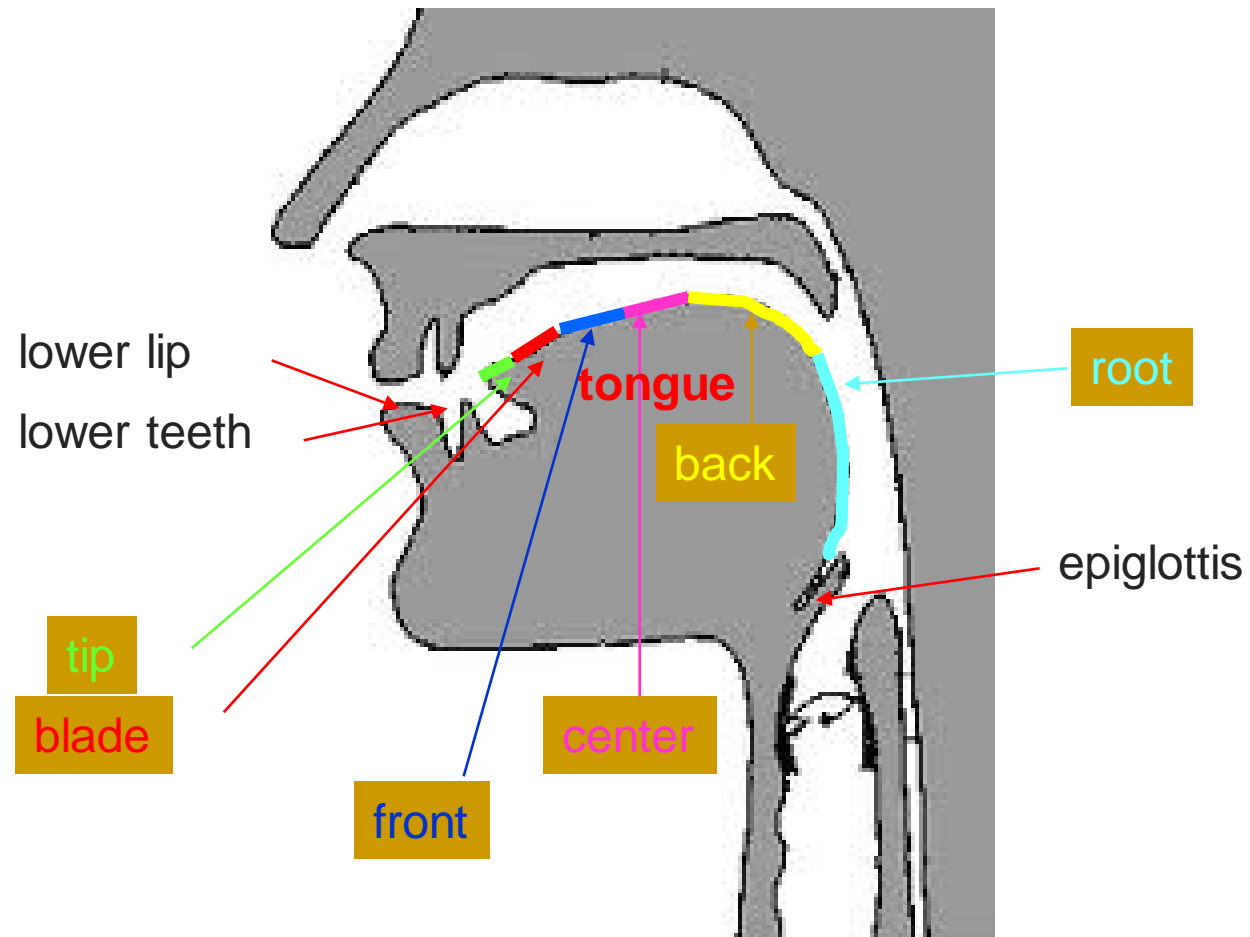
Exercise: Try saying the word “capital” and note the major movements of your tongue and lips.

[Parts of the upper surface of the vocal tract]



Soft palate/velum: muscular flap that can be raised to press against the back wall of the pharynx and shut off the nasal tract, preventing air from going out through the nose (**velic closure**).

Parts of the lower surface of the vocal tract



Άνω αρθρωτές –Upper articulators

Terms in Greek & English

■ χείλος	lip
■ οδόντες	teeth
■ φατνία	alveolar ridge
■ ουρανίσκος	hard palate
■ υπερώα	soft palate/velum
■ σταφυλή	uvula

[Κάτω αρθρωτές –Lower articulators Terms in Greek & English]

■ κάτω χείλος	bottom lip	
■ κάτω οδόντες	bottom teeth	
■ άκρο	tip	} γλώσσα tongue
■ προράχη	blade	
■ πρόσθιο τμήμα	front	
■ κέντρο	center	
■ ράχη	back/dorsum	
■ ρίζα	root	
■ επιγλωττίδα	epiglottis	

[Examples]

- “**peculiar**”

1. lips come together
2. back and center of the tongue are raised (towards hard palate or velum?)
3. tip of the tongue on alveolar ridge

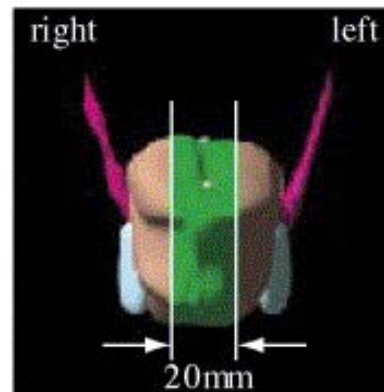
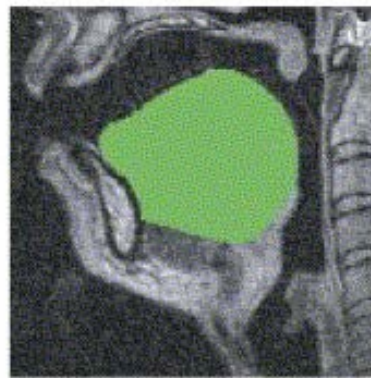
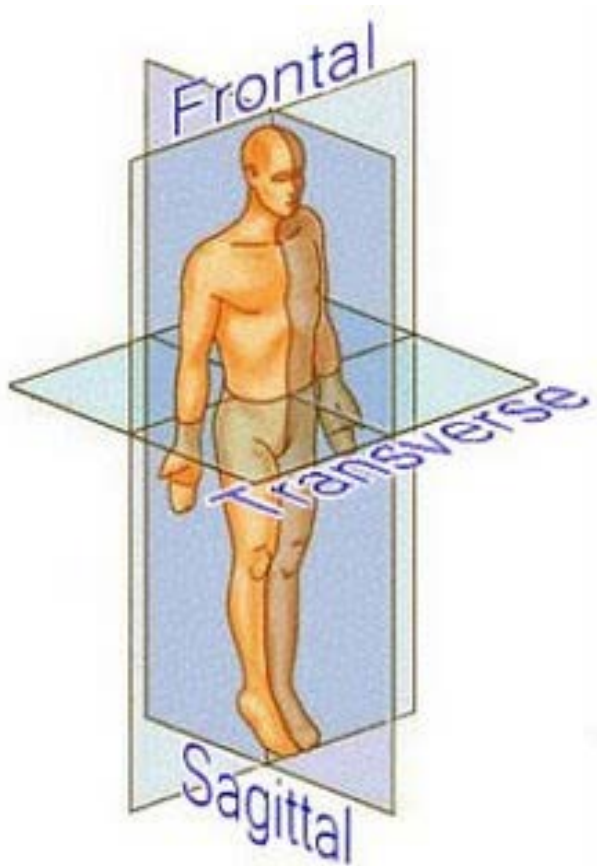
- “**true**” vs. “**tea**”

- “**sigh**” vs. “**shy**”

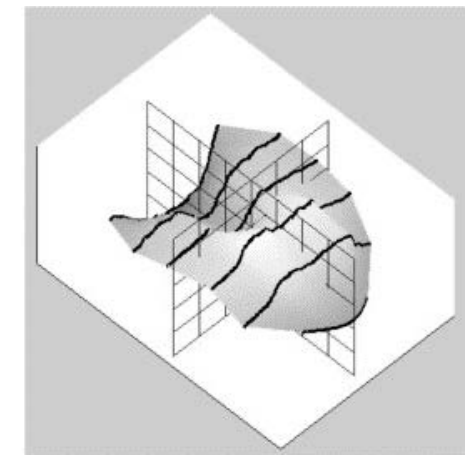
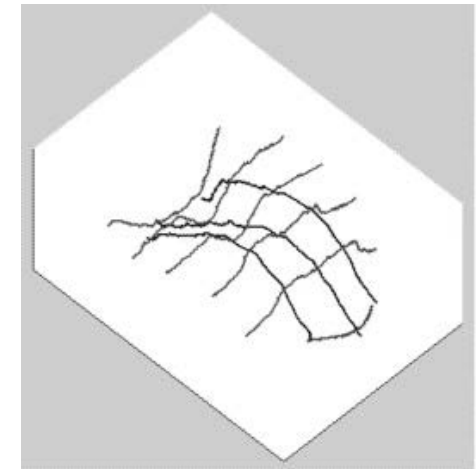


Tongue depiction

- Mid-sagittal vs. 3D view

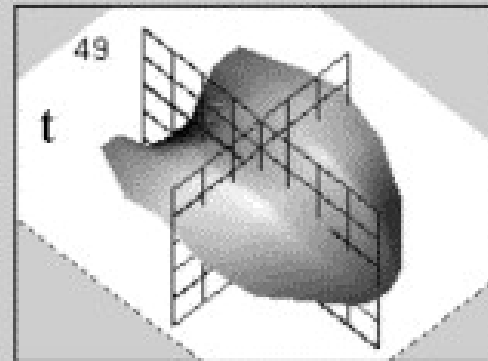
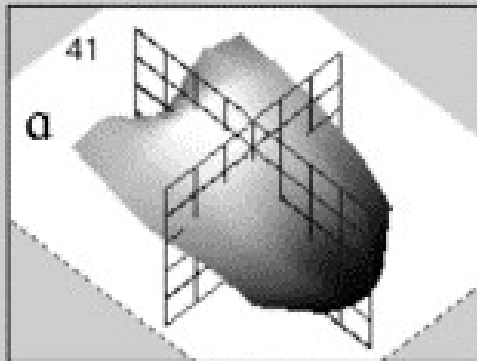
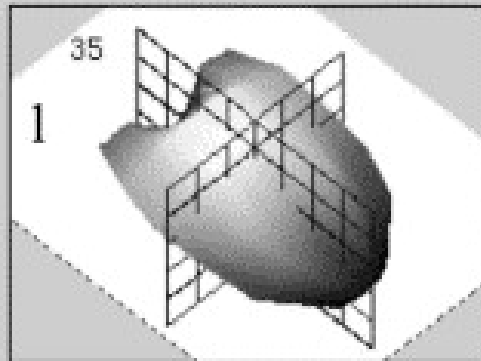
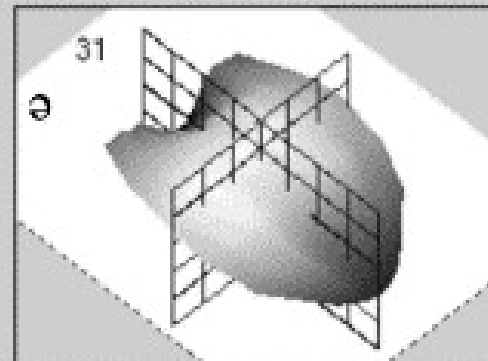
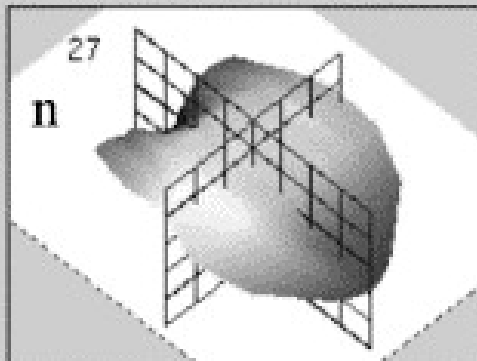
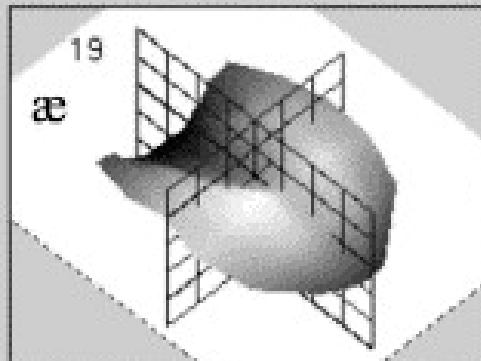
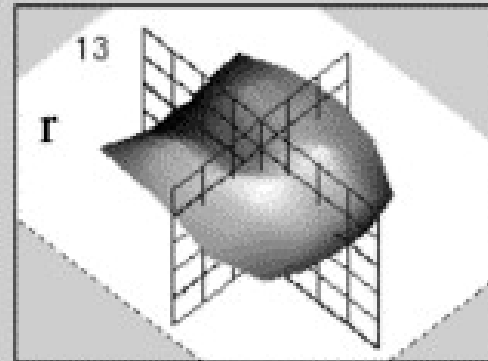
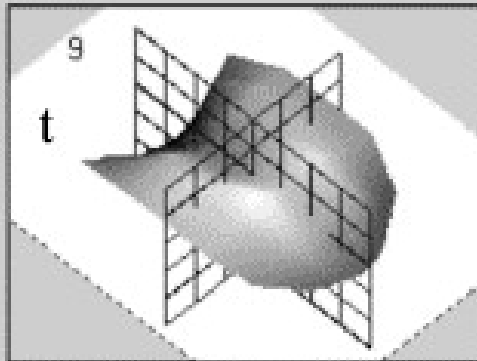
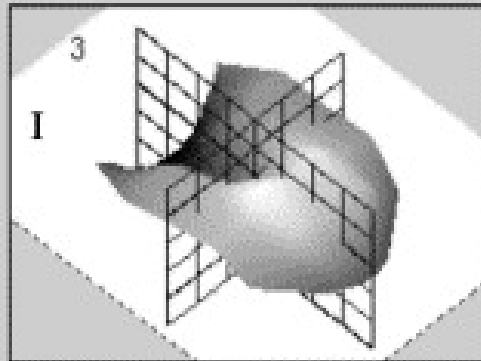


*Takano & Honda
(2007)*



[3D tongue depiction]

"It ran a lot"



Young & Stone
(2002)

[Basic places of consonant articulation]

- In order to form consonants, the airstream through the vocal tract must be **obstructed** in some way.
- Consonants can be classified according to the place and manner of this **obstruction**.

[Basic places of consonant articulation]

Articulator

- lips
- tongue tip and blade
- back of the tongue

Articulation

labial
coronal
dorsal

Example: “**topic**”

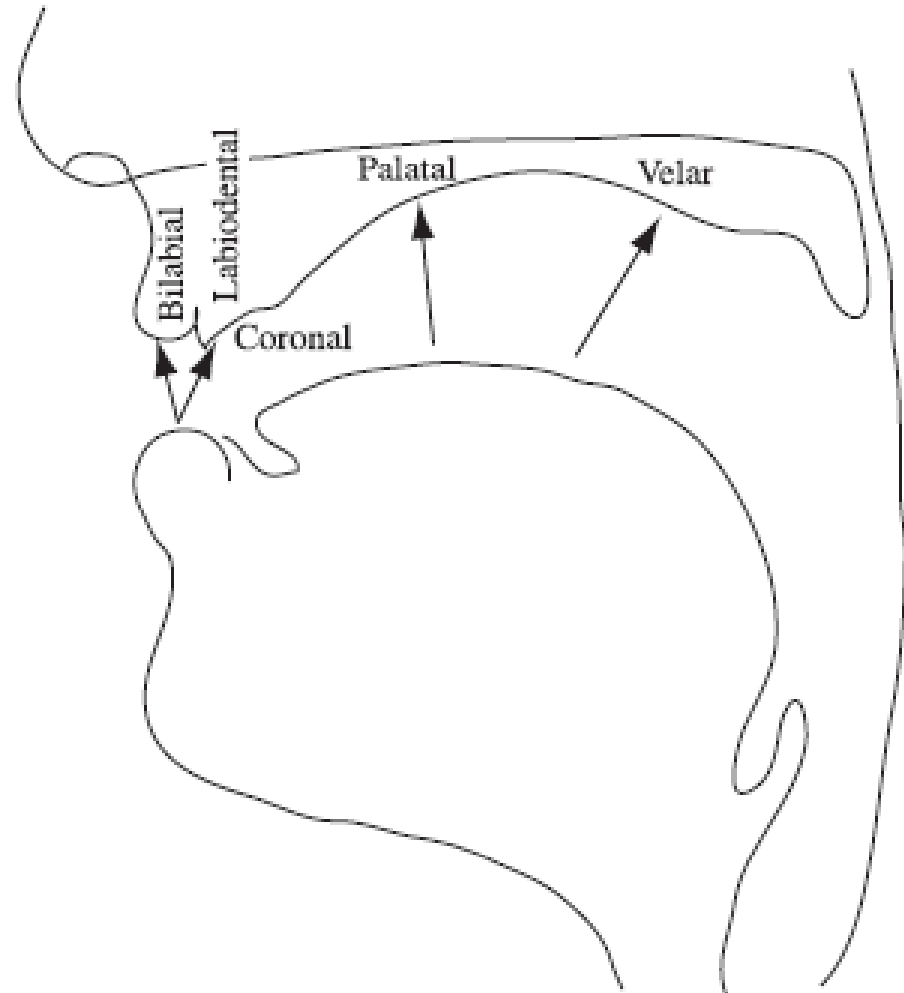
Places of consonant articulation

LABIAL ARTICULATION

- **bilabial**
The two lips come together.
 - *pie, buy, my*
- **labiodental**
The lower lip is raised and nearly touches the upper front teeth.
 - *fie, vie*

CORONAL ARTICULATION

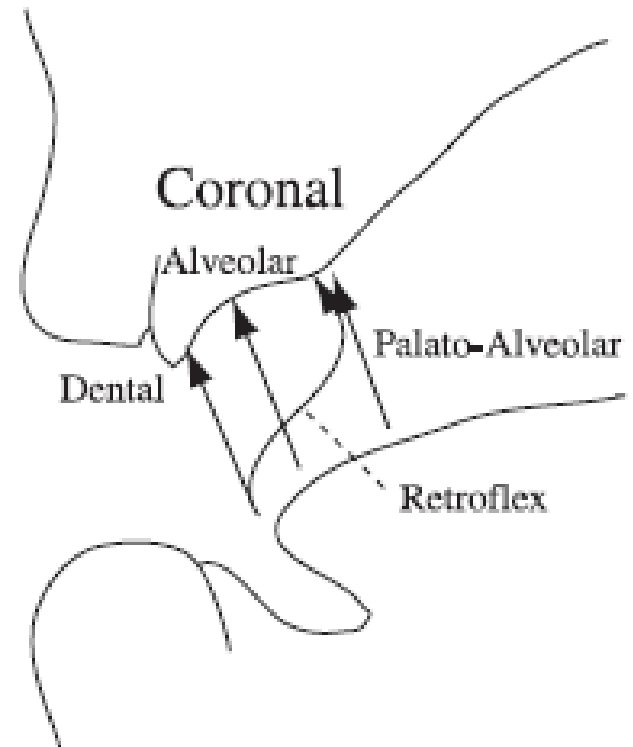
- **dental**
Tongue tip/blade protruding between upper and lower teeth (**interdental**) or close behind the upper front teeth
 - *thigh, thy*



Places of consonant articulation

CORONAL ARTICULATION (cont'd)

- **alveolar**
tip/blade of the tongue
at the alveolar ridge
tie, die, nigh
sigh, zeal
lie
- **retroflex**
tongue tip at the back of alveolar ridge
rye, row, ray / ire, hour, air
- **palato-alveolar** or **post-alveolar**
tongue blade at the back of alveolar ridge
shy, she, show



Tip: Articulate and hold the position while taking breath in

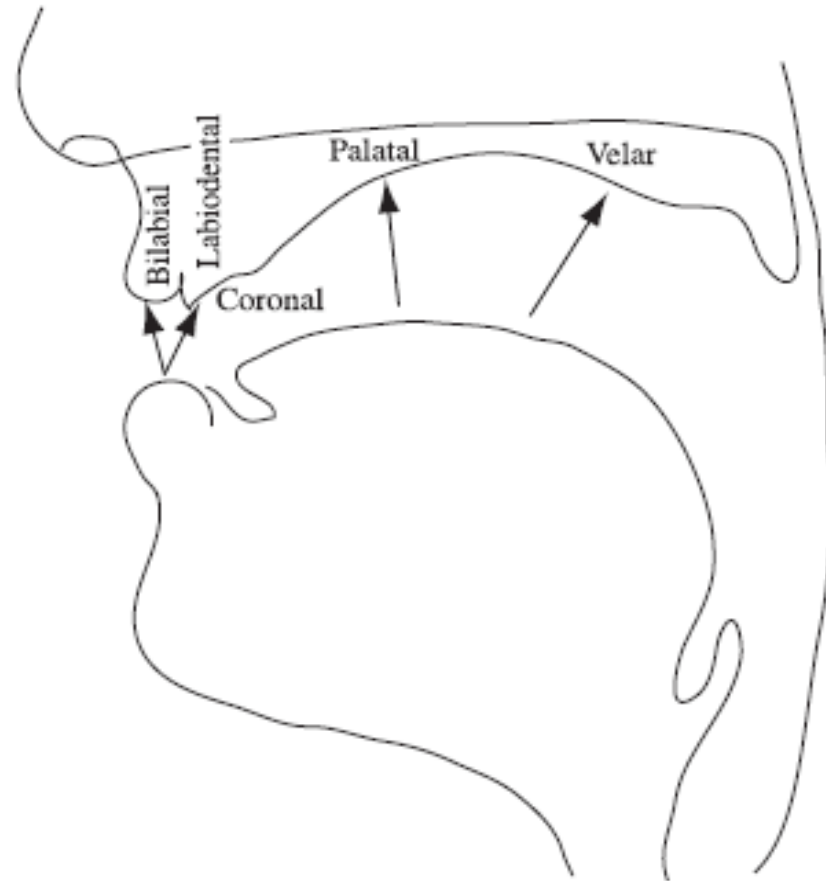
[Places of consonant articulation]

CORONAL / DORSAL ARTICULATION

- **palatal**
front of the tongue at hard palate
 - *y*ou

DORSAL ARTICULATION

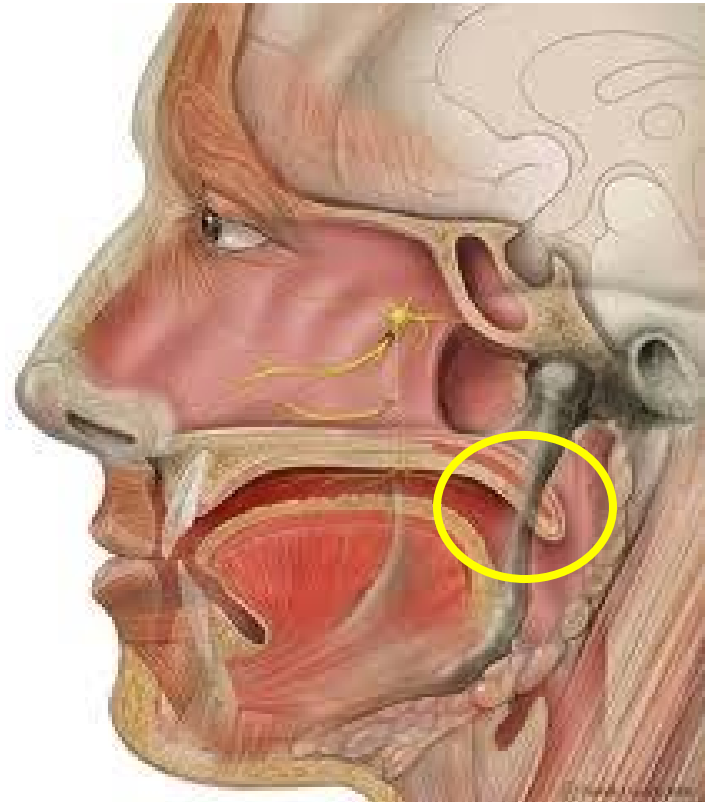
- **velar**
back of the tongue at soft palate
 - *ha***ck**, *ha***g**, *ha***ng**



Example: **f**ee → **th**eme → **s**ee → **sh**e
 labiodental → (inter)dental → alveolar → palato-alveolar

[The oro-nasal process]

- In most speech, the soft palate is raised so that there is a **velic closure (oral sounds)**.
- During production of **nasal sounds**:
 - There is an obstruction in the mouth.
 - The velum is lowered so that air escapes through the nasal cavity.



Example: rang → ran → ram
 velar → alveolar → bilabial

[Manners of articulation]

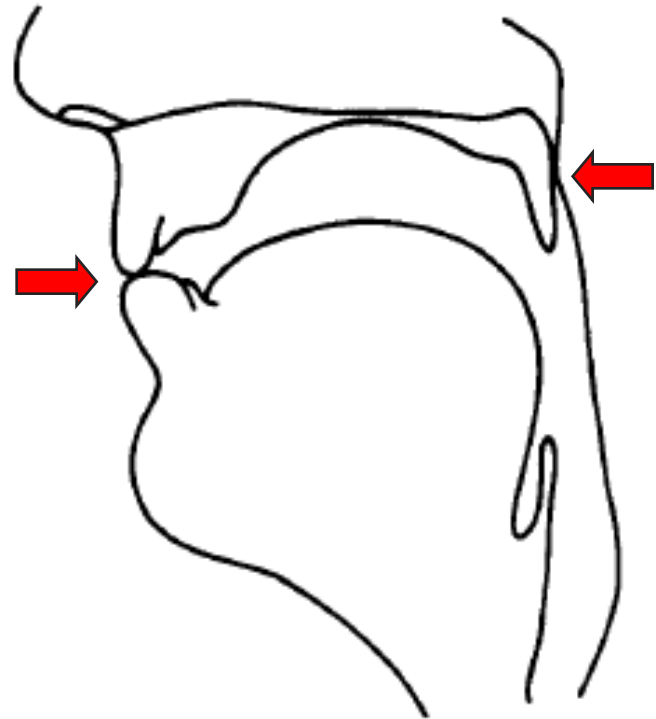
- At most places of articulation, there are several ways in which articulatory gestures can be accomplished.
 - Oral tract may close off
 - for an instant
 - for a longer period
 - The articulators may
 - narrow the space considerably
 - simply approach each other

[Manners of articulation: **stop**]

- Complete closure of articulators involved so that the airstream cannot escape through the mouth.
- Types of stops:
 - oral stop
 - nasal stop

[Oral stop]

- articulatory closure in the mouth
- the nasal tract is blocked off (raised soft palate)
- pressure in the mouth builds up
- airstream is released → **burst** → **plosives**



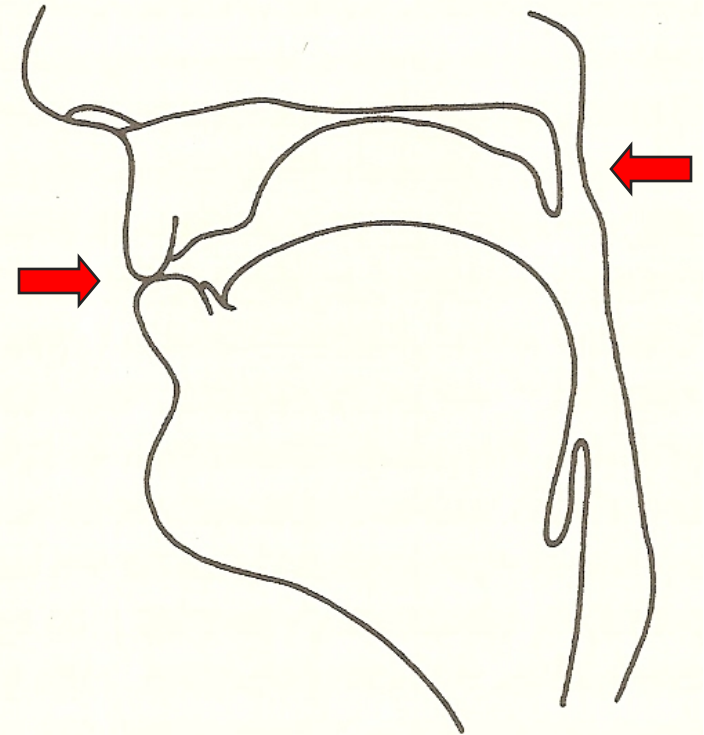
Example: **pie**, **buy** →
 bilabial →

tie, **dye** →
 alveolar →

kye, **guy**
 velar

[Nasal stop]

- articulatory closure in the mouth
- lowered soft palate → air goes through nasal cavity
- Usually:
 - stop = oral stop
 - nasal = nasal stop



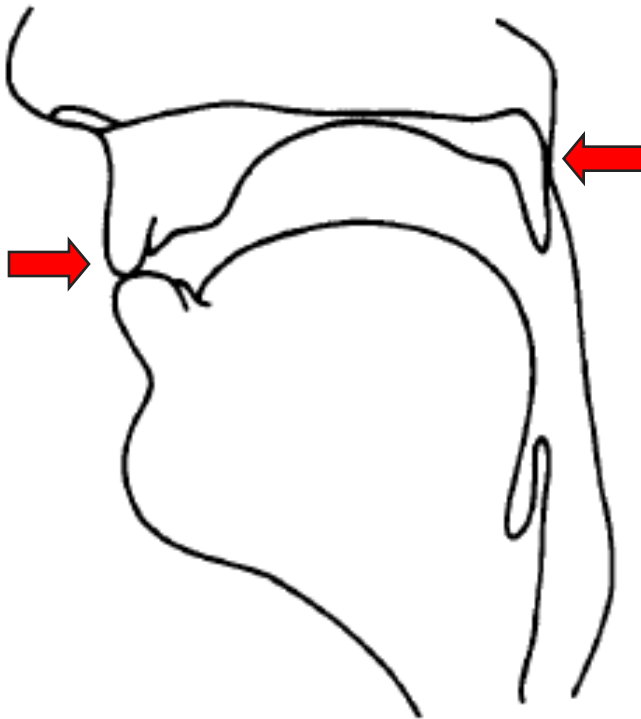
Example: **my** →
 bilabial →

nigh →
 alveolar →

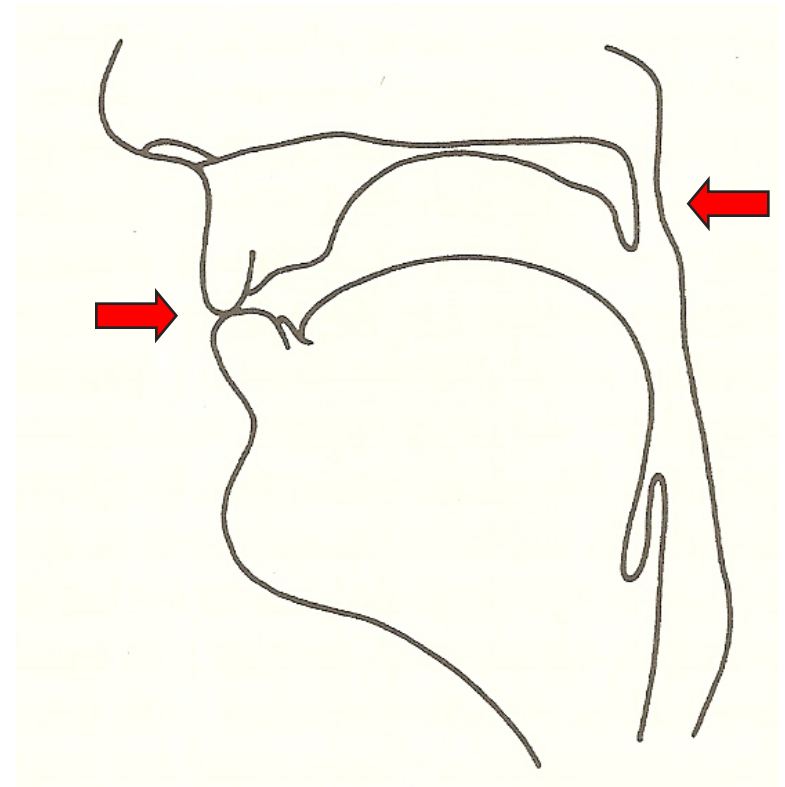
hang
 velar

[Oral vs. Nasal stop]

Oral

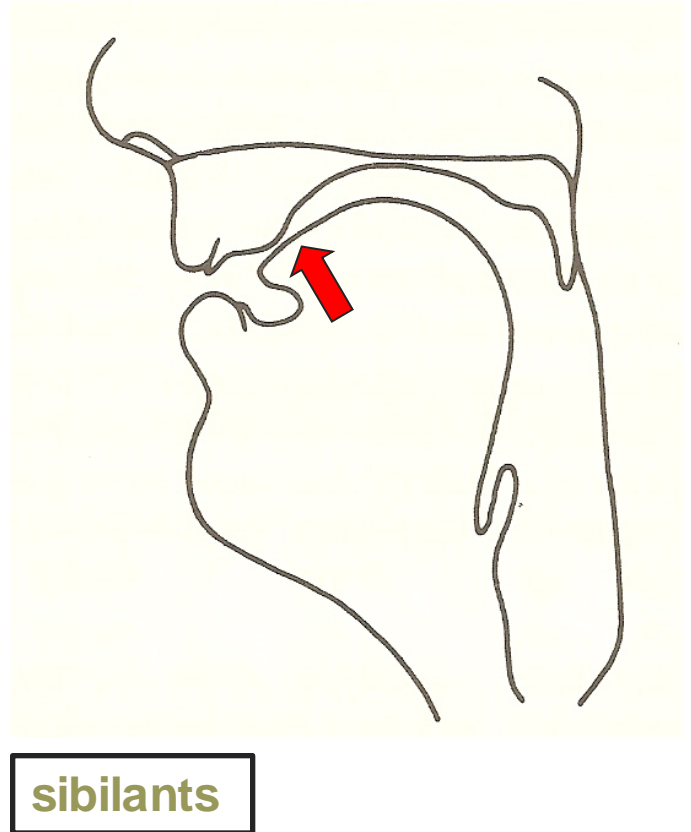


Nasal



[Fricative]

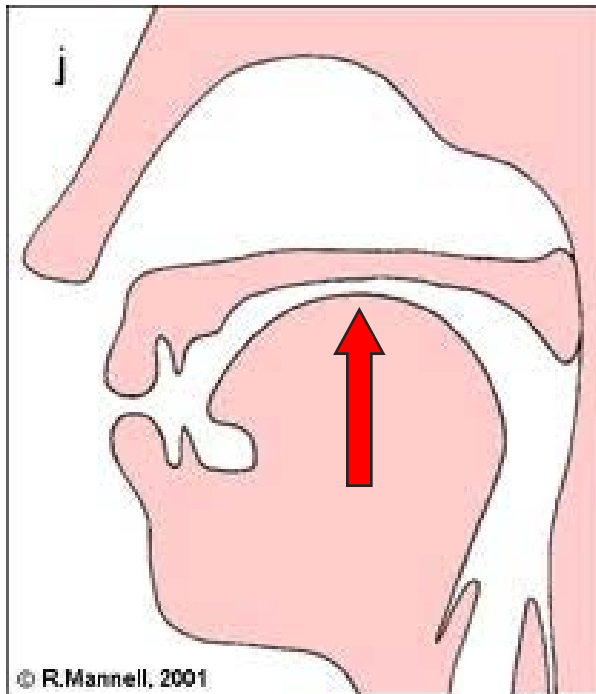
- close approximation of two articulators
- airstream is partially obstructed
- turbulent airflow is produced (hissing sound - **noise**)



Example: **f**ie, **v**ie → **th**igh, **th**y → **s**igh, **z**oo → **sh**y
 labiodental → dental → alveolar → palato-alveolar

[Approximant]

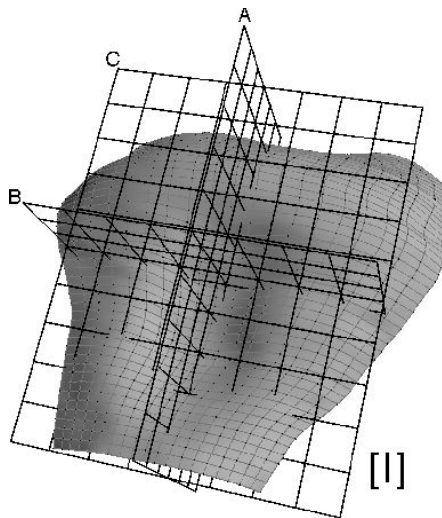
- approximation of two articulators
- vocal tract not narrowed to such an extent that turbulent airstream is produced



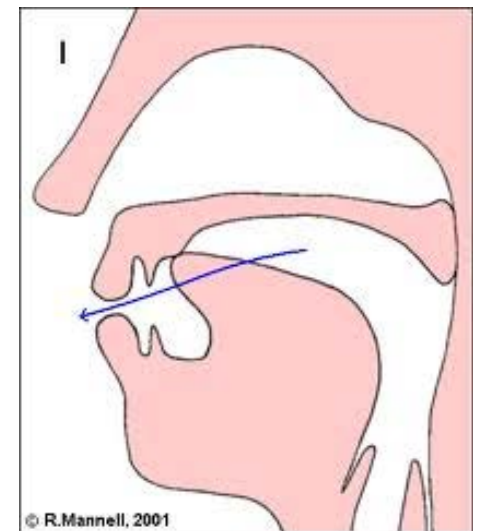
Example: **y**acht → **w**e → **r**aw
palatal → labial-velar → alveolar

[Lateral (approximant)]

- obstruction of airstream at a point along the center of the oral tract
- incomplete closure between one or both sides of the tongue and the roof of the mouth
- air flows freely over the side of the tongue



Example: lie, laugh, hill
alveolar



Additional consonantal gestures

- tongue-tip **trill** (roll)
rye, raw (Scottish English)
- **tap** (flap)
poʒ (Greek /r/) or *pitty* (American English)
- **affricate** (stop + fricative)
church, judge
- **glottal stop** [ʔ]
flee east vs. *fleece*

[Summary]

- Consonants are described in terms of five factors
 1. state of vocal folds
(voiced/voiceless)
 2. place of articulation
 3. central or lateral articulation
 4. soft palate raised or lowered
(oral/nasal)
 5. manner of articulation

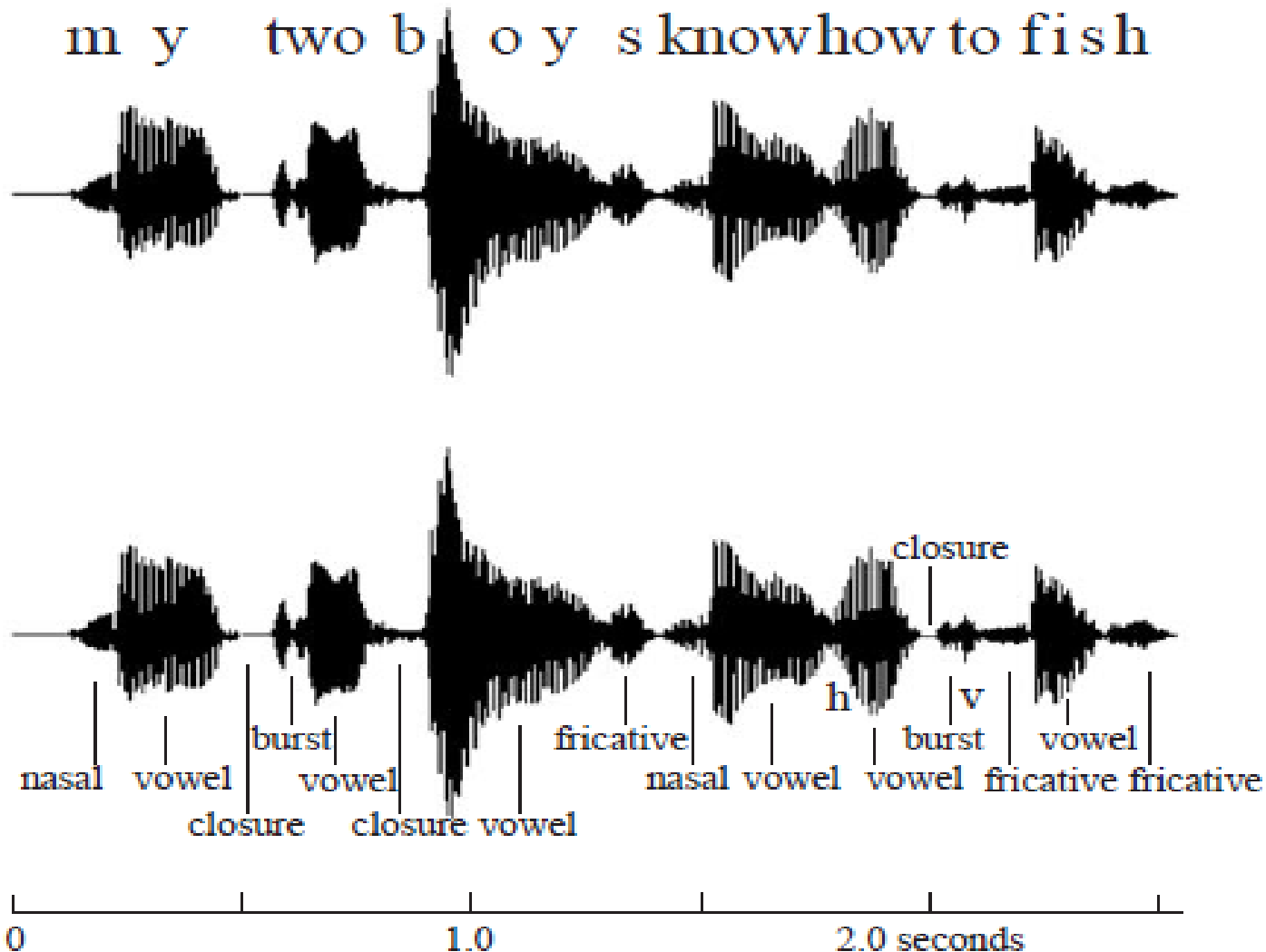
Exercise

- **s**ing
 1. **voiceless**
 2. **alveolar**
 3. central
 4. oral
 5. **fricative**
- **s**ing
 1. **voiced**
 2. **velar**
 3. central
 4. **nasal**
 5. stop

Phonetic chart of English consonants

	bilabial	labiodental	dental	alveolar	Alveolo-palatal	palatal	velar
nasal	m			n			ŋ
stop	p b			t d			k g
fricative		f v	θ ð	s z	ʃ ʒ		
(central) approximant	(w)			r		j	w
lateral (approximant)				l			

Waveforms of Consonants



Waveform of /t/ vs. /d/

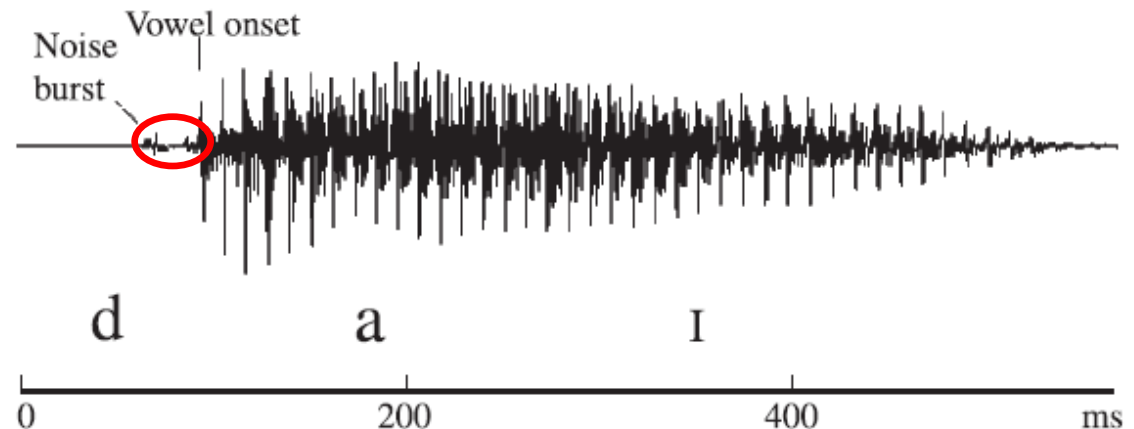
■ /t^h/

- spike indicating noise burst
- after burst very small semi-random variations during the aspiration



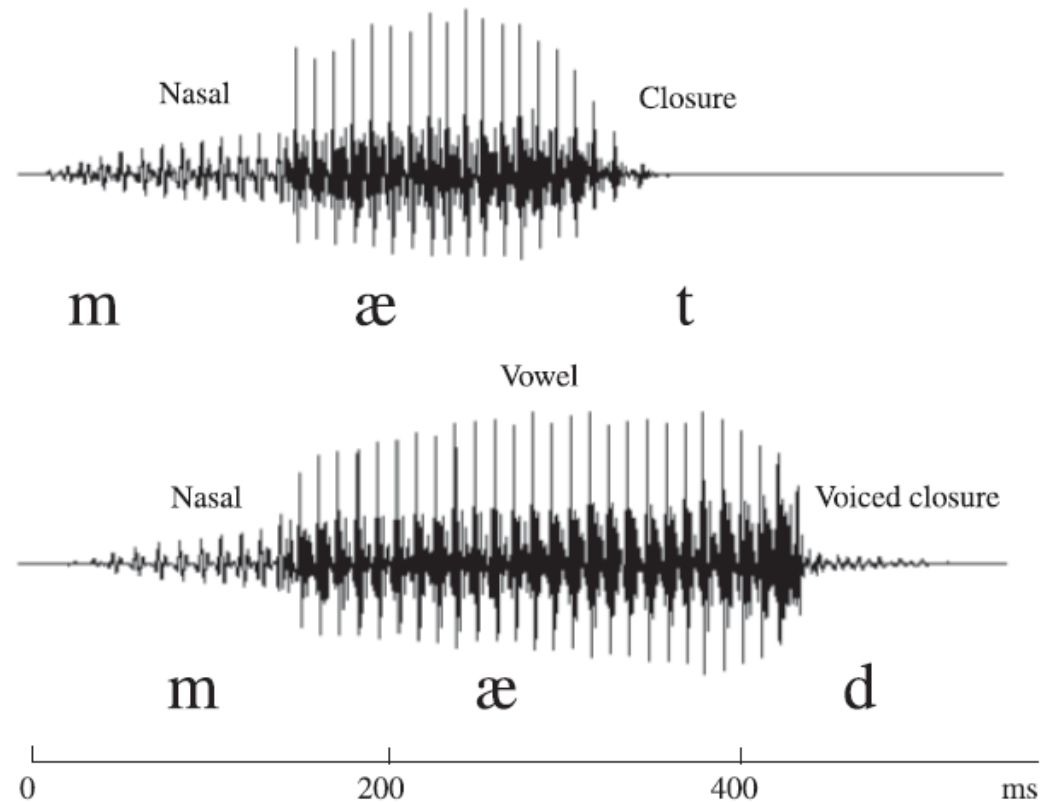
■ /d/

- no spike, smaller noise burst
- very little gap between burst and vowel start



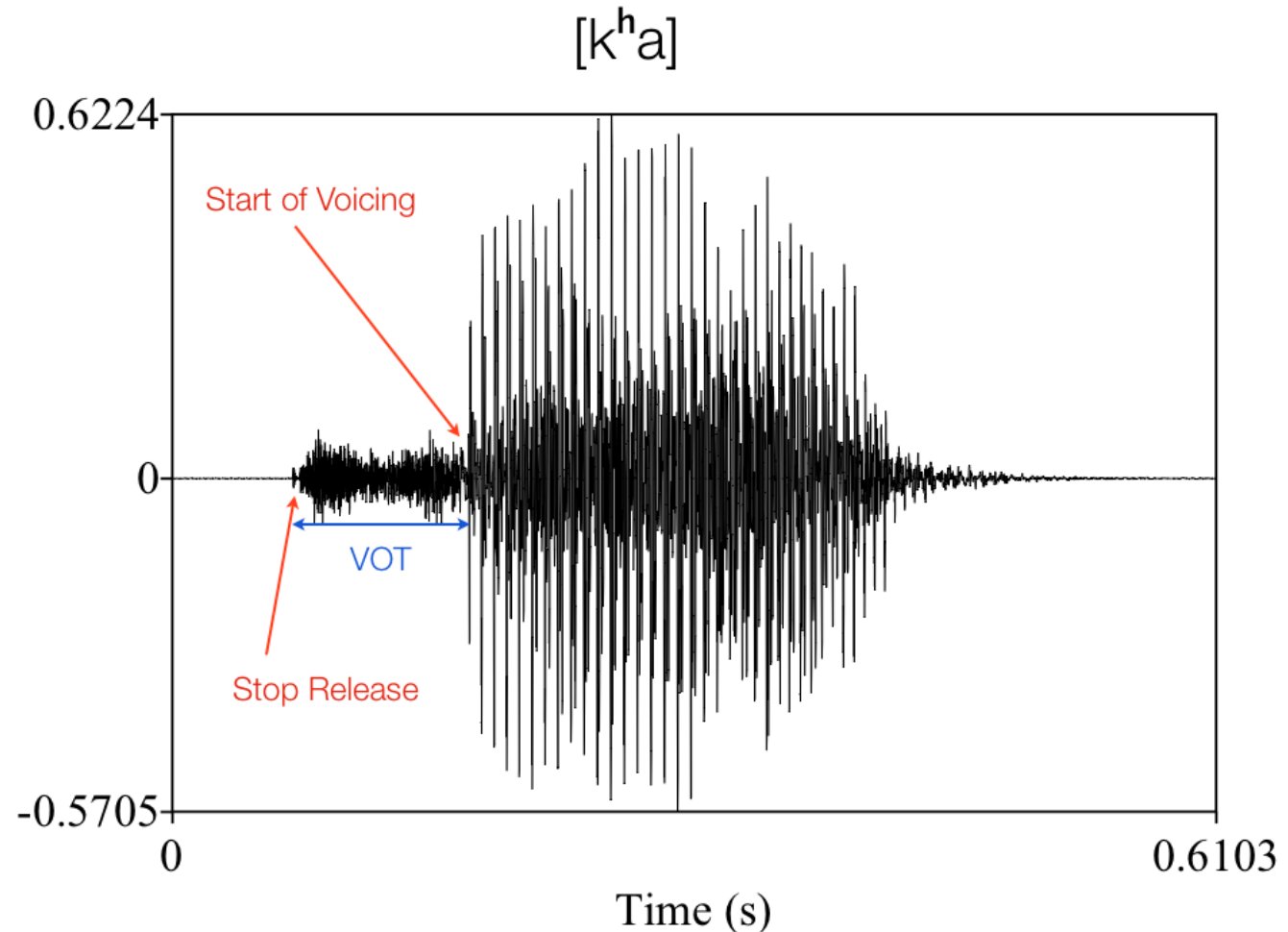
[/t/ vs. /d/]

- Difference of /t/ vs. /d/
 - in duration of previous vowel
- Vowels are much shorter before voiceless /p, t, k/ than voiced /b, d, g/.



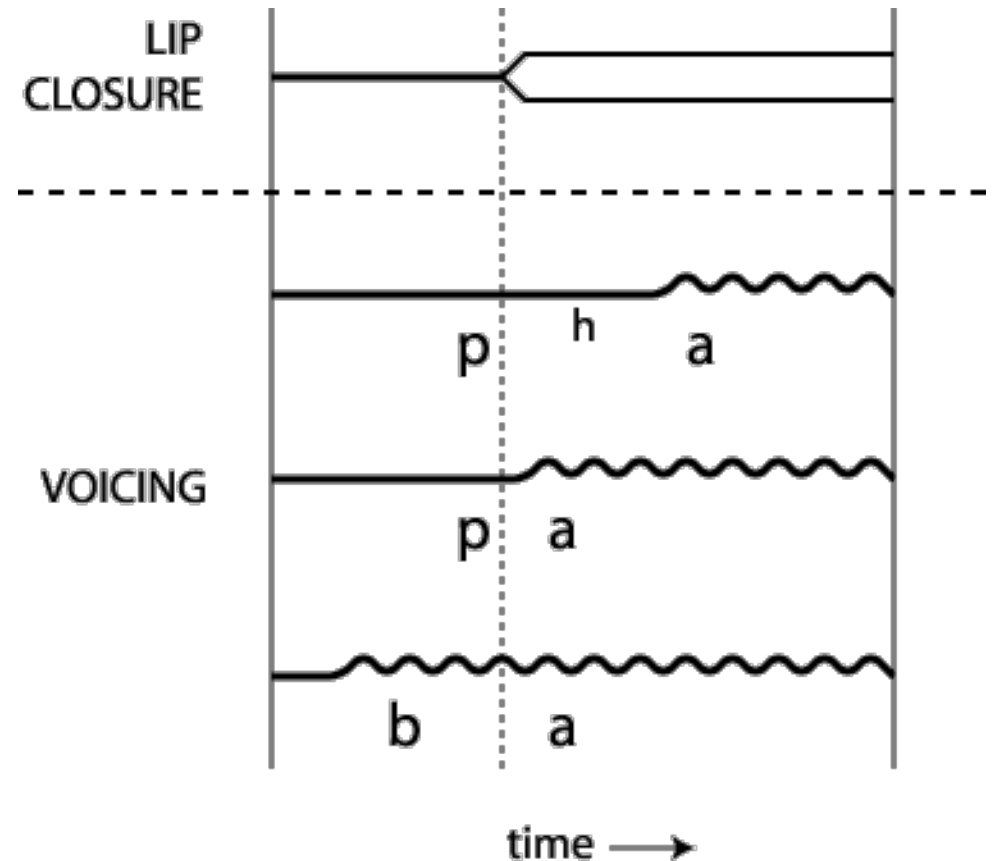
[VOT (Voice Onset Time)]

■ Voice Onset Time (VOT) is the duration of the period of time between the release of a plosive and the beginning of vocal fold vibration. This period is usually measured in milliseconds (ms).



[VOT (Voice Onset Time)]

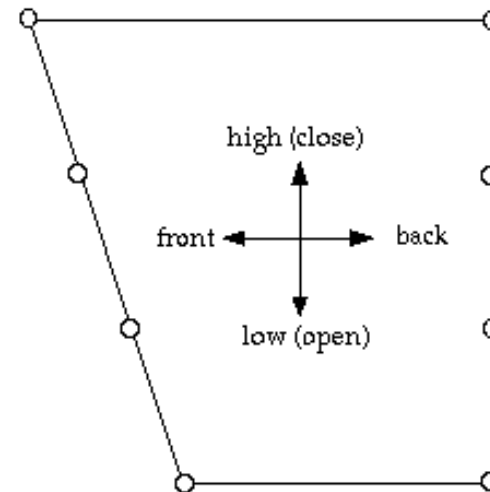
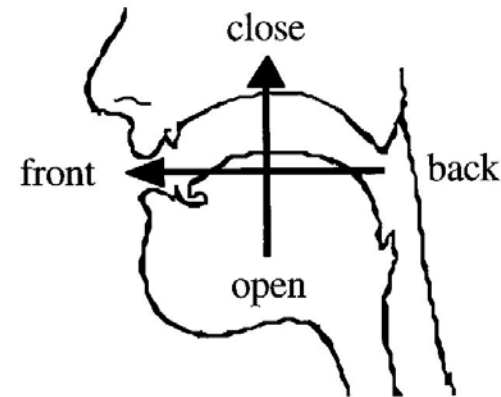
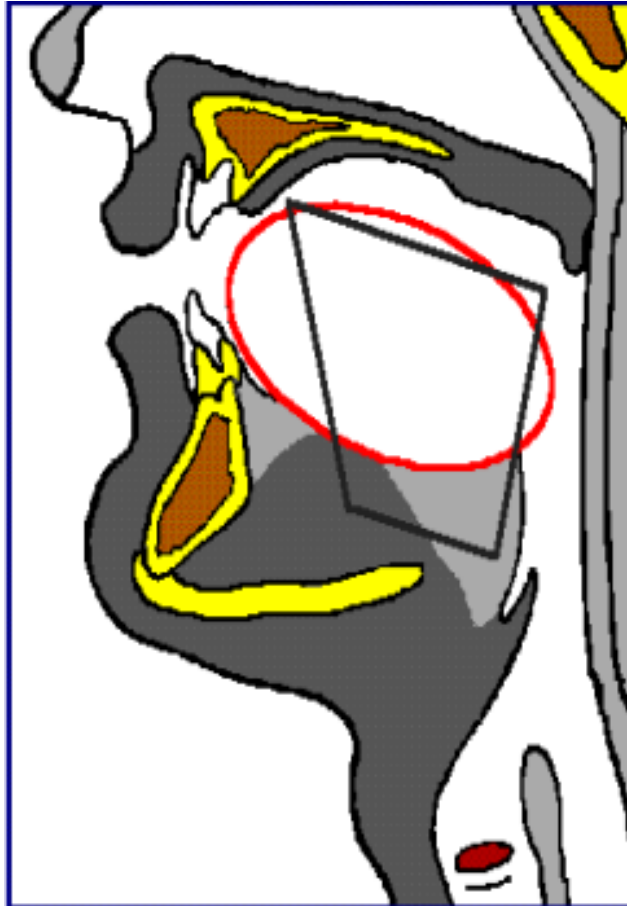
- **Positive VOT:** where there is a delay in the onset of vocal fold vibration after the plosive release
- **Zero VOT:** where the onset of vocal fold vibration coincides (approximately) with the plosive release
- **Negative VOT:** where the onset of vocal fold vibration precedes the plosive release



[The articulation of vowel sounds]

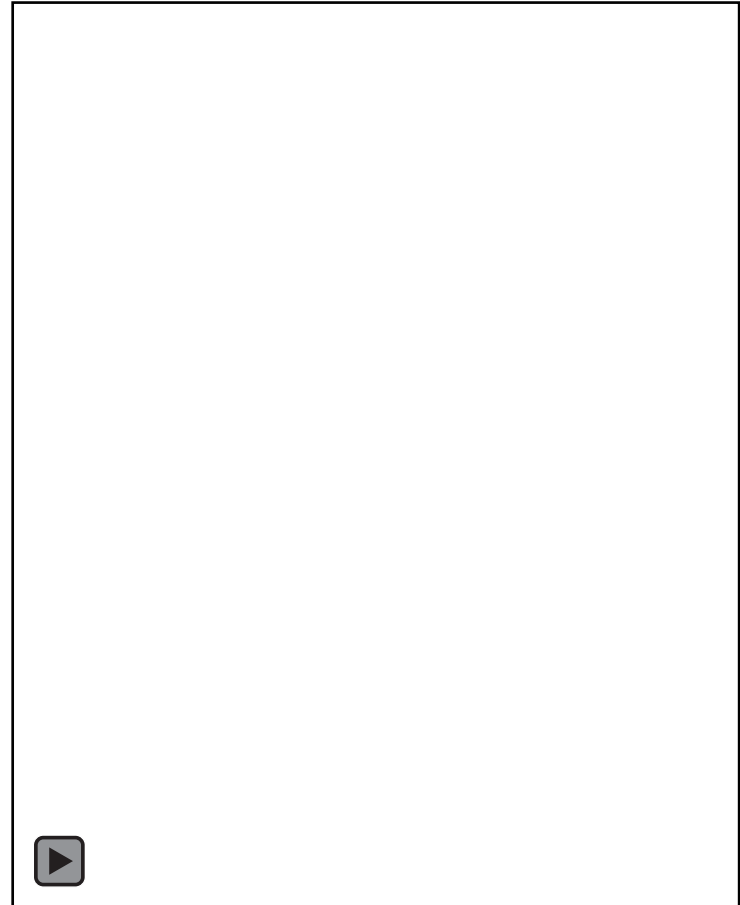
- Articulators do not come very close together → the passage of the airstream is relatively **unobstructed**.
- We describe vowel sounds in terms of
 - the position of the highest point of the **tongue**
 - the position of the **lips**.

[Tongue position]



[UCLA tongue video]

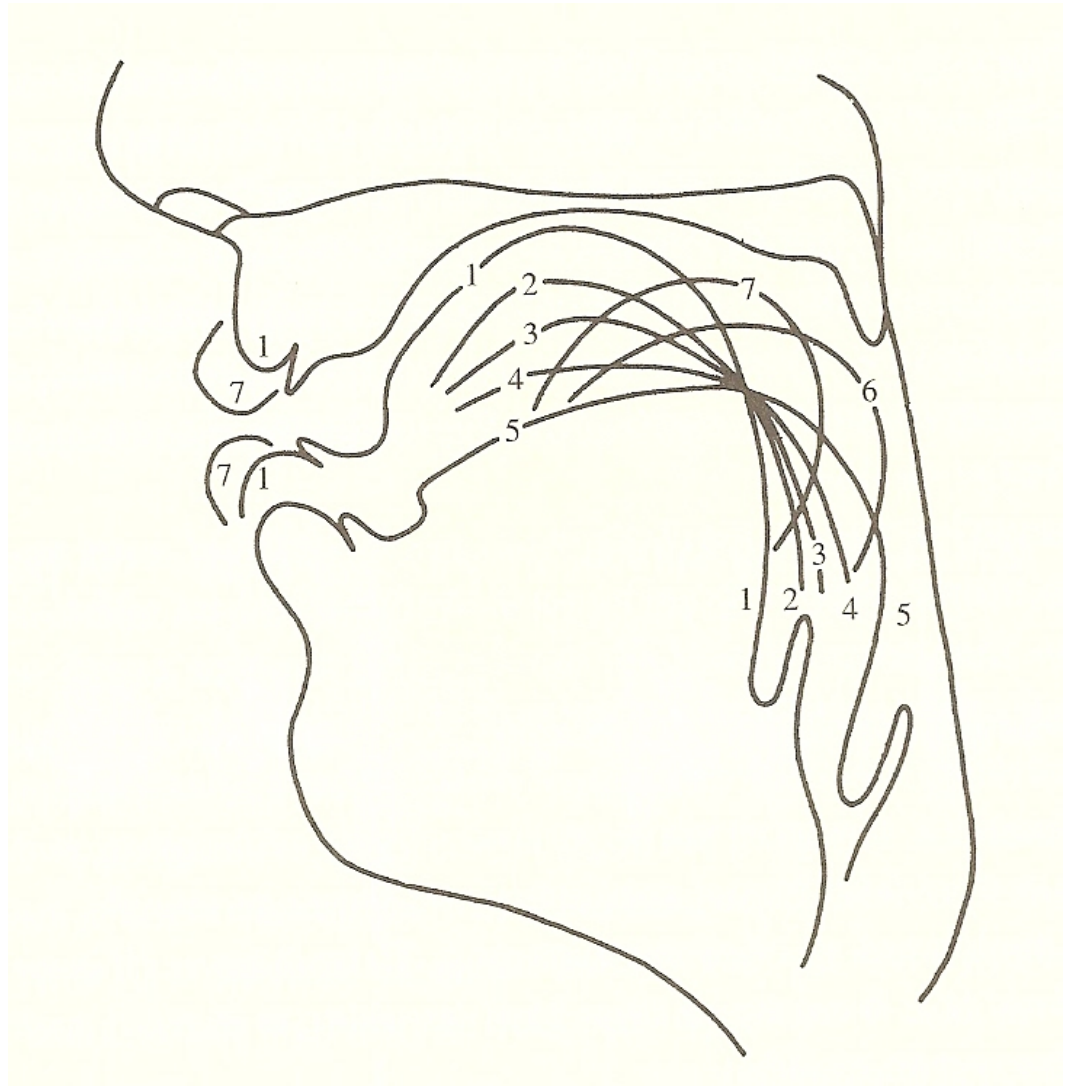
- X ray video of tongue and lip movement during production of vowels /i, e, a, o, u/.



Video: <http://www.phonetics.ucla.edu/vowels/chapter11/tongue.html>

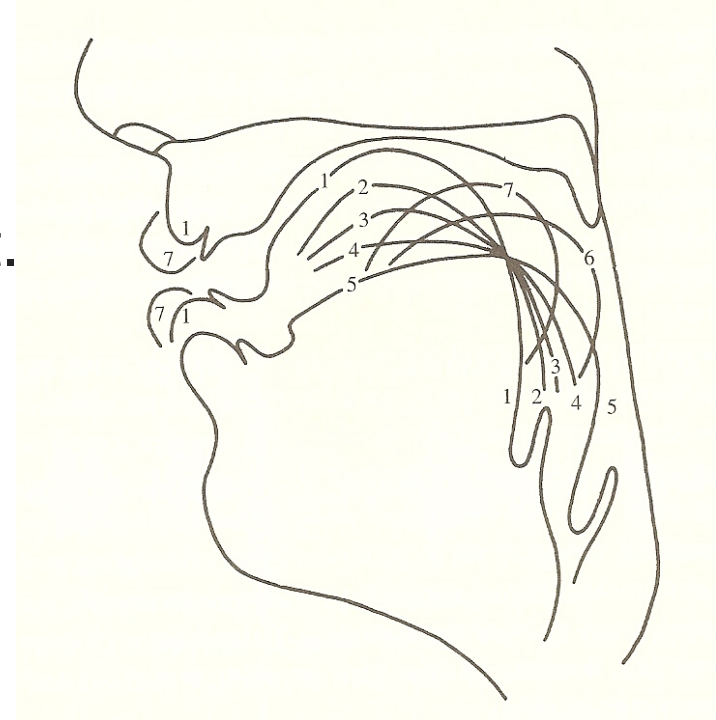
Targets for vowel gestures

1. heed
2. hid
3. head
4. had
5. father
6. good
7. food



[Front vowels]

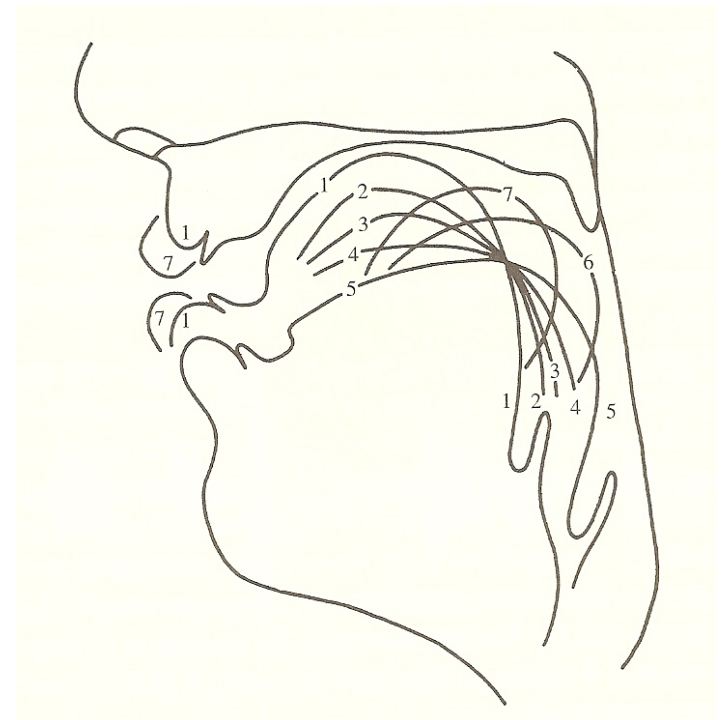
- The highest point of the tongue is in the front of the mouth.
- The mouth becomes progressively more open.
- The tongue remains in the front.
 1. **h**eed: high front
 2. **h**id: mid-high front
 3. **h**ead: mid-low front
 4. **h**ad: low front



Back vowels

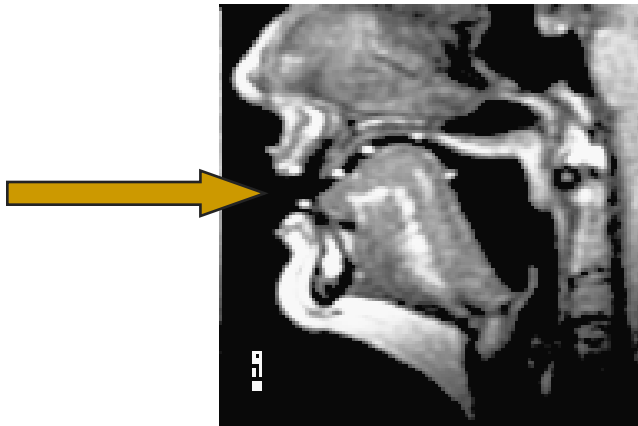
- The tongue is close to the back surface of the vocal tract.

5. f**a**ther: low back
6. g**oo**d: mid high back
7. f**oo**d: high back

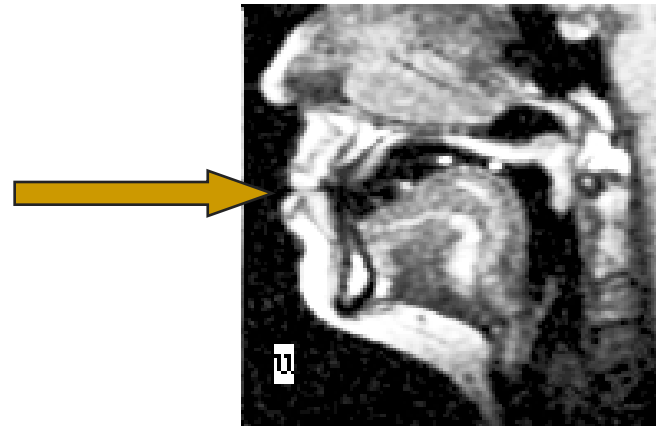


[Lip rounding]

- In **g**ood and **f**ood there is movement of the lips called lip rounding.



Unrounded vowels
heed, hid, head, had, father

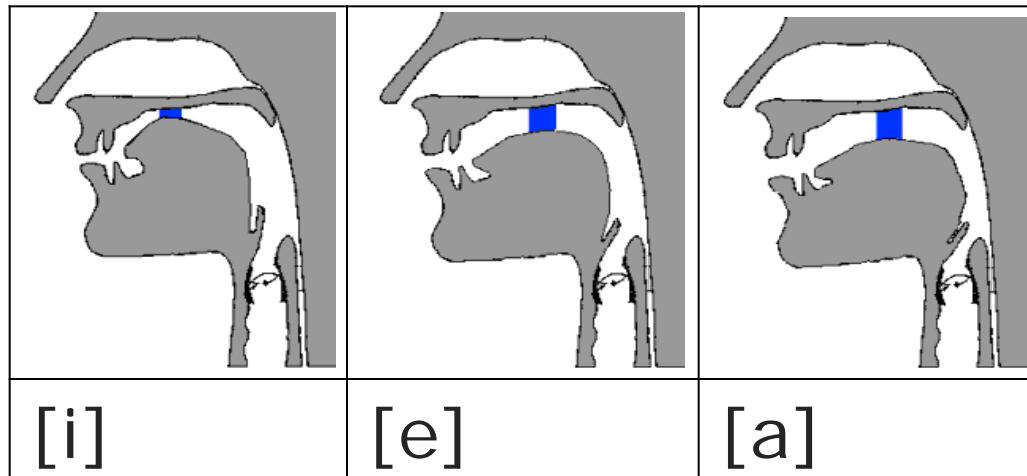


Rounded vowels
good, food

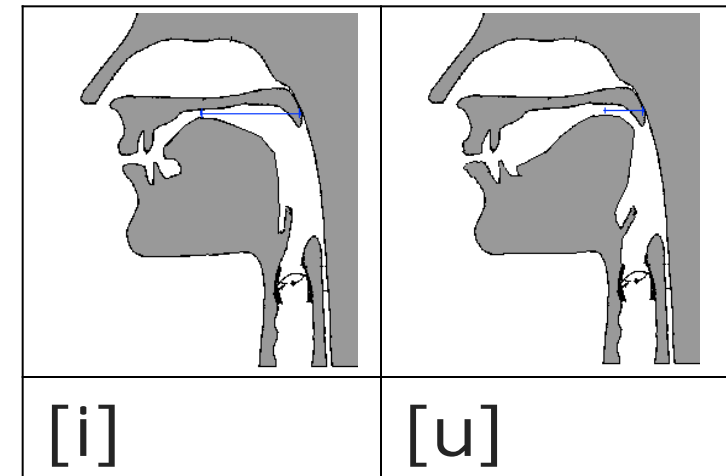
[Articulatory description of vowels]

1. **height** of tongue body
2. **front-back** position of the tongue
3. degree of lip **rounding**

high/low dimension



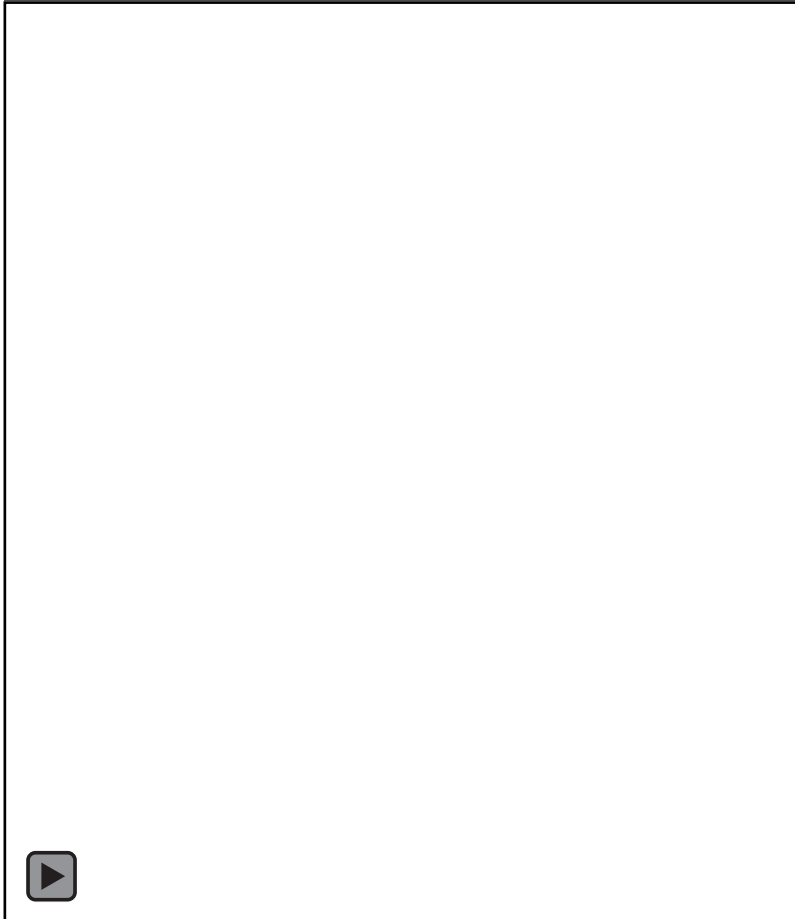
front/back dimension



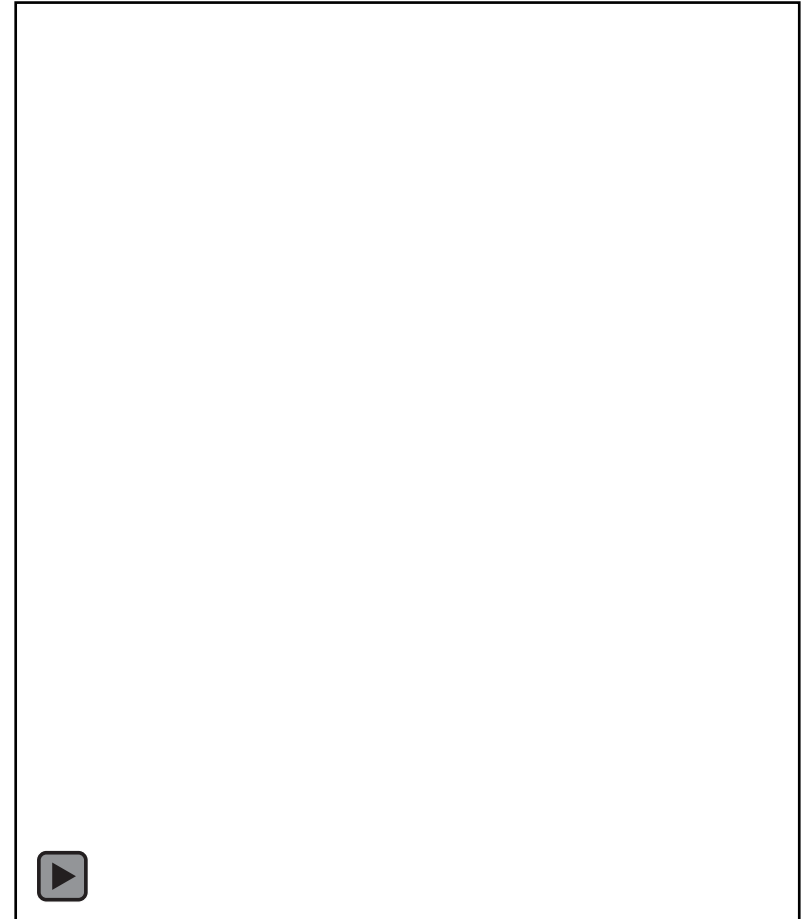
Articulatory description of vowels

- Very difficult to become aware of the position of the tongue in vowels.
- Get some impression of **tongue height** by observing position of jaw while saying the vowels in “*heed, hid, head, had*”.
- Compare *he* vs. *who* → Feel your tongue going from front to back and feel your lips become more rounded.

[UCLA jaw and larynx videos]



jaw

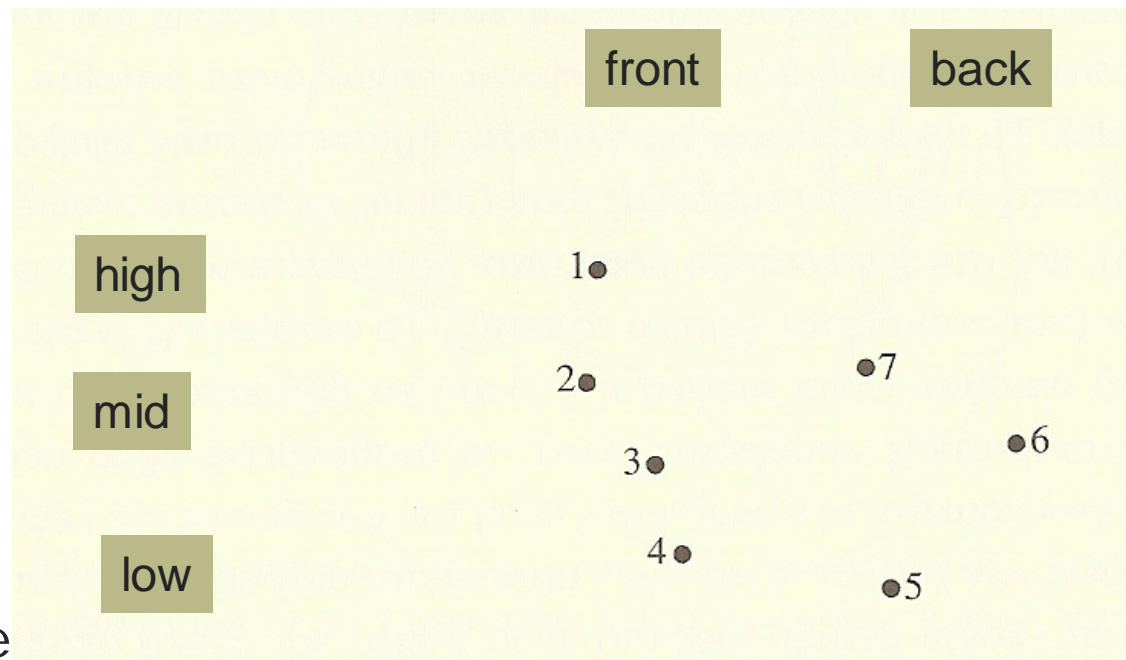


larynx

<http://www.phonetics.ucla.edu/vowels/chapter11/chapter11.html>

Relative positions of highest points of the tongue

- Specification of vowels in these terms is not so satisfactory.
- Vowels classified as “high” do not have same height (see 1 vs. 7).
- “Back” vowels vary in their degree of backness (see 5, 6, 7).
- Shape of the tongue and pharynx width are not taken into account.



[Suprasegmentals]

- Vowels & Consonants = Segments
- Segments → Syllables → Utterances
- Suprasegmentals:
 - Features superimposed on the syllables
 - They can affect single segments as well as whole syllables.

[Stress]

■ Stress can have a grammatical function

- an 'insult - to in'sult (noun - verb)
- a 'walkout - to 'walk 'out (noun - verb)
- a 'hot dog - a 'hot 'dog (compound noun – adjective+noun)
- 'diplomat → di'plomacy → diplo'matic
- 'photograph → pho'tography → photo'graphic
- 'monotone → mo'notony → mono'tonic

■ Contrastive Stress

- I want a **red** pen, not a **black** one.

[Stress]

- Stress in English is produced by
 1. increased activity in the respiratory muscles, producing **greater loudness**
 2. exaggeration of consonant and vowel **properties** (vowel height, stop aspiration)
 3. exaggeration of **pitch**

[Pitch]

- Pitch of the voice is what you alter to sing different notes in a song.
- The pitch of a sound is an auditory property that enables a listener to put it on a scale going from low to high.
- When a speech sound goes up in frequency, it also goes up in pitch.

[Intonation]

- The pitch pattern in a sentence is known as intonation.

■ This is my father. statement

■ Is this your father? question

[Intonation]

- That's a cat. statement
- That's a cat? question
- It is the **relative values** of pitch, length, or degree of stress of an item that are significant.
- The absolute values are never linguistically important!

[Read & visit...]



- Ladefoged & Johnson “Articulation & Acoustics”, chapter 1 (A course in phonetics”, 6th ed.)
- Visit the websites:
 - <http://soundsofspeech.uiowa.edu/index.html#english>
(Interactive Phonetic Library for American English, Spanish and German)
 - <http://speakgreek.web.auth.gr/dp/en/library/choose>
(Interactive Phonetic Library for Greek)
 - <http://smu-facweb.smu.ca/~s0949176/sammy/>
(Interactive Sagittal Section)
 - <https://corpus.linguistics.berkeley.edu/acip/course/chapter1/> (Material from UC Berkeley Linguistics for chapter 1 of the book “A course in phonetics”)

