Articulatory Phonetics

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CS-578 Digital Speech Signal Processing
Spring Term 2020-21
University of Crete

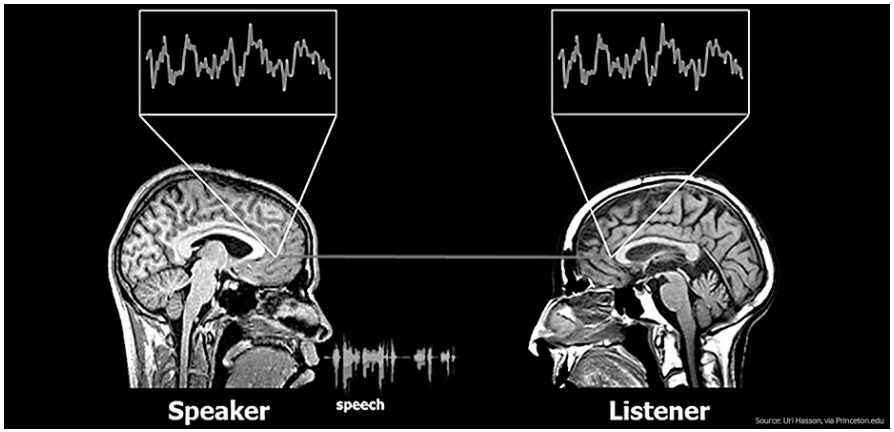
What is Phonetics?

- 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**

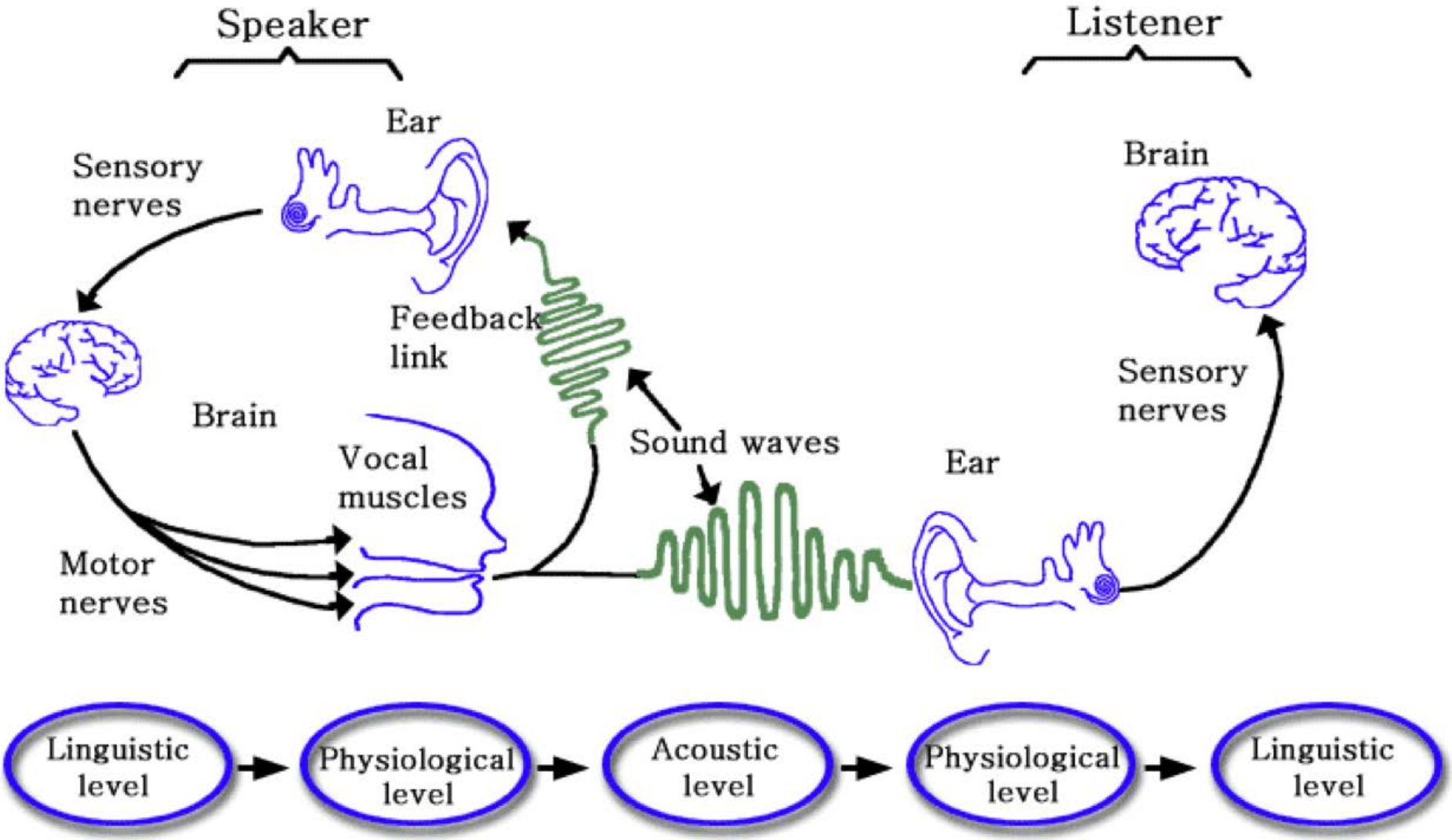
It is an interdisciplinary subject, theoretical as much as experimental.

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

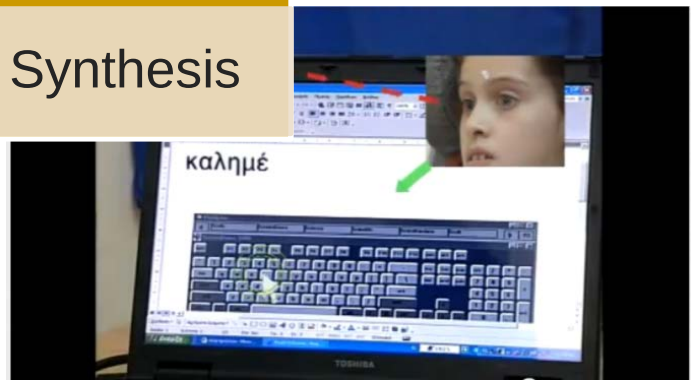
speech Segmentation

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…

- *Tuesday 10:00-12:00*

Articulatory Phonetics

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

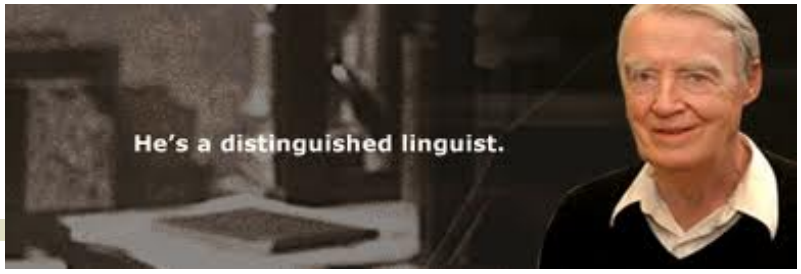
- *Thursday 10:00-12:00*

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
Spring Term

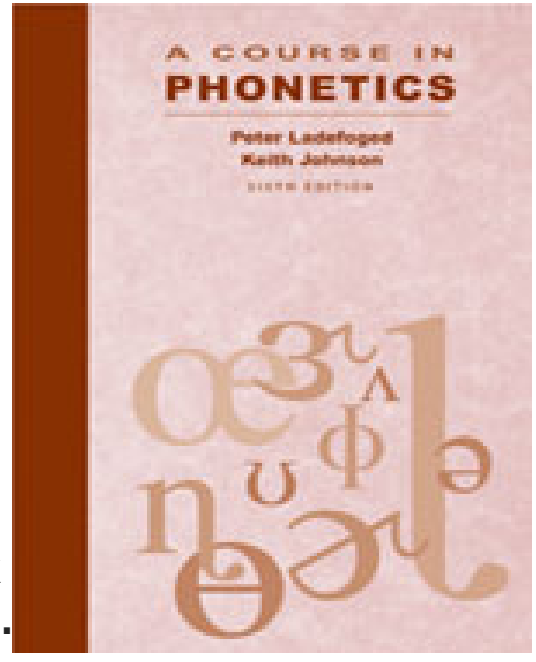
Peter Ladefoged



Home Page:
http://www.linguistics.ucla.edu/people/ladefoge/

- 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

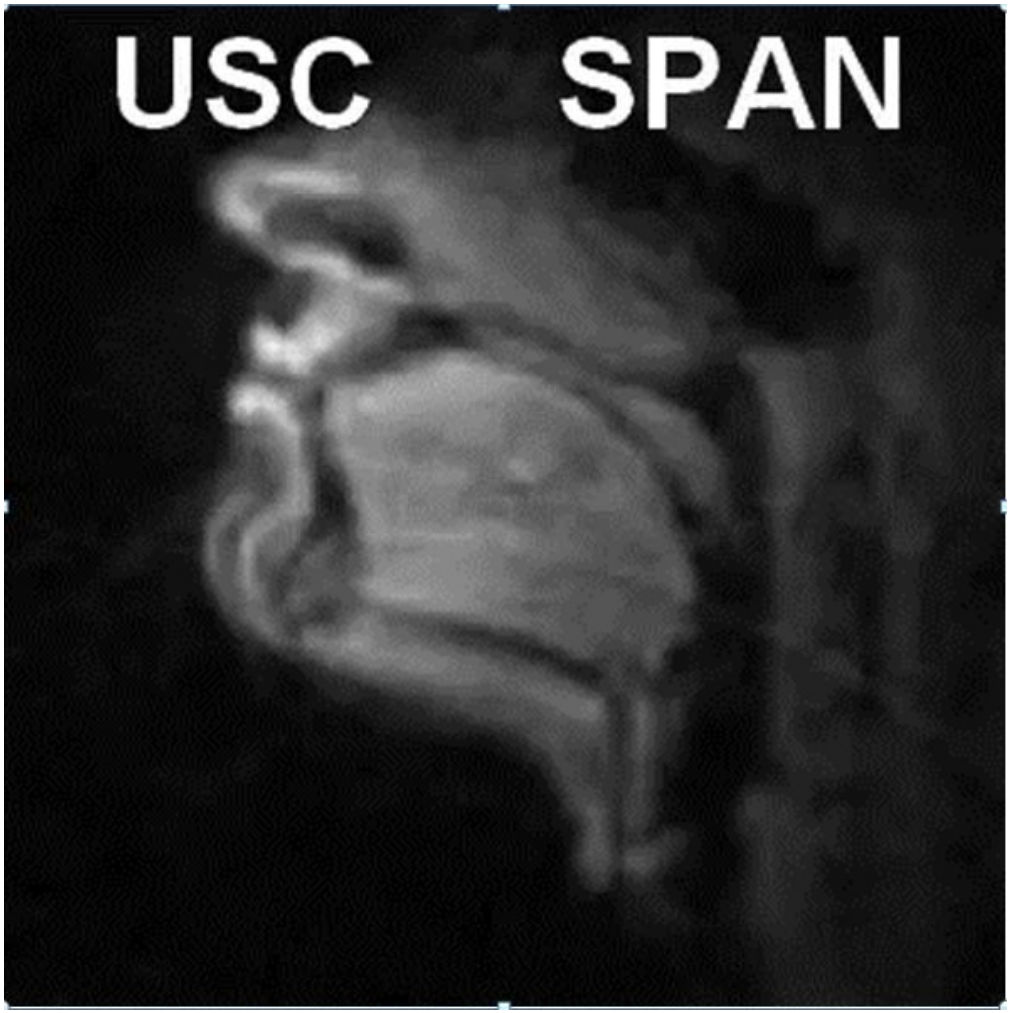
Material from this book was used in the slides.



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…



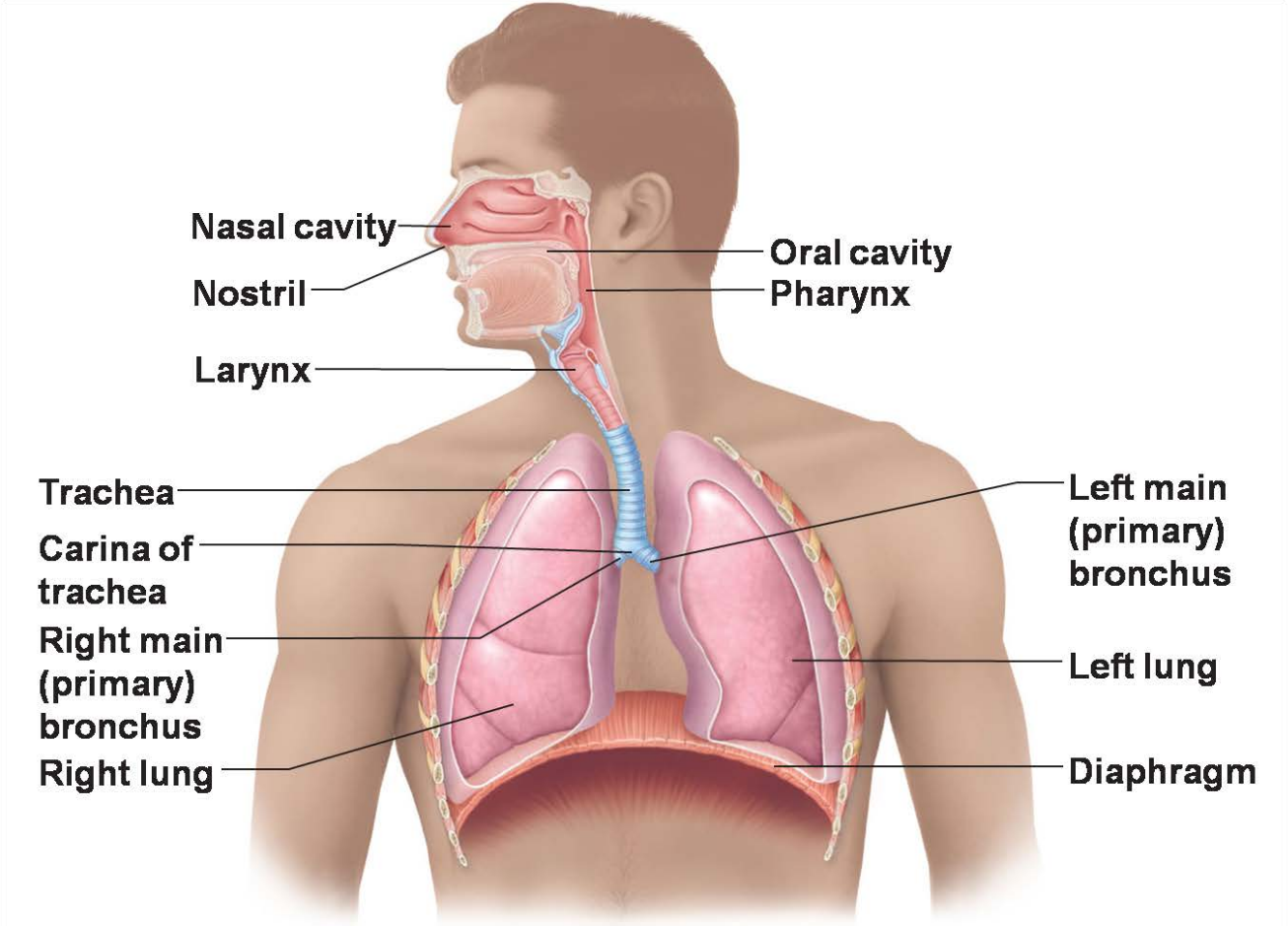
https://www.youtube.com/watch?v=0-aEN2xHBCc

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.

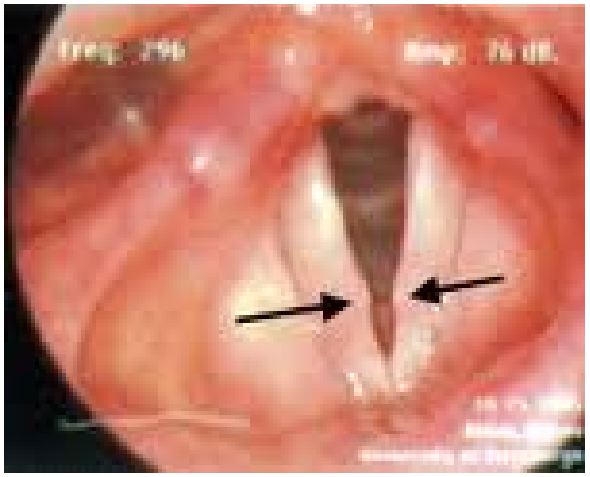
- The basic source of power for speech: the respiratory system
  - Pushing **air** out of the lungs
- **lungs → trachea → larynx → vocal folds**

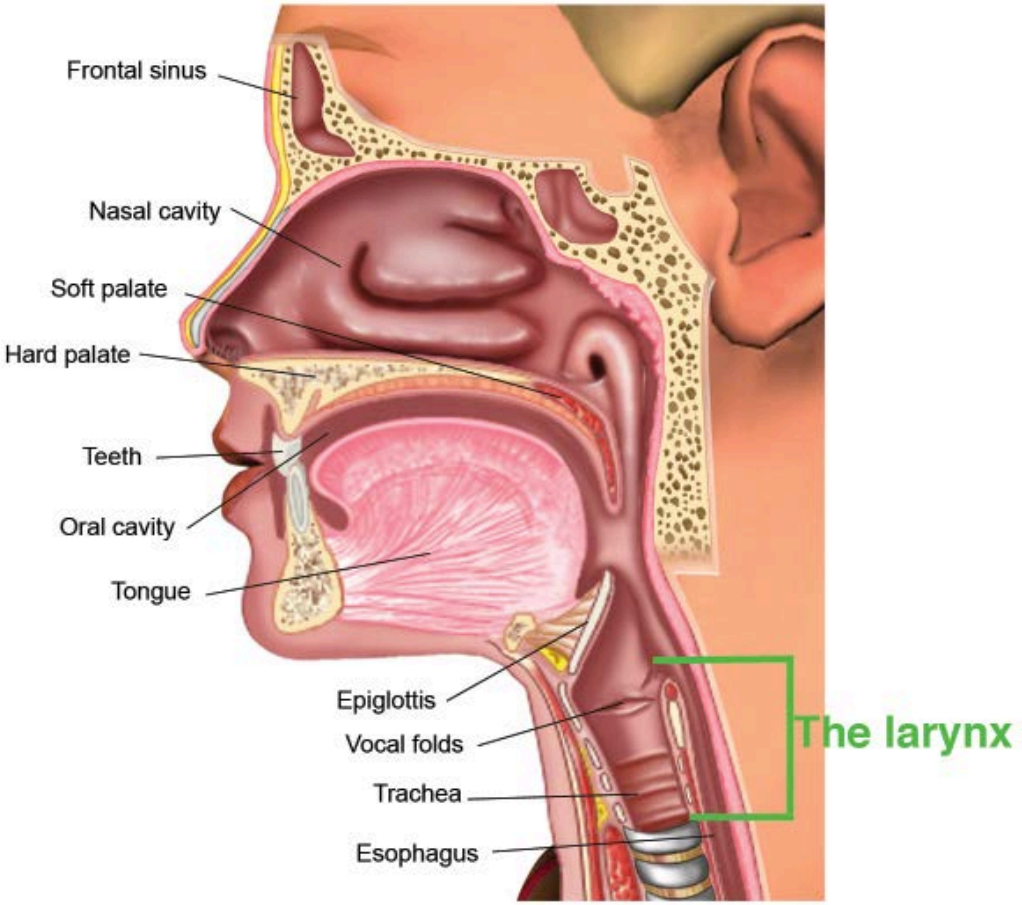
Try to talk while breathing in instead of out. What do you observe?



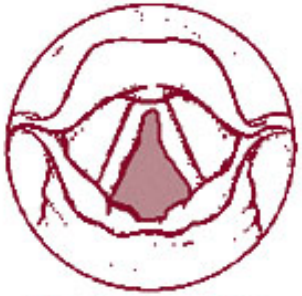
Speech Production - Vocal folds

- 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.

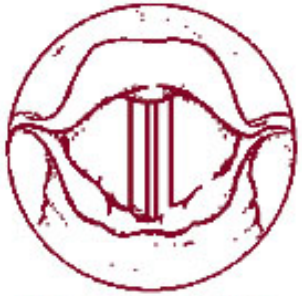




Speech Production - Vocal folds



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
[fffffffffvvvvvvvfffffffffvvvvvvvvvv]
• 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

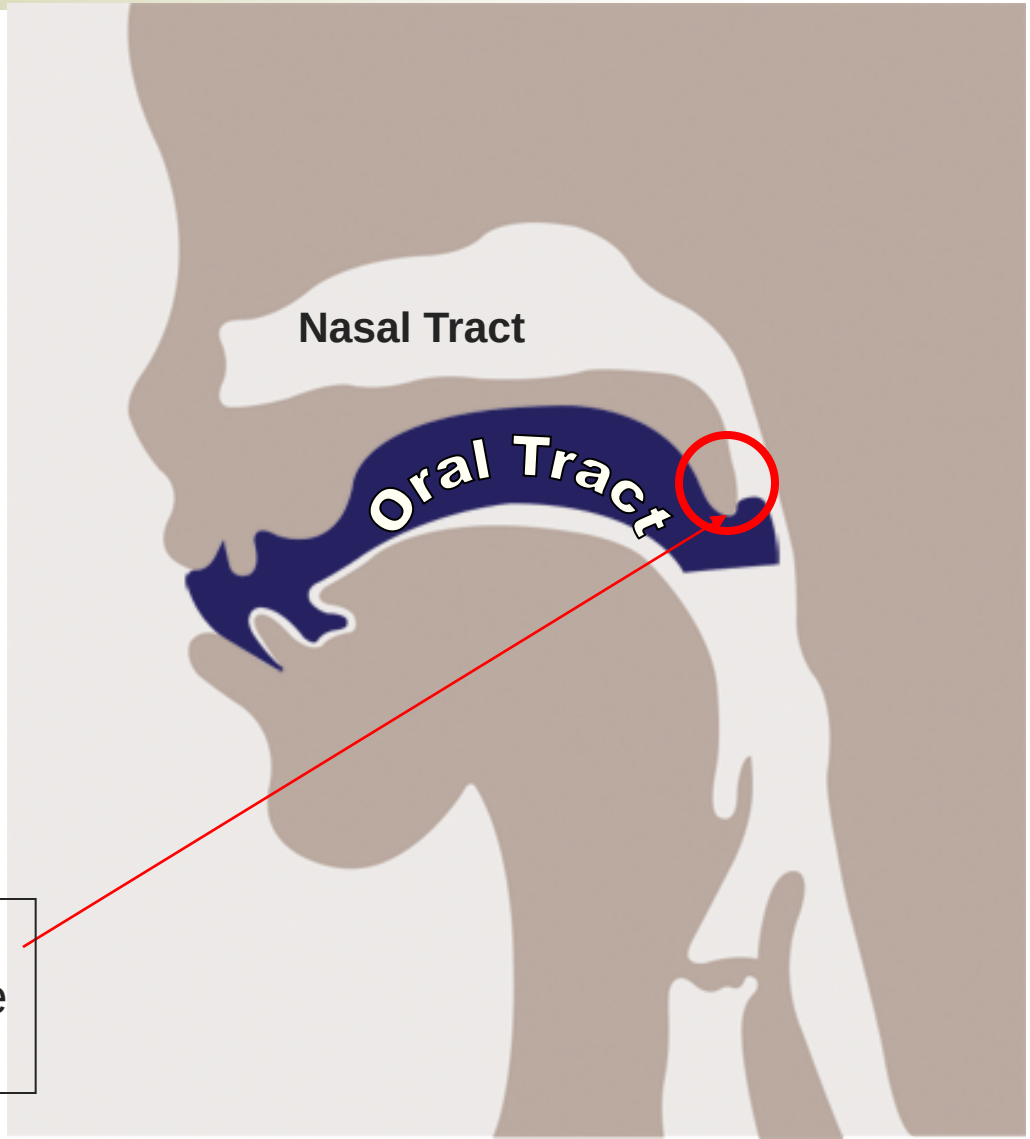
Voicing

- Distinguishing sounds on the basis of voicing:
  - **f**at vs. **v**at
  - **t**high vs. **t**hy
  - **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

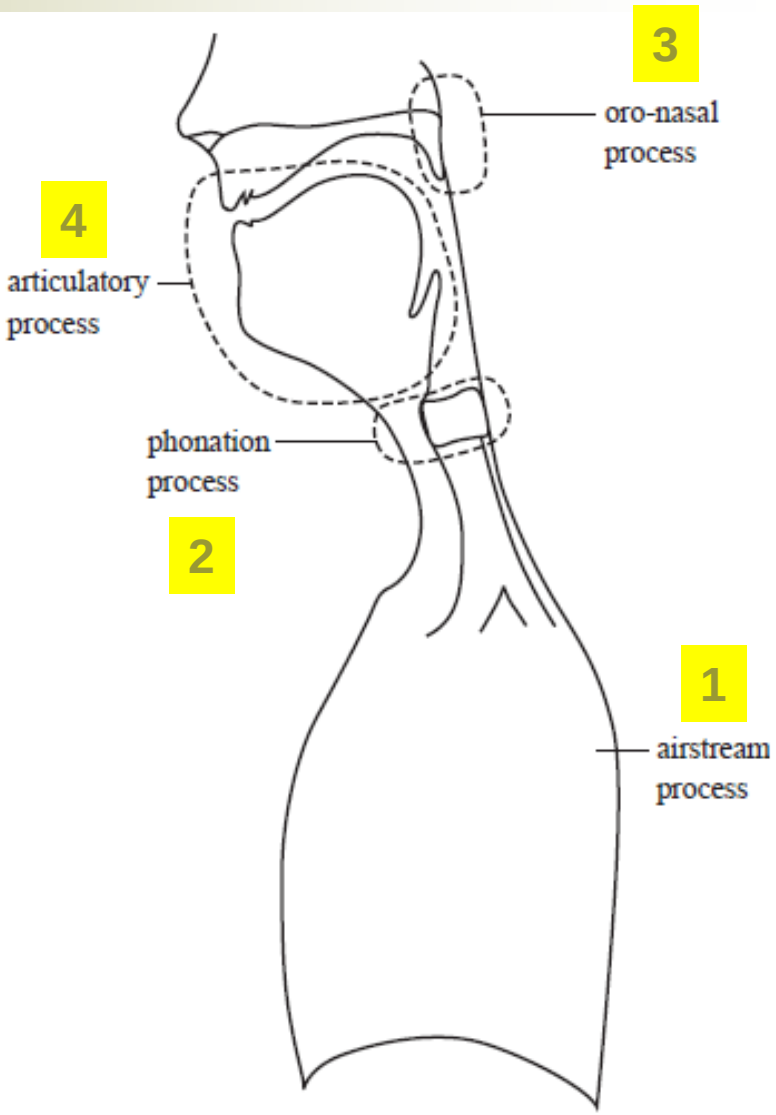


Flap at the back of mouth:
• air goes in and out through the nose
• production of [m] and [n]

Speech Production Mechanism

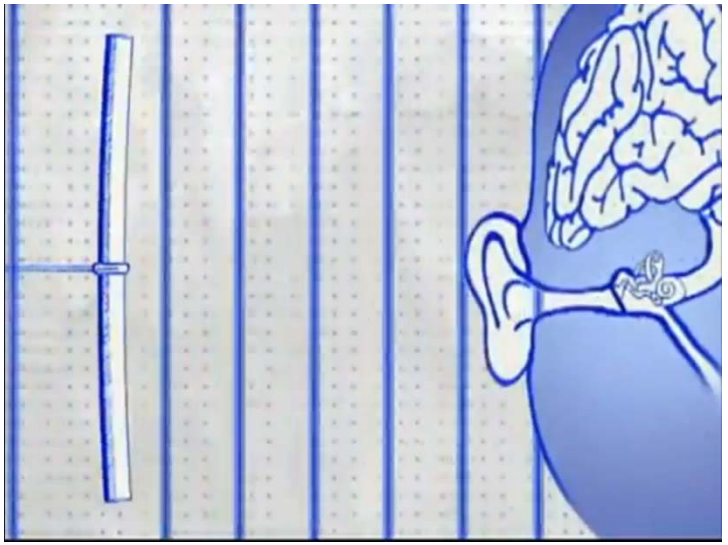
The four main components of the speech production mechanism:

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



Sound waves

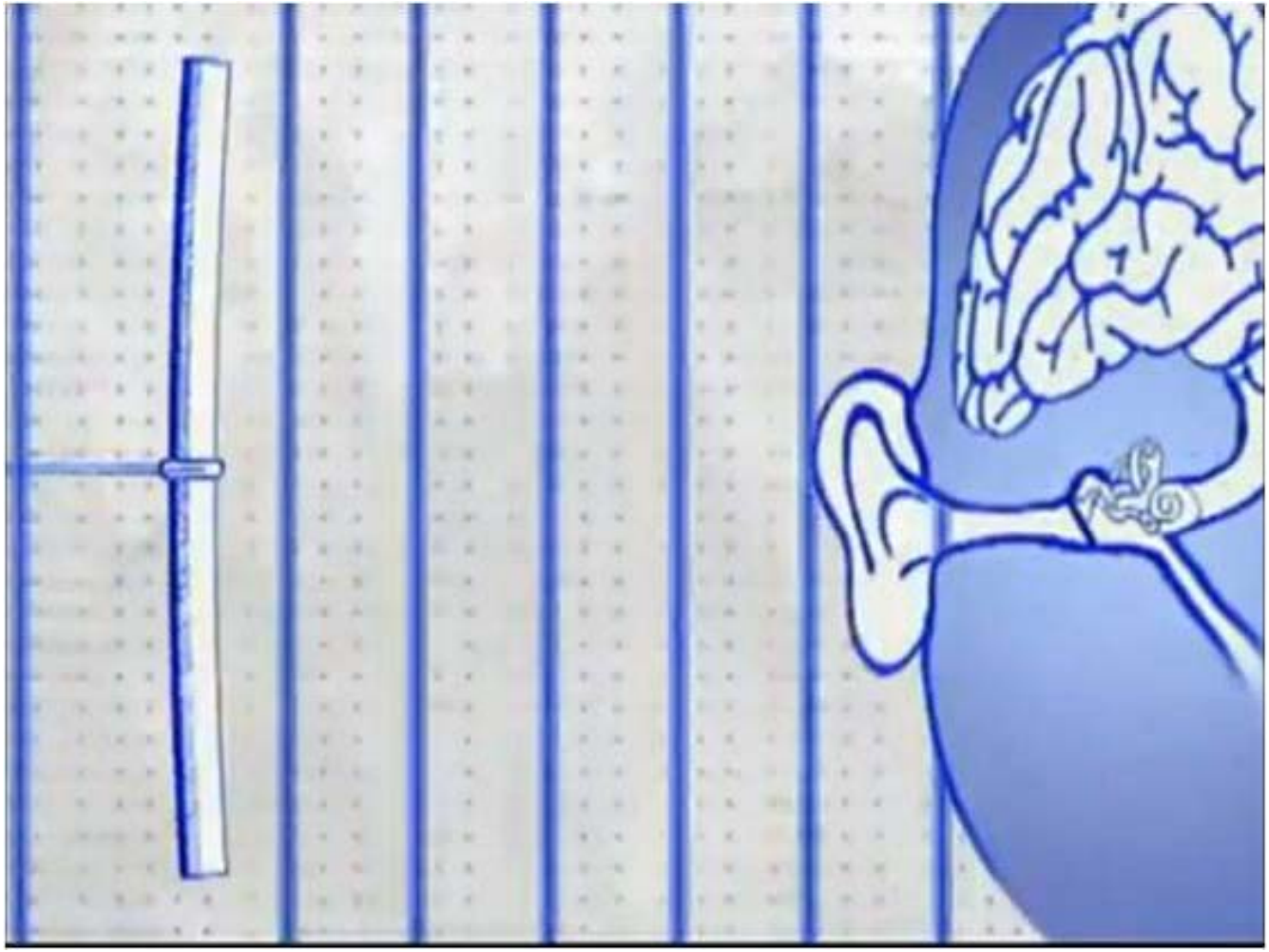
- The way in which we hear a sound depends on its **acoustic structure**.
- Speech sounds differ from one another in three ways
  1. **pitch/frequency**
  2. **loudness**
  3. **quality**



- How is sound produced

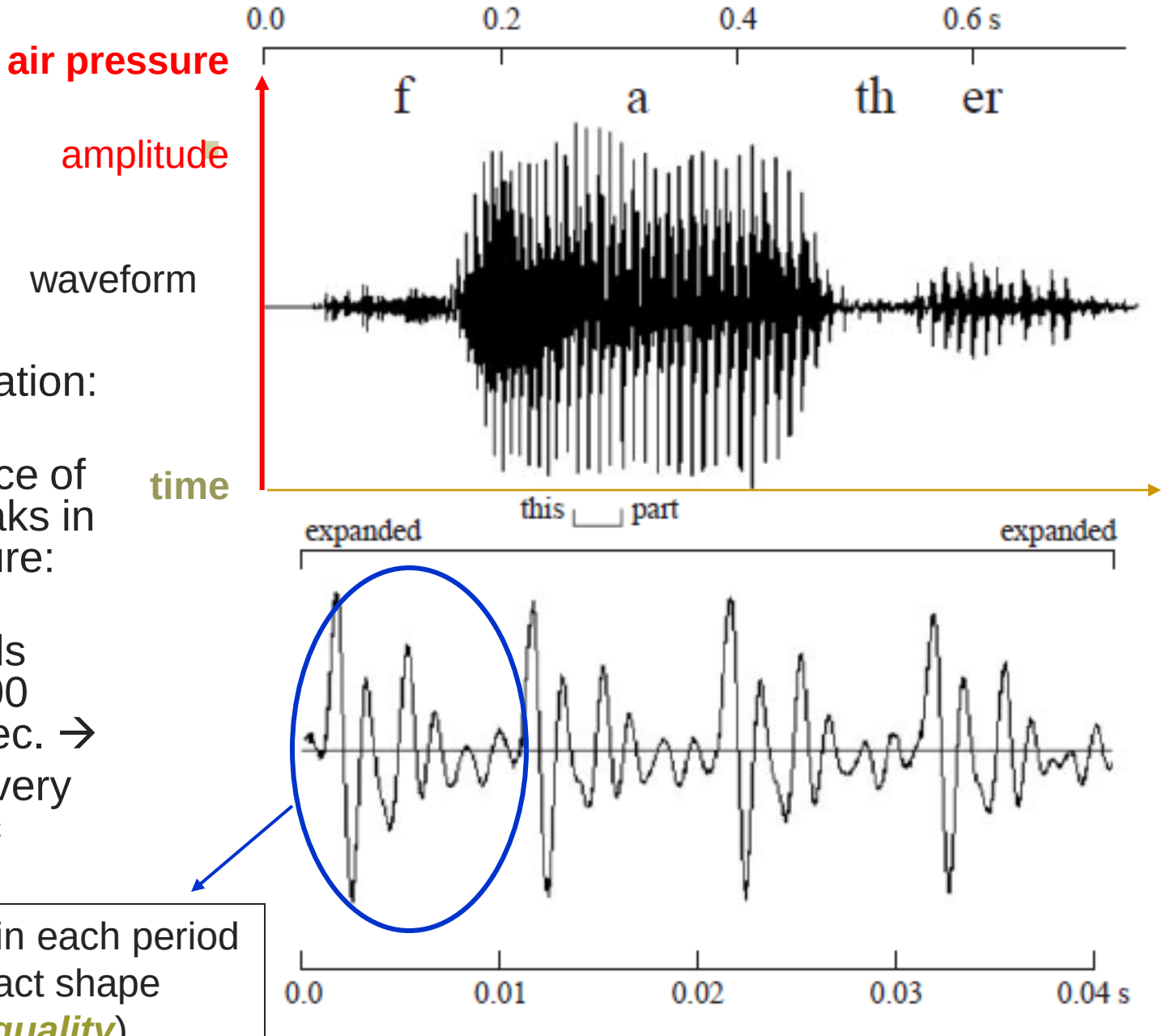
  articulatory movements superimposed on outgoing flow of lung air→ small variations in air pressure→ sound wave → vibrations in listener's eardrum

Sound waves



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

Variations in air pressure



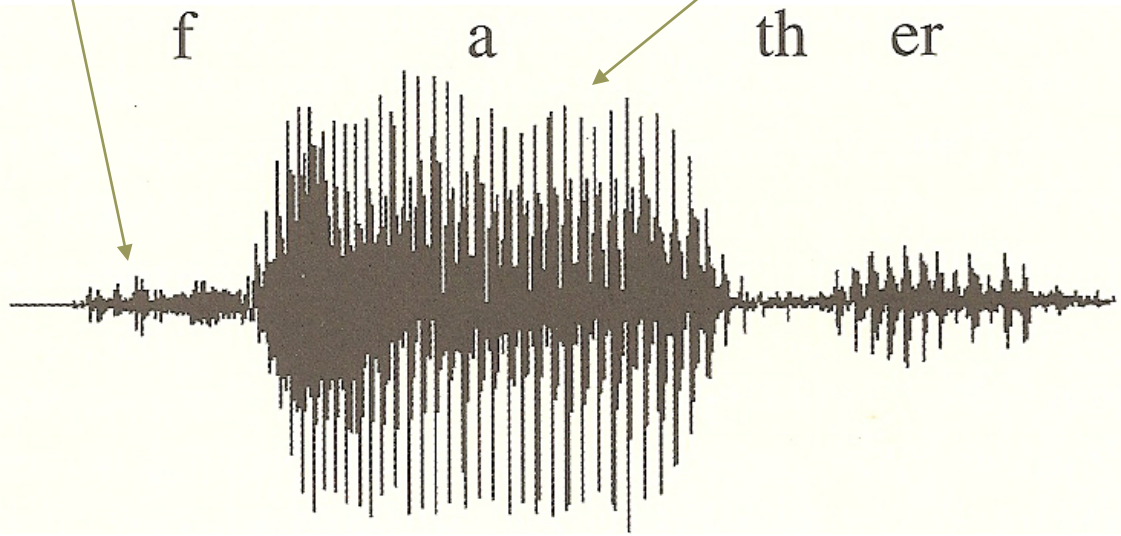
- Word duration: 0,6s
- Recurrence of major peaks in air pressure: 0,01s →
- Vocal folds vibrate 100 times a sec. →
- 1 pulse every 1/100 sec

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.

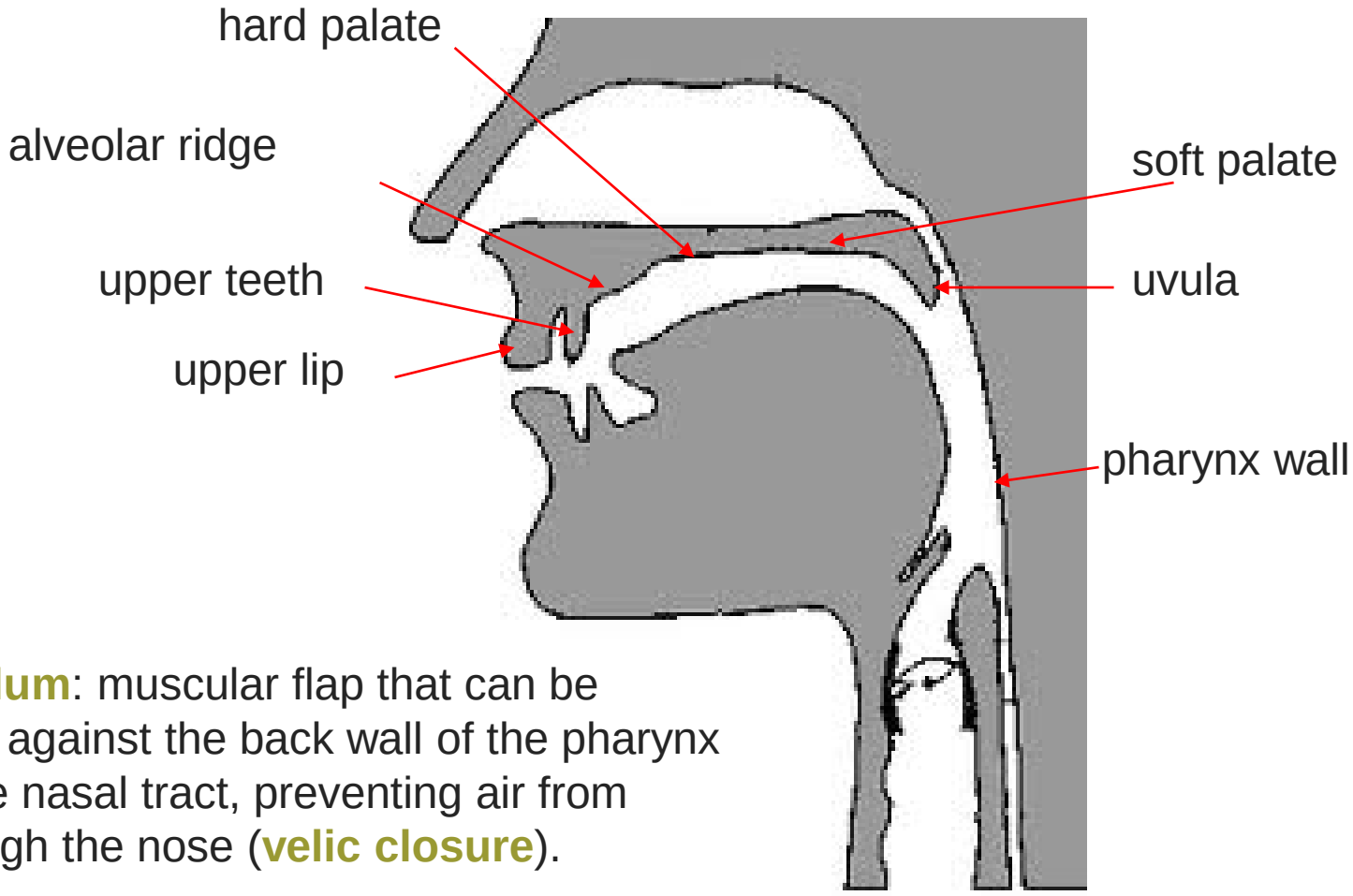


Places of articulatory gestures

- 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

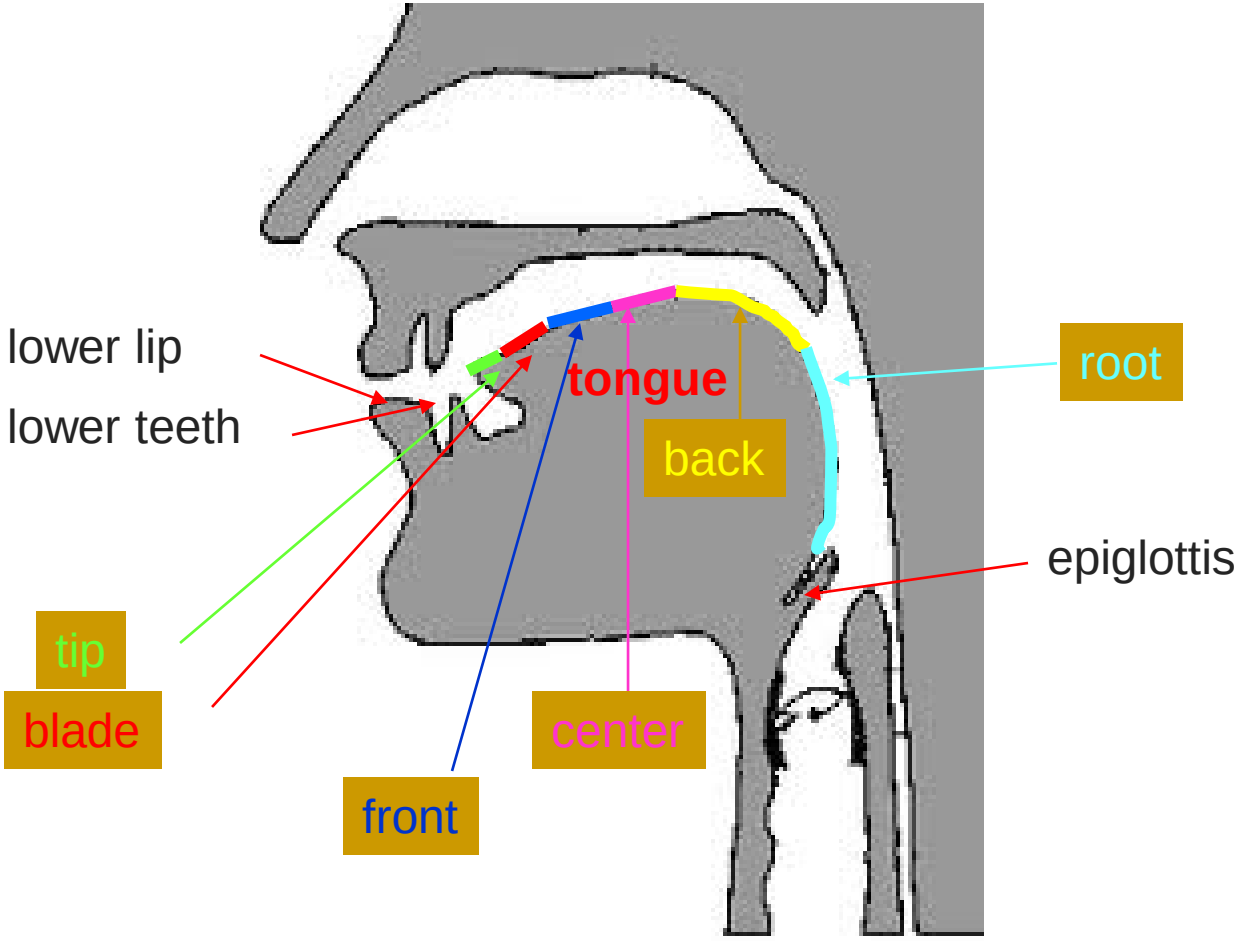
Exercise: Try saying the word “capital” and note the major movements of your tongue and lips.

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
προράχη	blade
πρόσθιο τμήμα	front
κέντρο	center
ράχη	back/dorsum
ρίζα	root
επιγλωττίδα	epiglottis

γλώσσα
tongue

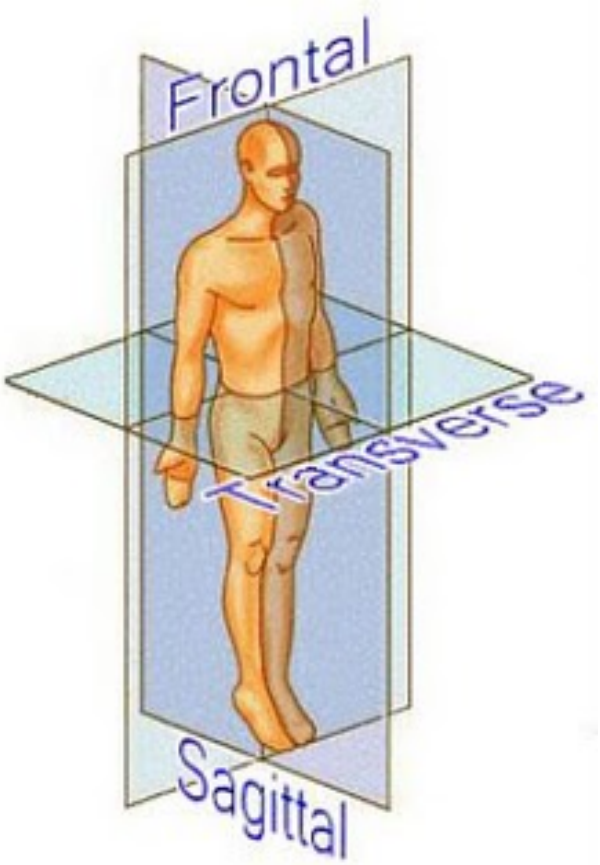
Examples

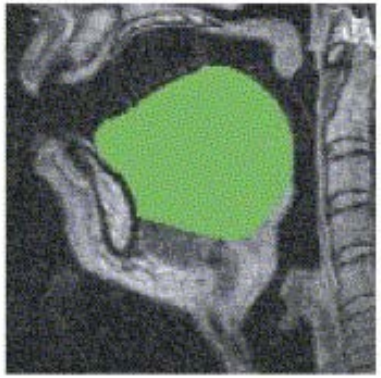
- “**peculiar**”
  1. lips come together
  2. back and center of the tongue are raised (towards hard palate or velum?)
  3. tip of the tongue on alveolar ridge

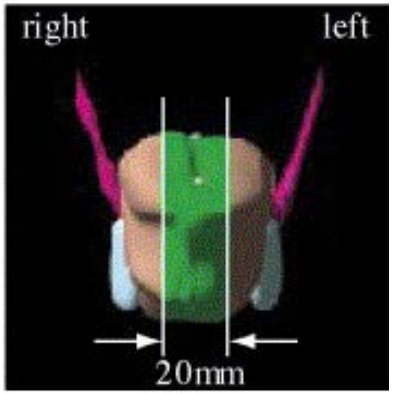
- “**true**” vs. “**tea**”
- “**s**igh” vs. “**sh**y”

Tongue depiction

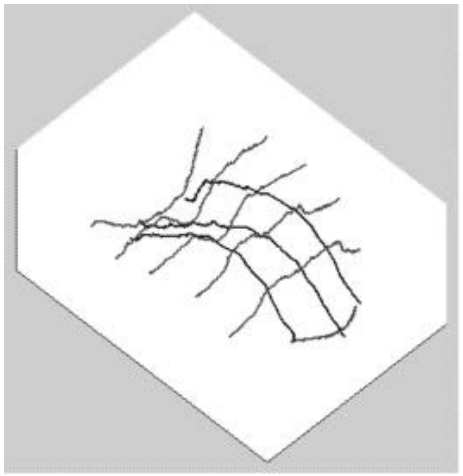
- Mid-sagittal vs. 3D view

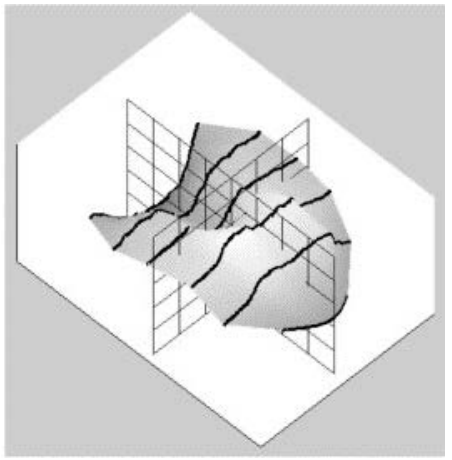






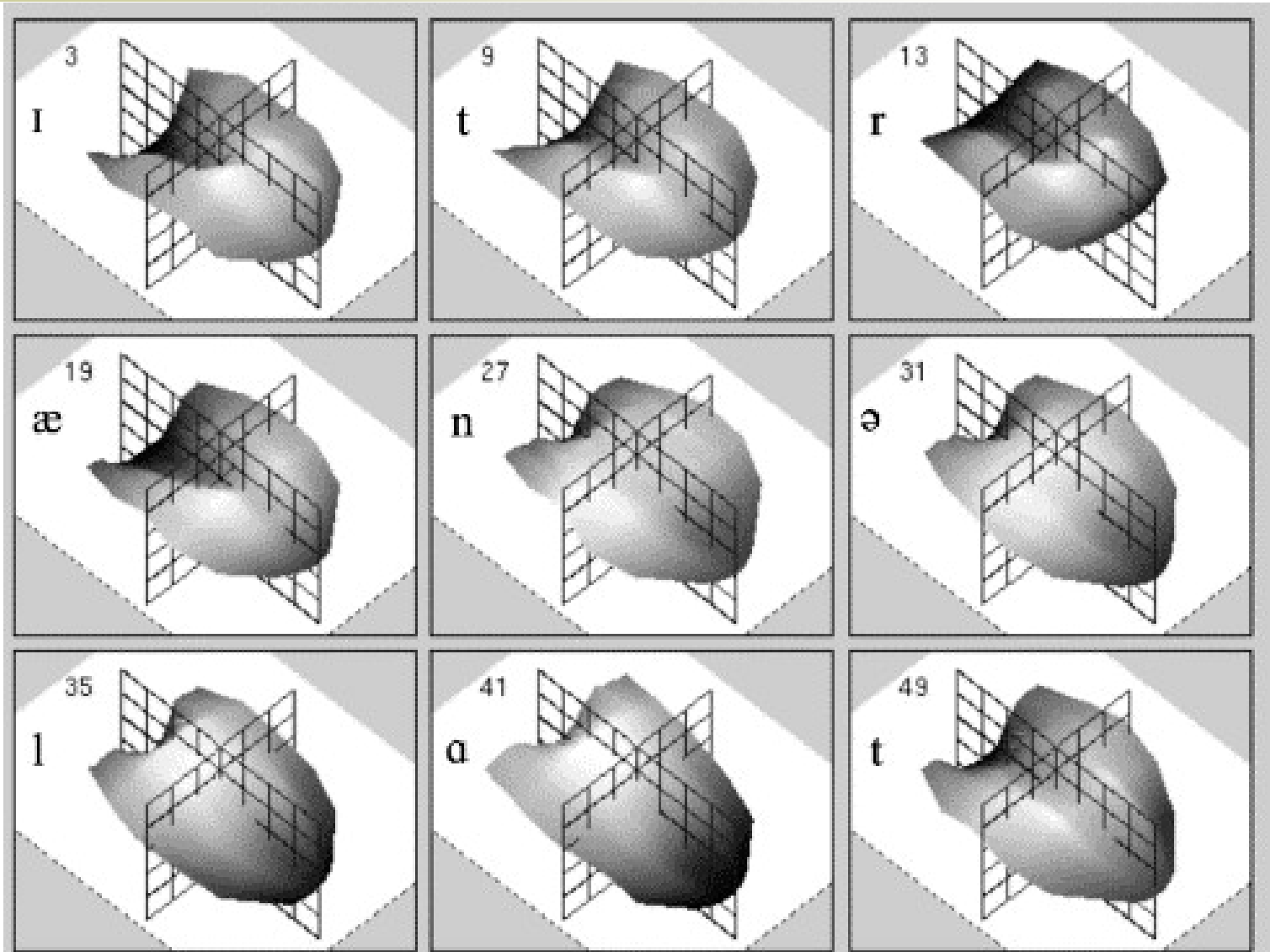
Takano & Honda (2007)





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	Articulation
lips	labial
tongue tip and blade	coronal
back of the tongue	dorsal

Example: “**t**o**p**i**c**”

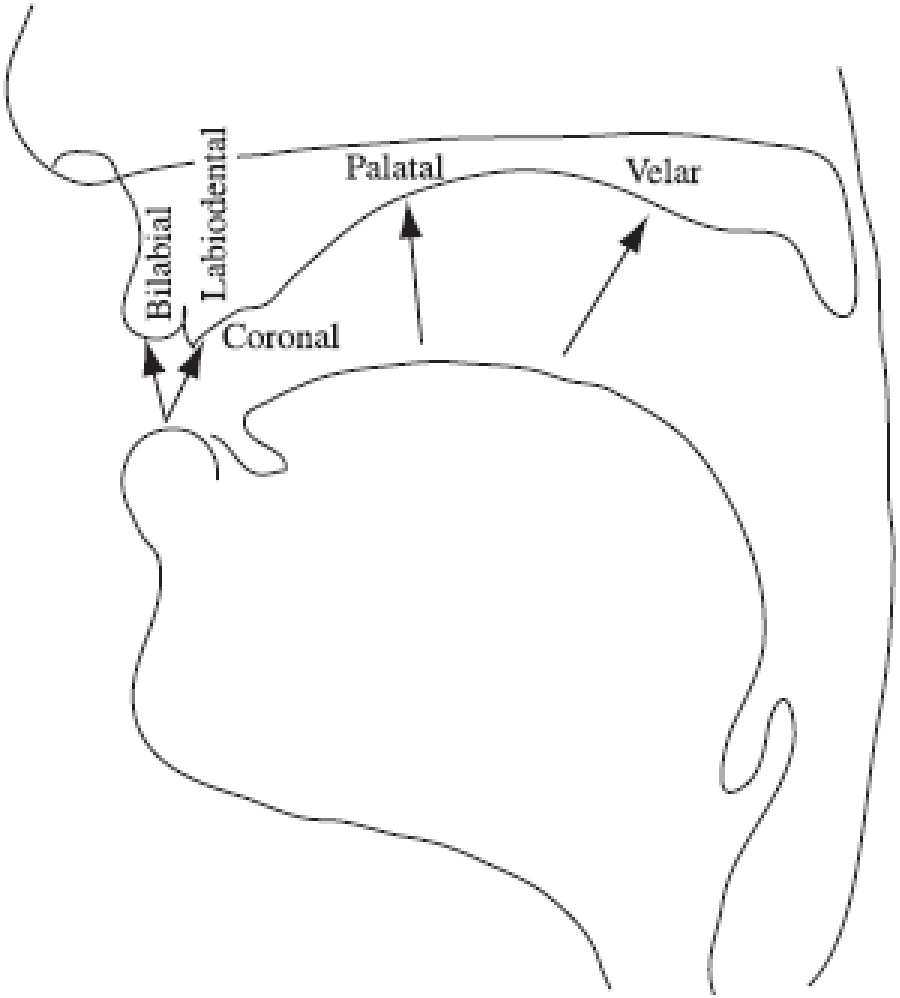
Places of consonant articulation

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

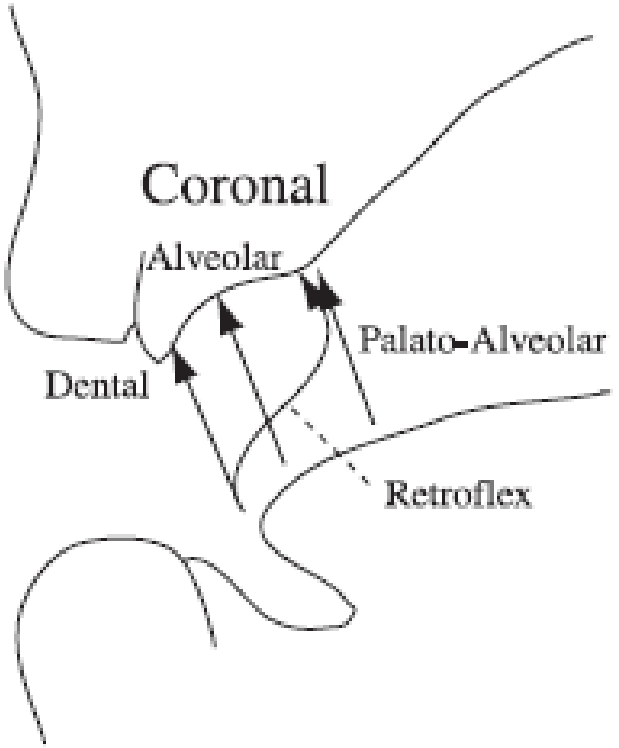
- **dental**
  Tongue tip/blade protruding between upper and lower teeth (**interdental**) or close behind the upper front teeth
  - ***thigh*, *thy***



Places of consonant articulation

CORONAL ARTICULATION (cont'd)

- **alveolar**
  tip/blade of the tongue
  at the alveolar ridge
  ***t*ie**, ***d*ie**, ***n*igh**
  ***s*igh**, ***z*eal**
  ***l*ie**
- **retroflex**
  tongue tip at the back of alveolar ridge
  r*ye**, ***r*ow**, ***r*ay / *i*re, hou*r*, ai*r
- **palato-alveolar** or **post-alveolar**
  tongue blade at the back of alveolar ridge
  ***sh*y**, ***sh*e**, ***sh*ow**



Tip: Articulate and hold the position while taking breath in

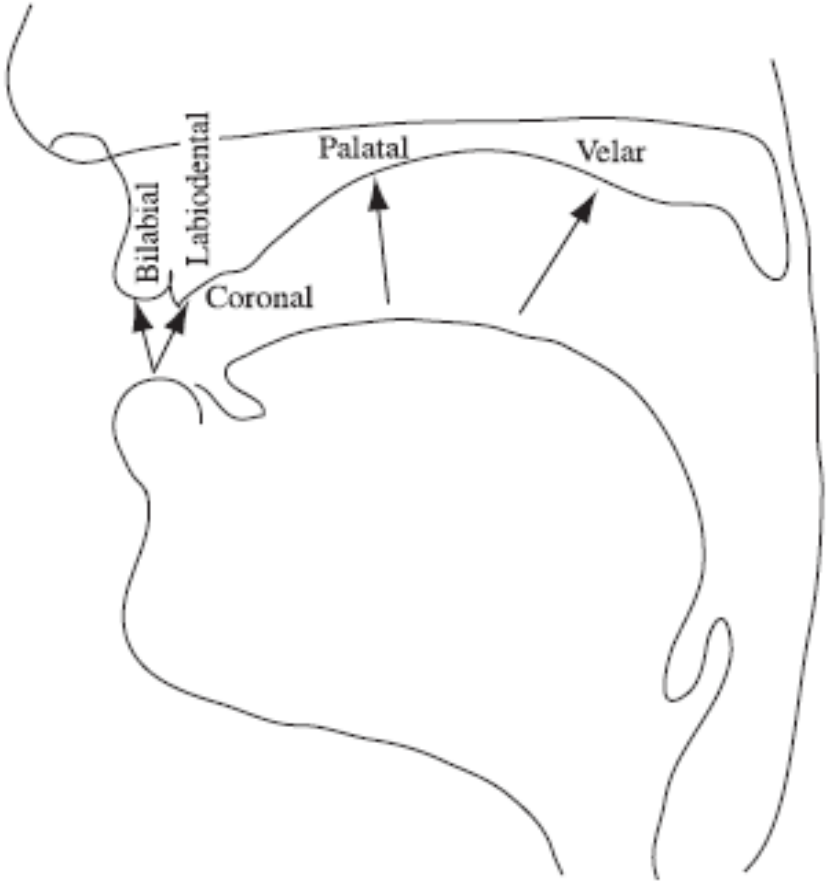
Places of consonant articulation

CORONAL / DORSAL ARTICULATION

- **palatal**
  front of the tongue at hard palate
  - *you*

DORSAL ARTICULATION

- **velar**
  back of the tongue at soft palate
  - *hack, hag, hang*

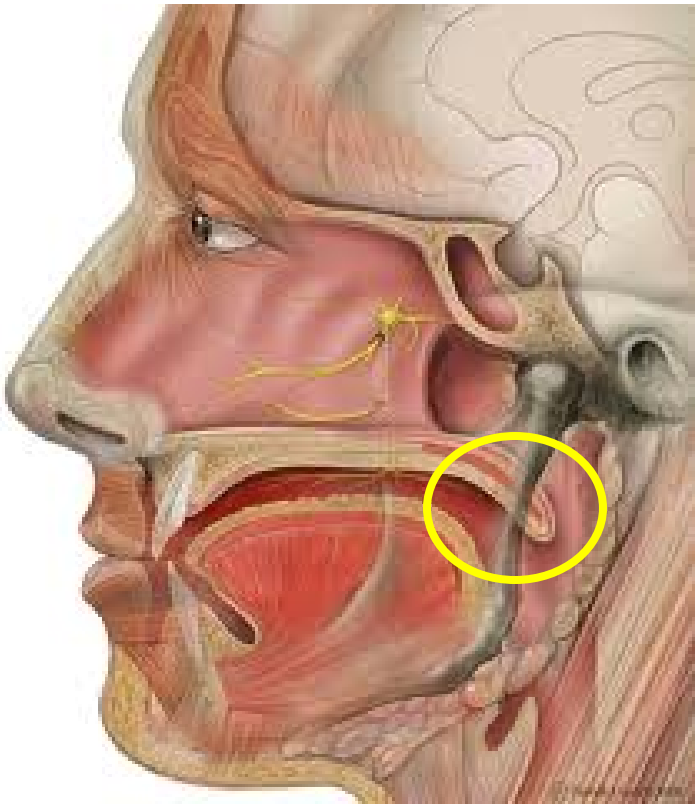


Example: fee → theme → see → she
labiodental → (inter)dental → alveolar → palato-alveolar

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 → velar → ran → alveolar → ram → bilabial

Manners of articulation

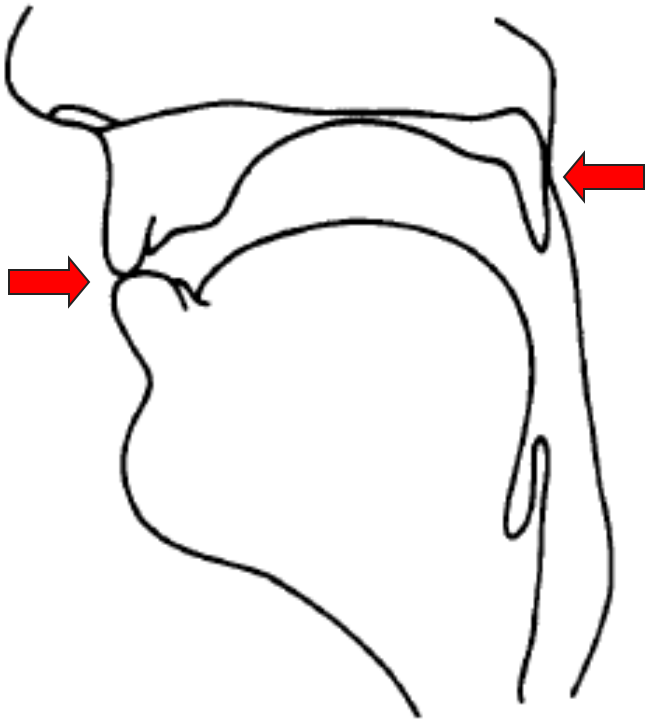
- At most places of articulation, there are several ways in which articulatory gestures can be accomplished.
  - Oral tract may close off
    - for an instant
    - for a longer period
  - The articulators may
    - narrow the space considerably
    - simply approach each other

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

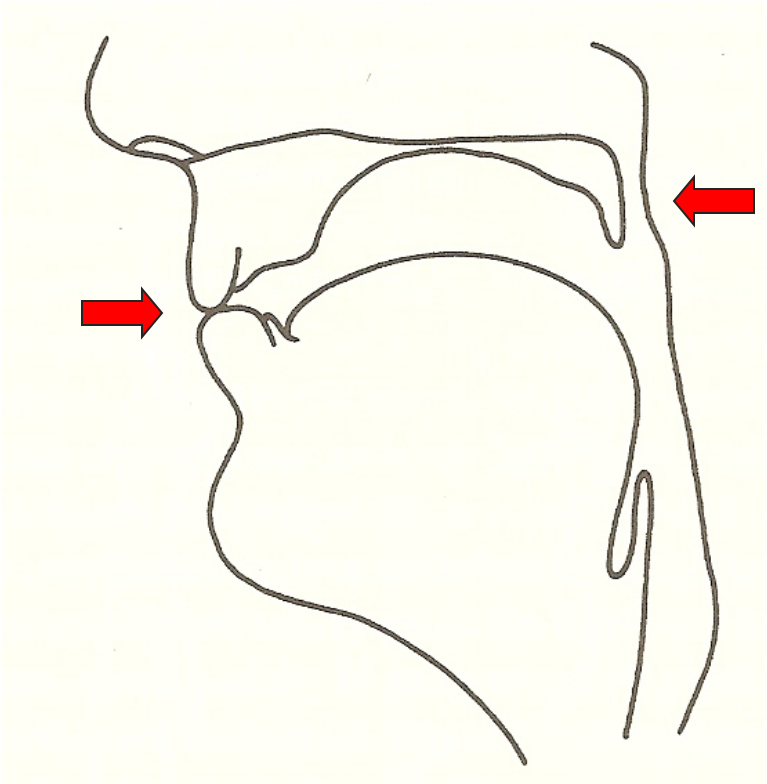
- articulatory closure in the mouth
- the nasal tract is blocked off (raised soft palate)
- pressure in the mouth builds up
- airstream is released→ **burst → plosives**



Example:	**p**ie, **b**uy →	**t**ie, **d**ye →	**k**ye, **g**uy
	bilabial →	alveolar →	velar

Nasal stop

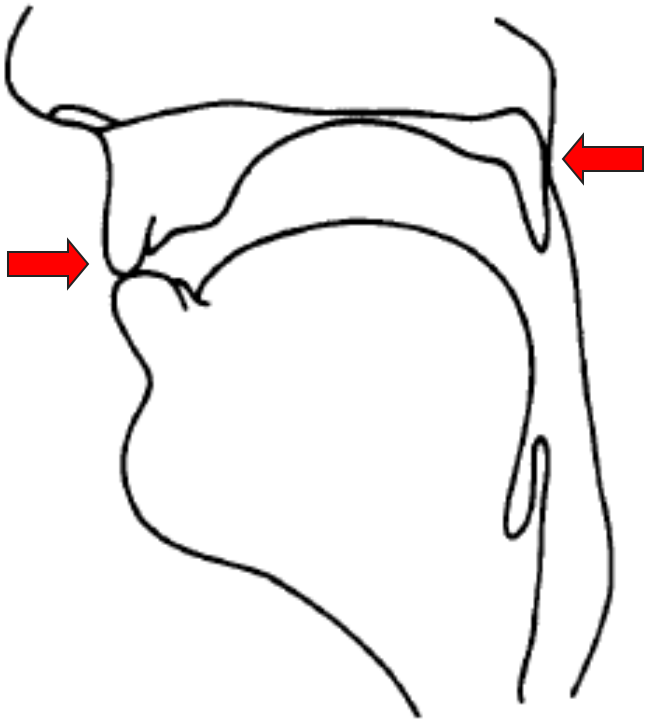
- articulatory closure in the mouth
- lowered soft palate→ air goes through nasal cavity
- Usually:
  - stop = oral stop
  - nasal = nasal stop



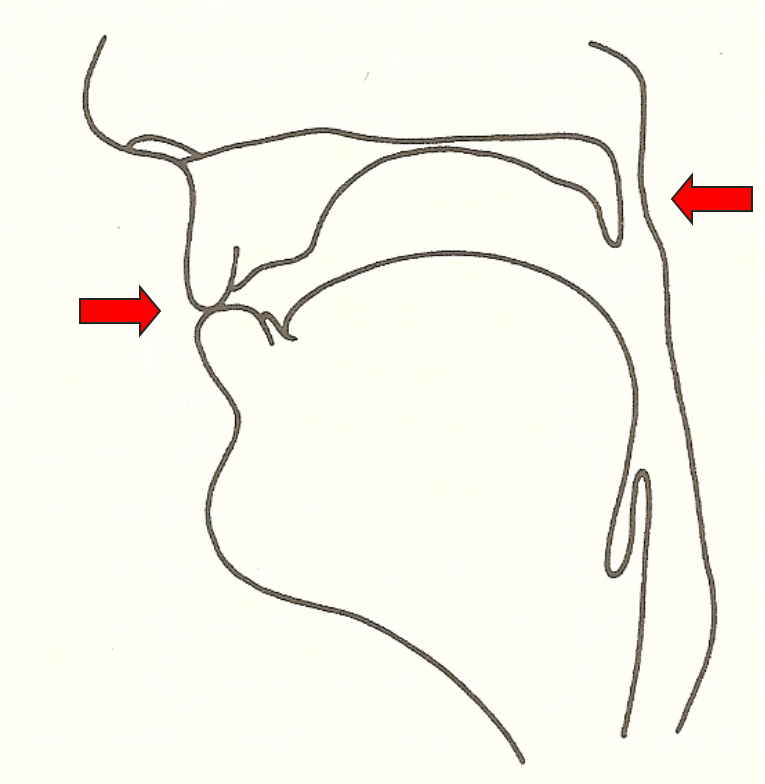
Example:	**m**y →	**n**igh →	ha**ng**
	bilabial →	alveolar →	velar

Oral vs. Nasal stop

Oral

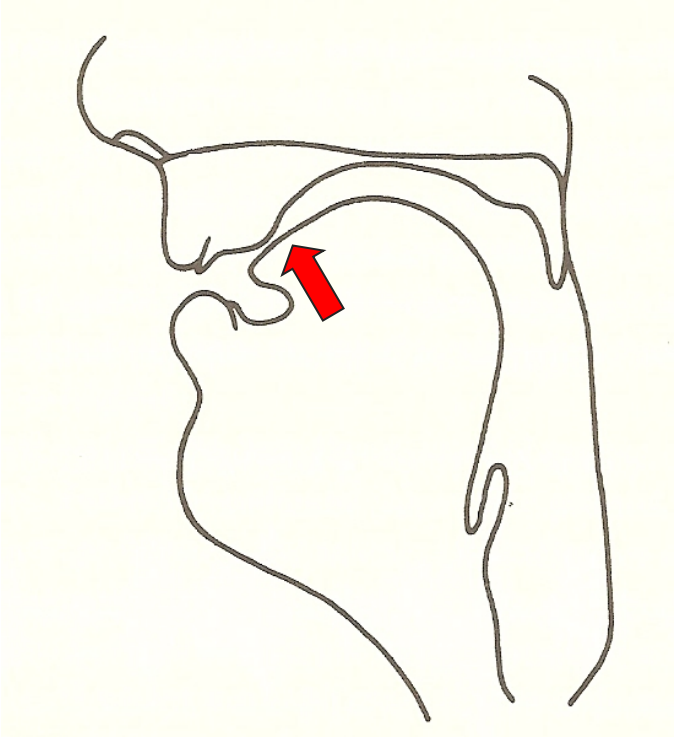


Nasal



Fricative

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

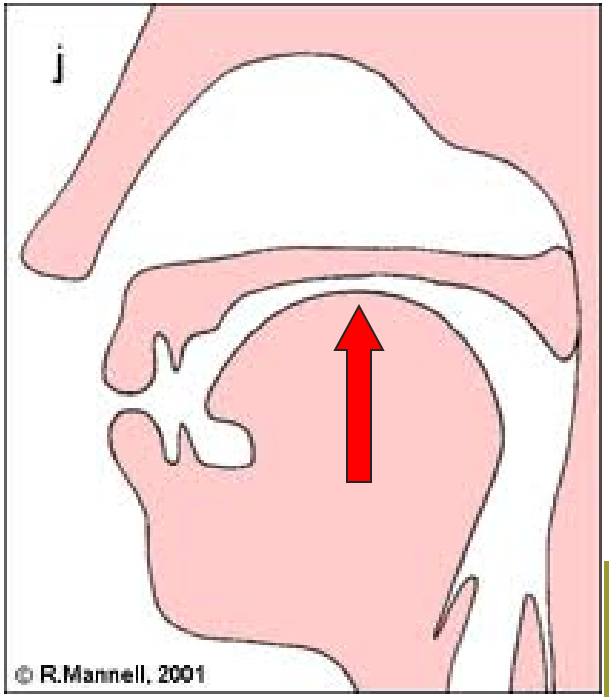


sibilants

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

Approximant

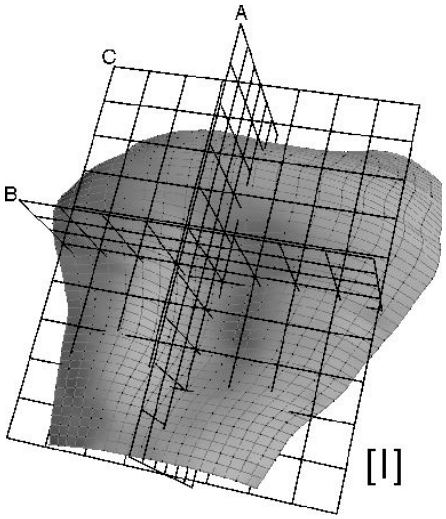
- approximation of two articulators
- vocal tract not narrowed to such an extent that turbulent airstream is produced



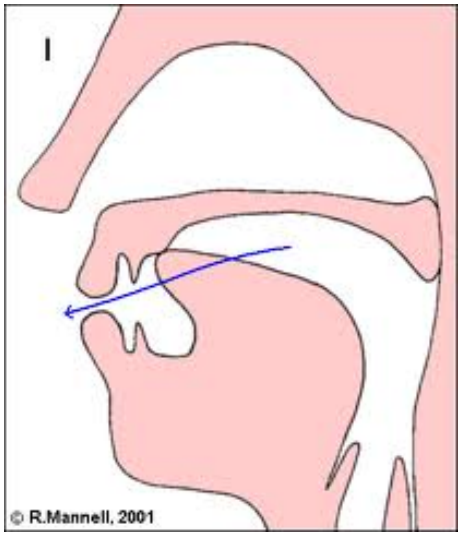
Example: **y**acht → **w**e → **r**aw
palatal → labial-velar → alveolar

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: **l**ie, **l**augh, hi**ll**
alveolar



Additional consonantal gestures

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

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

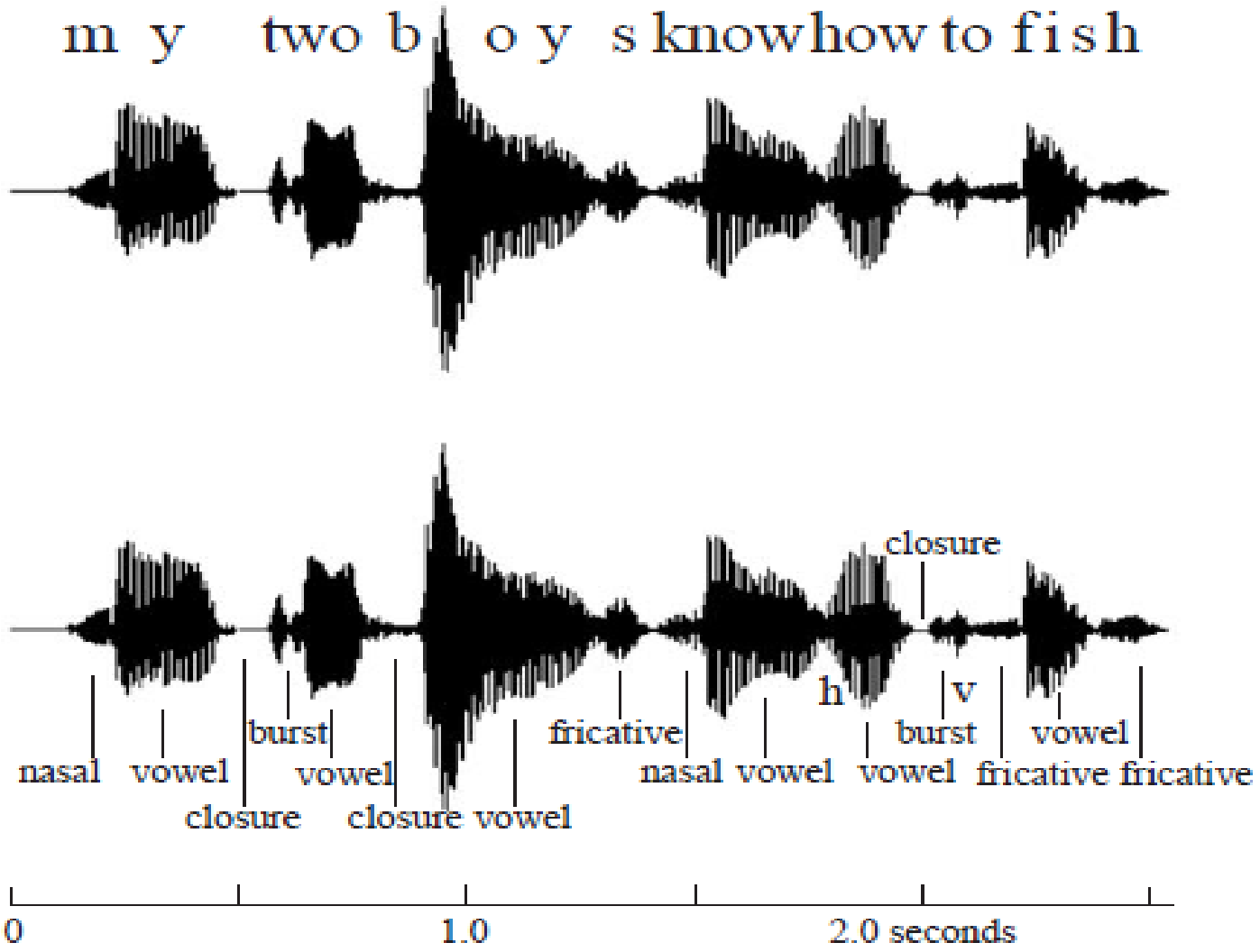
Exercise

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

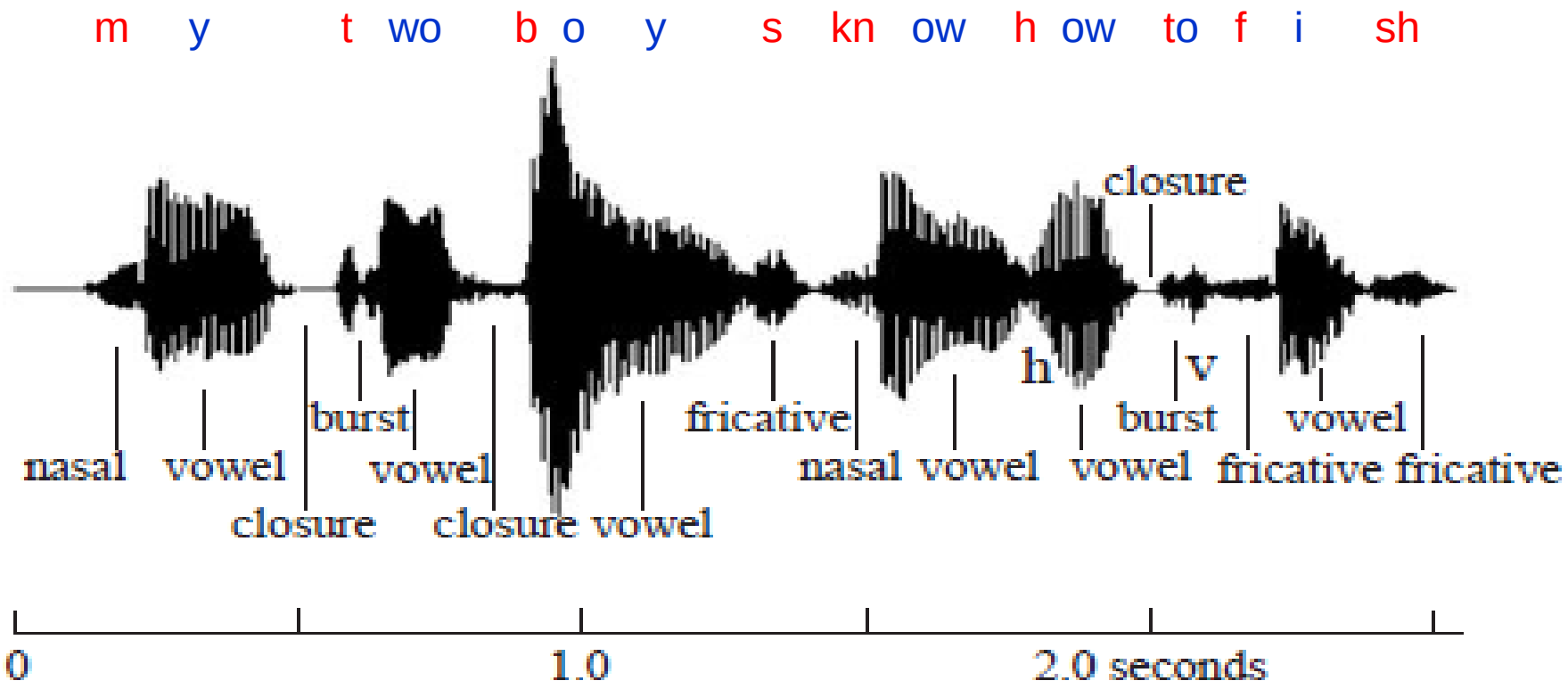
Phonetic chart of English consonants

	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



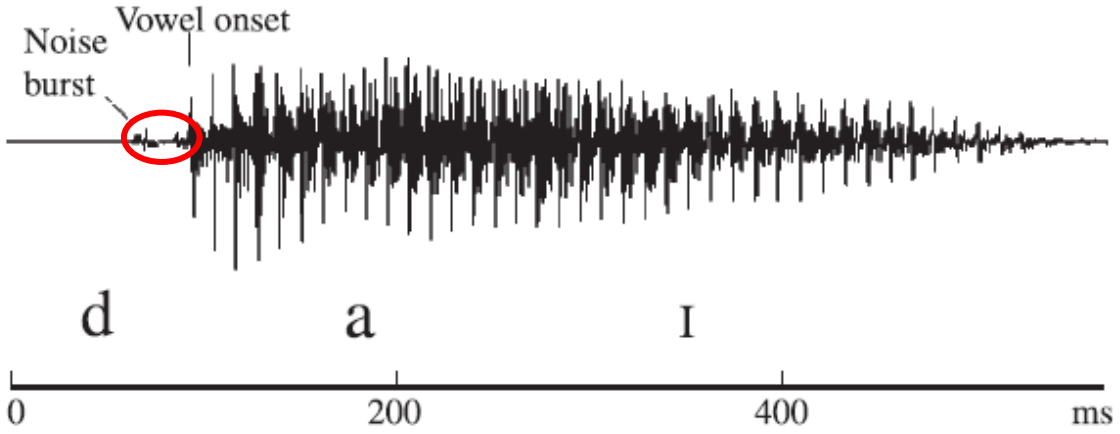
Waveforms of Consonants



Waveform of /t/ vs. /d/

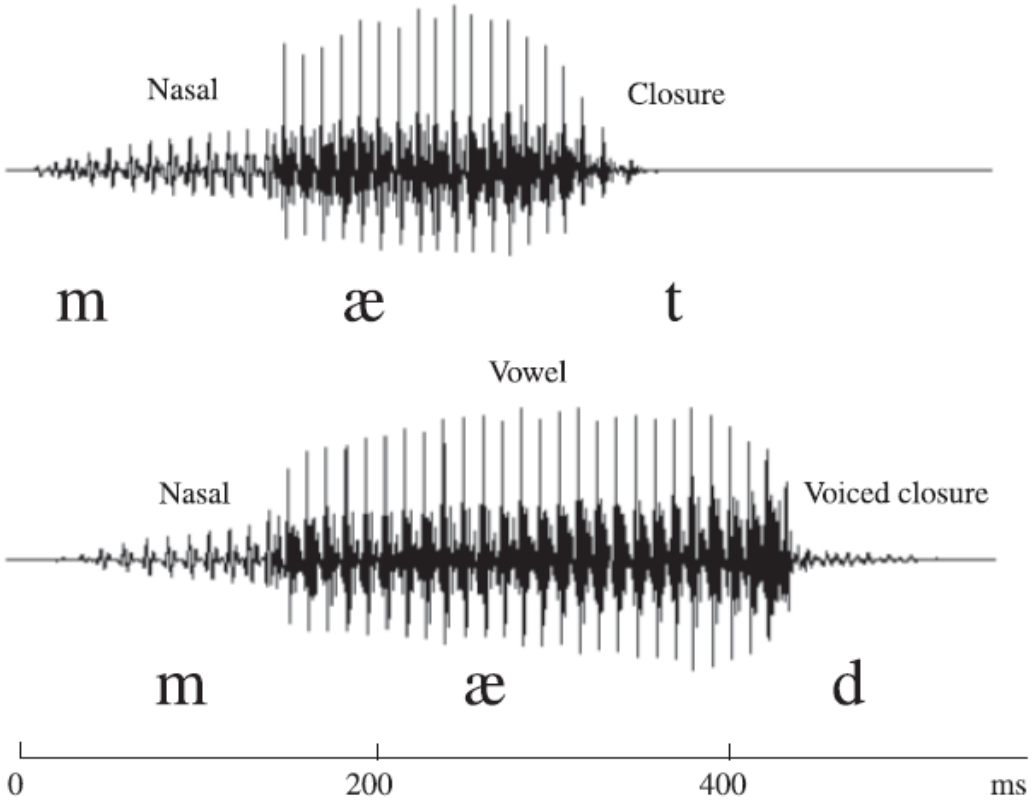
- /t^h/
  - spike indicating noise burst
  - after burst very small semi-random variations during the aspiration

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



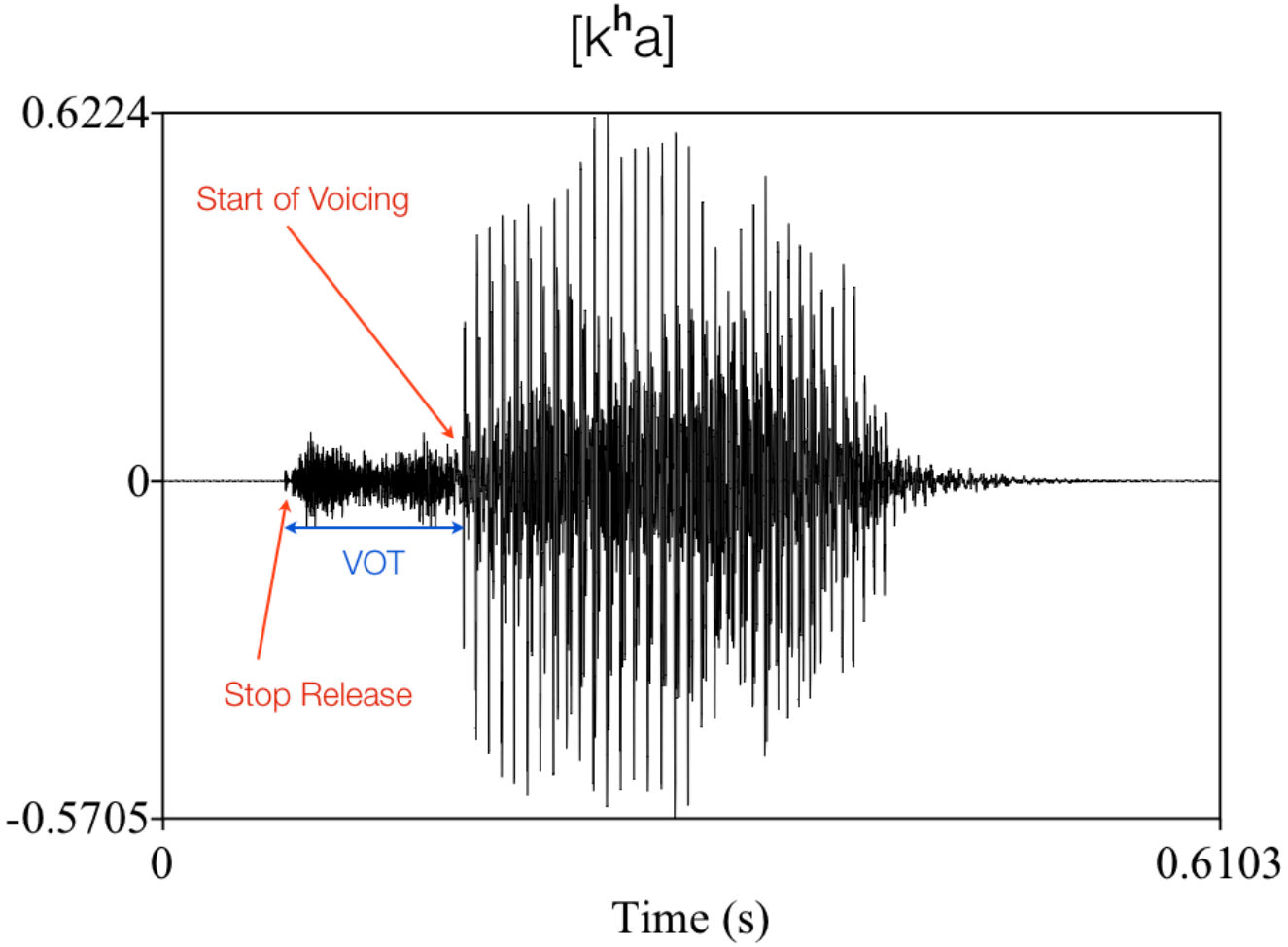
/t/ vs. /d/

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



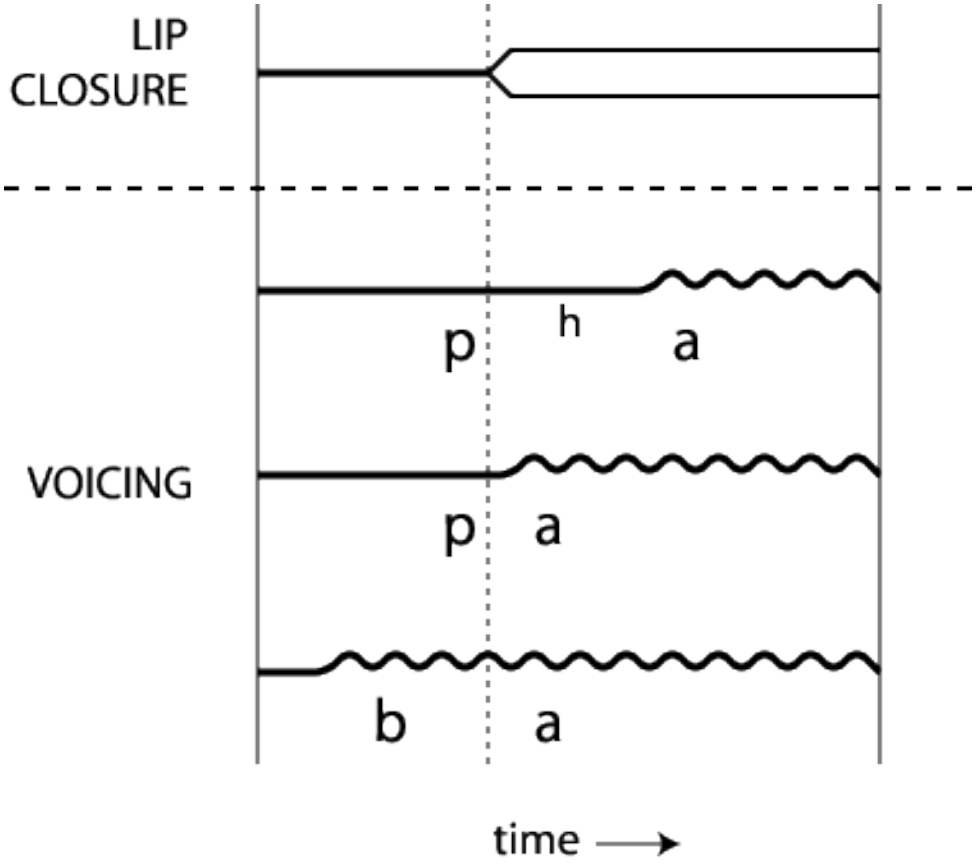
VOT (Voice Onset Time)

- 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

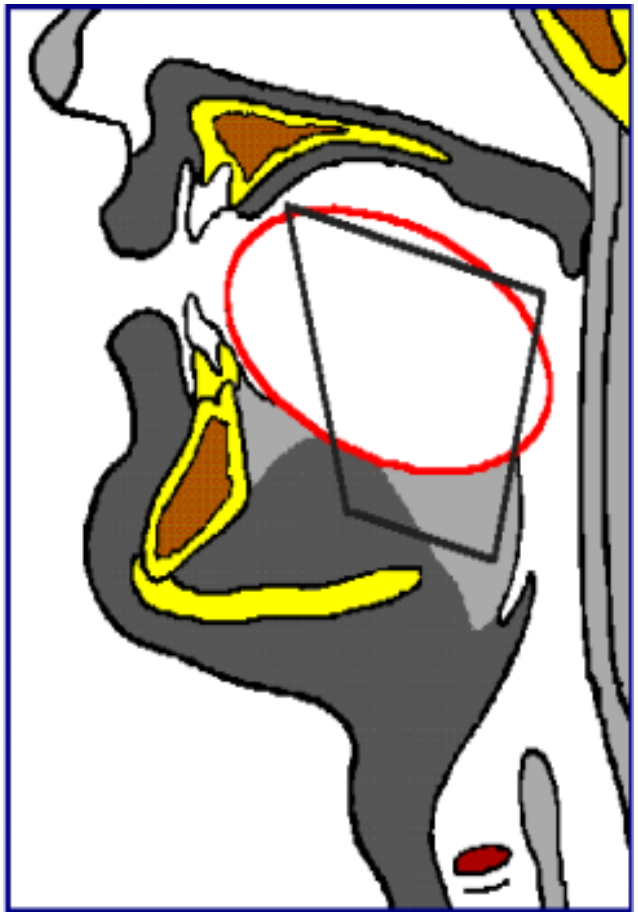


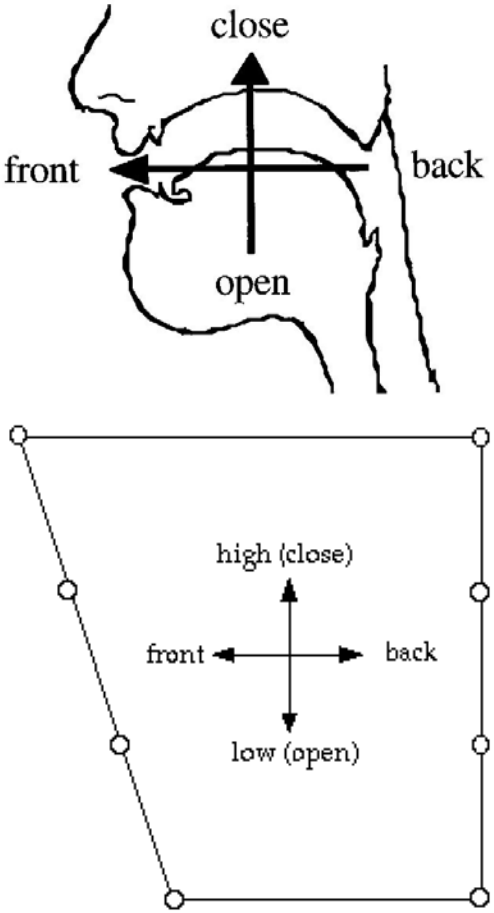
The articulation of vowel sounds

- 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





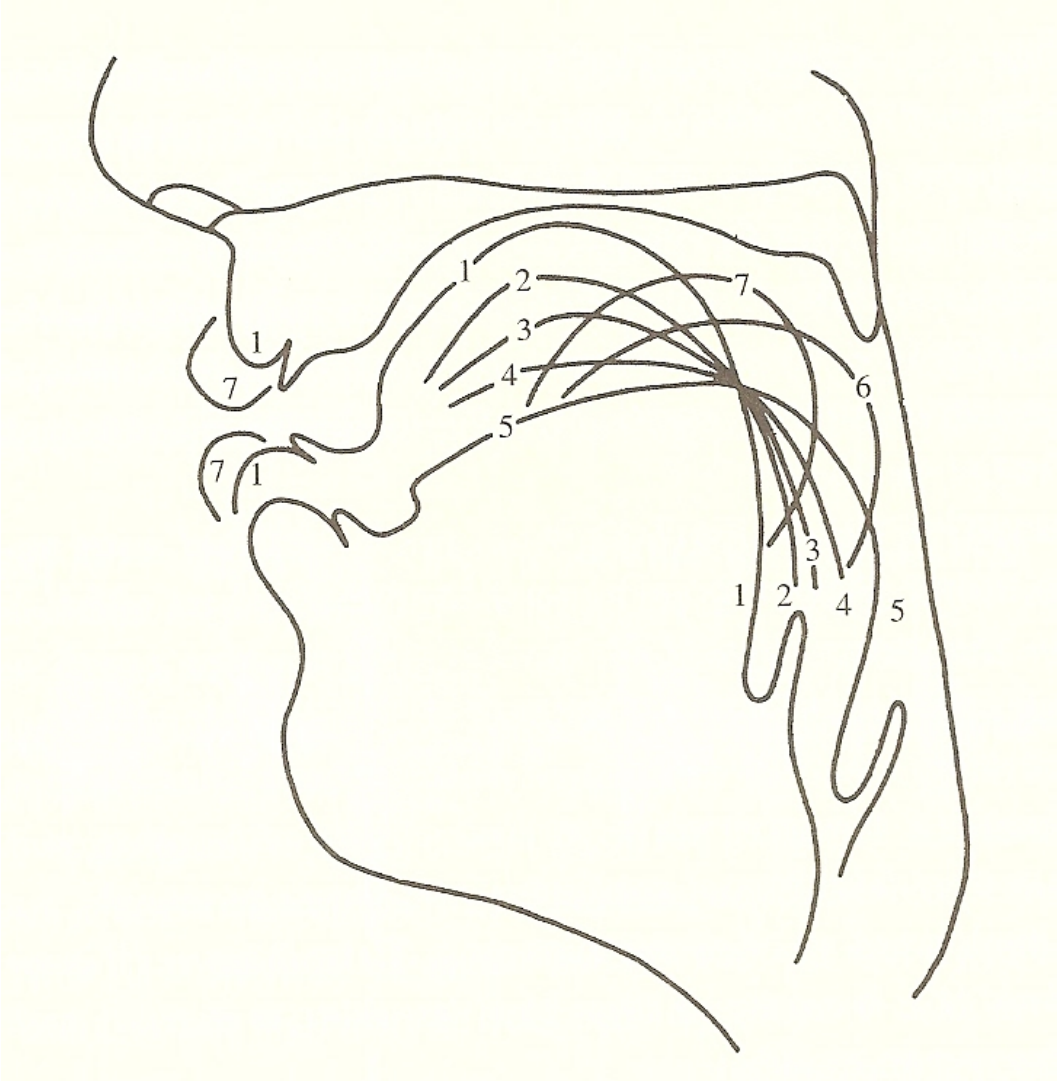
UCLA tongue video

- 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

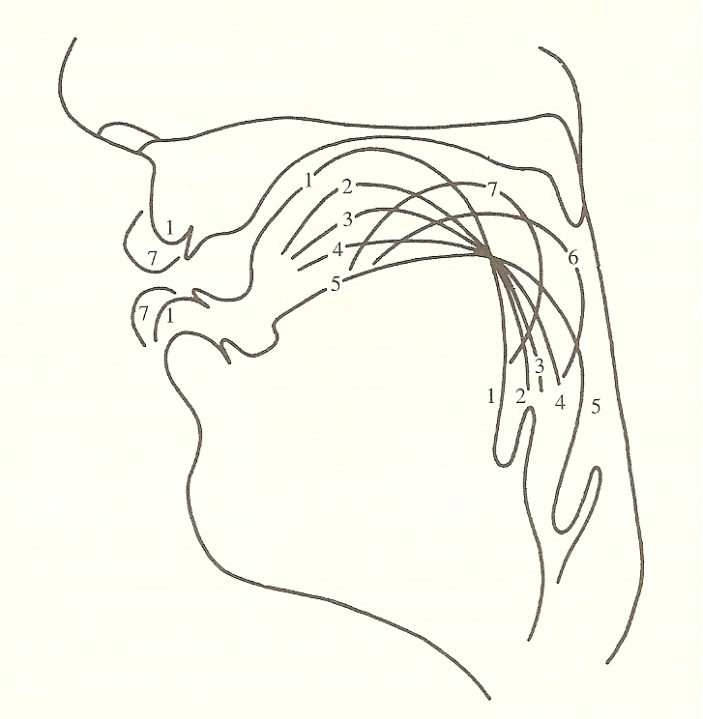
1. heed
2. hid
3. head
4. had
5. father
6. good
7. food



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.

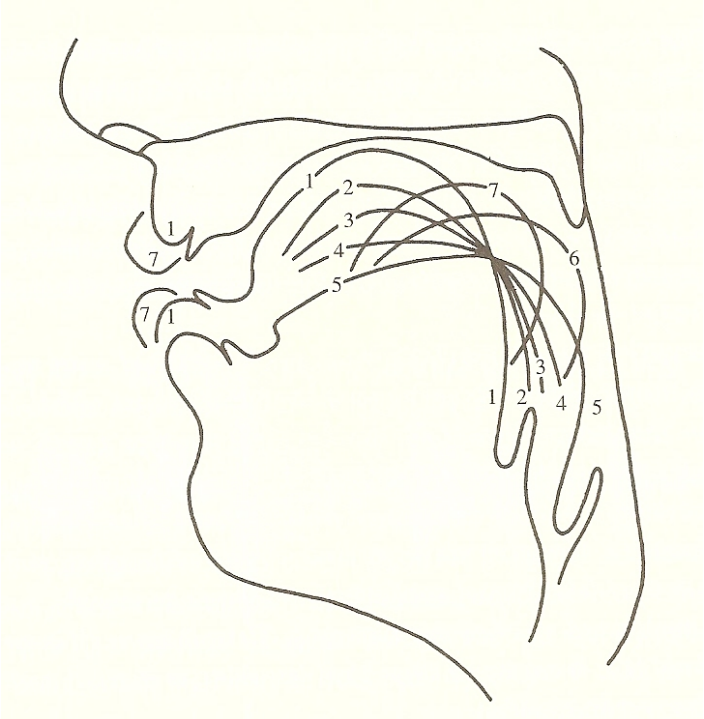
1. h**ee**d: high front
2. h**i**d: mid-high front
3. h**ea**d: mid-low front
4. h**a**d: low front



Back vowels

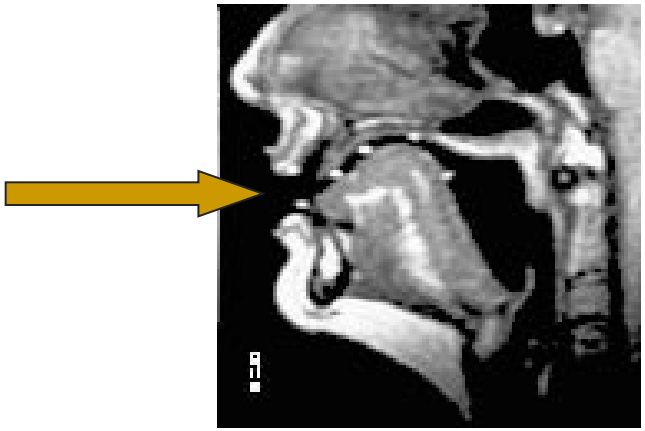
- The tongue is close to the back surface of the vocal tract.

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

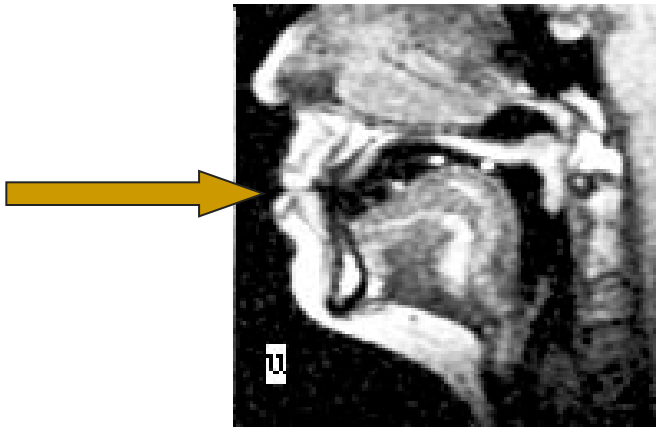


Lip rounding

- In good and food there is movement of the lips called lip rounding.



Unrounded vowels
heed, hid, head, had, father

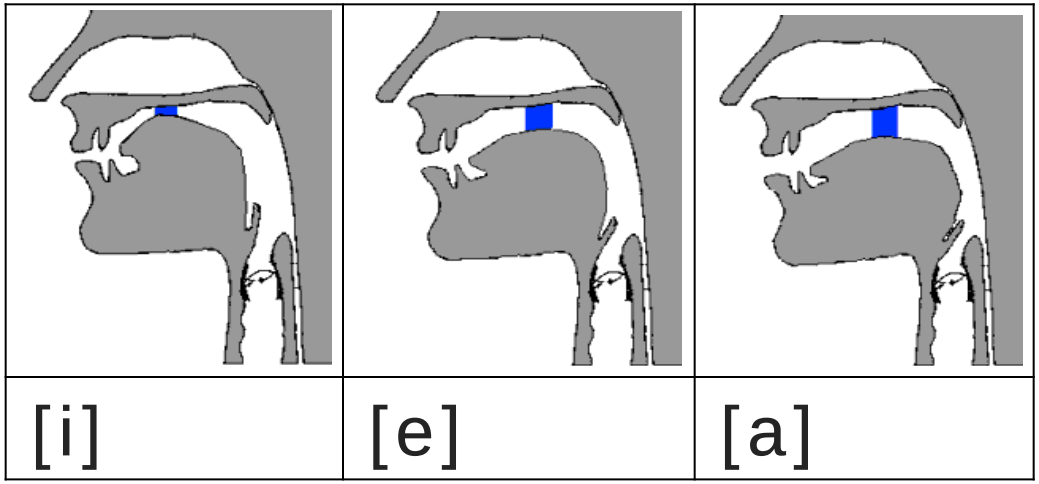


Rounded vowels
good, food

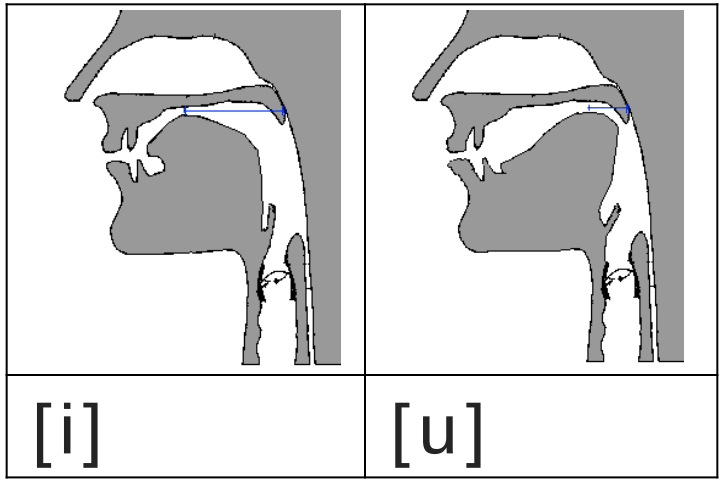
Articulatory description of vowels

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

high/low dimension



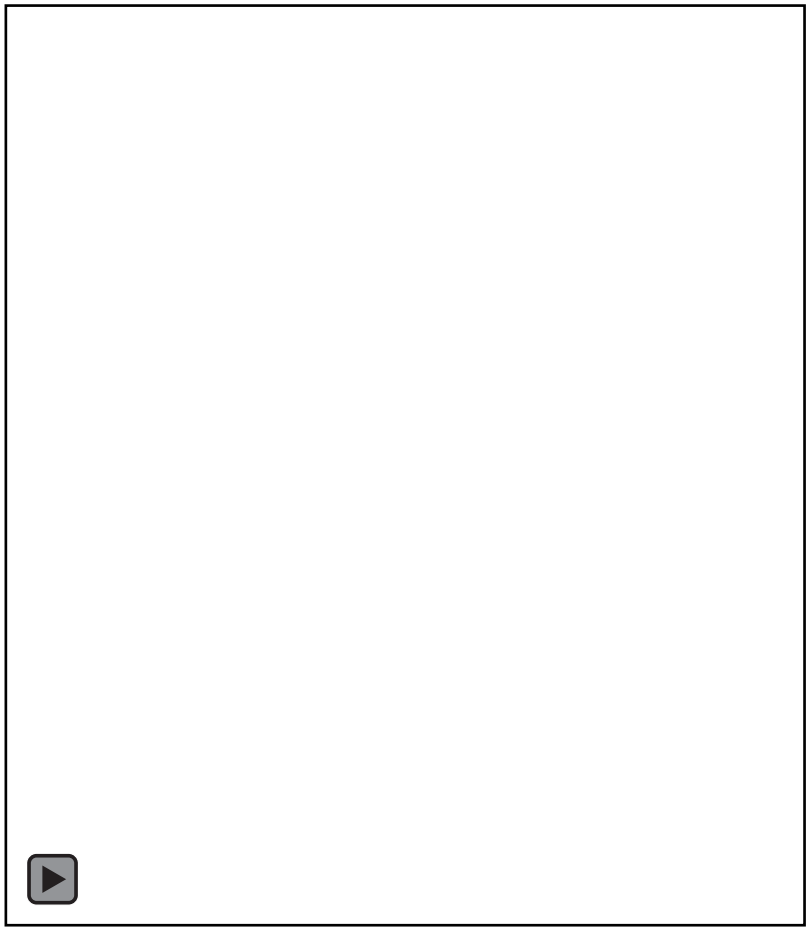
front/back dimension



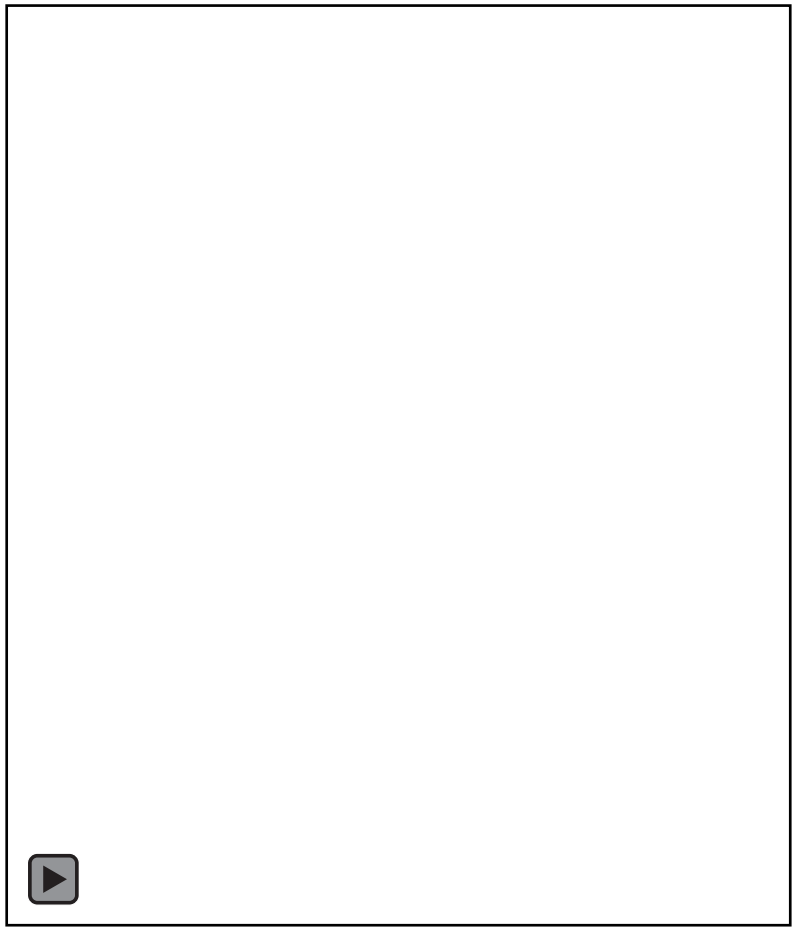
Articulatory description of vowels

- 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



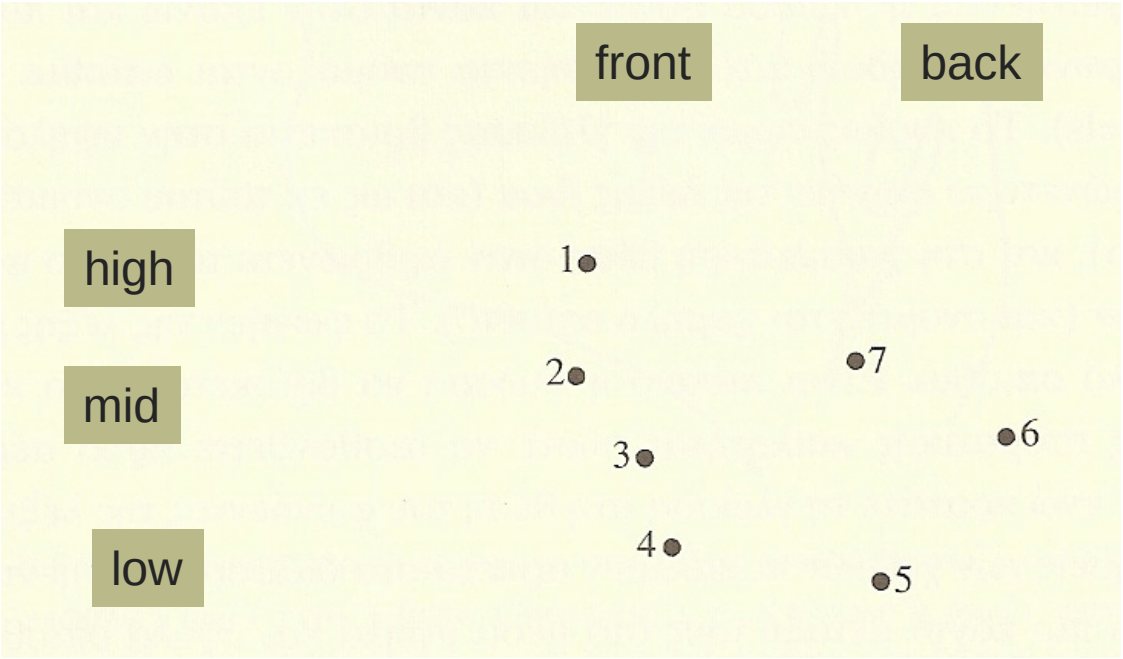
larynx

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 ˈinsult - to inˈsult (noun - verb)
  - a ˈwalkout - to ˈwalk ˈout (noun - verb)
  - a ˈhot dog - a ˈhot ˈdog (compound noun – adjective+noun)
  - ˈdiplomat → diˈplomacy → diploˈmatic
  - ˈphotograph → phoˈtography → photoˈgraphic
  - ˈmonotone → moˈnotony → monoˈtonic
- 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”)