Acoustics of Speech and Hearing

Lecture 2-3
Acoustics of Vowels

Term Plan

- Source
  - Voice & intonation (Weeks 1-2)
- Filter
  - Steady state (vowels & fricatives) (Weeks 3-4)
  - Dynamic (approximants & stops) (Weeks 5-6)
- Hearing
  - Vowel & consonant perception (Week 7)
  - Loudness, pitch & timbre (Weeks 8-10)

Vowels: Overview

- Describing vowels in the speech chain
- Category → Articulation
- Articulation → Sound
- Sound → Timbre
- Timbre → Category

Describing Vowels

- Phonologically (speaker)
  - mental pronunciation categories, e.g. cat/cut/cart/cot
- Phonetically
  - articulator position/trajectory
- Acoustically
  - spectrum
- Perceptually
  - timbre, vowel 'quality'
- Phonologically (listener)
  - chosen lexical entry defines vowel category

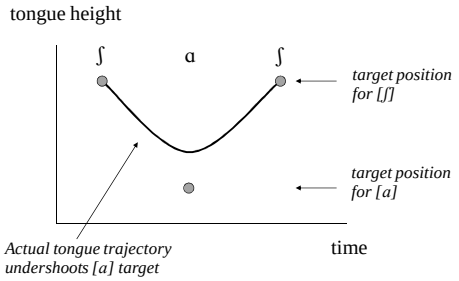
Category → Articulation

- Mental pronunciation
  - small number of contrasts
  - variation with accent: /æ/ /aʊ/
- Specifies production 'targets'
  - articulatory or acoustic
- Execution of motor-control plan
  - continuous smooth movement
  - contextual influences
  - 'undershoot'

X-Ray Movie of Speech

Why did Ken set the soggy net on top of his deck?

Vowel articulation undershoot



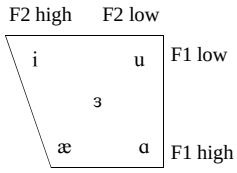
Articulation → Acoustics

- Articulation shapes vocal tract tube
- Tube has resonant characteristics dependent on shape, seen by variation in formant frequencies
- Observations of vowel formant frequencies show F1 & F2 most important
- Similarity of F1-F2 diagram to Vowel Quadrilateral leads to association between
  - increasing F1 frequency and increasing open-ness
  - increasing F2 frequency and increasing front-ness

Vowel Phonetics

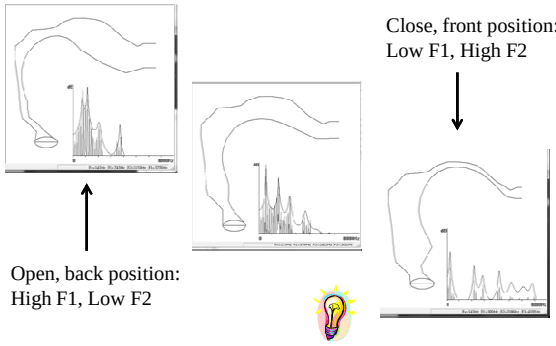
- Can roughly relate formant frequencies to position on Vowel Quadrilateral

Vowel	F1	F2
i:	low	high
æ	high	high
ɑ:	high	low
u:	low	low

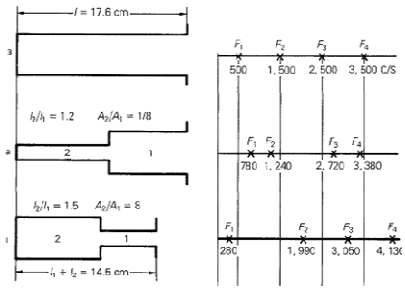


But why is there this relationship?

Tongue position affects VT shape



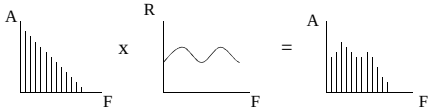
2-Tube VT Approximations



Even a simple 2-tube model shows the kind of formant frequency variation observed in vowels

Phonetics → Acoustics

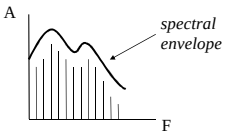
- Resonant system shapes source spectrum generated at larynx



Source-Filter model of vowel production

Acoustics → Perception

- Hearing mechanism estimates spectral envelope
  - overall shape of spectrum, largely independent of harmonics



shape of spectral envelope strongly influenced by formant frequencies

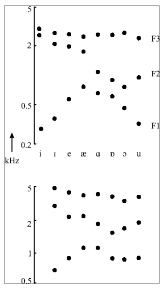
Acoustics → Perception

- Perceived timbre related to F1 & F2 position
  - similar vowel qualities have similar F1 & F2
- **But:** F1 & F2 normalised to speaker's range not absolute Hertz
  - compare adult and child
  - vowel quadrilateral is 'normalised' representation

Vowel Normalisation

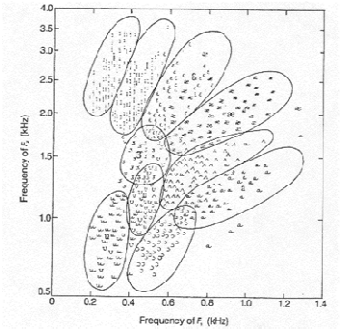
Adult

Child



- Absolute range of formant frequencies depends on size of cavities in vocal tract
- However relative pattern of variation in formant frequency similar from adult to child
- Listeners take context into account: another example of normalisation in perception

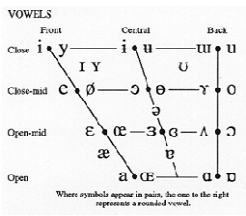
Acoustic Variability in Adults



Large formant frequency variation even in adult speakers and in a single phonetic context!

Peterson & Barney 1952

Vowel Quadrilateral



- Vowel Quadrilateral is a normalised map of vowel quality
- Shows relative position of vowels *for a single speaker*
- Periphery is defined by physical limits of speaker
- Interior position set by auditory quality

Perception → Category

- Given a normalised phonetic quality …
- Which is most likely phonological unit?
- Take into account what vowels used in lexicon
- Take into account what words used in lexicon
- Take into account accent of speaker
- Take into account context & undershoot

Summary

- Describing vowels in the speech chain
- Category, Articulation, Sound production, Perceived timbre
- Issues:
  - Consonantal context & undershoot
  - Formant frequency variability
  - Normalisation to speaker vocal tract size
  - Compensation for accent & context
  - Lexical choice constrains recognition

Lab Experiment

- Analyse recording of "Gene had thirty-four smart boots"
- Label a wide-band spectrogram
- Measure formant frequencies of vowels
- Compare with others in student group
- Compare with a child