Acoustic Phonetics

David House

Speech physiology and speech acoustics

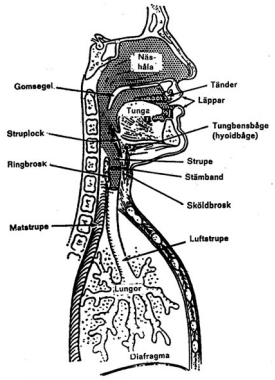
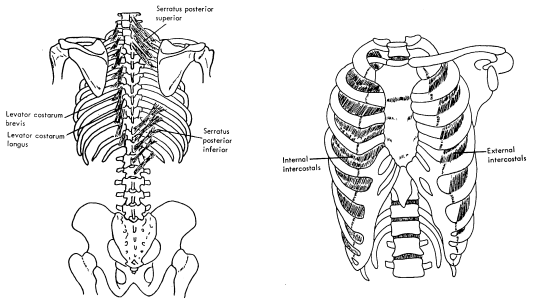
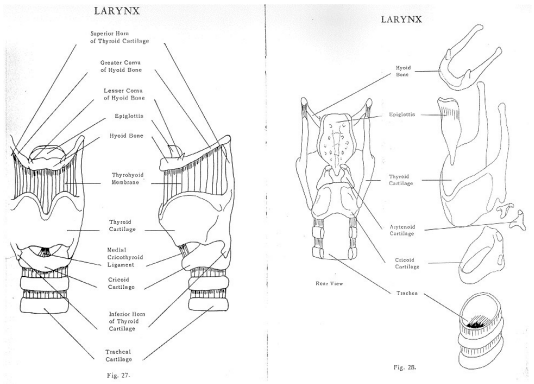


Fig. 17 Människans talorgan.

The lungs and the larynx

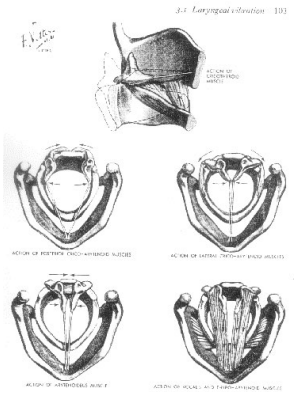
- Expiratory respiration – generate sound
- trachea luftstrupen
- larynx struphuvudet
  - cartilage, muscles and ligaments
  - glottis röstspringan
  - vocal folds stämläpparna
    - vocalis muscle, vocal ligament
- epiglottis struplocket





Voice

- Biological function of the larynx
  - Protect the lungs and airway for breathing
  - Stabilize the thorax for exertion
  - Expel foreign objects by coughing
- Phonation and voice source
  - Creation of periodic voiced sounds
  - Vocal folds are brought together, air is blown out through the folds, vibration is created



Muscular control of phonation

- Lateral control of the glottis
  - adduction (for protection and voiced sounds)
  - abduction (for breathing and voiceless sounds)
- Longitudinal control of the glottis
  - tension settings of the vocalis muscle
  - control of fundamental frequency (F0)

Voice quality

- Phonation type (lateral tension)
  - Tense (pressed) voice pressad
  - Normal (modal) voice modal
  - Flow phonation flödig
  - Breathy voice läckande
- Vocal intensity
  - Interaction between subglottal lung pressure and lateral (adductive) tension

Voice pitch

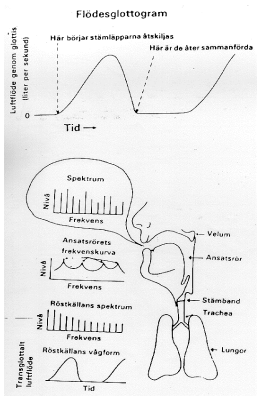
- Pitch level
  - high-pitched or low-pitched voice (average F0)
- Pitch range
  - large or small
- Register
  - modal
  - falsetto
  - creak knarr

Use of voice in normal speech

- Boundary signalling
  - vocal intensity greatest at phrase beginnings
  - pitch generally higher at phrase beginning
  - creak as a signal of phrase endings
- Social marker
  - voice quality as a signal of group identity (dialect)
- Expression of attitude and emotion
  - happy or angry
  - serious or sensual

Source-filter theory

- Voice-source waveform (during phonation)
  - Transglottal airflow measurements
- Spectrum of the voice source
  - Decreases in amplitude with increasing frequency
- Vocal tract resonances
  - Dependent on position of the tongue and lips
- Spectrum of radiated sound
  - Sum of voice source and vocal tract resonances



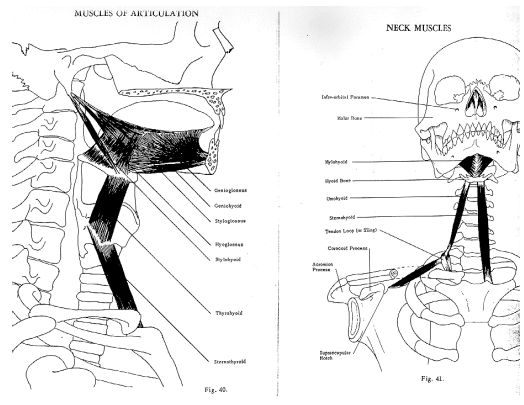
From Sundberg: Röstlära

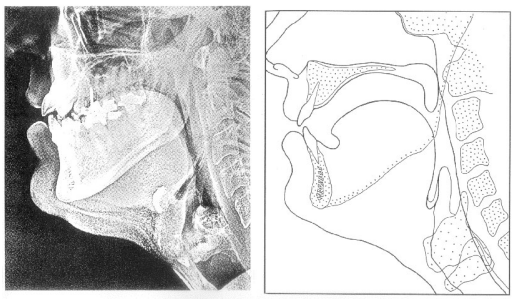
Vowels and consonants

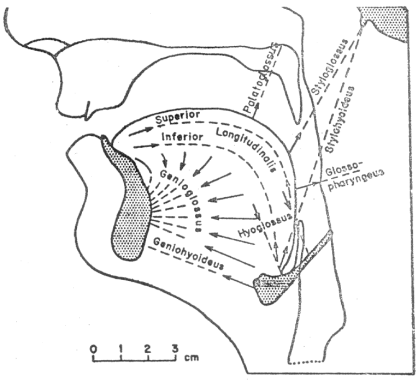
- Speech production (phonetics)
  - Free airpassage through the pharynx, mouth and the lips = vowel
  - Constricted or closed airpassage = consonant
- Function (phonology)
  - Nuclear in the syllable = vowel
  - Marginal in the syllable = consonant
- Exceptions
  - Some voiced consonants (e.g. syllabic ☯nll☸)
  - Approximants or semi-vowels (e.g. [j] [w])

The vocal tract

- Throat, (svalget): pharynx, faryngal
- Oral cavity, (munhålan): os, oral
- Nasal cavity, (näshålan): nasus, nasal



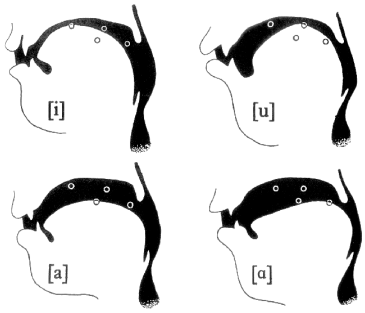

From Laver: Principles of Phonetics



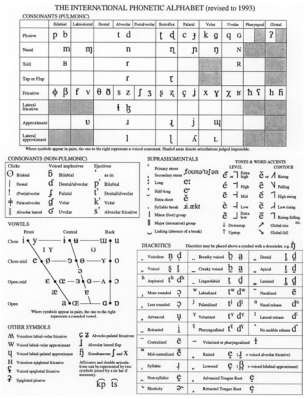
Vowel articulation

- Cardinal vowels
  - Reference vowels
  - Four corner vowels form the corners of the vowel chart
- Descriptive terminology
  - Close-open (high-low) sluten-öppen
  - Front-back främre-bakre
  - Unrounded-rounded orundad-rundad
  - Oral-nasal (e.g. French) oral-nasal

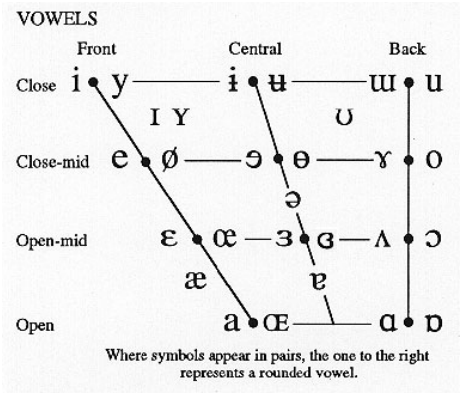
Tongue shapes of four of the cardinal vowels



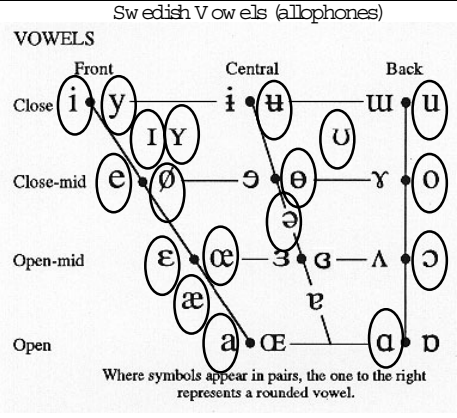
From Elert: Allmän och svensk fonetik



Swedish Vowels



Swedish Vowels (allophones)



Tabell 5.1 De långa och korta vokalerna i svenskt rikssspråksuttal.

Långa vokaler		*Korta vokaler*	
fonetiskt tecken	*nyckelord*	*fonetiskt tecken*	*nyckelord*
[ɑː]	*mat*	[a]	*matt*
[eː]	*vet*	[e]	*vett, året*
[iː]	*vit*	[ɪ]	*vitt*
[uː]	*bo*	[ʊ]	*bott*
[ɯː] el. [ʉ̟ː]	*hus*	[ɵ]	*hund*
[yː]	*byt*	[ʏ]	*bytt*
[oː]	*gå*	[ɔ]	*gått*
[ɛː]	*säl*	[ɛ]	*vätt*
[æː]	*här*	[æ]	*kärr*
[øː]	*hö*	[øˠ]	*höst*
[œː]	*hör*	[œ]	*förr*

From Elert: Allmän och svensk fonetik

Phonological features

- Binary features for vowels
  - e.g.
    - ± high
    - ± low
    - ± back
    - ± round
- Feature matrix
  - Feature specification for each phoneme

Vokalfonem
A. Svenska

		förträngningens läge			
		främre			bakre
tungkroppens läge	högt	i	y	ʉ	u
	mellan	e	ø		o
	lågt	ɛ			ɑ
		orun-dade	utrun-dade	inrundade	
		läppartikulation			

B. Finska

		förträngningens läge		
		främre		bakre
tungkroppens läge	högt	i	y	u
	mellan	e	ø	o
	lågt	ɛ		ɑ
		orun-dade	rundade	
		läppartikulation		

From Gårding: Kontrastiv fonetik och syntax med svenska i centrum

Vowel acoustics

- Spectrogram
  - Narrow band spectrogram
  - Wide band spectrogram
- Formants (F1, F2, F3, F4)
- Acoustic vowel diagram (F1, F2)
- Formant transitions

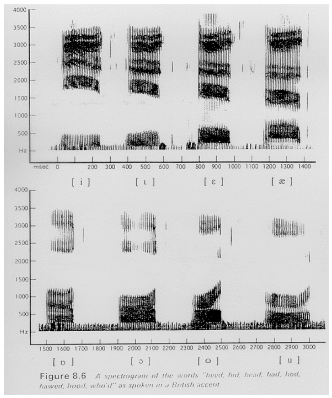
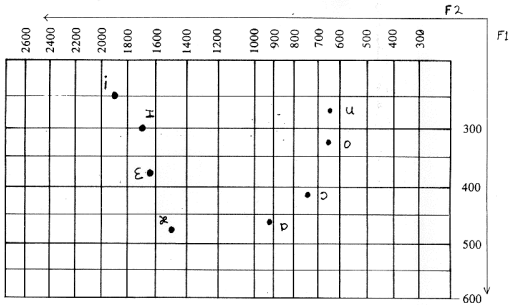
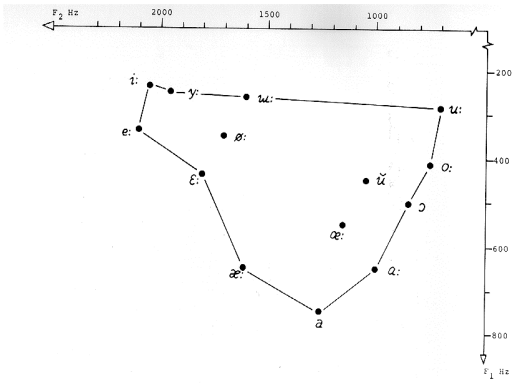


Figure 8.6 *A spectrogram of the words "heed, hid, heid, had, hud, hod, hawed, hoard, hood, who'd" as spoken in a British accent.*

From Ladefoged: A course in phonetics

Acoustic vowel diagram (F1, F2)





Figur 5. Akustiskt vokaldiagram med svenska vokaler. Formantvärden från Fant.

Consonant articulation

- Voiceless or voiced
  - fortis or lenis
  - aspirated or unaspirated
- Manner of articulation
  - How is the sound produced?
- Place of articulation
  - Where is the constriction or closure located?

Manner of articulation

- Fricatives frikativor (spiranter)
- Stops, plosives klusiler, explosivor
  - aspiration
  - unreleased
  - affricates (stop + fricative) affrikator
- Liquids likvidor
  - laterals lateraler
  - trills tremulanter (vibranter)
- Nasals nasaler

The tongue: lingua

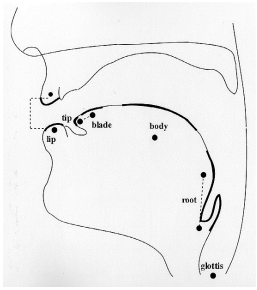
- Tongue tip: apex, apikal
- Tongue blade: predorsum, predorsal (also corona, coronal)
- Tongue back: dorsum, dorsal
- Tongue root: radix

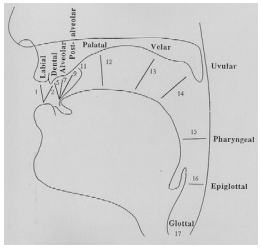
The palate

- Alveolar ridge (tandvallen): alveoli, alveolar
- Hard palate (hårda gommen): palatum, palatal
- Soft palate (mjuka gommen): velum, velar
- Uvula (tungspenen): uvula, uvular

The teeth and lips

- teeth: dentes, dental
- lips: labia, labial
  - rounded - labialised
  - unrounded - delabialised





From Ladefoged: A course in phonetics

Place of articulation (IPA)

- Bilabial
- Labiodental
- Dental
- Alveolar
- Postalveolar
- Retroflex
- Palatal
- Velar
- Uvular
- Pharyngeal
- Glottal (laryngeal)

THE INTERNATIONAL PHONETIC ALPHABET (revised to 1993)

CONSONANTS (PULMONIC)

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Glottal
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q G		ʔ
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	N		
Trill	B			r					R		
Tap or Flap				ɾ		ɽ					
Fricative	ɸ β	f v	θ ð	s z	ʃ ʒ	ʂ ʐ	ç ʝ	x ɣ	χ ʁ	ħ ʕ	h ɦ
Lateral fricative				ɬ ɮ							
Approximant		ʋ		ɹ		ɻ	j	ɰ			
Lateral approximant				l		ɭ	ʎ	ʟ			

Where symbols appear in pairs, the one to the right represents a voiced consonant. Shaded areas denote articulations judged impossible.

Swedish consonants

THE INTERNATIONAL PHONETIC ALPHABET (revised to 1993)

CONSONANTS (PULMONIC)

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Glottal
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q G		ʔ
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	N		
Trill	B			r					R		
Tap or Flap				ɾ		ɽ					
Fricative	ɸ β	f v	θ ð	s z	ʃ ʒ	ʂ ʐ	ç ʝ	x ɣ	χ ʁ	ħ ʕ	h ɦ
Lateral fricative				ɬ ɮ							
Approximant		ʋ		ɹ		ɻ	j	ɰ			
Lateral approximant				l		ɭ	ʎ	ʟ			

Where symbols appear in pairs, the one to the right represents a voiced consonant. Shaded areas denote articulations judged impossible.

SJ-LJUDET I SVENSKA

OTHER SYMBOLS

ʍ Voiceless labial-velar fricative

w Voiced labial-velar approximant

ɥ Voiced labial-palatal approximant

ʜ Voiceless epiglottal fricative

ʢ Voiced epiglottal fricative

ʡ Epiglottal plosive

ɕ ʑ Alveolo-palatal fricatives

ɺ Alveolar lateral flap

ʧ Simultaneous ʃ and x

Affricates and double articulations can be represented by two symbols joined by a tie bar if necessary.

k͡p t͡s

Phonological features

- ±consonant
- ±sonorant
- ±obstruent
- ±anterior
- ±coronal
- ±continuant
- ±voice

Konsonantfonem

A. Svenska

Artikulationssätt				Artikulationsställen				
				lab	lab-dent	dent alv	pal vel	glott
egentliga konsonanter	klusiler		tonlösa	p		t	k	
			tonande	b		d	g	
	frikativor		tonlösa	ɧ	f	s	ç	h
			tonande		v		j	
vokalliknande konsonanter	likvidor	later				l		
		vibr				r		
	nasaler			m		n	ŋ	

B. Finska

egentliga konsonanter	klusiler			p		t	k	
	frikativor		tonlösa			s		h
			tonande		v		j	
vokalliknande konsonanter	likvidor	later				l		
		vibr				r		
	nasaler			m		n	ŋ	

From Gårding: Kontrastiv fonetik och syntax med svenska i centrum

Consonant acoustics (1)

- Fricatives
  - Noise frequency
  - Formant transitions in adjoining vowels
- Stops
  - Occlusion phase (silence)
  - Plosive release
  - Aspiration
  - Formant transitions in adjoining vowels

Consonant acoustics (2)

- Liquids
  - Laterals
    - Formants similar to vowels, lower intensity
    - Formant transitions
  - Trills
    - Quickly repeated stops
    - Short vowel-like pulses
    - Formant transitions

Consonant acoustics (3)

- Nasals
  - Vowel-like with lower intensity
  - Nasal resonances (nasal formants)
  - Formant transitions in adjoining vowels

Prosody

- Suprasegmental speech characteristics
  - Temporal relationships
  - Stress patterns
  - Speech rhythm
  - Intonation
- Functions of prosody
  - Lend prominence (emphasize, de-emphasize)
  - Grouping function (combine, separate)

Prosodic categories

- Stress (syllable)
  - Speech rhythm, alternating stressed-unstressed
- Word accent (word)
  - accent I (acute), accent II (grave)
- Focus (phrase accent)
  - Emphasis, contrastive emphasis
- Juncture (phrase, utterance)
  - Boundary signals and connective signals

Acoustic features of prosody

- Time (quantity)
- Fundamental frequency (F0) (pitch, intonation)
- Intensity (loudness)

References

- Elert, Claes-Christian (1995) Allmän och svensk fonetik. Norstedts Förlag, Stockholm
- Ladefoged, Peter (1982) A course in phonetics. Harcourt Brace Jovanovich, New York
- Laver, John (1994) Principles of phonetics. Cambridge University Press, Cambridge
- Sundberg, Johan (1986) Röstlära. Proprius, Stockholm

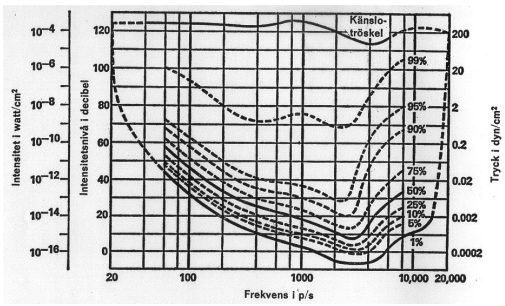
Psychoacoustics and speech perception

David House

Hearing acuity

- Sensitive for sounds from 20 to 20 000 Hz
- Greatest sensitivity between 1000-6000 Hz
- Non-linear perception of frequency intervals
  - E.g. octaves
    - 100Hz - 200Hz - 400Hz - 800Hz - 1600Hz
  - 100Hz - 800Hz perceived as a large difference
  - 3100Hz - 3800 Hz perceived as a small difference

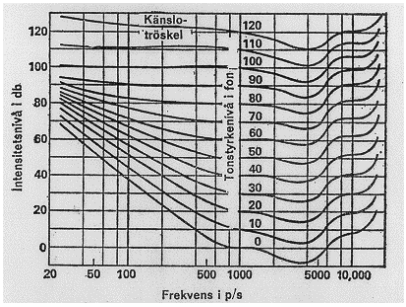
Absolute auditory threshold



Demo: SPL (Sound pressure level) dB

- Decreasing noise levels
  - 6 dB steps, 10 steps, 2*
  - 3 dB steps, 15 steps, 2*
  - 1 dB steps, 20 steps, 2*

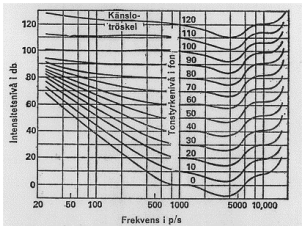
Constant loudness levels in phons

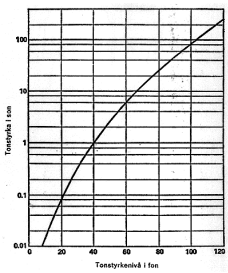


Demo: SPL and loudness (phons)

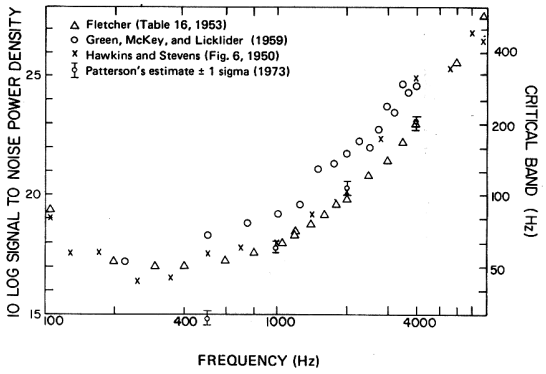
- 1) 50-100-200-400-800-1600-3200-6400 Hz
  - 1a: constant SPL 40 dB, 2*
  - 1b: constant 40 phons, 2*
- 2) 125-250-500-1000-2000-4000-8000 Hz
  - Decreases by 5dB in 10 steps at each freq.
  - Count how many steps you hear at each frequency

Relationship phon - sone





Demo: 0,01-0,1-1-10 son (2*)

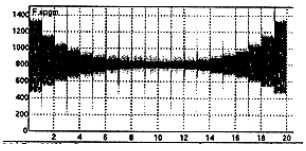


Critical bands

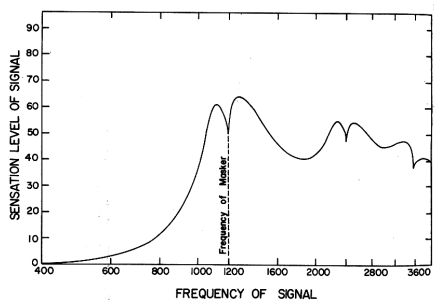
- Bandwidth increases with frequency
- Demo: critical bands by masking
  - 2000 Hz tone decreases by 5 dB in 10 steps (2*)
  - Masking with noise (wideband) (2*)
  - Masking with noise (1000 Hz bandwidth) (2*)
  - Masking with noise (250 Hz bandwidth) (2*)
  - Masking with noise (10 Hz bandwidth) (2*)
- How many steps can you hear?

Critical bands demo (2)

- Fm = 200 Hz (critical bandwidth 50 Hz)
  - B = 300,204,141,99,70,49,35,25,17,12 Hz
- Fm = 800 Hz (critical bandwidth 80 Hz)
  - B = 816,566,396,279,197,139,98,69,49,35 Hz
- Fm = 3200 Hz (critical bandwidth 200 Hz)
  - B = 2263,1585,1115,786,555,392,277,196,139,98 Hz



Effects of masking

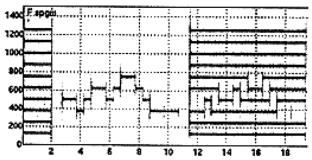


Effects of masking

- Low frequencies more effectly mask high frequencies
- Demo: how many steps can you hear?
  - a) masking tone 1200 Hz, stimulus 2000 Hz
  - b) masking tone 2000 Hz, stimulus 1200 Hz

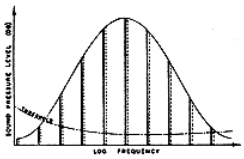
Holistic vs. analytic listening

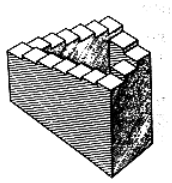
- Demo 1: audible harmonics (1-5)
- Demo 2: melody with harmonics
- Demo 3: vowels and audible formants



Circularity in pitch

- R N Shepard
- J-C Risset
- J Liljencrants





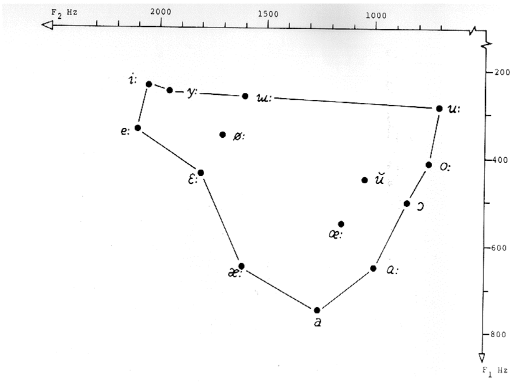
http://asa.aip.org/sound.html

Perception of vowels

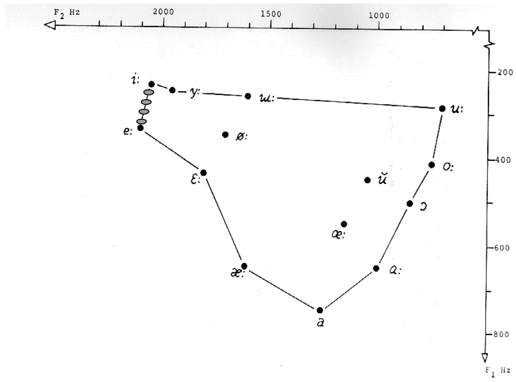
- Formants (general relationship acoustics-articulation)
  - F1: information on jaw opening
    - higher F1 = more open
  - F2: information on front-back
    - higher F2 = more front
  - F3: information on lip rounding
    - lower F3 = more rounded

Perception of vowels

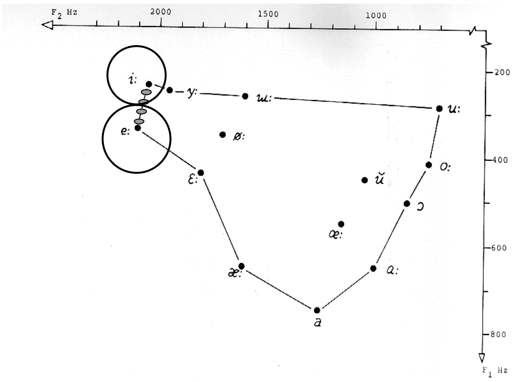
- Identification
  - Perceive which vowel is pronounced
- Discrimination
  - Hear that two vowel sounds are different
- Categorical perception
  - Difficult to discriminate within a category
  - Easy to discriminate between categories



Figur 5. Akustiskt vokaldiagram med svenska vokaler.
Formantvärden från Fant.



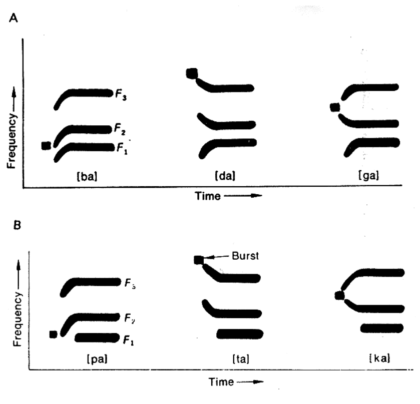
Figur 5. Akustiskt vokaldiagram med svenska vokaler.
Formantvärden från Fant.



Figur 5. Akustiskt vokaldiagram med svenska vokaler.
Formantvärden från Fant.

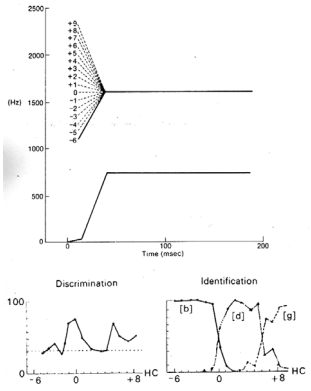
Perception of stops

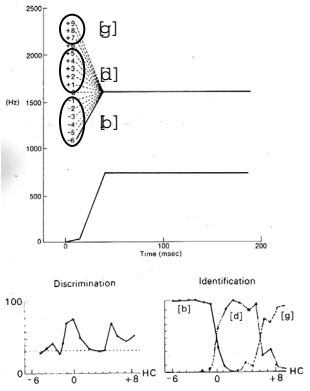
- Frequency of the burst release
  - Provides information on place of articulation
- Formant transitions in adjoining vowels
  - Also information on place of articulation
- Voiced occlusion or aspiration
  - Provides information on manner of articulation



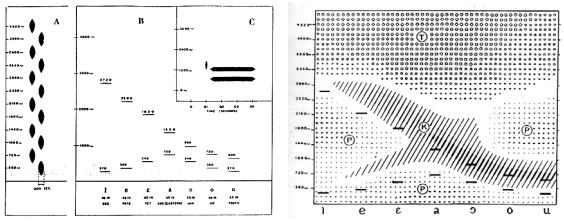
Perception of stops

- Early experiments with speech synthesis
  - Formant transitions alone were sufficient to identify place of articulation (ba-da-ga)
  - Identification and discrimination of stops
- Categorical perception of stops
  - Difficult to discriminate within a category
  - Easy to discriminate between categories





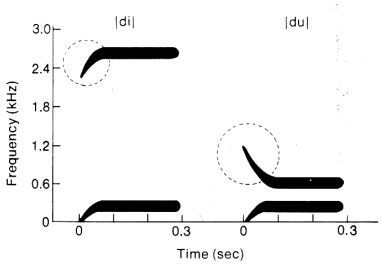
Early perception experiment: noise burst preceding different vowels



stimuli results

Liberman et al. JASA 24, 1952, 599

Invariance and segmentation problem



Invariance and segmentation problem

- The same phoneme has different cues in different contexts, e.g. F2-transitions for [di] [du].
- Where are the segment boundaries?
- Problem is a result of coarticulation
- Problem has inspired the classic perception theories

Classic theories of speech perception

- Invariance theory
  - The acoustic signal is the most important (invariant)
- Motor theory
  - Speaker's nerve impulses for speech motor control are calculated by the brain by analysing the acoustic signal.
  - Articulation is the most important
- Direct perception
  - The speaker's articulatory movements are directly perceived by the listener

Cognitive theories

- Top-down speech processing
  - Expectation and linguistic knowledge set the frame
  - Incoming words are compared to hypotheses
- Bottom-up processing
  - Acoustic signal is transferred to words
  - Message formed from words

Psycholinguistics

- The mental lexicon
- "Top-down" perception and context
  - experiments with filtered speech
  - experiments with phoneme detection (e.g. [s])
    - "They had been up all night and needed to sleep"
    - "They didn't know if they would be able to sleep"

Speech acquisition theories

- Innate
  - Possible psychophysical limits
  - e.g. the number of vowels that can be discriminated
- Acquired
  - Language-specific categories
    - Several high, front vowels in Swedish: language categories develop making use of psychophysical limits
    - One high front vowel in Japanese: category differences are lost