Speech perception

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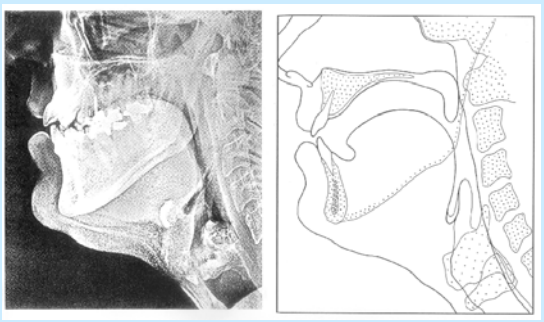
DT2350 Human Perception for Information Technology 2015
Lecture 8

Literature

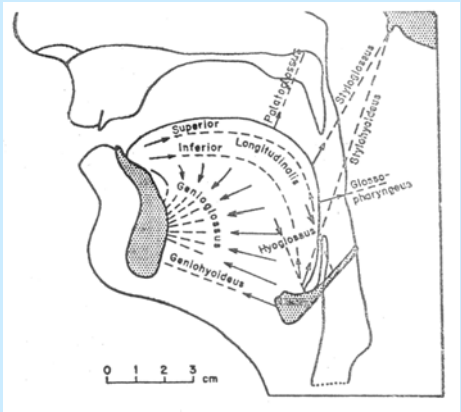
- **Goldstein, E. (2010-2014). Sensation and Perception.**
  - Chapter 13 (Editions 8 and 9): *Speech Perception*
- **Weinschenk, S.M. (2011). 100 Things Every Designer Needs to Know About People.**
  - Chapter 68: Speakers' brains and listeners' brains sync up during communication

Basic units of speech

- Phonemes
  - Vowels
  - Consonants
- Prosody
  - Intonation (melody)
  - Rhythm (duration)
  - Intensity



From Laver: Principles of Phonetics

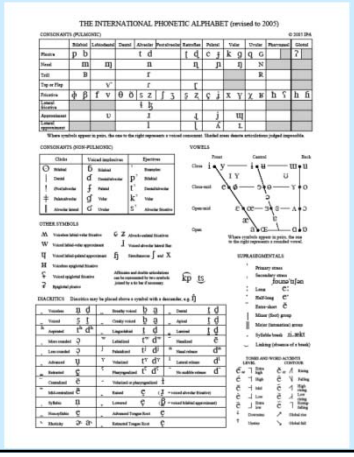


Vowel articulation

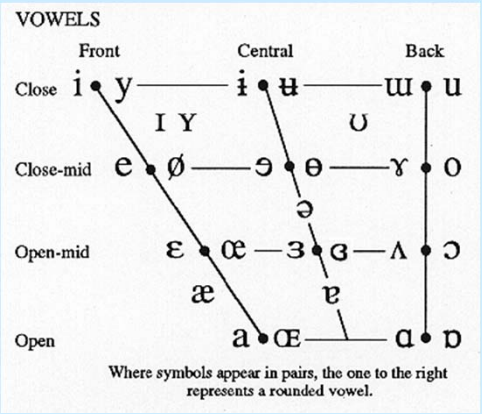
- Cardinal vowels
  - Reference vowels
  - Four corner vowels form the corners of the vowel chart
- Descriptive terminology
  - Close-open (high-low) *sluten-öppen*
  - Front-back *främre-bakre*
  - Unrounded-rounded *orundad-rundad*
  - Oral-nasal (e.g. French) *oral-nasal*

Tongue shapes of four of the cardinal vowels

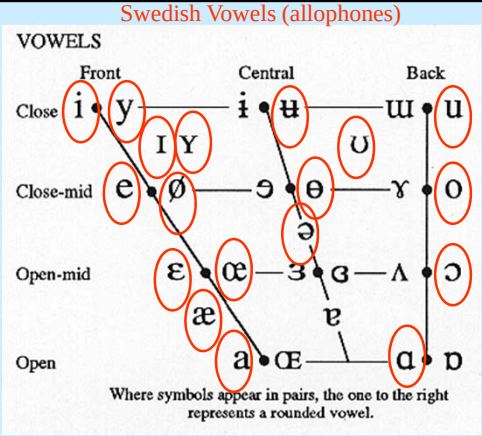
From Elert: Allmän och svensk fonetik



IPA charts from the International Phonetic Association (Department of Theoretical and Applied Linguistics, School of English, Aristotle University of Thessaloniki, Thessaloniki 54124, GREECE).

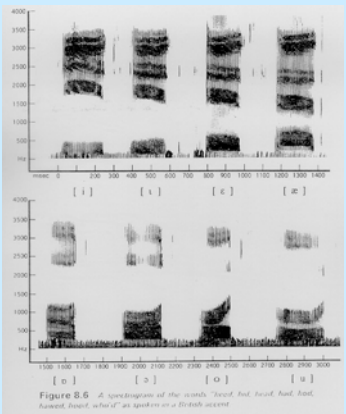


Swedish Vowels (allophones)



Vowel acoustics

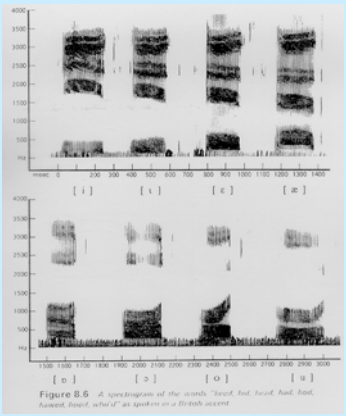
- Speech spectrogram
- Formants (F1, F2, F3, F4)
- Acoustic vowel diagram (F1, F2)



From Ladefoged: A course in phonetics

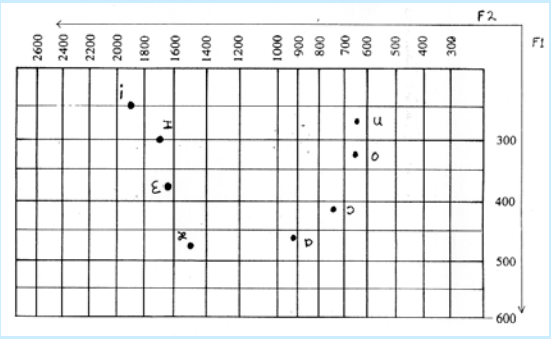
Formant transitions

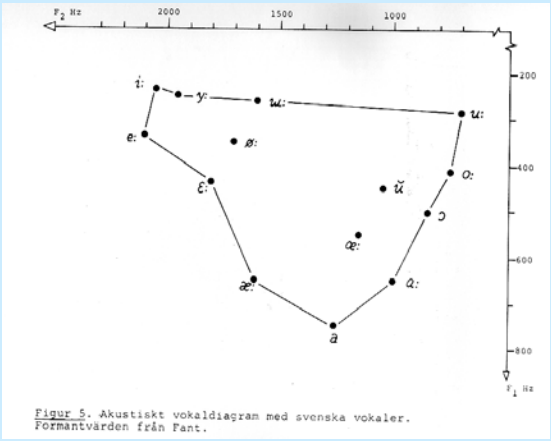
- Articulators move towards upcoming phonemes before reaching target: coarticulation
- Coarticulation causes formants to shift in frequency creating overlapping information
- Critical concept for speech perception



From Ladefoged: A course in phonetics

Acoustic vowel diagram (F1, F2)

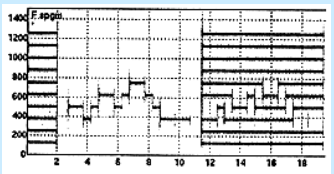




Figur 5. Akustiskt vokaldiagram med svenska vokaler. Formantvärden från Fant.

Holistic vs. analytic listening

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

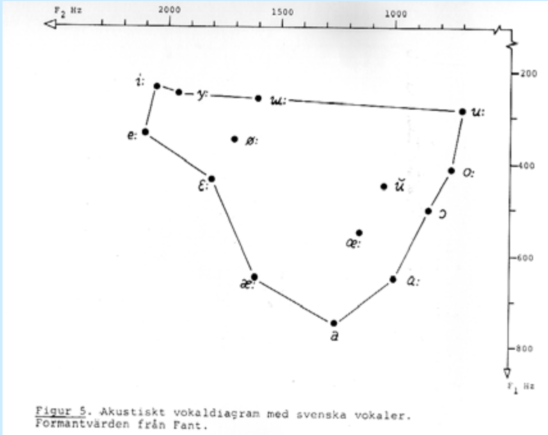


Perception of vowels

- 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



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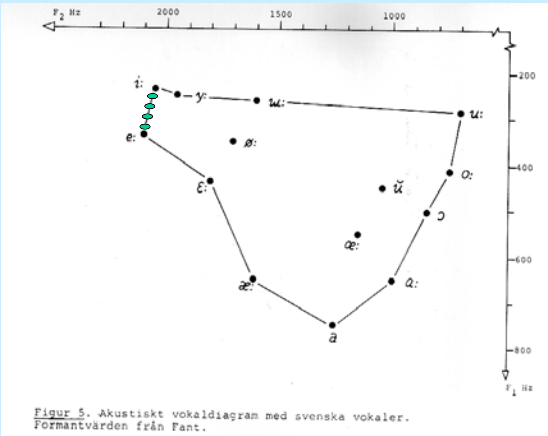
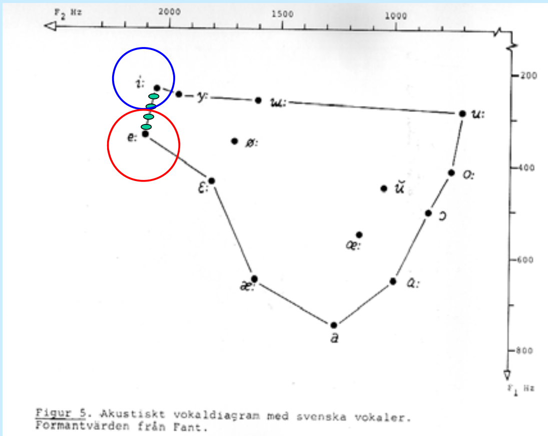


Figur 5. Akustiskt vokaldiagram med svenska vokaler. Formantvärden från Fant.



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

Consonant articulation

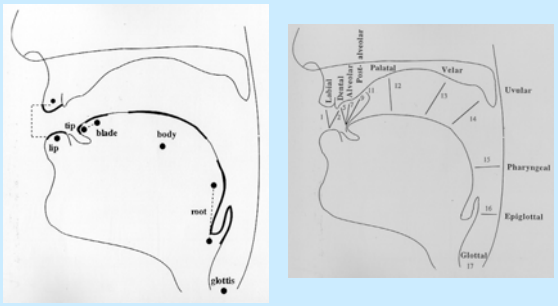
- Voiceless or voiced
- Manner of articulation
  - How is the sound produced?
- Place of articulation
  - Where is the constriction or closure located?

Manner of articulation

- Fricatives *frikativor (spiranter)*
  - f, v, s, z, h
- Stops, plosives *klusiler, explosivor*
  - p, b, t, d, k,
- Liquids *likvidor*
  - r, l
- Nasals *nasaler*
  - n, m

Place of articulation (IPA)

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



From Ladefoged: A course in phonetics

THE INTERNATIONAL PHONETIC ALPHABET (revised to 2005)

CONSONANTS (PULMONIC) © 2005 IPA

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Glottal
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q ɢ		ʔ
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	N		
Trill	B			r					R		
Tap or Flap		ⱱ		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 2005)

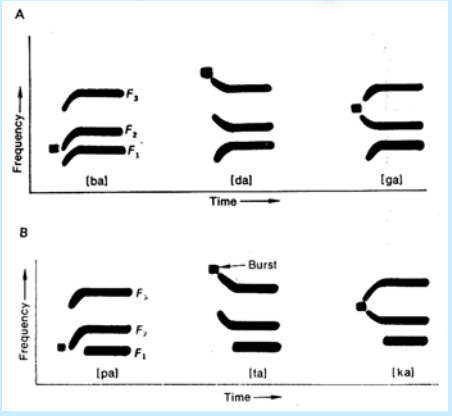
CONSONANTS (PULMONIC) © 2005 IPA

	Bilabial	Labiodental	Dental	Alveolar	Postalveolar	Retroflex	Palatal	Velar	Uvular	Pharyngeal	Glottal
Plosive	p b			t d		ʈ ɖ	c ɟ	k g	q ɢ		ʔ
Nasal	m	ɱ		n		ɳ	ɲ	ŋ	N		
Trill	B			r					R		
Tap or Flap		ⱱ		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.

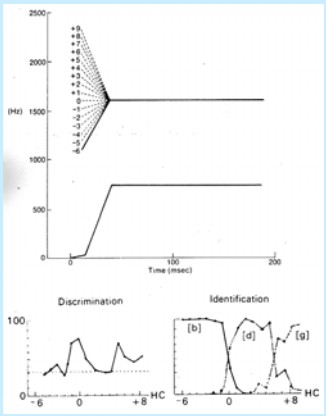
Perception of stops

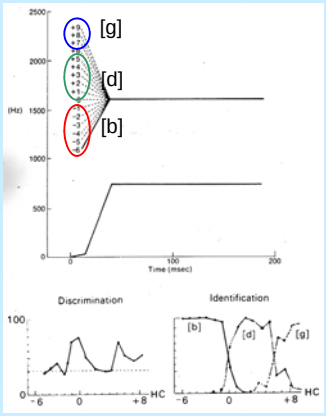
- Frequency of the burst release
  - Provides information on place of articulation
- Formant transitions in adjoining vowels
  - Also information on place of articulation
- Voicing during occlusion and burst
  - Provides information on manner of articulation



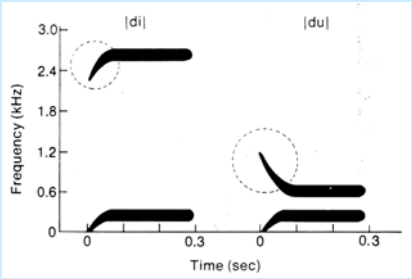
Perception of stops

- 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





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.
  - Activation of motor mechanisms is the most important

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 transformed to words
  - Message formed from words

Psycholinguistics

- The mental lexicon
- "Top-down" perception and context
  - 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"
  - experiments with filtered speech

Demo: Low-pass filtered speech (speech below 300 Hz)

Original recording

Speech acquisition theories

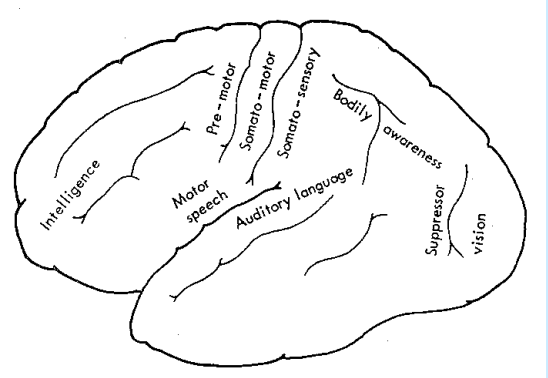
- Innate
  - Possible psychophysical limits
  - e.g. the number of vowels that can be discriminated
- Acquired
  - Language-specific categories
    - Several high, front vowels in Swedish: language categories develop making use of psychophysical limits
    - One high front vowel in Japanese: category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

Some of the main functions of language and speech

- Informative (provide information)
- Interrogative (obtain information)
- Influence (make someone perform an action)
- Social (make contact)
- Expressive (express feelings)
- Speaker-specific information (gender, age, background, identity)

Language and the brain

- Neurolinguistics
  - Language lateralization to the left hemisphere
  - Aphasia
    - Paul Broca, 1861
    - Carl Wernicke, 1874



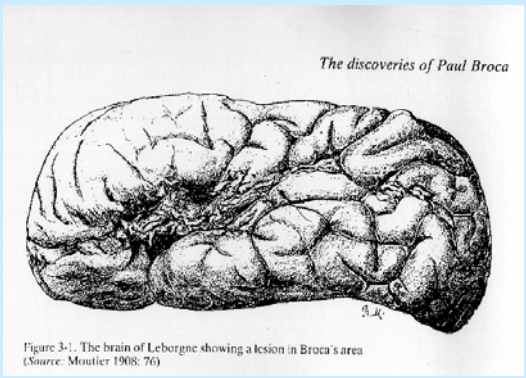
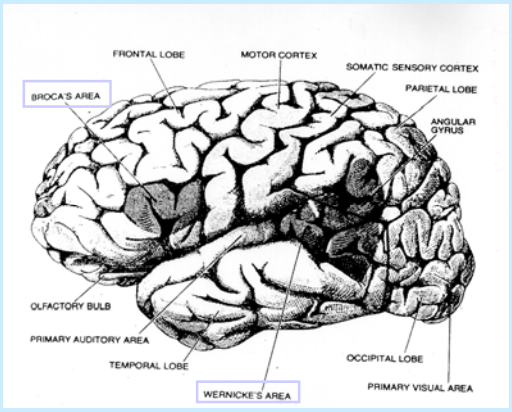


Figure 3-1. The brain of Leborgne showing a lesion in Broca's area (*Source:* Moutier 1908: 76)



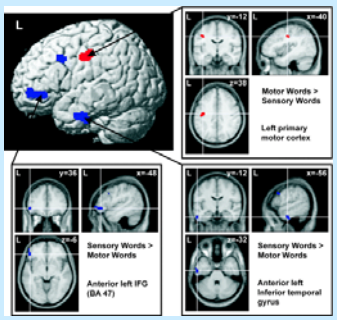
Semantics

- The linguistic sign (word) *Ferdinand de Saussure*
  - Arbitrary union between sound and meaning (e.g. hund, dog, chien)
  - But there are onomatopoetic words (sound imitation: e.g. whisper, mumble, susa, mumla)
- Homonyms
  - Two signs have the same form (e.g. vad-vad, bear-bear-bear)
- Lexicon
  - Semantic features (e.g. häst-sto-hingst, horse-mare-stallion)
  - Language dependent categories (e.g. tak, roof-ceiling)

Semantic representation in the brain

- PET-study (Positron Emission Tomography)
  - Cerebral blood flow
- Subjects listened to words (Italian)
  - Motor words (e.g. dive, skate)
  - Sensory words (e.g. darkness, shine)
- Used both nouns and verbs

Semantic representation in the brain

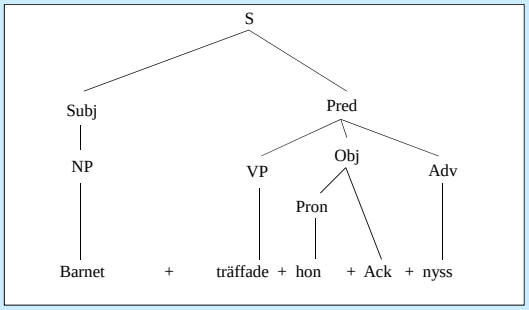


Vigliocco,G., Warren,J., Siri,S., Arcuili,J., Scott,S.K., Wise,R. (2006). The role of semantics and grammatical class in the neural representation of words. *Cerebral Cortex* 16(12), 1790–1796.

Syntax and grammar

- Grammatical analysis
  - Word class (e.g. noun, verb, adverb)
  - function (e.g. subject, object)
- Position analysis
- Phrase structure rules *(Noam Chomsky)*
- Parsing (phrase structure analysis)
- Generative grammar

Phrase structure trees



Example of syntactic ambiguity

- Igår sköt jag en hare med gevär på 100 meter.

- Hade du ett så långt gevär?

- Nej, jag menar att jag sköt med gevär en hare på 100 meter.

- Jaså, finns det så långa harar?

- Nej, jag sköt på 100 meter en hare med gevär.

- Då hade du tur att inte haren sköt först.

Efter Sigurd: Språk och språkforsking

Example of syntactic ambiguity

- Do you want to see my synthetic cow hide?

- I didn't know you had a synthetic cow.

- No, I mean do you want to see the cow hide.

- Oh, is she so shy?

- No, I mean a synthetic cow hide.

- Yes, I know, but what happened to the real one?

Syntax in the brain

- Studies of aphasia
  - What kinds of linguistic problems do patients display? (e.g. problems with passive construction)
- fMRI-study (functional magnetic resonance imaging)
  - Subjects are asked to interpret complex syntactic structures

Syntax in the brain

pink=phrase structure, yellow=sentence constituents, striped=integration:syntax/lexicon

Yosef Grodzinsky and Angela D Friederici, Neuroimaging of syntax and syntactic processing, *Current Opinion in Neurobiology* 2006, 16:240–246

Phonology

- Phoneme: The smallest distinctive unit of sound
  e.g. /b/ /p/ in Swedish (bil pil)
  - allophones: variants of a phoneme (t.ex. /r/ > [ɾ], [ʀ])
  - minimal pairs (bil/pil, par/bar)
  - commutation test (used to define phonemes in a language)
  - /r/ /l/ are two phonemes in Swedish and English but not in Japanese
- Distinctive features (e.g. voicing)
- Phonotactic structures (e.g. pferd, stone)
- Syllable structure

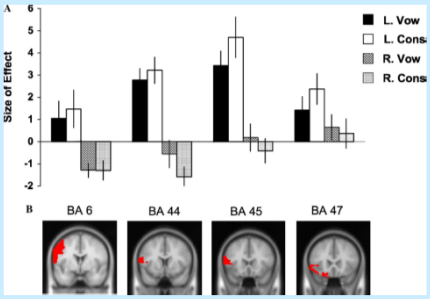
Vowels and consonants

- Speech production (phonetics)
  - Free air passage through the pharynx, mouth and the lips = vowel
  - Constricted or closed air passage = consonant
- Function (phonology)
  - Nuclear in the syllable = vowel
  - Marginal in the syllable = consonant
- Exceptions
  - Some voiced consonants (e.g. syllablic nasal)
  - Approximants or semi-vowels (e.g. [j] [w])
- Information
  - Consonants carry more information than vowels

Representation of phonemes in the brain

- PET-study (Positron Emission Tomography)
  - Cerebral blood flow
- Subjects had to reconstruct words
  - Real words (repeat the word)
  - Non-word (wrong vowel, say the real word)
  - Non-word (wrong consonant, say the real word)
- Left hemisphere (Words with wrong consonants produced more brain activity)

Representation of phonemes in the brain



Sharp,D., Scott,S.K., Cutler,A., Wise,R.J.S. (2005). Lexical retrieval constrained by sound structure: The role of the left inferior frontal gyrus. *Brain and Language 92*, 309–319.

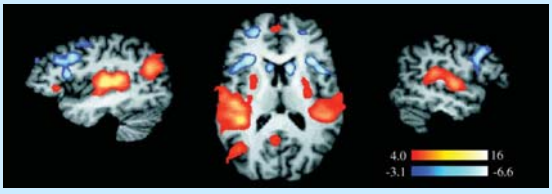
Prosody

- Functions of prosody
  - Lend prominence (emphasize, de-emphasize)
  - Grouping function (combine, separate)
  - Facilitate dialogue: turntaking and feedback
  - Signal attitude and emotion
- Word prosody
  - quantity, intensity (stress), accent
- Phrase prosody
  - Focus, emphasis, intonation

Prosody in the brain

- Prosody lateralized to the right hemisphere?
- Studies of aphasia
  - Lesions or injuries to the right hemiphere can result in deviant prosody
- fMRI-study
  - Subjects listened to emotional speech
  - Complex prosodic stimuli seem to activate several areas in the brain (not exclusively right hemisphere)

Prosody in the brain



Normal speech = red Prosodic speech = blue

Sonja A. Kotz, Martin Meyer, Kai Alter, Mireille Besson D., Yves von Cramon, and Angela D. Friederici. *On the lateralization of emotional prosody: An event-related functional MR investigation. Brain and Language 86* (2003) 366–376

Brain synchrony in dialogue

- Speakers' and listeners' brains sync up during communication
- 68 (p.156) in "100 things every designer needs to know about people".

Lab exercises

- 13.2 McGurk Effect
  - Audiovisual speech
- 13.4 Phonemic restoration
- 13.7 Speech reconstruction
  - Sound stimulus reconstructed from brain signals

References

- Caplan, David (1987) *Neurolinguistics and linguistic aphasiology*. Cambridge University Press, Cambridge.
- Elert, Claes-Christian (1995) *Allmän och svensk fonetik*. Norstedts Förlag, Stockholm
- Engstrand, Olle (2004) *Fonetikens grunder*. Studentlitteratur, Lund
- Laver, John (1994) *Principles of phonetics.* Cambridge University Press, Cambridge
- Sigurd, Bengt (1991) *Språk och språkforskning*. Studentlitteratur, Lund