Psychoacoustics, speech perception, language structure and neurolinguistics

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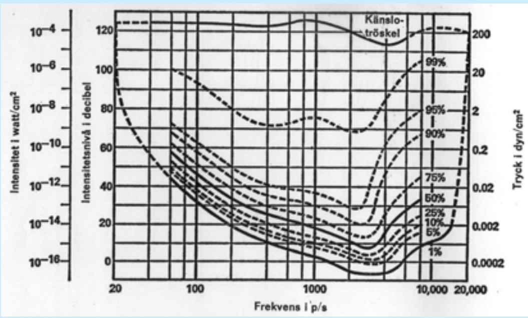
Hearing acuity

- 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

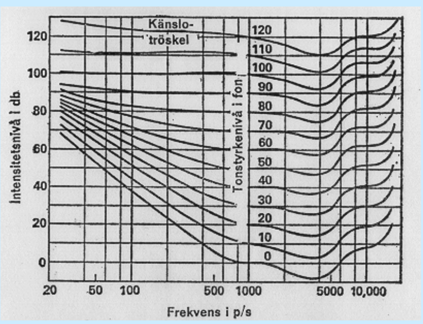
Absolute auditory threshold



Demo: SPL (Sound pressure level) dB

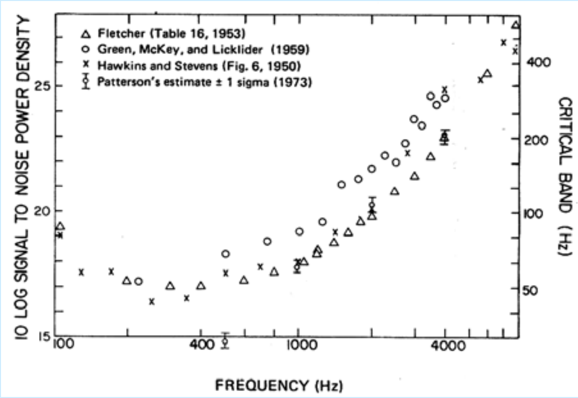
- Decreasing noise levels
  - 6 dB steps, 10 steps, 2*
  - 3 dB steps, 15 steps, 2*
  - 1 dB steps, 20 steps, 2*

Constant loudness levels in phons



Demo: SPL and loudness (phons)

- 50-100-200-400-800-1600-3200-6400 Hz
  - 1: constant SPL 40 dB, 2*
  - 2: constant 40 phons, 2*

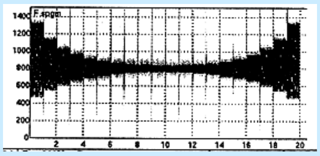


Critical bands

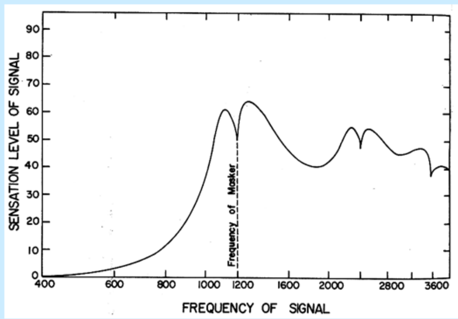
- Bandwidth increases with frequency
  - 200 Hz (critical bandwidth 50 Hz)
  - 800 Hz (critical bandwidth 80 Hz)
  - 3200 Hz (critical bandwidth 200 Hz)

Critical bands demo

- 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

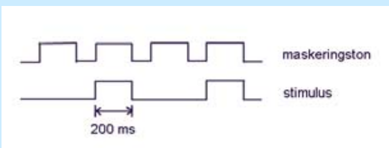


Effects of masking



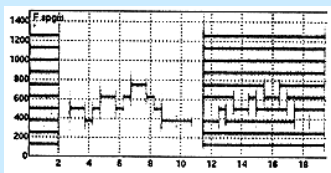
Effects of masking

- Low frequencies more effectively 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



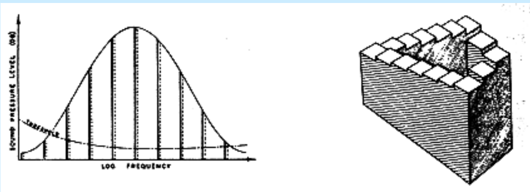
Holistic vs. analytic listening

- 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



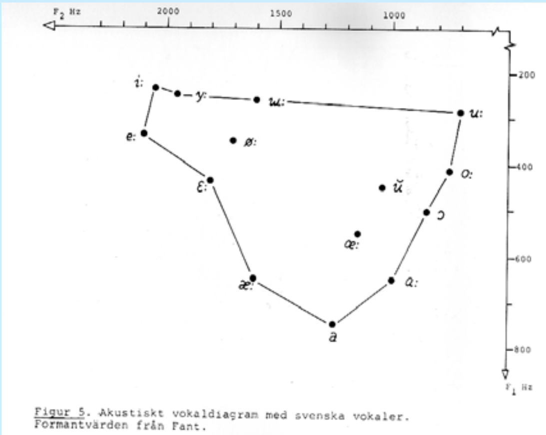
http://asa.aip.org/sound.html

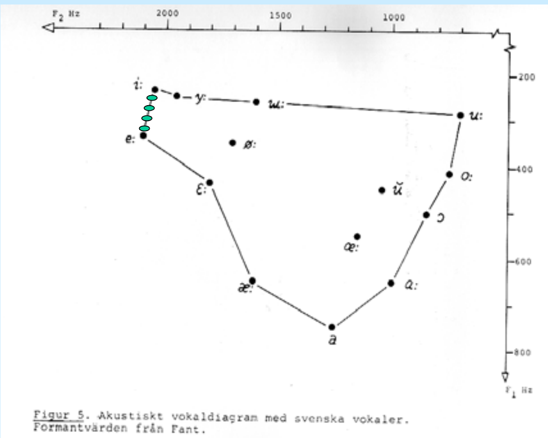
Perception of vowels

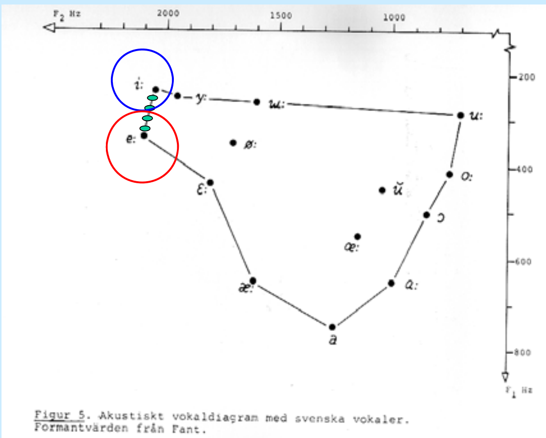
- Formants (general relationship acoustics-articulation)
  - F1: information on jaw opening
    - higher F1= more open
  - F2: information on front-back
    - higher F2=more front
  - F3: information on lip rounding
    - lower F3=more rounded

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

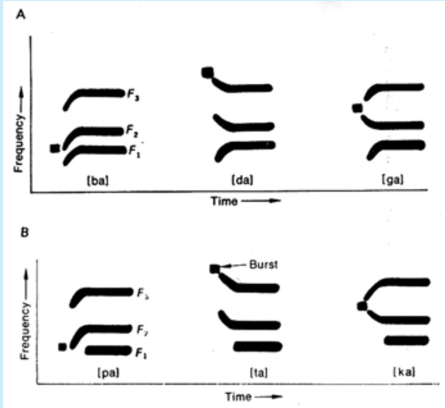






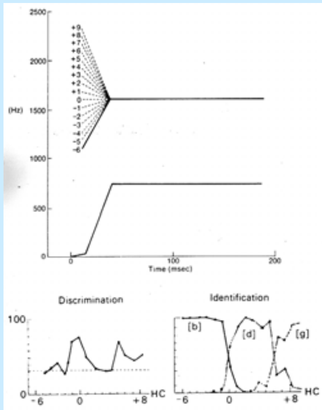
Perception of stops

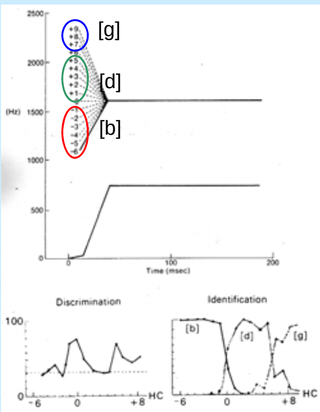
- Frequency of the burst release
  - Provides information on place of articulation
- Formant transitions in adjoining vowels
  - Also information on place of articulation
- Voiced occlusion or aspiration
  - Provides information on manner of articulation



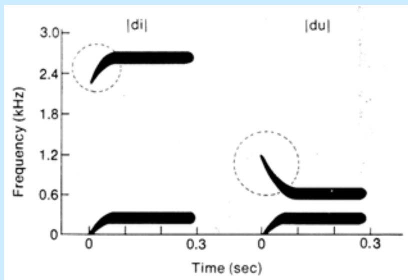
Perception of stops

- 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





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 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

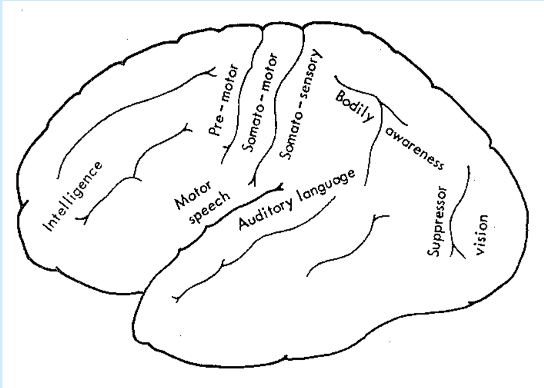
- Innate
  - Possible psychophysical limits
  - e.g. the number of vowels that can be discriminated
- Acquired
  - Language-specific categories
    - Several high, front vowels in Swedish: language categories develop making use of psychophysical limits
    - One high front vowel in Japanese: category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

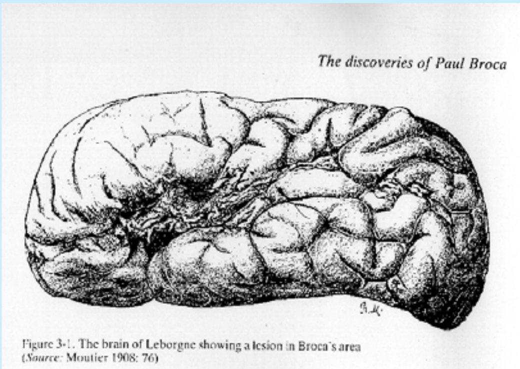
Some of the main functions of language and speech

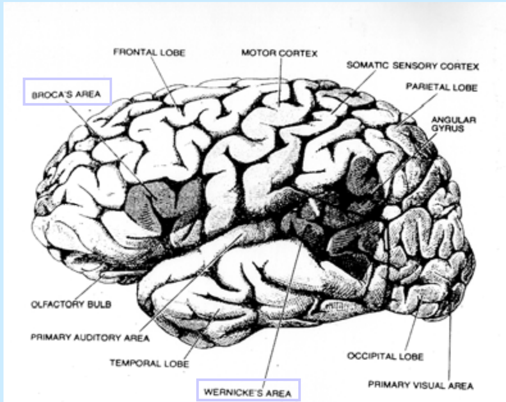
- Informative (provide information)
- Interrogative (obtain information)
- Influence (make someone perform an action)
- Social (make contact)
- Expressive (express feelings)
- Speaker-specific information (gender, age, background, identity)

Language and the brain

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







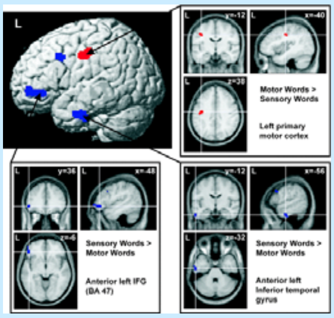
Semantics

- 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

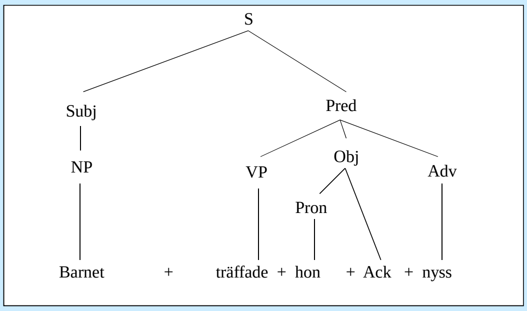


Vigliocco,G., Warren,J., Siri,S., Arcuili,J., Scott,S.K., Wise,R. (2006). The role of semantics and grammatical class in the neural representation of words. *Cerebral Cortex* 16(12), 1790–1796.

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



Phrase structure rules

Den lille mannen på gatan.

1. np → art + a + n + pp
2. art → den
3. a → lille
4. n → mannen, gatan
5. pp → p np
6. p → på

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

Morphology

- Morpheme: the smallest unit of linguistic meaning
  stol-en bord-et bord-en
  se-r the table
  - allomorph: variant of a morpheme (a, an) (-en, -et)
- Morpheme classes
  - Lexical/grammatical
    - Lexical morphemes (häst, horse)
    - Grammatical morphemes (-ar, -s)
  - Free/bound
    - Free morpheme (book, bok)
    - Bound morpheme (o-klart, un-happy)
      - (genetiv -s: Kungen-s, The King's)

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

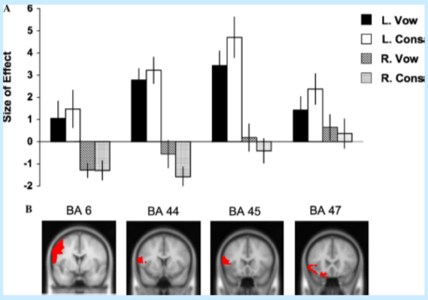
Vowels and consonants

- 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.

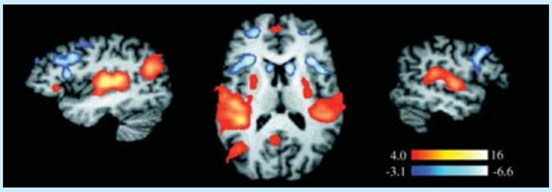
Prosody

- 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

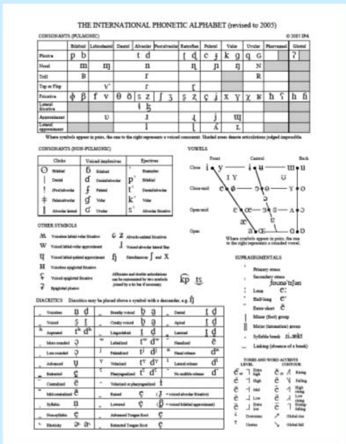


Normal speech = red Prosodic speech = blue

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

Transcription

- Phonetic transcription
  - What are the speech sounds?
  - Transcription of allophones [ ]
- Phonological (phonemic) transcription
  - What is the function in the phoneme system?
  - Only phonemes are transcribed / /
- IPA chart



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

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