WHY WE NEED DISTINCTIVE FEATURES?

The role of distinctive features in natural languages

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Outline

- Feature Theory development
- Basis of features
- Feature architecture
- Role of features
- Features and speech perception
- Electrophysiological mismatch response related to features
  - mismatch as measure for phonological contrast
  - mismatch to exploit natural class
  - mismatch to exploit mental lexicon
- Ferrets' phonemic representation in auditory cortex
- To conclude…Is speech special?

Feature theory development

Feature theory was most famously developed for phonology by Trubetzkoy (1939), with significant extensions by Jakobson, Fant, Halle (1952) and Chomsky and Halle (1968).

Trubetzkoy *Grundzüge der Phonologie*(1939)

Trubetzkoy *Grundzüge der Phonologie* (1939)

First attempt to provide a universal framework of the features that are exploited for phonological proposes in the languages of the world (as opposed to purely phonetic descriptive work).

Trubetzkoy was a structuralist thinker, i.e. he did not think that phonemes could be defined by themselves, but only in relation to each other.

The phoneme can be defined neither by its psychological character nor by its relationship with its phonetic variants, but by its function to signal differences in word meaning.

Trubetzkoy *Grundzüge derPhonologie* (1939)

System of phonemes was considered as a whole in which each element entertains specific relations of fundamental importance with each of the other elements to which it is opposed.

Oppositions are not all of the same type, they could be:

- privative opposition: a property is either present or absent (i.e., nasality, voicing, rounding)
- equipollent opposition: both members are of equal contrast [+coronal] vs. [-coronal]
- gradual oppositions: several gradations of one property (i.e. vowel height)

Trubetzkoy *Grundzüge der Phonologie* (1939)

Set of parameters:

- large number of features (around 40), each with a language-independent definition, some articulatory others acoustic
- different sets for V and C

Jakobson (1939)

Jakobson (1939)

- Features not phonemes are the fundamental units of linguistic analysis;
- few Trubetzkoy's features that are not binary are decomposable in two or more equipollent oppositions.

Jakobson, Fant, Halle (1952) *Preliminaries to speech analysis*

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Systems of contrasts

Jakobson et al. provide every feature with definitions in both articulatory and auditory terms, relying that language is in its essence a spoken system, and therefore its primitive must have an external basis in the acoustic signal as well as in the articulatory activity of the speaker.

Small language universal set of binary features (12), which exist independently of the segments that they compose.

Jakobson, Fant, Halle (1952) *Preliminaries to speech analysis*

- Acoustic aspects of features were more important because "we speak in order to be heard in order to be understood, and the nearer our descriptions fitted with what was being understood the better they were." (1952: 12) Articulatory stage of speech was viewed as the means used to obtain each pair of acoustically contrastive effects.

16 years between Preliminaries and SPE

Acoustic research

- Studies of the acoustics of vowels and consonants (Stevens & House 1955, House & Stevens 1956)

- Accounts of the Haskins laboratories of the acoustics of speech (Cooper et al. 1952, Liberman 1957)

16 years between Preliminaries and SPE

Articulatory

Motor Theory of speech perception (Lieberman et al. 1967), has given new prominence to articulatory definitions. According to Motor Theory the listener internally resynthesizes the movements that are likely to have produced the speech sounds they hear. Object of speech perception are phonetic gestures.

Phonologically: gestures could be conceived as groups of features such as labial, stop, nasal, but these features were considered attributes of the gestures, not events as such.

Chomsky & Halle (1968) *Sound pattern of English*

Chomsky & Halle (1968) *Sound pattern of English*

Explanation of the **patterns of sounds** within a language by reference to phonological features in a speaker's mind.

24 binary features with emphasis on articulatory definitions. They describe the articulatory correlate of every feature but speak of the acoustical correlates of features only occasionally.

Chomsky & Halle (1968) *Sound pattern of English*

Aim Book:
showing how rules apply to underlying sequences of phonological units to the phonetic forms of speech production, to shed light on UG and the mental processes in general.

Features are used in phonological rules, setting the scene for Standard Generative Phonology.

Example: Palatalization rule that changes dentals to palato-alveolars before [y] and unstressed vowel:

$$\begin{pmatrix} \text{-sonor} \\ \text{+cor} \end{pmatrix} \rightarrow \begin{pmatrix} \text{-ant} \\ \text{+strid} \end{pmatrix} / \_\_\_ \begin{pmatrix} \text{-back} \\ \text{-cons} \\ \text{-voc} \end{pmatrix} \begin{pmatrix} \text{-cons} \\ \text{-stress} \end{pmatrix}$$

Chomsky & Halle (1968) Sound pattern of English

Mentalist approach

- Phonetic representations are mentally constructed by the speaker and the hearer.
- What is perceived depends on: physical constitution of the signal, hearer's knowledge of the language (deep structure and phonological rules), and extra-grammatical factors.
- Phonetic features appear in lexical entries as phonological features (abstract classificatory markers), which indicate whether or not a given lexical item belongs to a given category (i.e. begins with a voiced stop, contains a vowel).
- Universality: cognitive basis (UG) (vs. physiological before Chomsky)

Stevens (1972, 2005)
Quantal Theory of speech

Steven's *Quantal Theory*

Focus: Similarities in feature realization across speakers and languages

Equal status to acoustic, auditory, and articulatory dimensions.

Regions of stability: phonetic regions in which the relationship between an articulatory configuration and its corresponding acoustic output is not linear. Within such regions of stability small changes along the articulatory dimensions have little effect on the acoustic output.

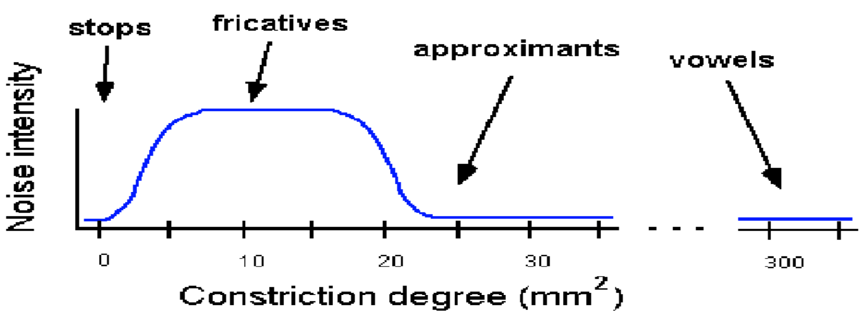
Each of this regions corresponds to a feature, it is an articulatory-acoustic coupling.

Stevens (1972, 2005)
Quantal Theory of speech

Degrees of constriction can be ordered along an articulatory continuum extending from a large opening (low vowels) to complete closure (oral stops).

3 stable acoustic regions:

- sounds with an unobstructed vocal tract constriction - sonorants (vowels, semivowels, liquids)
- constriction degree passes the critical threshold for noise production - continuant obstruent (fricatives)
- further discontinuity vocal tract reaches complete closure - noncontinuant obstruents (oral stops)



Adapted from Clements & Ridouane (2006)

Stevens et al. (1986) Enhancement Theory of Speech

- Focus: Regular patterns of crosslinguistic variation

When the acoustic difference between two sounds is insufficiently great risking confusion, a supplementary gesture may be introduced to increase the acoustic difference between them. This gesture may corresponds to a redundant feature.

Example feature:

- [+rounded] is introduced to enhance the difference between back vowels and front vowels.

This feature has the effect of increasing the auditory difference between front and back vowels by increasing their difference in F2 frequency.

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Basis of features

To sum up

Distinctive features dimensions

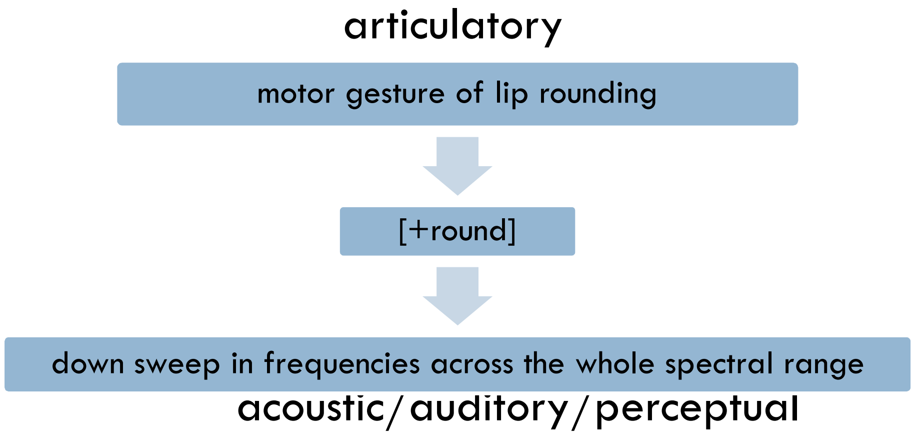
- Trubetzkoy: some articulatory some acoustic
- Jakobson et al.: both but emphasis on acoustic
- Chomsky & Halle: all articulatory, some also acoustic, emphasis on articulatory
- Stevens: all same status

Basis of features

The features have dual definitions and provide the fundamental connection between action (articulation) and perception (audition).

This is possible, because distinctive features are stated in both articulatory (i.e. as gestures performed in a motor coordinate system) and acoustic/auditory terms (i.e. as events stable in an acoustic coordinate system).

Example: feature [+round]



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Goldsmith (1976) Autosegmental Phonology

Until SPE the theories represented words in terms of segments, in a linear sequence. Therefore, phonemes are definable as 'bundles' of simultaneous features, having no internal organization.

Goldsmith (1976) introduced autosegmental phonology which differently to the generative phonology of SPE argues for:

- the development of a multi-linear phonological analysis in which different features may be placed on separate tiers and in which the various tiers are organized by association lines;

Analysis of phonological phenomena less in terms of feature-changing rules, and more in terms of that delete and reorganize the various autosegments through the readjustment of association lines.

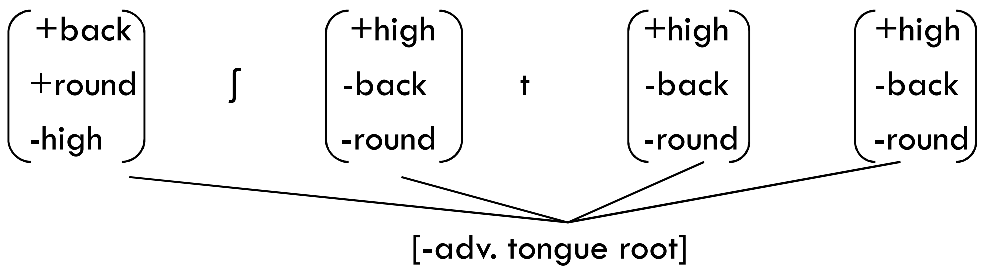
Goldsmith (1976) Autosegmental Phonology

A non-linear approach to phonology that allows phonological processes, such as tone and vowel harmony, to be independent of and extend beyond individual C and V, therefore the phonological processes may influence more than one V/C.

Example:

Mende (Goldsmith 1976)

Akan (Clements 1976): vowel harmony ‘ofitii’



Feature hierarchy

In 1980's feature hierarchy

In the work before features were all at the same level, there were different groups such as 'major class features' an 'place of articulation' features, but this groupings were established by simply listening the features within them, it is phonological features are simultaneous and unstructured at the phonological level.

Later it became apparent that some higher level features were best described in terms of other features and the notion of hierarchical feature structure emerged with Clements 1985, who proposed a model of feature geometry.

Clements (1985) The Geometry of Phonological Features

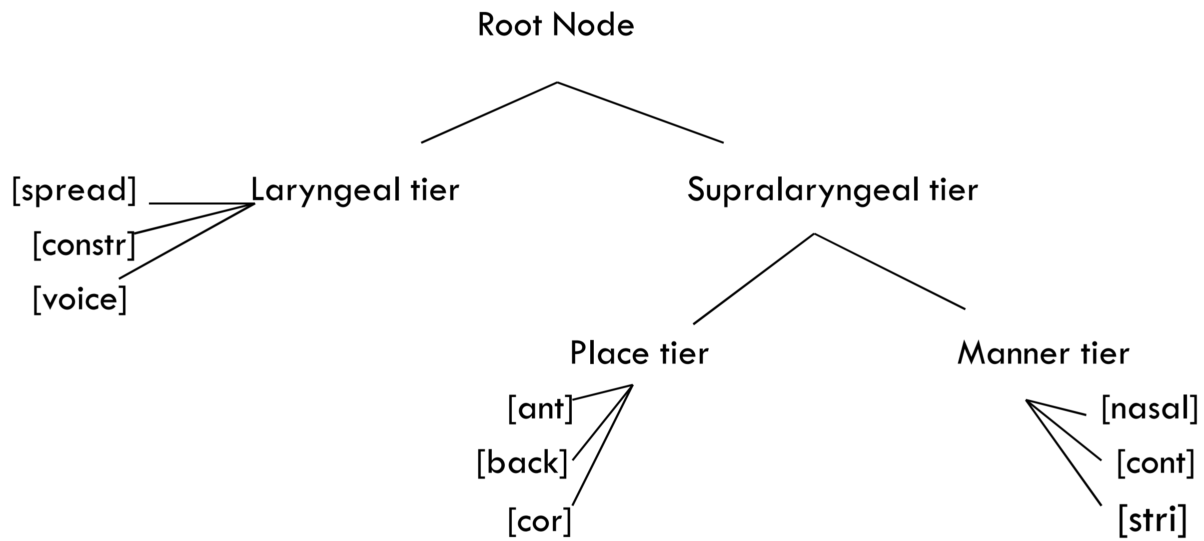
Clements (1985) Feature Geometry

Segments are no longer bundles of unordered features but feature trees (trees of hierarchically organized features).

Clements (1985) The Geometry of Phonological Features

These relationships are expressed in terms of multitired representations, in which individual features and group of features are assigned to separate tiers. The hierarchy is determined by the analyses of processes that reveal the independence of certain features with respect to others.

The following tree was the original feature tree proposed by Clements (1985):



Articulatory Theory

Articulatory Theory (Sagey 1990, Halle 1995)

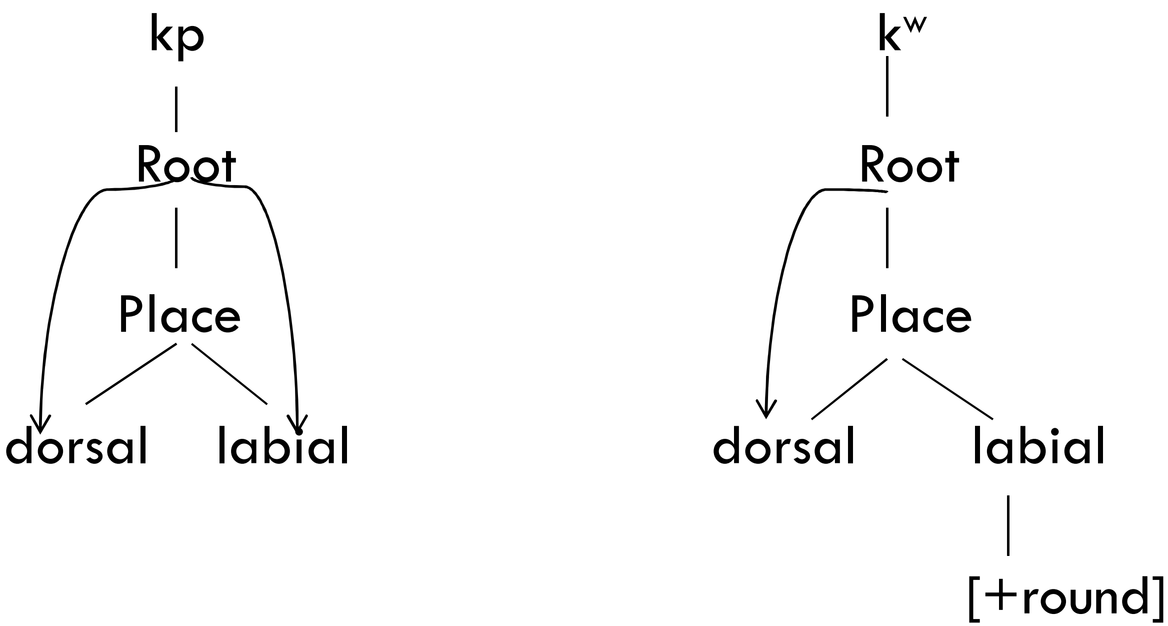
An important development came from Articulatory Theory, that noted that autosegmentally represented features can be divided into features that depend for their execution on one or another of the articulators, termed articulator-dependent, and those that are not, termed articulator-free:

- articulator-dependent features:
  [+/-anterior] and [+/- distributed], executed exclusively by the tongue-front articulator [coronal]

- articulator-free features:
  [+/- continuant] and [+/- consonantal], which can be executed by any of several articulators

Articulatory Theory

Examples : labiovelar stop (two primary articulations) vs. labialized velar (one primary articulation) (Sagey 1986: 91,207)

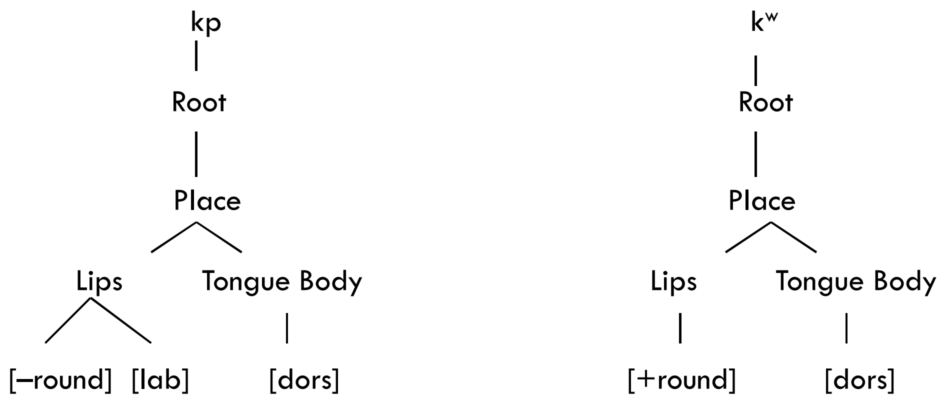


Revised Articulatory Theory

Revised Articulator Theory (Halle, Vaux, Wolfe, 2000)

- designated articulators are indicated by unary features

Example: labiovelar stop (two primary articulations) vs. labialized velar (one primary articulation)
(Halle et al.2000:392)



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Why we need features?

Features are necessary to capture contrasts in natural languages: a speaker must know which sounds contrast are relevant for storing words in memory and which sound contrasts are not.

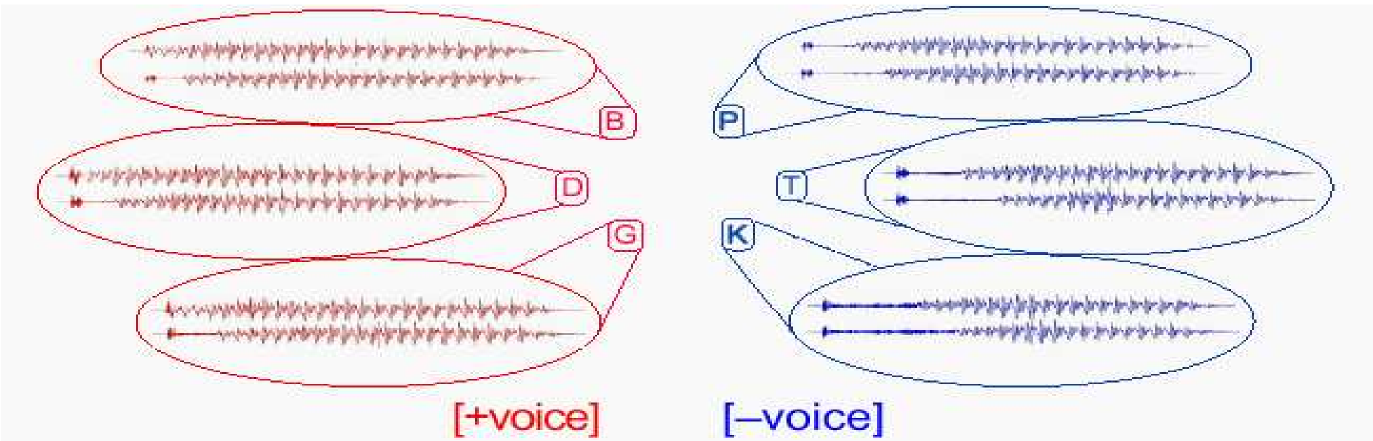
Example:
/p t k/ contrast with /p^h t^h k^h/ in many languages

The feature [+/- spread] is required where [+spread] corresponds to the spreading of the glottis characterized by aspirated sounds and [-spread] to no aspiration.

Why we need features?

Features are necessary to account for natural classes. Phonological segments can be grouped into sets that differ as to their 'naturalness'. Sets of segments that have features in common are more natural than sets of segments that have no common features.

Example: /d/ is [+voice] this means that it groups with the class of sounds that is [+voice]



Adapted from Phillips, Pellathy & Marantz (2000)

Why we need features?

Features are needed for:

- formal explanations of phonological alternations (writing rules or constraints).
- instructions to articulatory actions;
- make up the representations of words an morphemes in speakers'/listeners' memories.

Phonological evidence for distinctive features

- patterning in natural classes: in synchronic alternations & diachronic sound changes;
- acquisition studies (L1 & L2) argue that learners can extract feature-based generalizations better than others;
- speech perception based on features (see Quantal Theory);
- speech production (speech errors).

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Features and speech perception

Speech perception involves a mapping from continuous acoustic waveforms onto phonological units used to store words in the mental lexicon.

Following Poeppel et al. (2008) this mapping from a spectro-temporal acoustic representation to the lexical-phonological one is mediated by an intermediate representation named phonological primal sketch (PPS), it is temporal windows of different sizes (shorter=segmental; longer=syllabic) .

Features and speech perception

Three steps in the process of transforming signals to interpretable internal representations

1. Multi-time resolution processing in core auditory cortex to fractionate the signal into appropriate 'temporal primitives' – segmental and syllabic scale: physically continuous information is broken apart and processed in temporal windows.

2. Construction of distinctive features that form the basis for lexical representations and transformation between sensory and motor coordinates: landmarks (Stevens) which correspond to the articulator-free features define a PPS of the segmental time-scale. The PPS is then fleshed out by identifying the articulator-bound features within the detected landmarks.

3. Analysis by synthesis linking top-down and bottom-up operations in auditory cortex: acoustic measurements yield guesses about distinctive feature values in the string.

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Electrophysiological measures

EEG and MEG

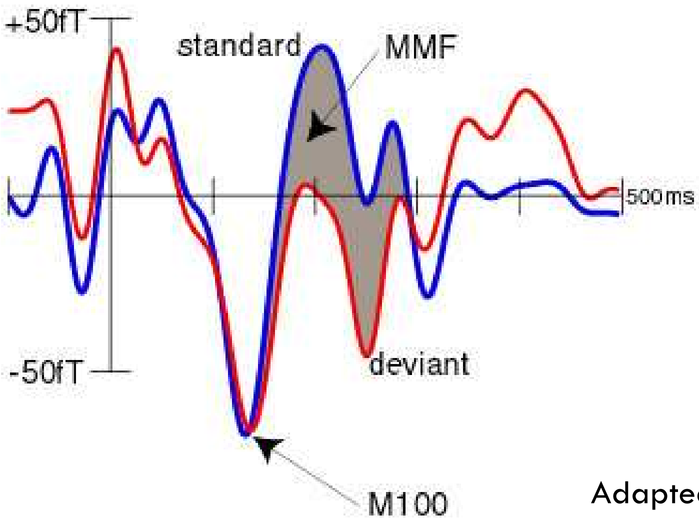
Electroencephalography (EEG) and magnetoencephalography (MEG) provide non invasive measures of neuronal activity in the brain. Electrodes positioned on the scalp, or magnetic field sensors positioned close to the scalp, measure changes in scalp voltages or scalp magnetic fields, entirely passively and with millisecond resolution.

Two evoked responses: N(M)100 and mismatch response (MMN/MMF)

- N(M)100: automatically evoked by any acoustic stimulus with a well-defined onset
- MMN/MMF: response component elicited when a sequence of identical sounds (standards) is interrupted by infrequent (deviant) sounds

Mismatch Response

X X X X X Y X X X X Y X X X X X X Y X X X Y X X X...



Adapted from Phillips, Pellathy & Marantz (2000)

Latency: 150-250 msec.
Localization: Supratemporal auditory cortex
Many-to-one ratio between standards and deviants

Mismatch (MEG) phonological contrast

Phillips, Pellathy, Marantz, Yellin, Wexler, Poeppel, McGinnis, Roberts (2000)

Mismatch as a measure of identity among the members of a phonological category

- Phonetic categories, graded internal structure
- Phonological categories, within-category differences are *irrelevant*

Phonological contrast experiment: contrast /dæ/-/tæ/ (standard vs. deviant)

Acoustic contrast experiment: acoustic distribution of VOT values

Mismatch (MEG) phonological contrast

Phillips, Pellathy, Marantz, Yellin, Wexler, Poeppel, McGinnis, Roberts (2000)

Phonological contrast experiment: A MMF was elicited

Acoustic contrast experiment: No MMF was elicited.

This results implicate phonological representation, because the generator of the MMF must treat the acoustically different tokens of each category as identical in order to detect the many-to-one ratio of standards to deviants.

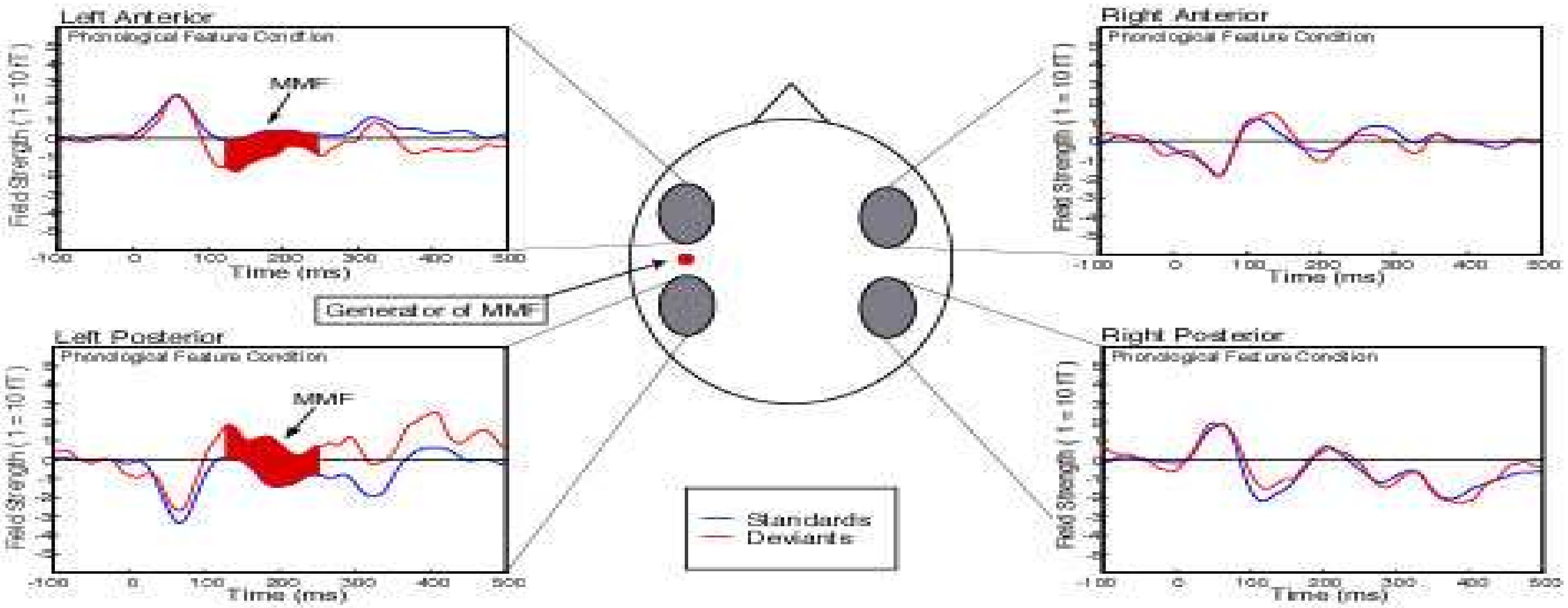
Mismatch (MEG) natural classes

Phillips, Pellathy & Marantz (2000)

Experiment: voiceless phonemes are in many-to-one ratio with [+voice] phonemes

Mismatch stimuli: pæ tæ tæ kæ dæ pæ kæ tæ pæ kæ bæ tæ …

Findings: left hemisphere mismatch response elicited by phonological feature contrast



Adapted from Philips, Pellathy & Marantz (2000)

Mismatch (EEG) mental lexicon

Eulitz & Lahiri (2004)

Investigate the German contrast between back vowel [o] and front vowel [ø] in a MMN-paradigm

(adopting Full Underspecified Lexicon model); (Subjects: 12 L1 German)

- conflict situation arises when the feature [CORONAL] is extracted from the deviant sound [ø] and mapped onto the standard representation of [o] which is specified for [DORSAL], the reversal [ø] standard and [o] deviant does not lead to a conflict because [CORONAL] is underspecified.

- higher MMN amplitude and shorter MMN latency for conflicting than for non-conflicting situations

	front vowel [ø]	back vowel[o]
Features in the acoustic signal (deviant)	[CORONAL] [LABIAL]	[DORSAL] [LABIAL]
Features in the mental representation (standard)	[ ] [LABIAL]	[DORSAL] [LABIAL]

Mismatch (EEG) mental lexicon

Lipski, Lahiri, & Eulitz (2007)

Tested by the use of MMN tongue height specification of the front vowels /i/ and /e/ in Turkish and German (adopted Full Underspecified Lexicon Model) (Subjects: 15 Turkish-German bilingual).

- differential specification of tongue height features, i.e. in Turkish /e/ is specified for [LOW] and not underspecified as in German; whereas /i/ is underspecified for height in Turkish and specified for [HIGH] in German

- significantly stronger MMN amplitude mapping [i] → /e/

Language	Direction	Surface and lexical features	Mapping result
Turkish German	[e] → /i/	[low] → /__/ [__] → /high/	no-mismatch no-mismatch
Turkish German	[i] → /e/	[high] → /low/ [high] → /__/	**mismatch** no-mismatch

Mismatch response

To sum up

- 1st study: evidence for phonological contrast
- 2nd study: evidence for natural class
- 3rd+4th study: evidence for underspecified lexical representation

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Ferrets' phonemic representation in auditory cortex

Mesgarani, David, Fritz & Shamma (2008)

Aim: test phonemic categorically discrimination of 4 ferrets

- Recording of responses of A1 neurons (90) to American English phonemes from continuous speech.
- Findings: neural responses reveal an explicit multidimensional representation that is sufficiently rich to support the discrimination. This representation is made possible by the wide range of spectro-temporal tuning in A1 to stimulus .

Ferrets' phonemic representation in auditory cortex

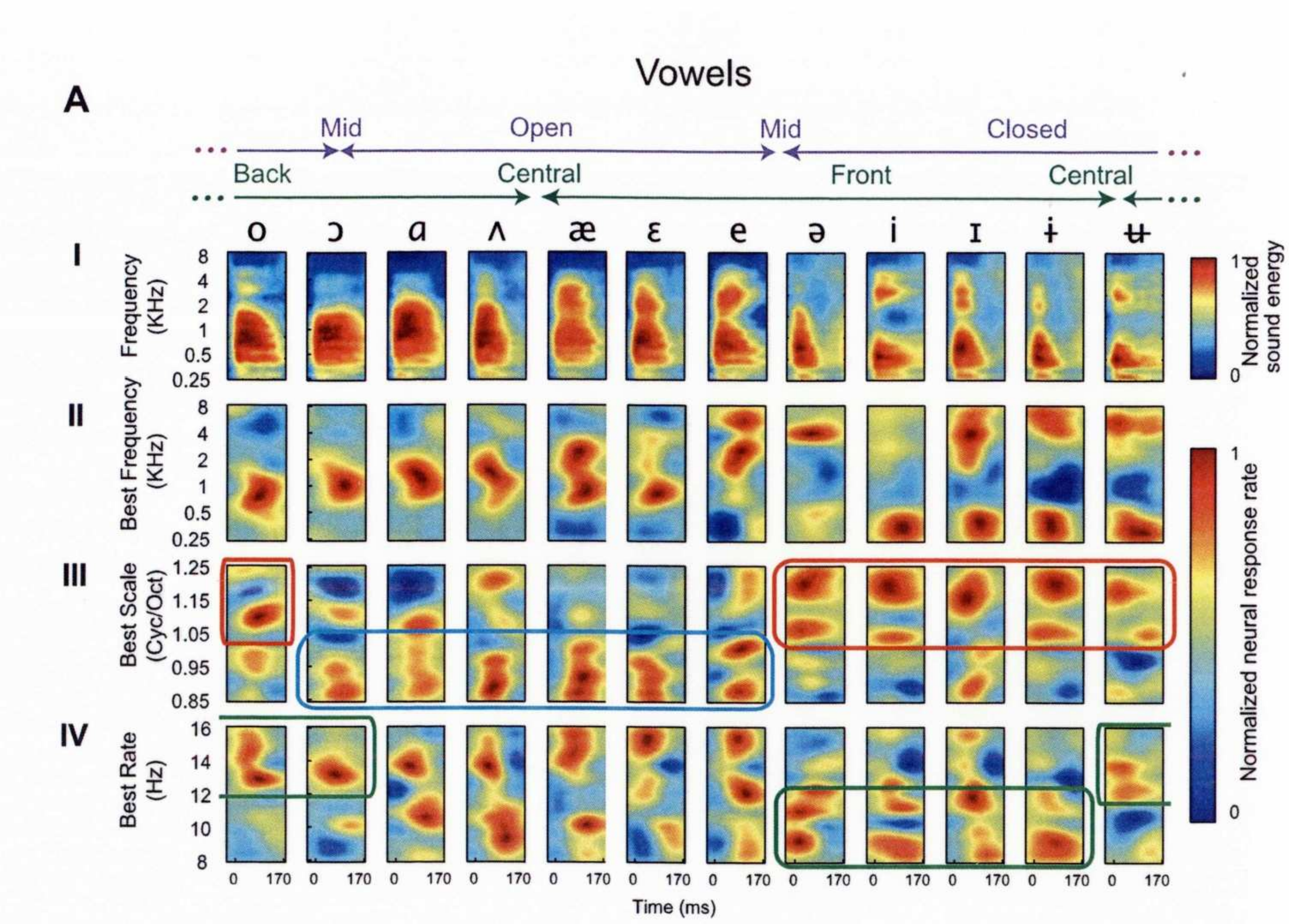
Mesgarani, David, Fritz & Shamma (2008)

The advantage of the wide range of spectro-temporal tuning in A1 is that there is always a unique subpopulation of neurons that responds well to the distinctive acoustic features of a given phoneme.

Example: perception of /k/ in a CV syllable

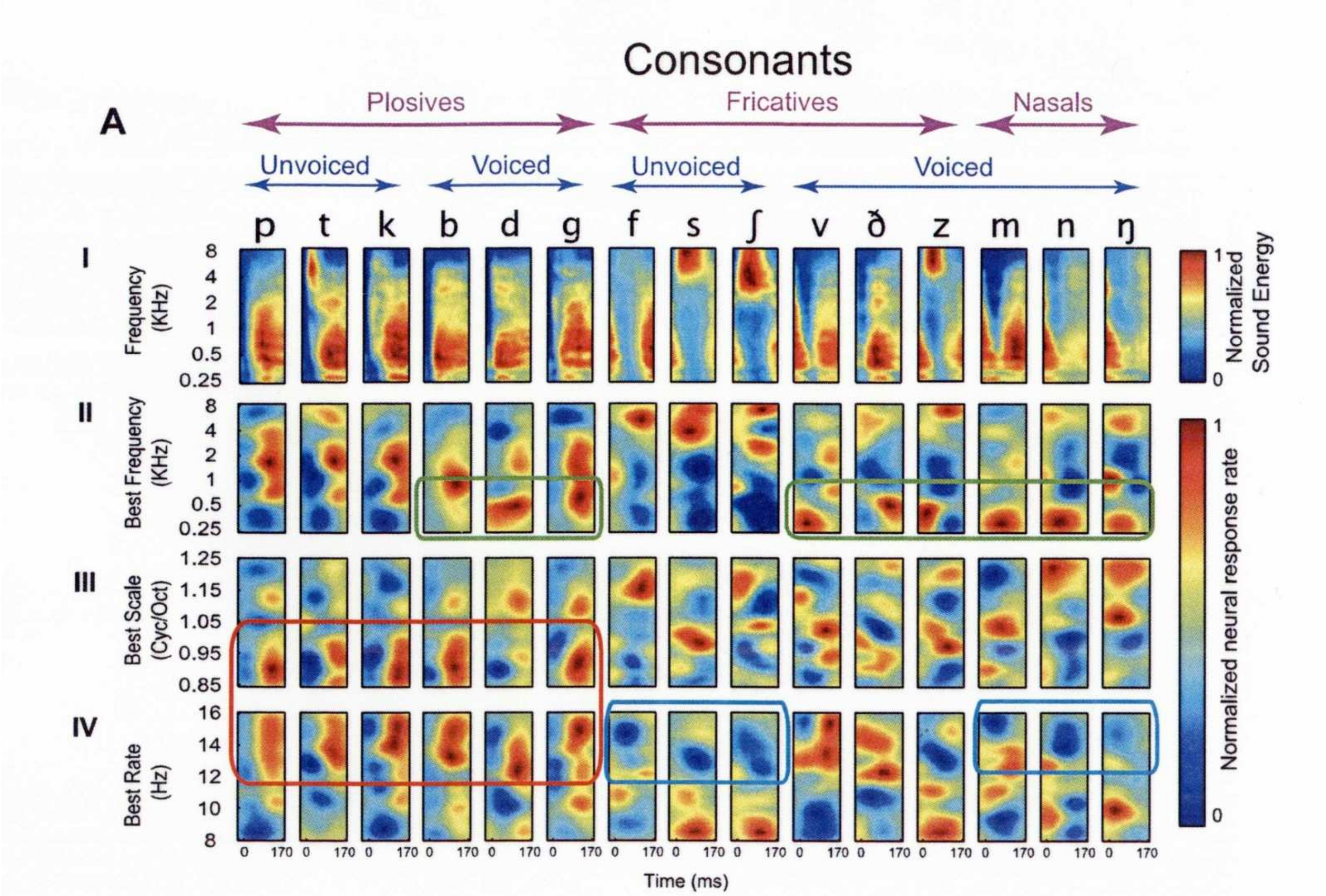
- neurons selective for broad spectra respond selectively to the noise burst
- rapid neurons respond well following the VOT
- directional neurons selectively encode the vowel formant transitions

Ferrets' vocalic perception



Adapted from Mesgarani et al. (2008)

Ferrets' consonantal perception



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To conclude…Is speech special?

Is speech special?

It may or may not be the case that there are populations of neurons whose response properties encode speech in a preferential manner.

To conclude…Is speech special?

Sound-word interface

There must be some specialization, for the following reason: lexical representations are used for subsequent processing, entering into phonological, morphological, syntactic and compositional semantic computations. For this, the representation has to be in the correct format, which appears to be unique to speech.

Format composed probably of distinctive features.

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