Language and Cognitive Neuroscience

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Subject-object ambiguities in language comprehension

- empirical findings on mis-analysis and subsequent reanalysis as means of modeling real-time language comprehension

Schlesewsky, 2006
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- object to subject reanalysis:
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- “garden path strength”

- observed as modulations of positive event-related brain potential (ERP) responses either in terms of latency or amplitude

Examples from:
- Sturt and Crocker, 1996
- Friederici, 1998
Lecture Outline

- an example: subject-object ambiguities
- language and the brain
  - early neurological models
  - locationist vs. connectivist approach
- (psychological) experiment
- neuroimaging: fMRI
  - principle of fMRI
  - image processing
- scalp-recorded even-related potentials (ERPs)
- computational neurolinguistics
- references
Language and the Brain

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Neurolinguistics

Paul Broca (1824-1880)
- discovery of the speech production center (Broca's area)
- post-mortem autopsy of aphasic patients
- Broca's aphasia
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For a long time, information about language processing only came from the study of effects of neurological disease in humans.
Neurolinguistics: damage to the brain

Broca's aphasia:

kid ... kk ... can ... candy ... cookie ... caandy... well I don't know but it's ... writ ... easy ... does it ... slam ... early ... fall ... men ... many ... no ... girl. dishes ... soap ... water ... water ... falling ... pah ... that's all ... dish ... that's all.
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Wernicke's aphasia:

*"Is this some of the work that we work as we did before? ... All right... From when wine [why] I'm here. What's wrong with me because I ... was myself until the taenz took something about the time between me and my regular time in that time and they took the time in that time here and that's when the the time took around here ...”*
Early neurological models of language

- Wernicke-Geschwind model

[Diagram showing brain areas and functions: Spoken word → Cognition → Written word, Area 41 → Wernicke’s area → Area 17, Wernicke’s area (contains sound images of words) → Broca’s area (stores motor programs for speaking words) → Area 18, 19, Area 39 (angular gyrus) → Wernicke’s area → Read, Cranial nerves → Speak, Motor cortex → Wernicke’s area, Broca’s area]
Localization of speech centers has been the primary interest since the dawn of neurolinguistics.

Brain imaging methods such as fMRI enable scientists to identify brain areas active during language processing.

E.g. attempts to map syntax and semantics to Broca's and Wernicke's area, respectively ("Broca for syntax, Wernicke for semantics").

Various locationist models ("language brain maps") have been/are developed and are under hot debate.
A schematic view of the main areas activated during syntactic processing. Pink areas (frontal operculum and anterior STG) are involved in the build-up of local phrase structures, the yellow area (Broca’s area, BA 44/45) supports the computation of dependency relations between constituents of a sentence, and the striped area (posterior STG/STS) is involved in integration processes, possibly involving syntactic and syntax-relevant lexical information.

Grodzinsky, 2006
A number of researchers now reject classic locationist models of language. Instead, they conceptualize language, and cognitive functions in general, as being distributed across anatomically separate areas that process information in parallel (rather than serially, from one “language area” to another).

For example, the single act of recalling words involves a highly distributed network that is located primarily in the left brain and that includes the inferolateral temporal lobe, the inferior posterior parietal lobule, the premotor areas of the frontal lobe, the anterior cingulate gyrus, and the supplementary motor area.
90% of people are right-handed

About 95% of right-handed people have their language areas on the left side of their brain.

That leaves about 5% right-handers who are either right-lateralized or have their language areas between their two hemispheres.

Among left-handers, all patterns can be found, including left-lateralization.
An Experiment

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A (psychological) experiment

The scientist creates the **conditions** and monitors the subject's behaviour, response time or physiological response depending on the different conditions to **verify a hypothesis**.
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**experiment phases:**
- preparation
  - create conditions model
  - preparation of the conditions (video, images)
  - control group selection (= invite the subjects)
- variations of the conditions
  - independent variable (condition) – condition manipulated by the experimentator
  - dependent variable (condition) – participant's reaction
- data cleaning and results extraction
- evaluation
reaction time experiment

the subject must choose the proper reaction to different stimuli

as assigned task becomes more complex, the reaction time increases

incremental increases in reaction time indicate the operation of deeper mental processes
reaction time experiment
functional magnetic resonance
scalp-recorded event-related potentials (ERPs)
  - EEG
magneto-encephalogram
  - MEG
“Now I want you to relax completely!”

Andreassi, 2006
Functional Magnetic Resonance

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fMRI = Functional Magnetic Resonance Imaging
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- very strong magnet – 1.5T (clinical use), 3T or even 7T in research (Earth magnetic field ~ 50 microTesla)
- It measures the hemodynamic response (change in blood flow) related to neural activity in the brain.
- low invasiveness, absence of radiation exposure, relatively wide availability
active neurons consume energy
local increase in blood flow in the area of increased neuronal activity
delay 1-5 s
peak in 5 s
oxygenated and deoxygenated hemoglobin have different magnetic properties
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Differences in oxygenation and blood flow (collectively known as hemodynamics) create blood-oxygen-level dependence (BOLD) signal.
The BOLD signature of activation is relatively weak.

Source of noise:
- scanner noise
- environment noise
- physiological noise
- participant's movement

Each trial has to be repeated many times (tens to hundreds) with many participants (10-25).

Statistical measures are then applied.
fMRI: neuroimaging

voxel = space unit ("pixel in space")
    usually 3x3x3mm
slice = horizontal plane
    e.g. 30 slices
matrix size = number of space units (pixels) in one slice
    e.g. 64x64
scan, run = one scanning without interruption
    e.g. 5 minutes
session = all scans from one participant taken in one day
experiment = data from all participants
we assume to have acquired our (raw) data:
	files from the program, scanner logs, exact stimuli onset and duration times
preprocessing:
realignment
correction for head movements
unwarping
correction for field non-homogenity
correction for different tissue properties combined with head movement
slice time correction
correction of different slice acquisition time – ascending, descending, interleaved
spatial normalization
normalization to one brain template – one template brain shape (Talairach, MNI space) with coordinates
smoothing
realign & motion correction → smoothing → General Linear Model → random field theory

image data → design matrix

smoothed kernel

normalisation

anatomical reference

Statistical Parametric Map

corrected $p$-values
independent voxel-by-voxel analysis

General Linear Model

  voxel value prediction from model parameters
  experiment parameters are described by regressors (x)
  GLM estimates, how regressor contributes to voxel value
  (that is, how important it is) – these coefficients are
called beta
independent voxel-by-voxel analysis

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\[ Y = X \ast \beta + \epsilon \]
raw fMRI time series

adjusted for global & low Hz effects

scaled for global changes

residuals
raw fMRI time series

scaled for global changes

adjusted for global & low Hz effects
1\textsuperscript{st} level analysis

- statistical analysis of one participant's data
  - 2\textsuperscript{nd} level = group analysis
- for each voxel, a statistical t-test is made
  - null hypothesis: no effect (no activation)
  - alternative hypothesis: effect of the condition on the brain (activation)
- p-value
  - summarizes evidence against the null
  - the chance of observing value more extreme than t under the null hypothesis \( p(T > t|H_0) \)
- Colourful pixels in the brain images are statistical test results(p-values)!
Time and space resolution comparison

Huettel, 2009
Event-related potentials

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Electroencephalography (EEG) is the recording of electrical activity along the scalp produced by the firing of neurons within the brain.

Event-related potentials (ERPs) are scalp-recorded changes in electrical activity that occur in response to a sensory, cognitive, or motor event.
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Neuronal origins of ERPs is electrical activity in neurons, namely, postsynaptic potentials rather than action potentials.

The postsynaptic potential creates a tiny dipole.

The summation of the individual dipoles creates a current, which is conducted throughout brain.

The voltage will be present on the scalp.
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ERPs spread as they travel and spread laterally when encountering the resistance of the skull. This blurs the surface distribution of the voltage.
An oddball paradigm

- 80% Xs and 20% Os
- each letter presented on a video monitor for 100ms
- followed by 1,400ms blank interstimulus interval

Luck, 2005
The resulting (grand average) ERP waveform consists of a sequence of positive and negative voltage deflections: **peaks** (waves, components).
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The number indicates a peak's position within the waveform.

It is also common to give a precise latency, such as N400 (for a negative peak at 400ms post-stimulus)
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Problem of assessing which ERP component is influenced by a given experimental manipulation.
ERP latent components summation

Luck, 2005
Language-related ERP components: N400

The N400 is negative-going wave typically seen in response to violations of semantic expectations.

- *I planted string beans in my garden/sky.*
- *or even: He bought her a pearl necklace for her birthday/collection.*

First reported by Kutas and Hillyard, 1980

Appears primarily in the left temporal lobe

Words with higher frequency of use in a given language have been found to elicit N400s of smaller amplitude Rugg, 1990

Non-linguistic stimuli can also elicit N400
syntactic violations also elicit distinctive ERP components, e.g. P600

see Osterhout & Holcomb, 1992, 1995

P600 examples:
*The broker persuaded to sell the stock. (larger P600)
The broker hoped to sell the stock.
Computational Neurolinguistics

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Predicting Human Brain Activity Associated with the Meaning of Nouns

Mitchell et al., 2008
References

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