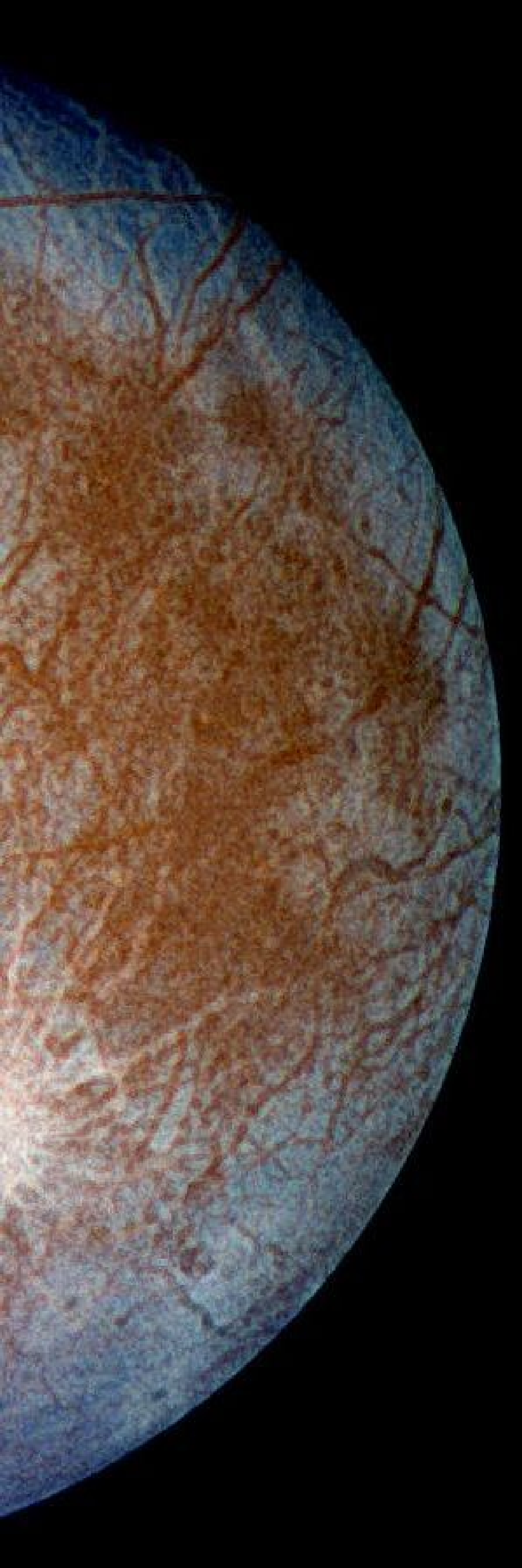

Language and Cognitive Neuroscience

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2010-09-14

Subject-object ambiguities in language comprehension

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

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examples from Sturt and Crocker, 1996

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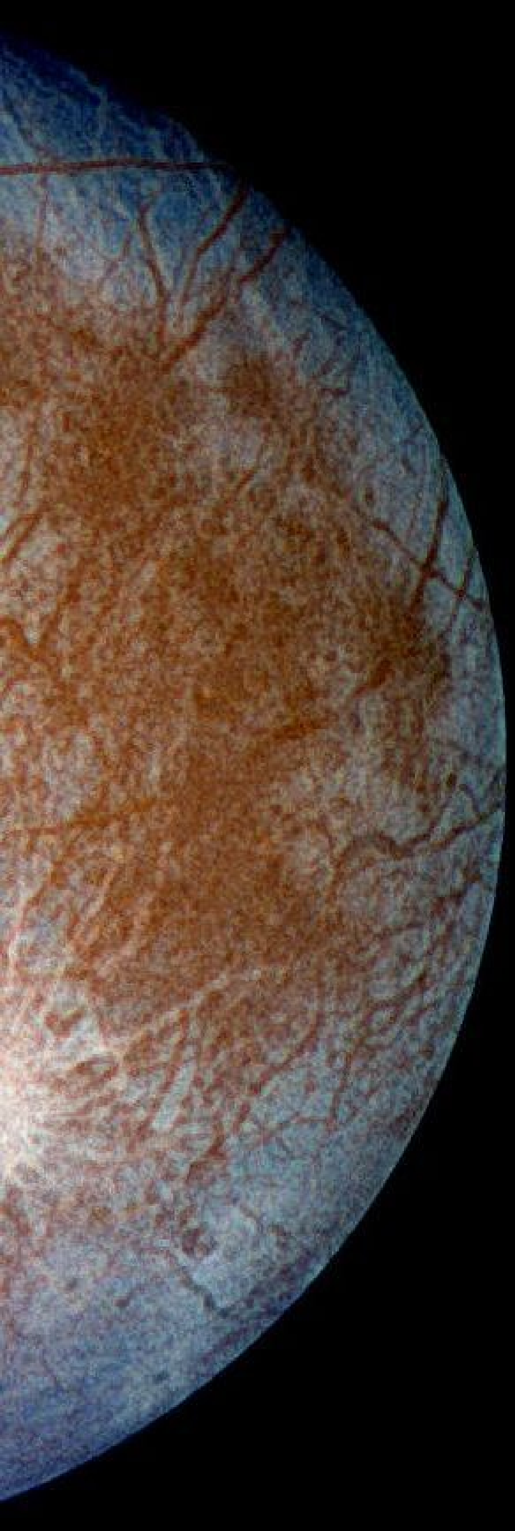
examples from Sturt and Crocker, 1996

- reanalysis towards a subject requires additional processing costs
- “garden path strength”
  - observed as modulations of positive event-related brain potential (ERP) responses either in terms of latency or amplitude

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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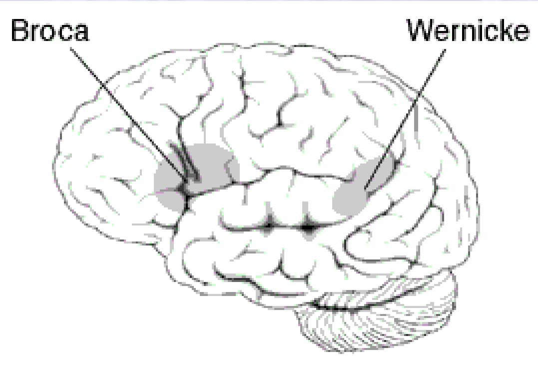
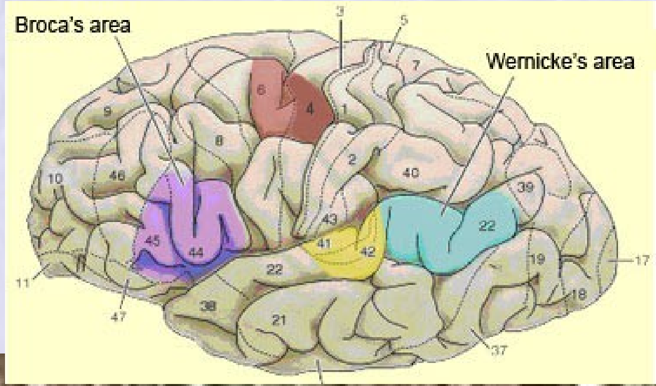
- For a long time, information about language processing only came from the study of effects of neurological disease in humans.

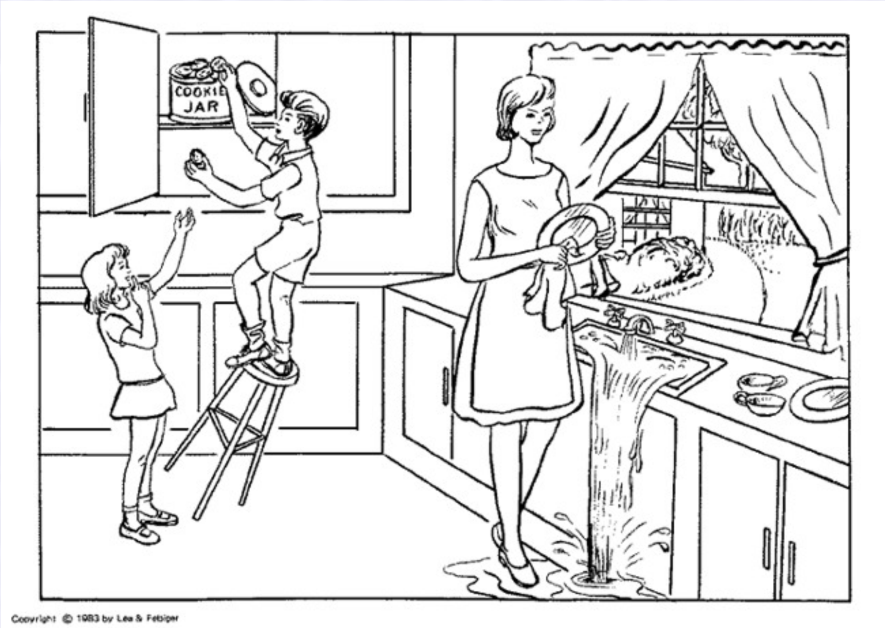




Neurolinguistics: damage to the brain

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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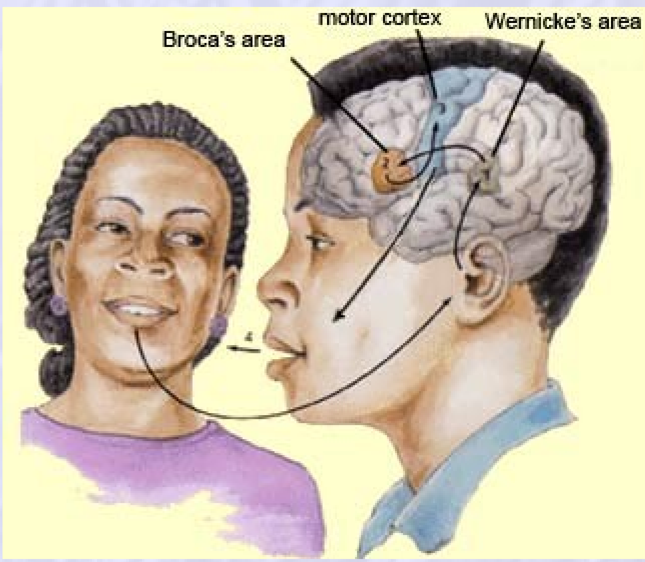
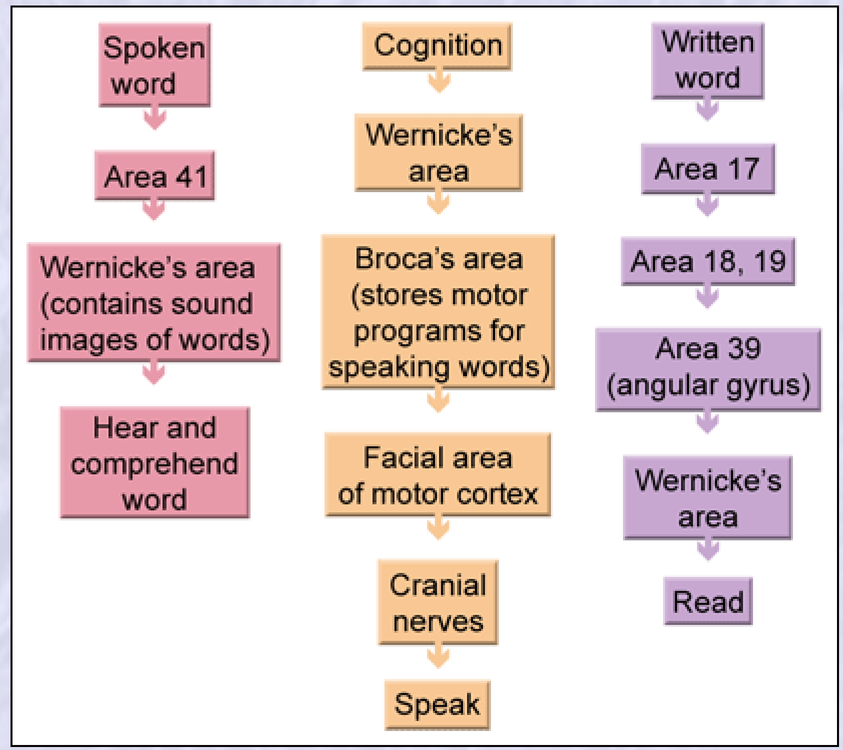
Wernicke's aphasia:

“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

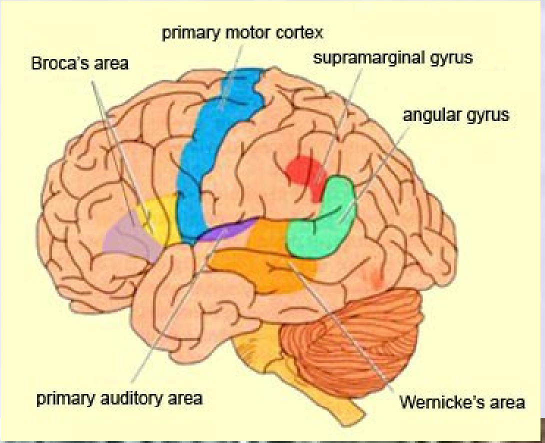
- Wernicke-Geschwind model





Locationist models

- 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.



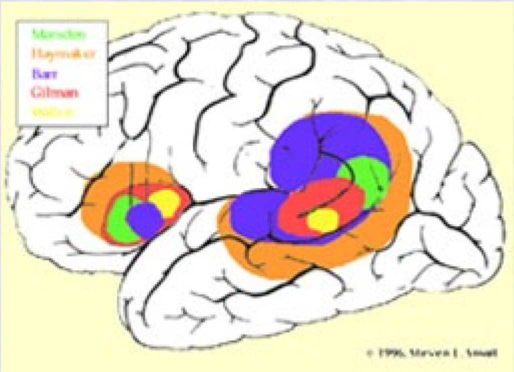


Figure 1

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

Connectivist models of language

- 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.

Lateralization for language

- 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**.

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**.
- experiment phases:
  - preparation
    - create conditions model
    - prepation 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

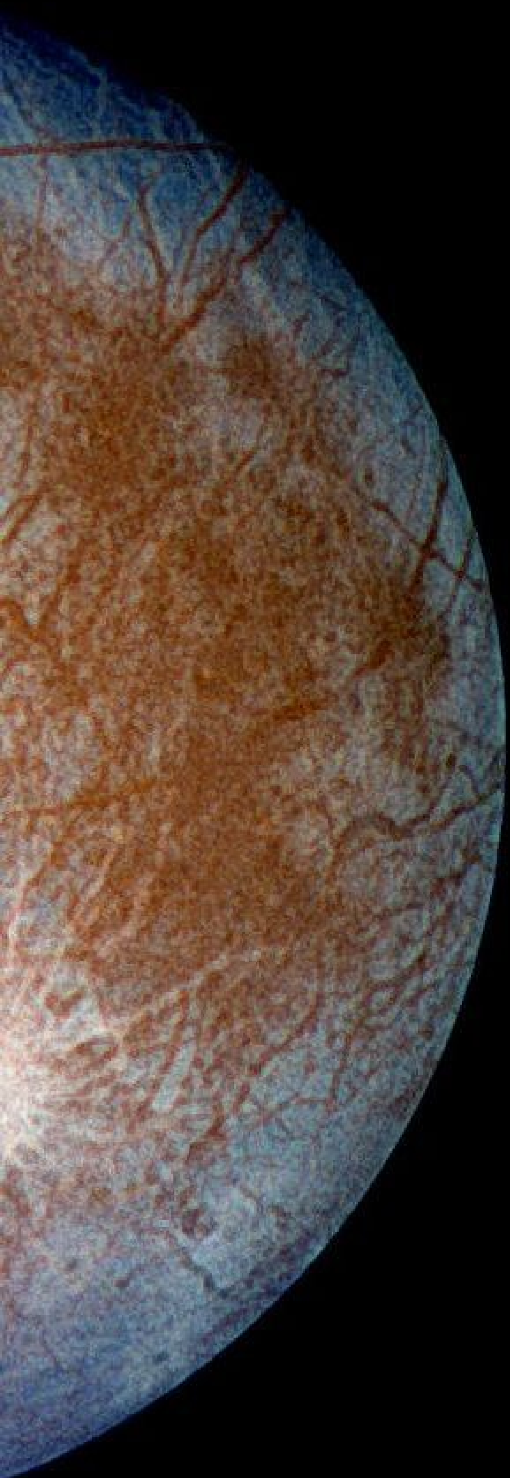
An experiment

- 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

An experiment

- reaction time experiment
- functional magnetic resonance
- scalp-recorded event-related potentials (ERPs)
  - EEG
- magneto-encephalogram
  - MEG

Andreassi, 2006



Functional Magnetic Resonance

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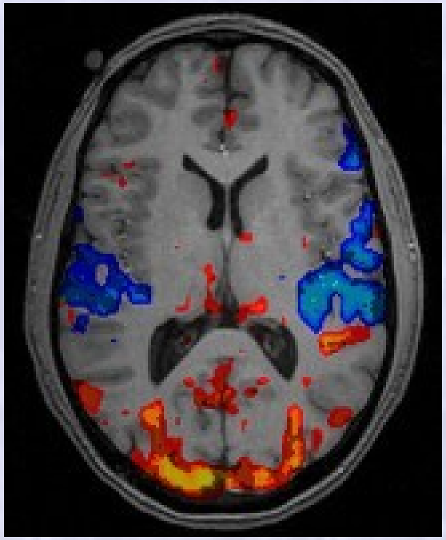
2010-09-14

fMRI = Functional Magnetic Resonance Imaging



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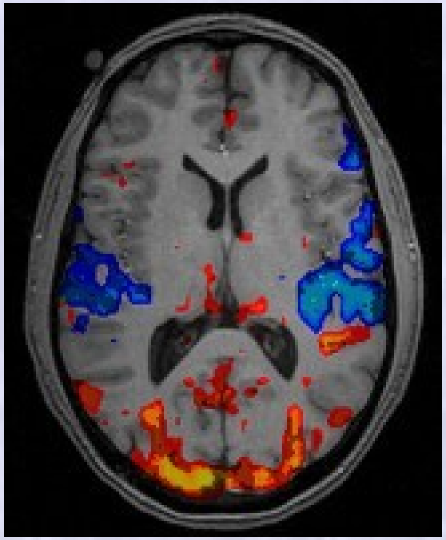

- very strong magnet – 1.5T (clinical use), 3T or even 7T in research (Earth magnetic field ~ 50 microTesla)
- It measures the hemodynamic response (change in blood flow) related to neural activity in the brain.
- low invasiveness, absense of radiation exposure, relatively wide availability

BOLD signal

- 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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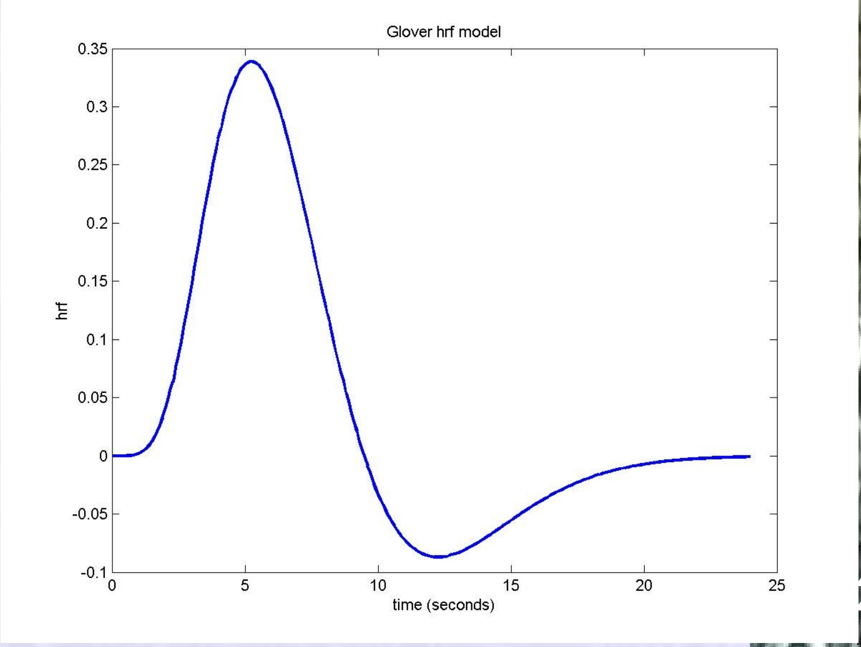
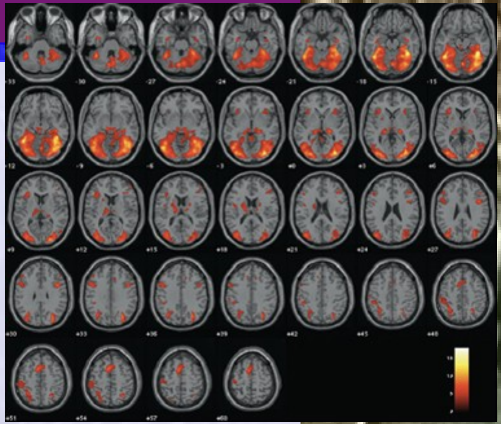
Differences in oxygenation and blood flow (collectively known as hemodynamics) create blood-oxygen-level dependence (BOLD) signal.



Signal-to-noise ratio

- 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 = numer of space units (pixels) in one slice

  e.g. 64x64

scan, run = one scanning without interruption

  e.g. 5 minutes

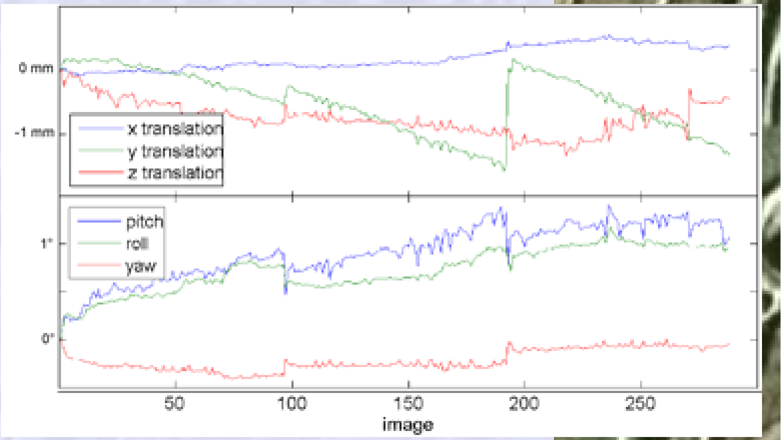
session = all scans from one participant taken in one day

experiment = data from all participants

Image data preprocessing

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 fifferent 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

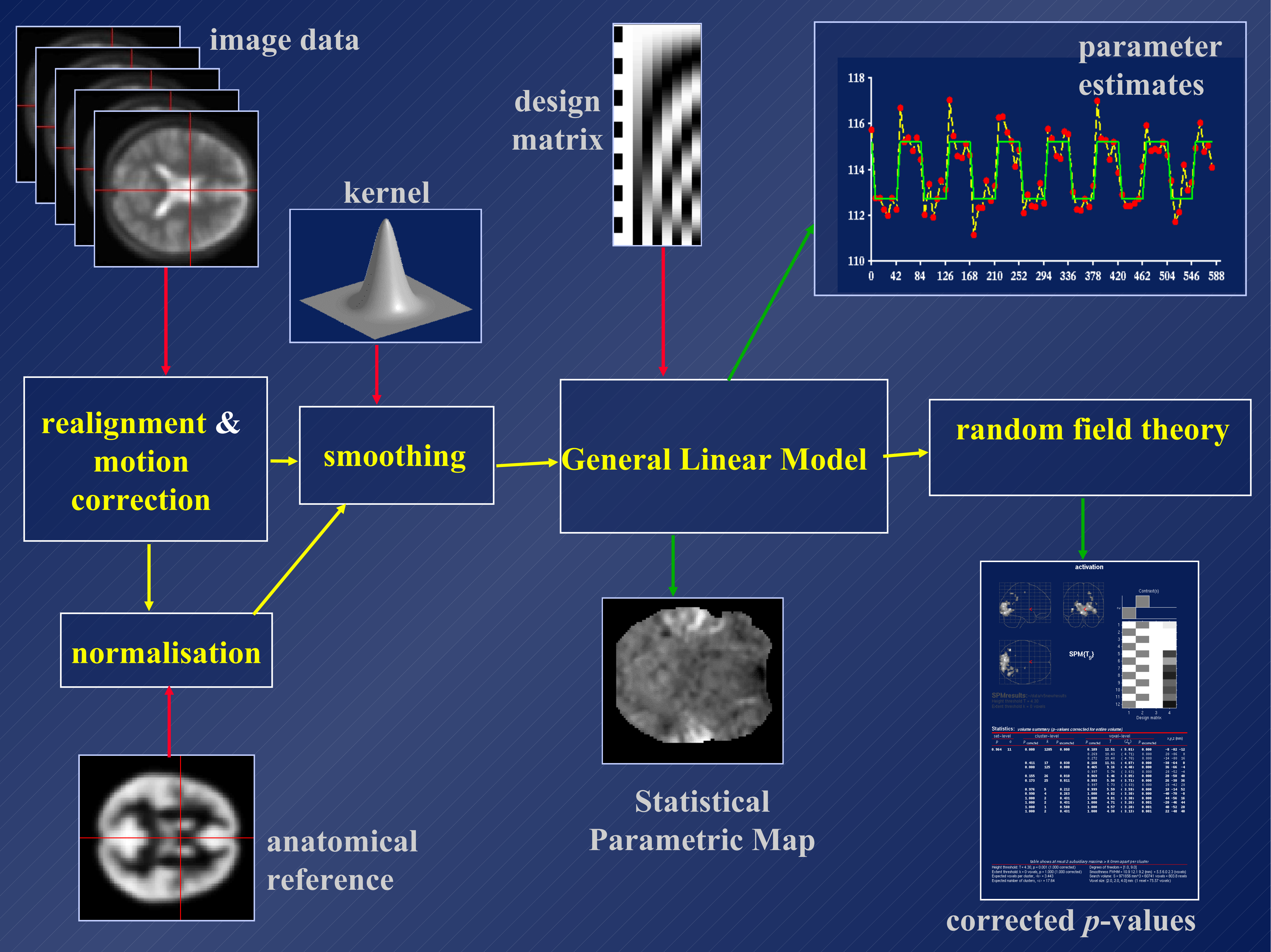


image data
kernel
design matrix
parameter estimates
118
116
114
112
110
0 42 84 126 168 210 252 294 336 378 420 462 504 546 588
realignment & motion correction
smoothing
General Linear Model
random field theory
normalisation
anatomical reference
Statistical Parametric Map
activation
corrected p-values

General Linear Model

- 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

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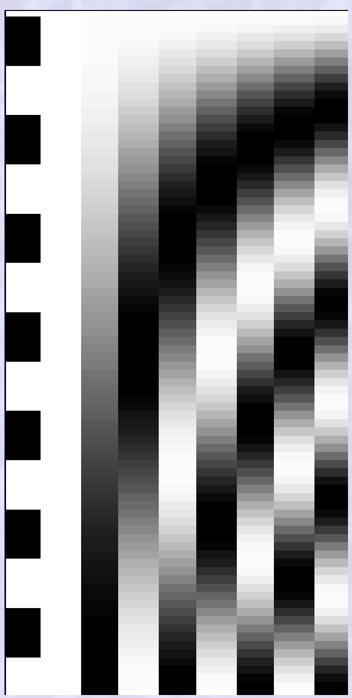
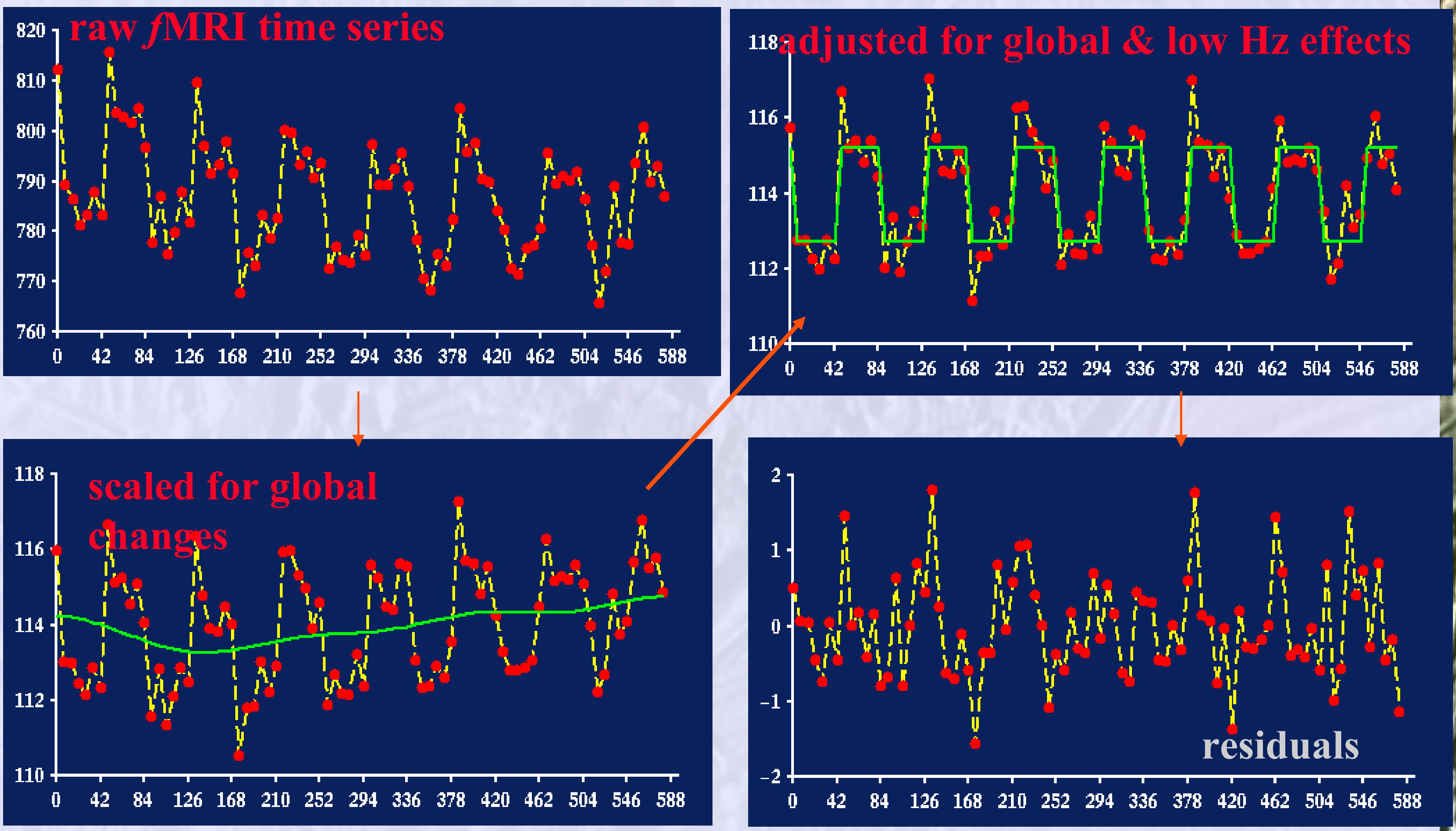
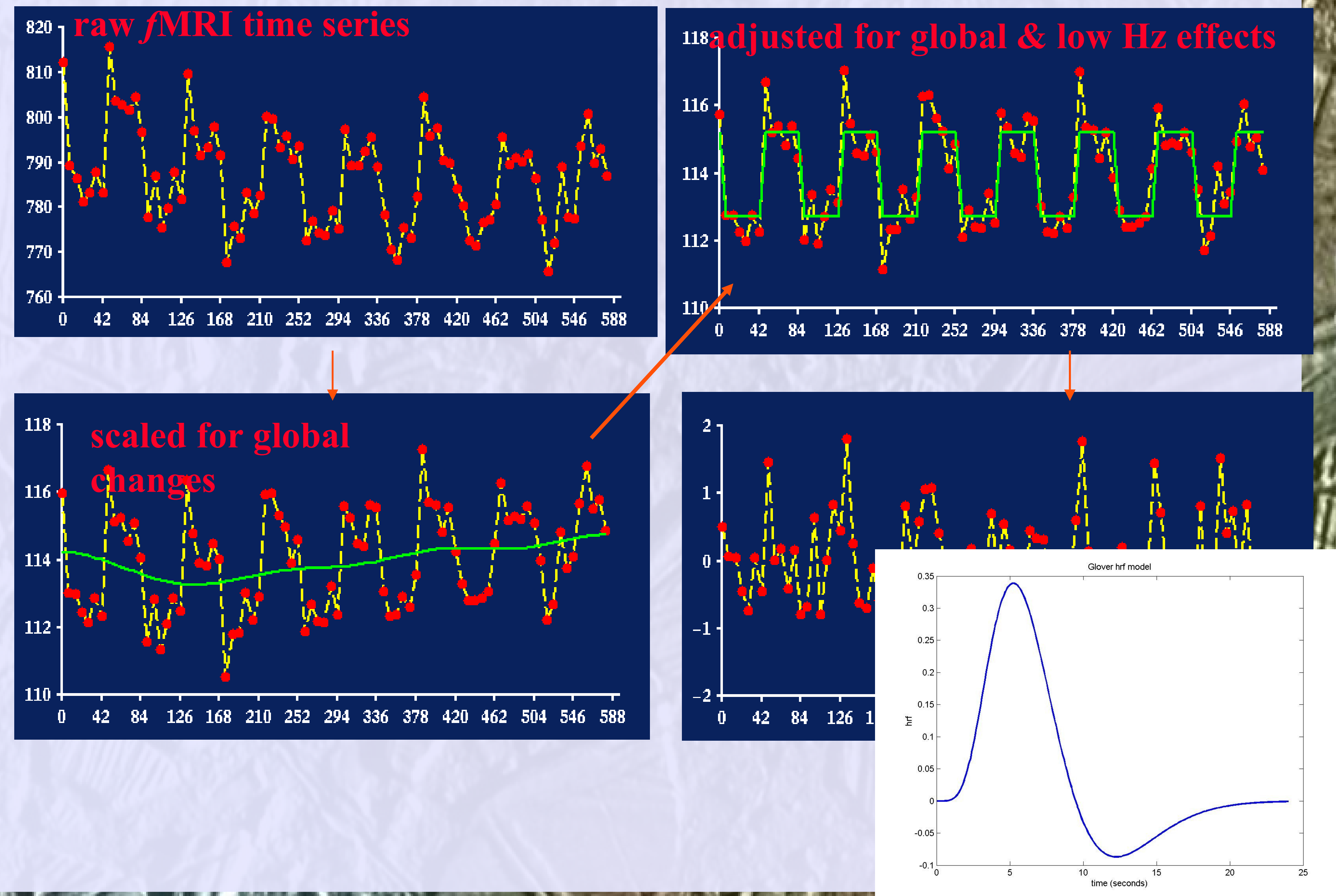


data vector
design matrix
parameters
error

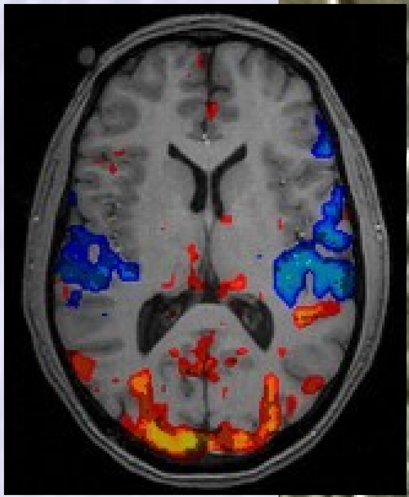
$$Y = X * \beta + \epsilon$$

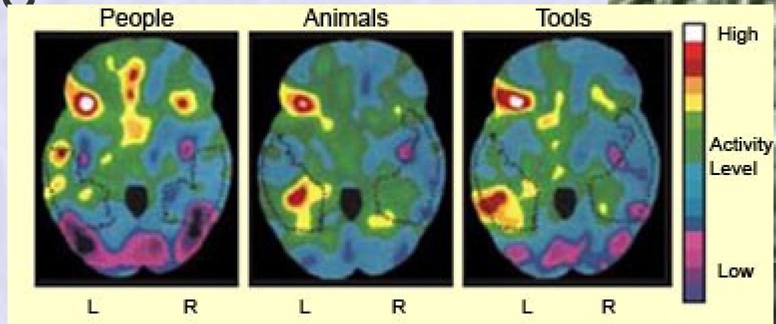

raw fMRI time series
adjusted for global & low Hz effects
scaled for global changes
residuals


raw fMRI time series
adjusted for global & low Hz effects
scaled for global changes
Glover hrf model
hrf
time (seconds)

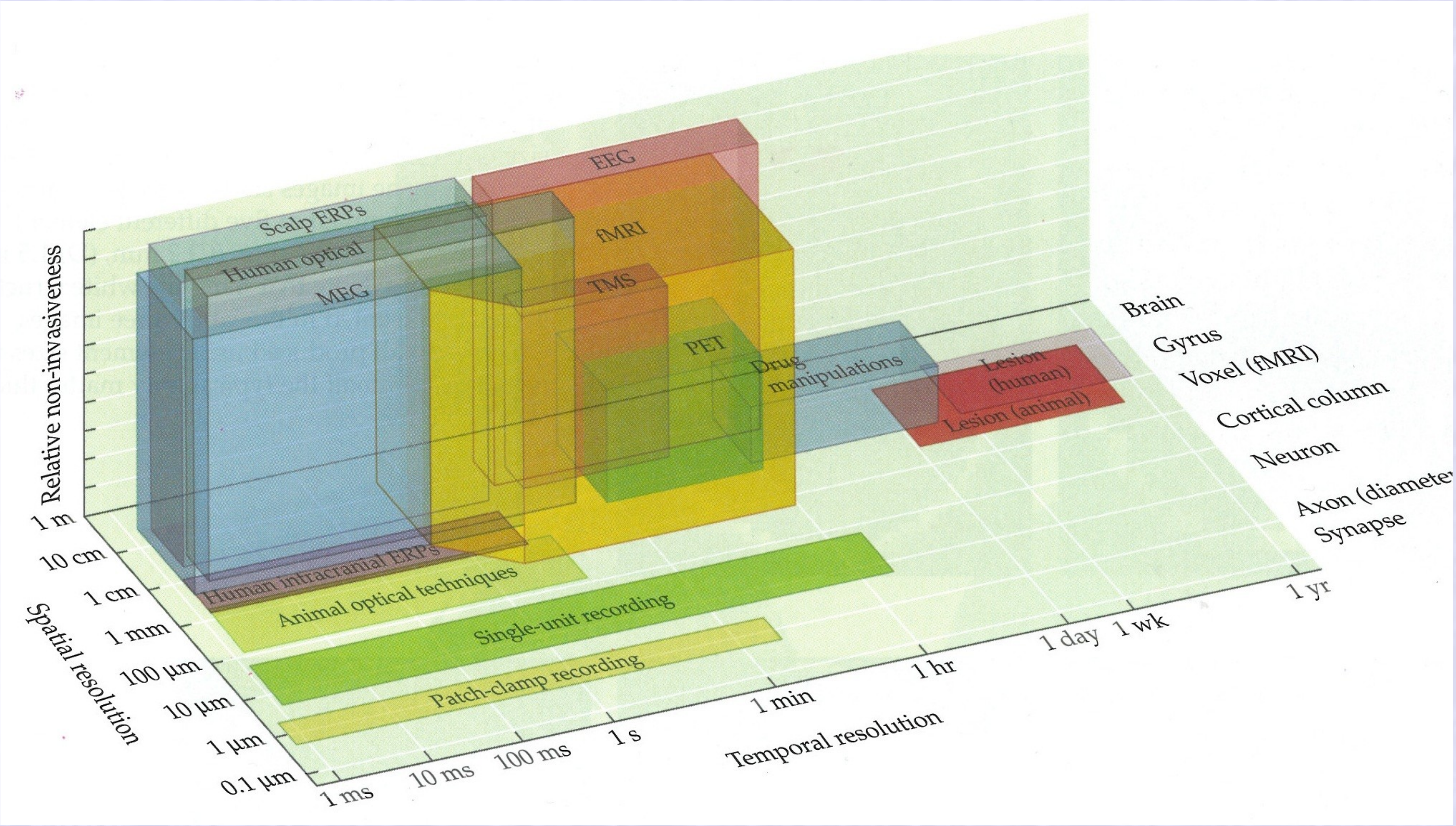
1st level analysis

- statistical analysis of one participant's data
  - 2nd 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)!

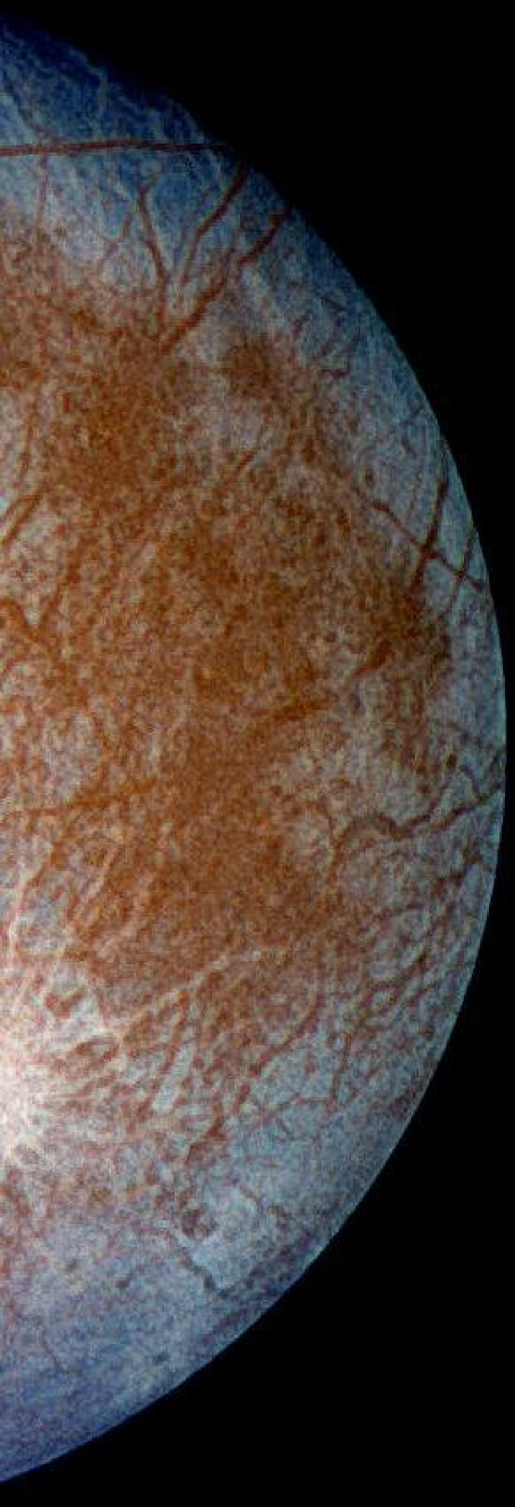




Time and space resolution comparison



Huettel, 2009



Event-related potentials

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2010-09-14

Event-related potentials

- **Electroencephalography (EEG)** is the recording of electrical activity along the scalp produced by the firing of neurons within the brain.
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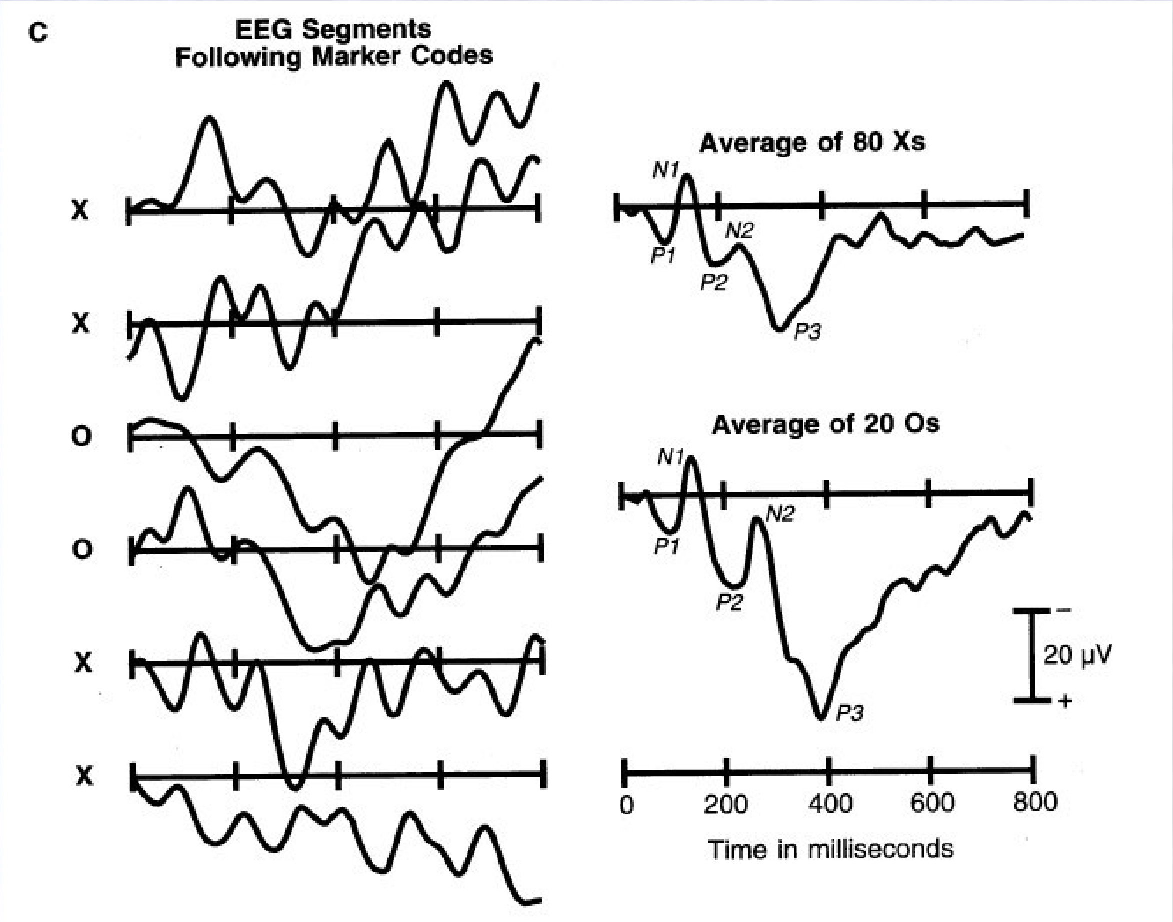
- ERPs spread as they travel and spread laterally when encountering the resistance of the skull. This blurs the surface distribution of the voltage.

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

ERP components

- The resulting (grand average) ERP waveform consists of a sequence of positive and negative voltage deflections: **peaks** (**waves, components**).

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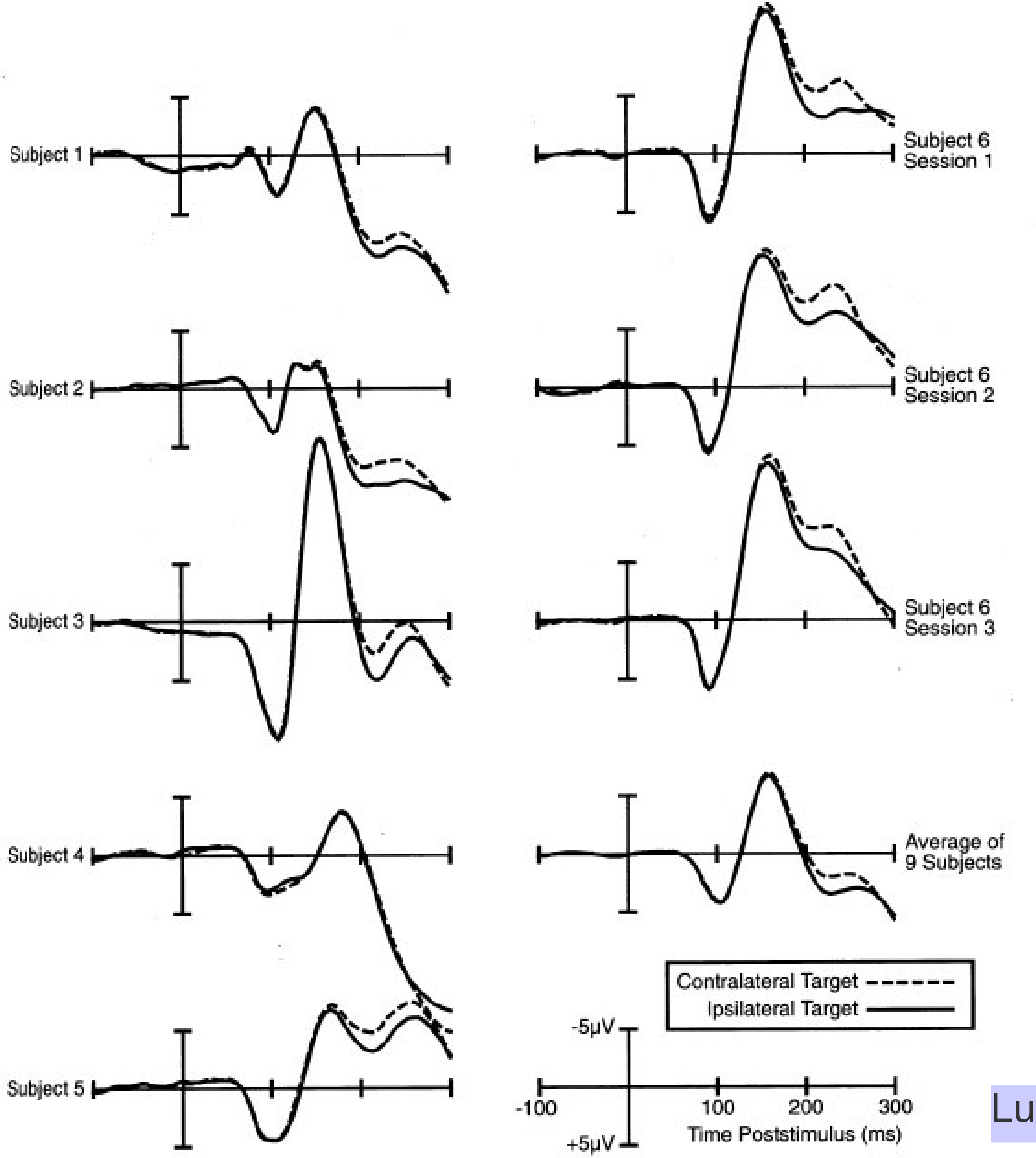
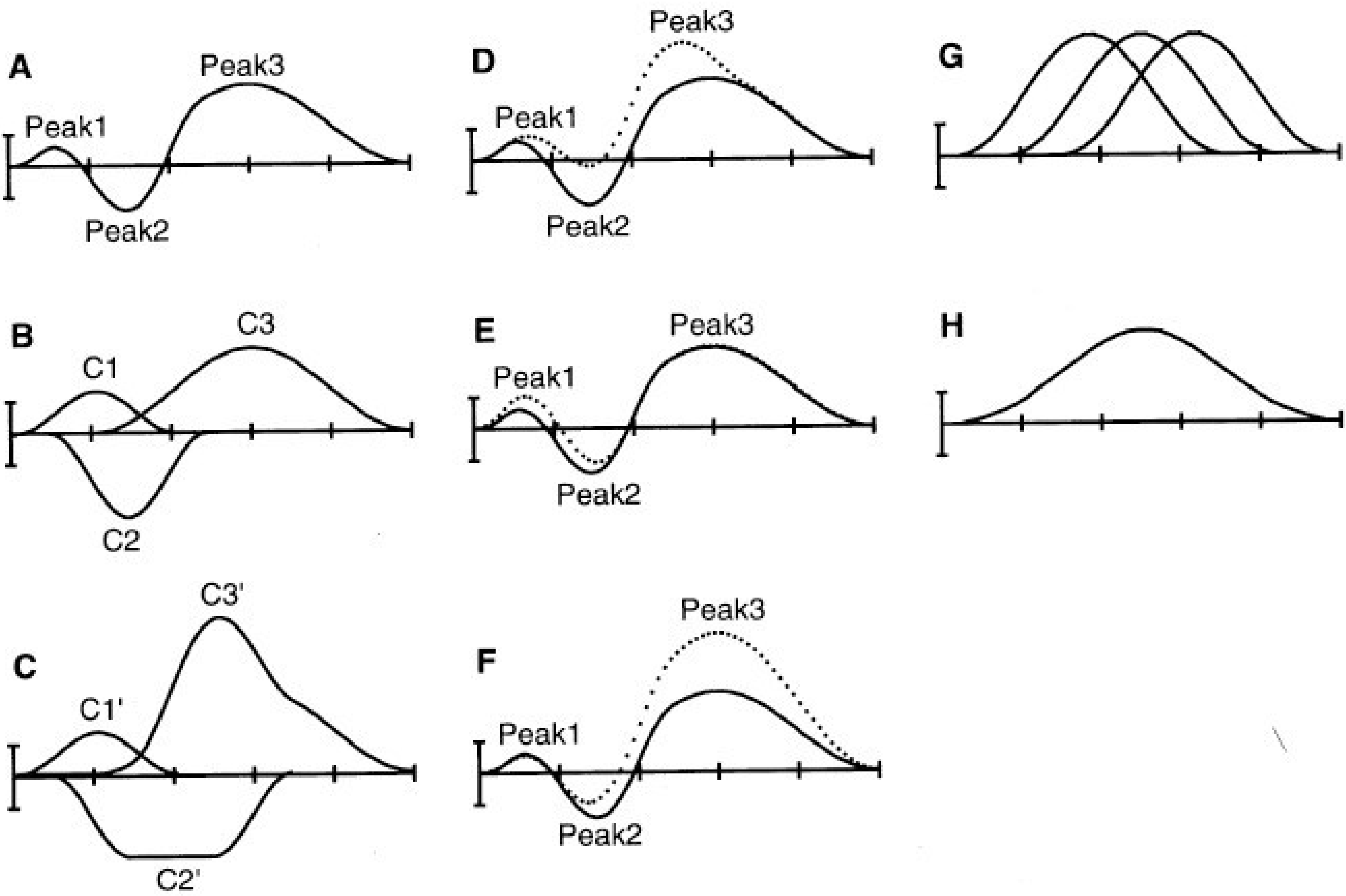
- It is also common to give a precise latency, such as N400 (for a negative peak at 400ms post-stimulus)
- Problem of assessing which ERP component is influenced by a given experimental manipulation.



Subject 1
Subject 2
Subject 3
Subject 4
Subject 5
Subject 6 Session 1
Subject 6 Session 2
Subject 6 Session 3
Average of 9 Subjects
Contralateral Target
Ipsilateral Target
-5μV
+5μV
-100
100
200
300
Time Poststimulus (ms)

Luck, 2005

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

Language-related ERP components: P600

- 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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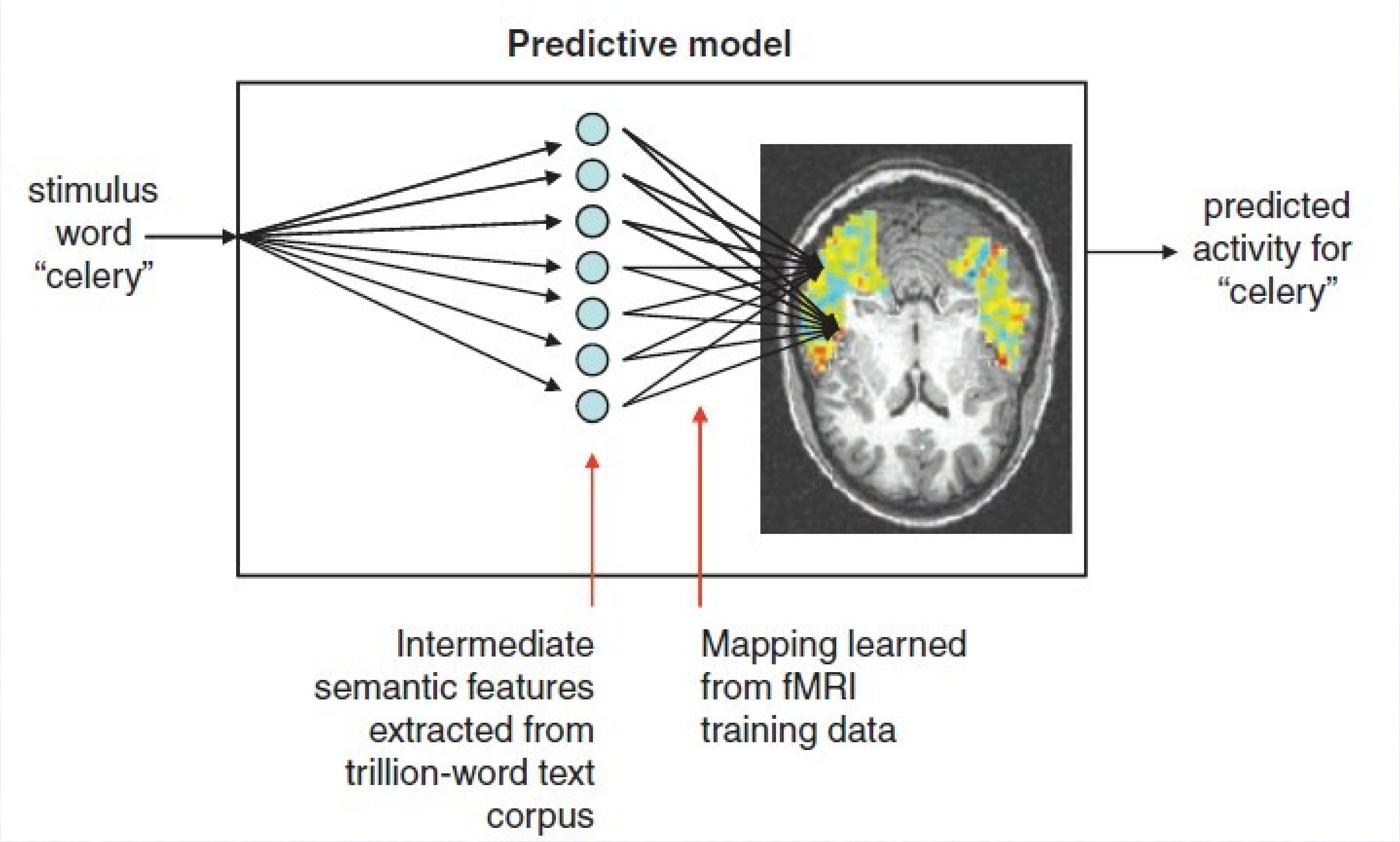
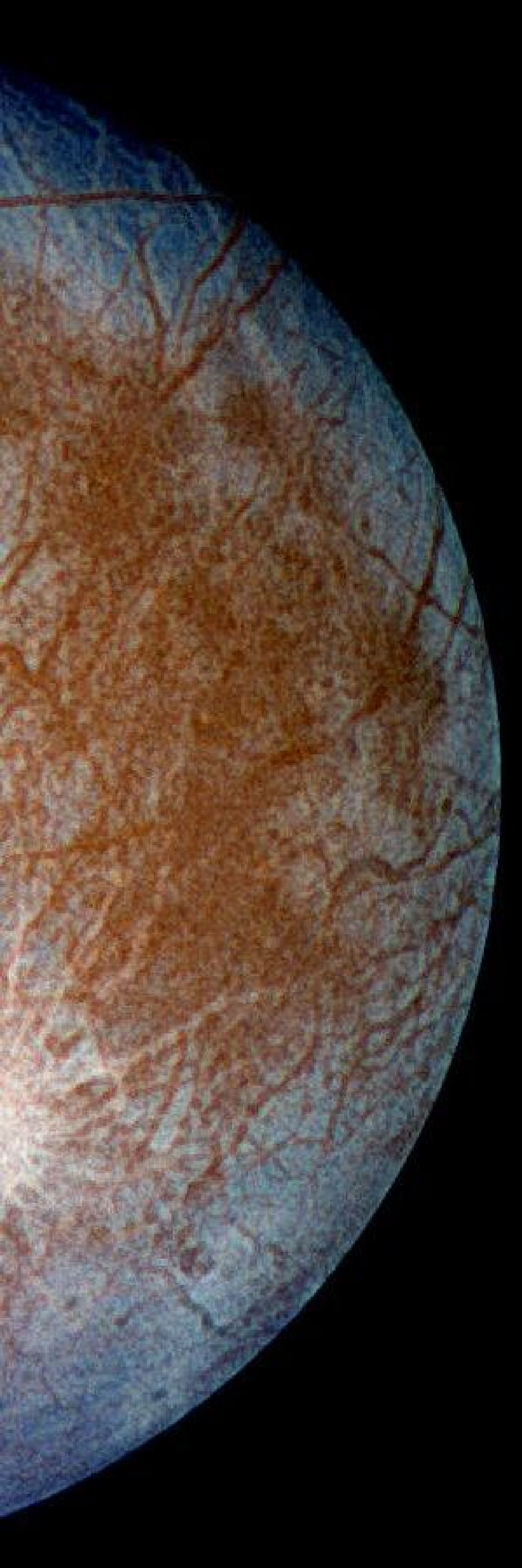
Predicting Human Brain Activity Associated with the Meaning of Nouns



Mitchell et al., 2008



References

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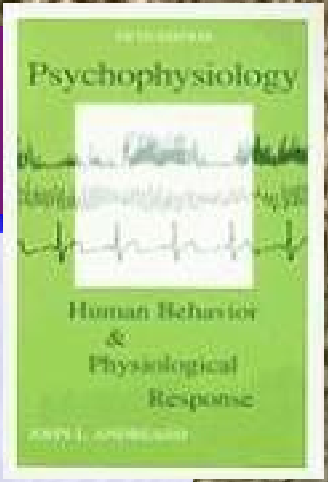
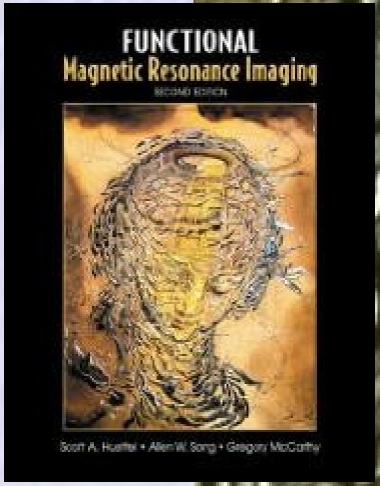
References: Subject-object ambiguities

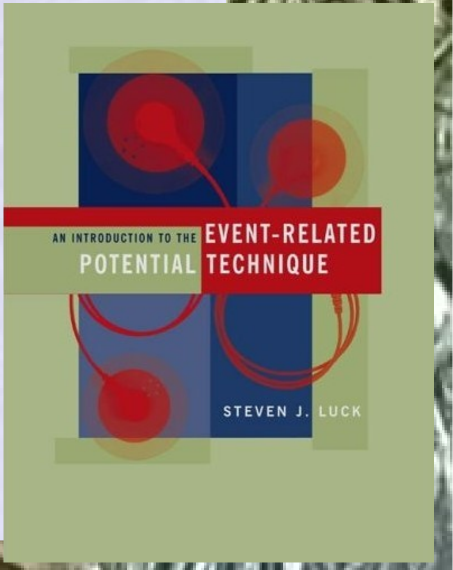
- Schlesewsky, M., Bornkessel, I., 2006. *Context-sensitive neural responses to conflict resolution: Electrophysiological evidence from subject-object ambiguities in language comprehension*
- Sturt, P., Crocker, M.W., 1996. *Monotonic syntactic processing: a cross-linguistic study of attachment and reanalysis*
- Friederici, A.D., 1998. *Diagnosis and reanalysis: two processing steps the brain may differentiate*

References: books

- Andreassi, J.L. 2006. *Psychophisiology: Human Behavior and Physiological Response*
- Huettel, S.A., Song. A.W., McCarthy, G. 2009. *Functional Magnetic Resonance Imaging*
- Steven, J.L. 2005. *An Introduction to the Event-Related Potential Technique*







References

- Grodzinsky, Y., Friederici, A.D. 2006. *Neuroimaging of syntax and syntactic processing*
- Mitchell et al. 2008. *Predicting Human Brain Activity Associated with Nouns*
- *Kutas, M. & Hillyard, S.A. 1980. Reading senseless sentences: Brain potentials reflect semantic incongruity*
- Rugg, M. D. 1990. *Event-related brain potentials dissociate repetition effects of high- and low-frequency words*