FLST: Cognitive Foundations

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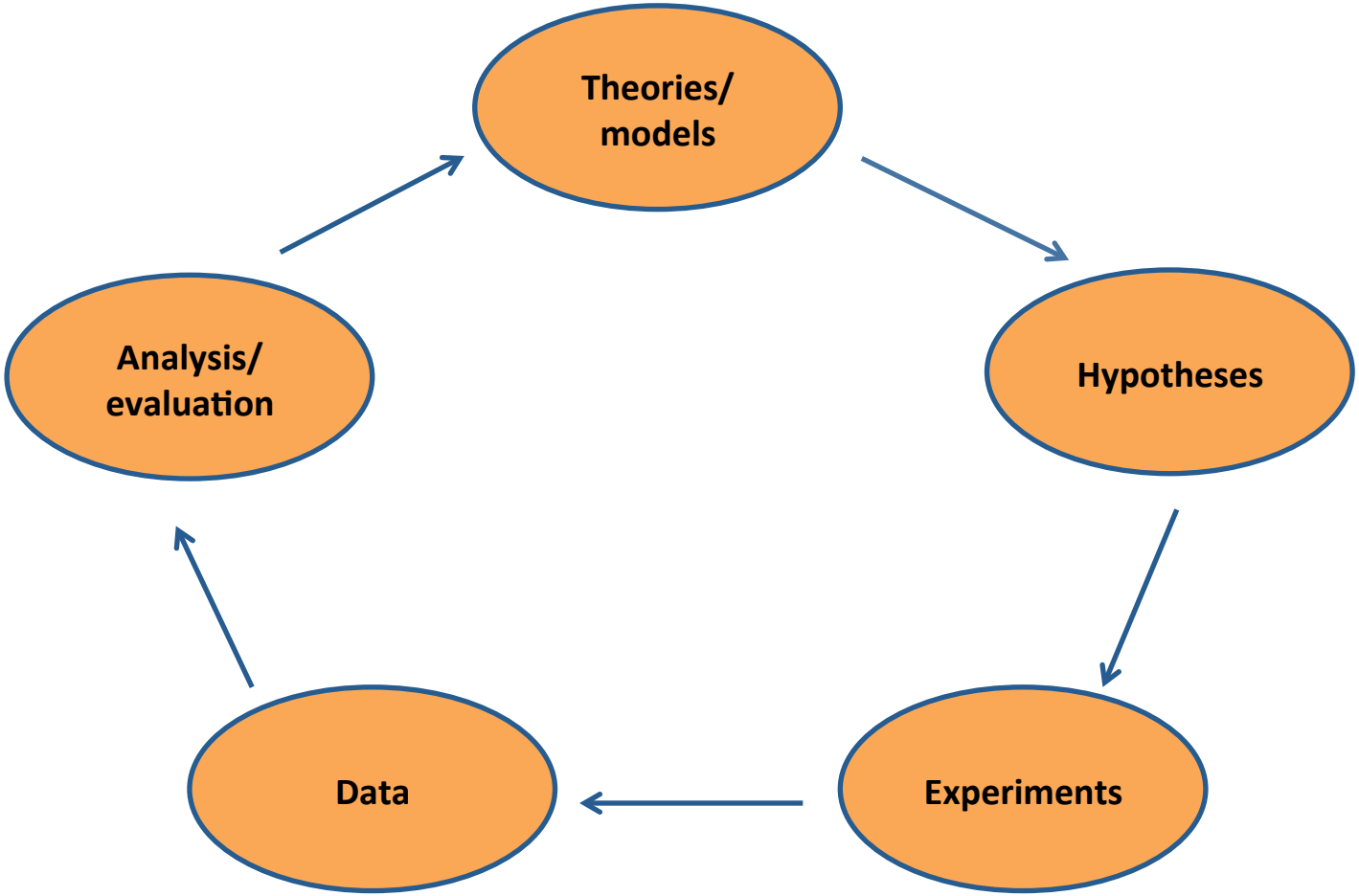
http://www.coli.uni-saarland.de/courses/FLST/2014/

Schedule

Experimental research in psycholinguistics

- Today
  - Experimental methods in psycholinguistic research
- Wednesday
  - Principles of experimental design
  - Basic statistics for data analysis
- Monday
  - Tutorial

The Research Cycle



Language processing

- Language processing is rapid and largely automatic
  - People understand language at a rate of about 300 words per minute
  - Lexical retrieval, syntactic parsing and semantic interpretation all occur in a matter of a few hundreds milliseconds
  - Time is important!

- Language processing is incremental (it occurs word-by-word)
  - How are local and global ambiguity resolved?
  - How are interpretations revised?
  - What sources of information are used?

What is an experiment?

- Given a hypothesis, a few, selected factors are varied (or *manipulated*) to observe their influence on some outcome
  - Anything else that could influence the outcome is kept constant or otherwise controlled
- What is manipulated is called **independent variable**
  - E.g., Whether or not ink color matches word meaning
- What is measured is called **dependent variable**
  - Accuracy, reaction time, etc. → depend on which experimental method we use

Research methods in psycholinguistic

Offline paradigms/methods

- Measure variables reflecting *the outcome* of processing
  - E.g., comprehension questions → interpretation

Online paradigms/methods

- Measure variables that tap into language processing *as it happens.*
  - E.g., reading times → if and *when* interpretations are revised

- On-line and off-line techniques can complement each other => time-course of processing + outcome of processing

Some off-line techniques

- Comprehension questions
  - *Accuracy*
- Rating studies (e.g., Plausibility judgment task)
  - *Measured on a scale (definitely implausible → definitely plausible)*
- Cloze task
  - *Cloze probabilities: proportion of people who provide a certain word as a completion for a fragment sentence*

Christianson, Hollingworth, Halliwell, Ferreira (2001) *Cogn Psychol. (42)*

- ***Garden path***
  While Anna dressed the baby that was small and cute spit up on the bed.

  ➔ 57% incorrect “yes” responses

- ***Control***
  While Anna dressed, the baby that was small and cute spit up on the bed.

  ➔ 11% incorrect “yes” responses

- ***Question***
  Did Anna dress the baby?

- People simultaneously maintain the temporarily ambiguous NP (*the baby*) as both the patient of the subordinate clause verb (*dressed*) and as the agent of the matrix verb (*spit*)

Online methods

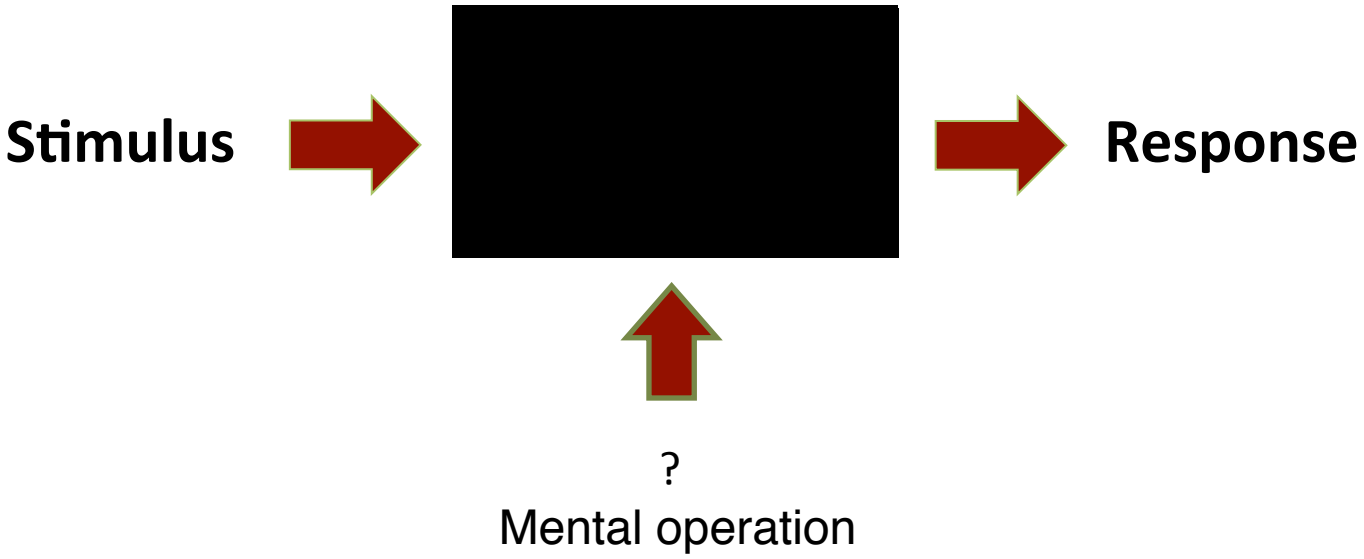
Seek to answer three questions:

- When?
  - When is something happening?
- What?
  - What is happening?
- Where?
  - Where in the brain is it happening?

Online methods

- Behavioral methods
  - Lexical decision, priming, eye-tracking, self-paced reading, visual world, picture naming, etc.
- Electrophysiological methods
  - Electroencephalography (EEG), Magnetoencephalography (MEG)
- Neuroimaging methods
  - Functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), and others

Why behavioral?



Stimulus/response/task

- **Stimulus**: a sensory event
  - Visual or auditory stimuli (words, sentences, pictures)
  - A combination of the two (pictures + spoken language)

- **Task**: the way participants are asked to respond to stimuli, e.g.
  - Read and press a button to proceed (self-paced reading)
  - Name the color of the ink

- **Response**: what is measured, e.g.,
  - time taken to press the button - reaction time (**RT)**
  - fixation latency, position, etc. – reading time, proportion of fixation

What can be inferred?

- To infer something about the mental processes, we need a **linking hypothesis**
  - How do mental processes map onto observed behavior?
- Assumption in behavioral research: the complexity of the mental process is reflected in the response latency
- Assuming that mental operations take time,
  - A more difficult mental operation will take more time
  - If more more steps are needed, they will take more time

Behavioral methods in written language comprehension

- Lexical decision, Priming techniques
  - Investigate Mental lexicon
- Self-paced reading
  - Syntactic, semantic, pragmatic processing
- Eye-tracking
  - Syntactic, semantic, pragmatic processing

Lexical decision task

- **Stimuli**: Words flashing on a computer screen

- **Task**: say whether the word is a real word or a non-word by pressing the appropriate button

- **Dependent variables** (what is measured):
  - Response latency = how long it takes the subject to decide if the string is a real word or a non-word
  - Response accuracy = whether the subject is correct or not

Demo

http://www.intro2psycholing.net/experiments/visual/word_nonword/wnw_index.php

Lexical decision task

- The lexical decision task is employed to study the mental lexicon
  Some questions:
  - How do we access lexical entries (serial or parallel search)?
  - How is the lexicon structured?

- **Independent variables** (what is manipulated) can be:
  - Word vs. non-word → basic manipulation
  - Word frequency (e.g., low-medium-high)
  - Context (i.e. what other entries you've just accessed)
    - Phonological relatedness
    - Semantic relatedness
  - etc.

Priming techniques

Frequency effect

(Embick et al., 2001)

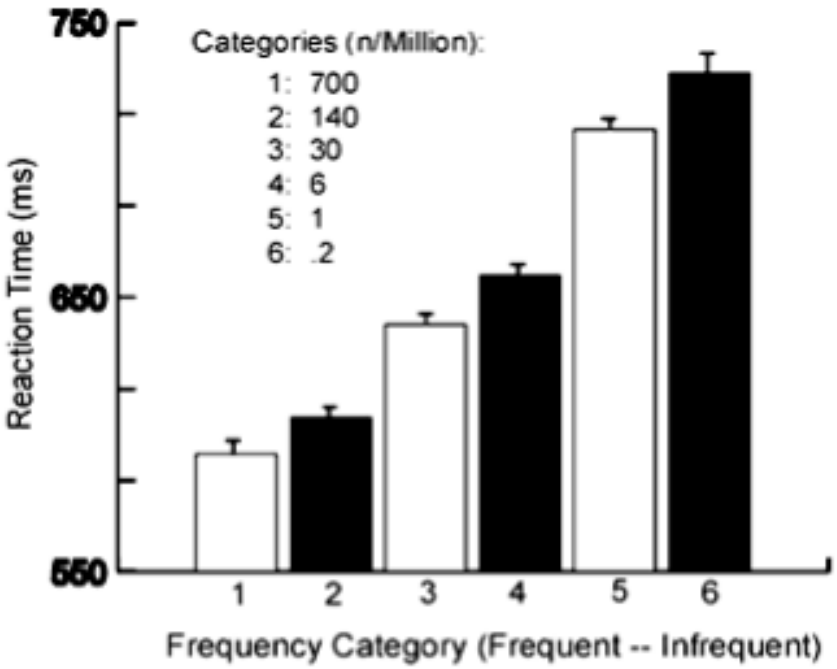


Fig. 1. Reaction time by frequency category (Mean and S.E.).

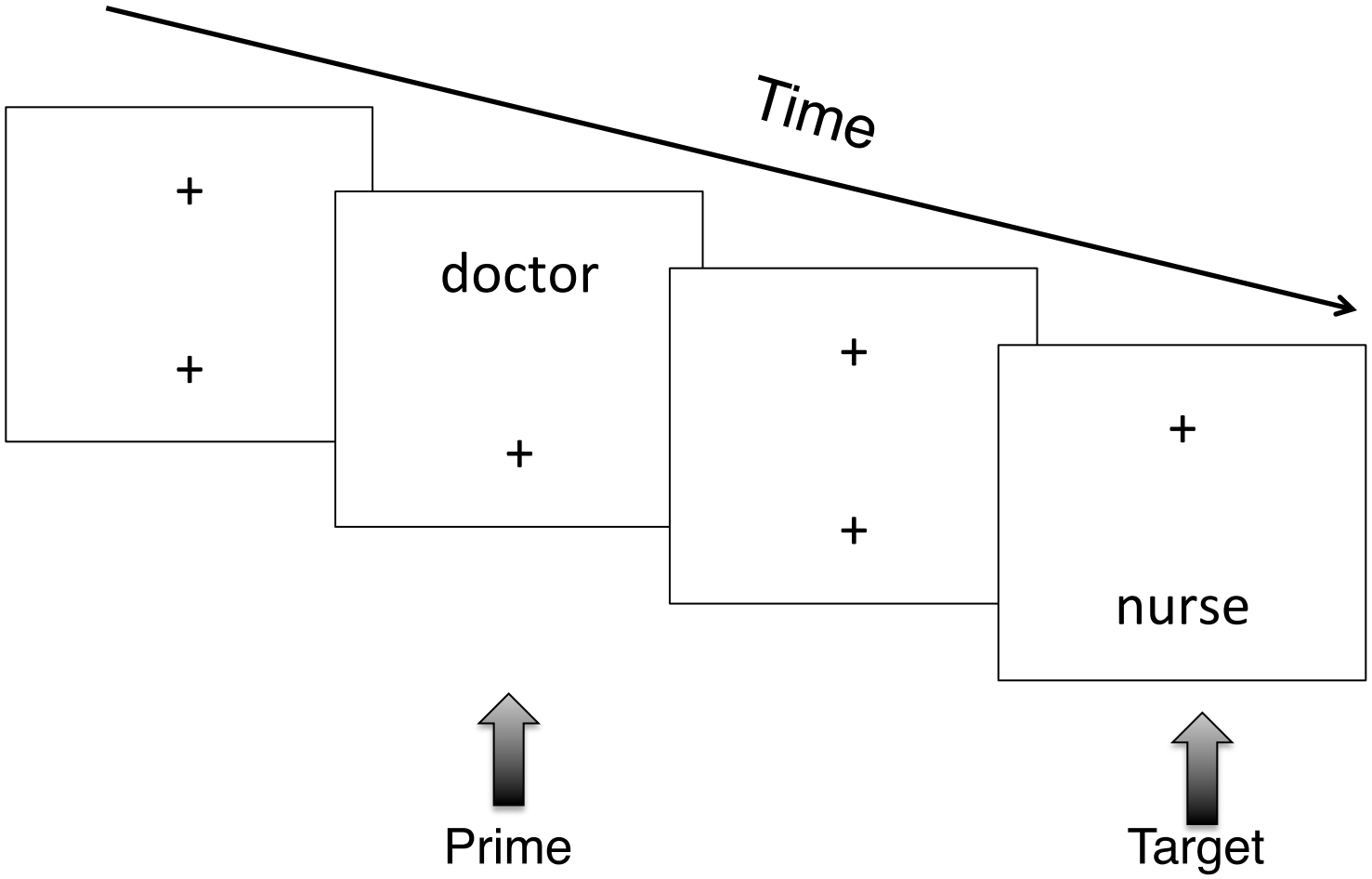
Linking hypothesis:

- RTs reflect time to access the mental lexicon
- The 'ease' of accessing a lexical entry depends on the level of activation in that entry prior to access
- Higher frequency words are more active than lower frequency words → faster RTs

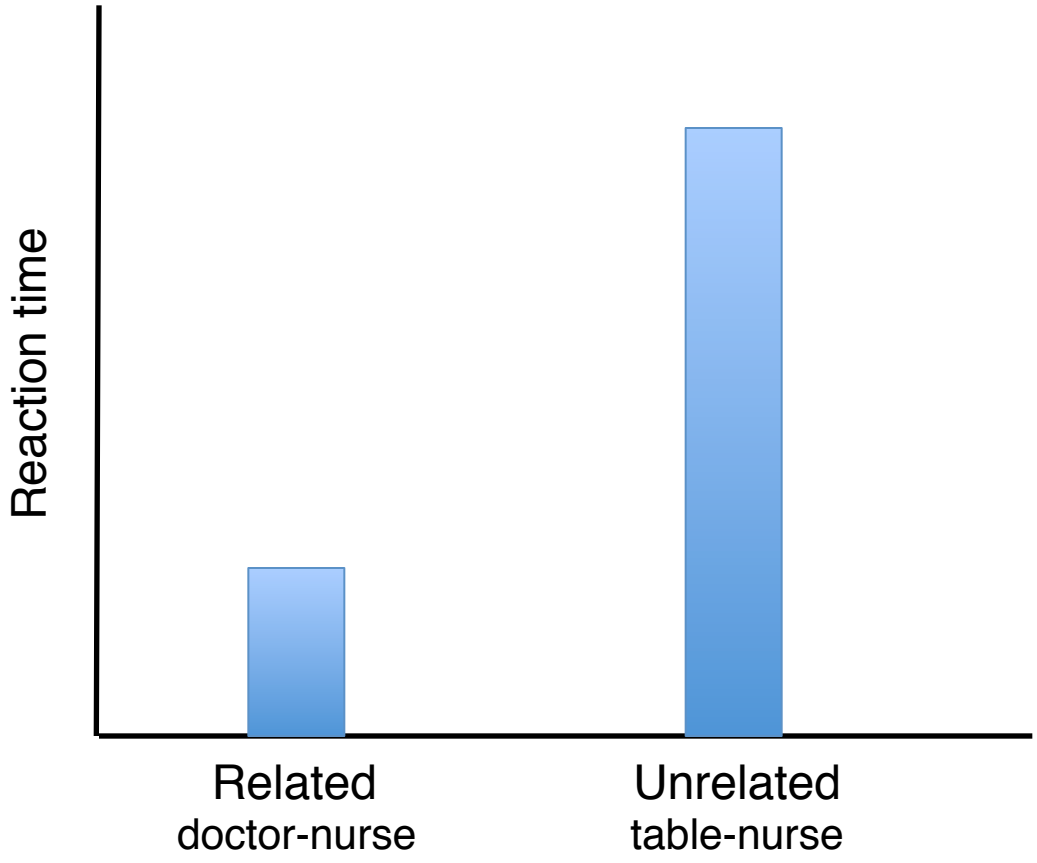
Priming techniques

- **Stimuli**: *prime* word and a *target* word presented serially
- **Task**: lexical decision on the target word
- **Independent variables (manipulated factors)** can be**:**
  - The type of relationship between prime and target (Semantic, phonological, orthographic, etc.)
  - Stimulus Onset Asynchrony (SOA) → the time between the onset of the prime and the onset of the target
  - The degree to which the prime reaches awareness (Masked priming)
- **Dependent variables**: Response latency and accuracy

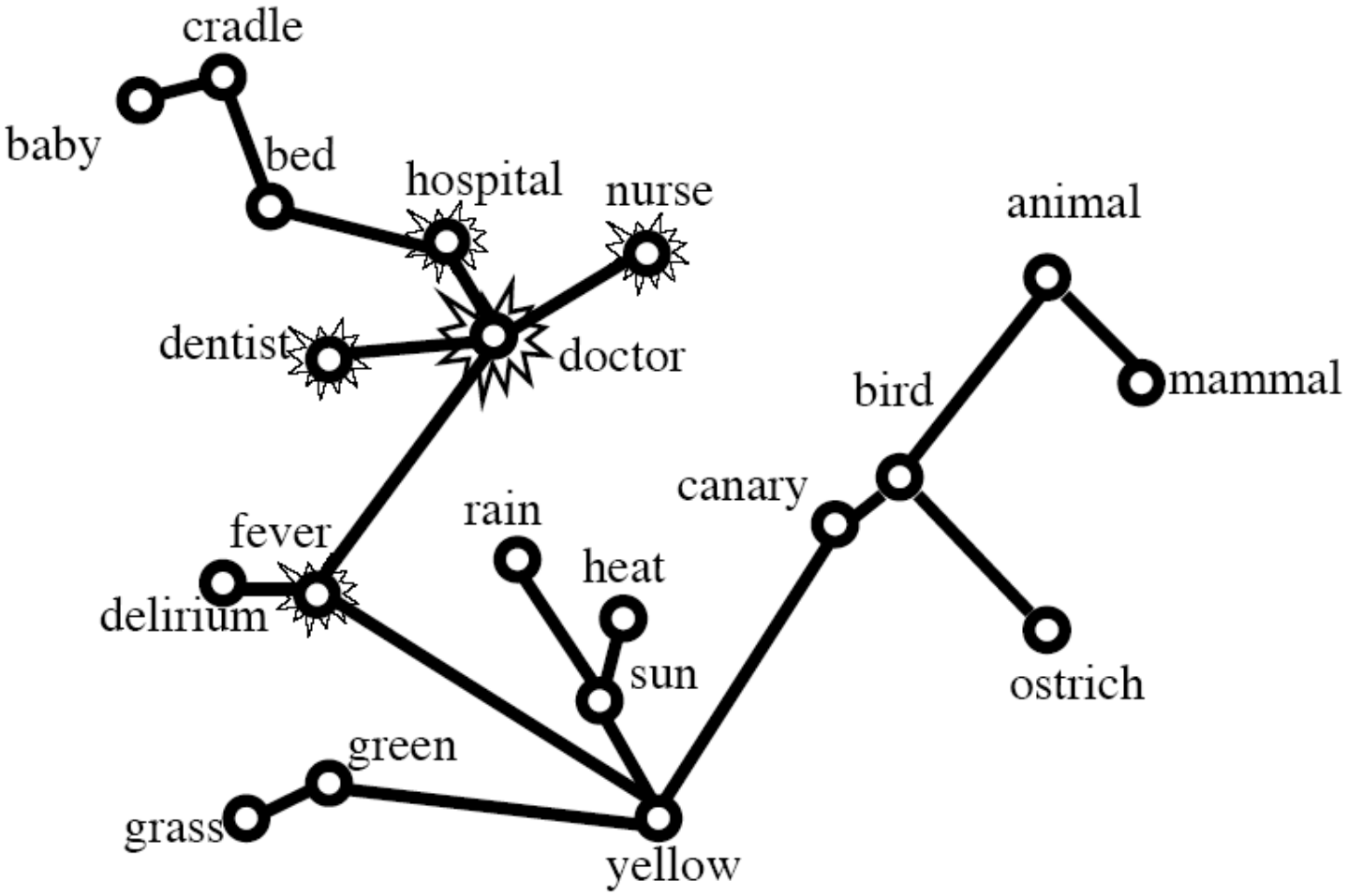
Semantic priming



Semantic priming effect



Spreading of activation model



Behavioral methods in written language comprehension

- Lexical decision, Priming techniques
  - Investigate Mental lexicon
- Self-paced reading
  - Syntactic, semantic, pragmatic processing
- Eye-tracking
  - Syntactic, semantic, pragmatic processing

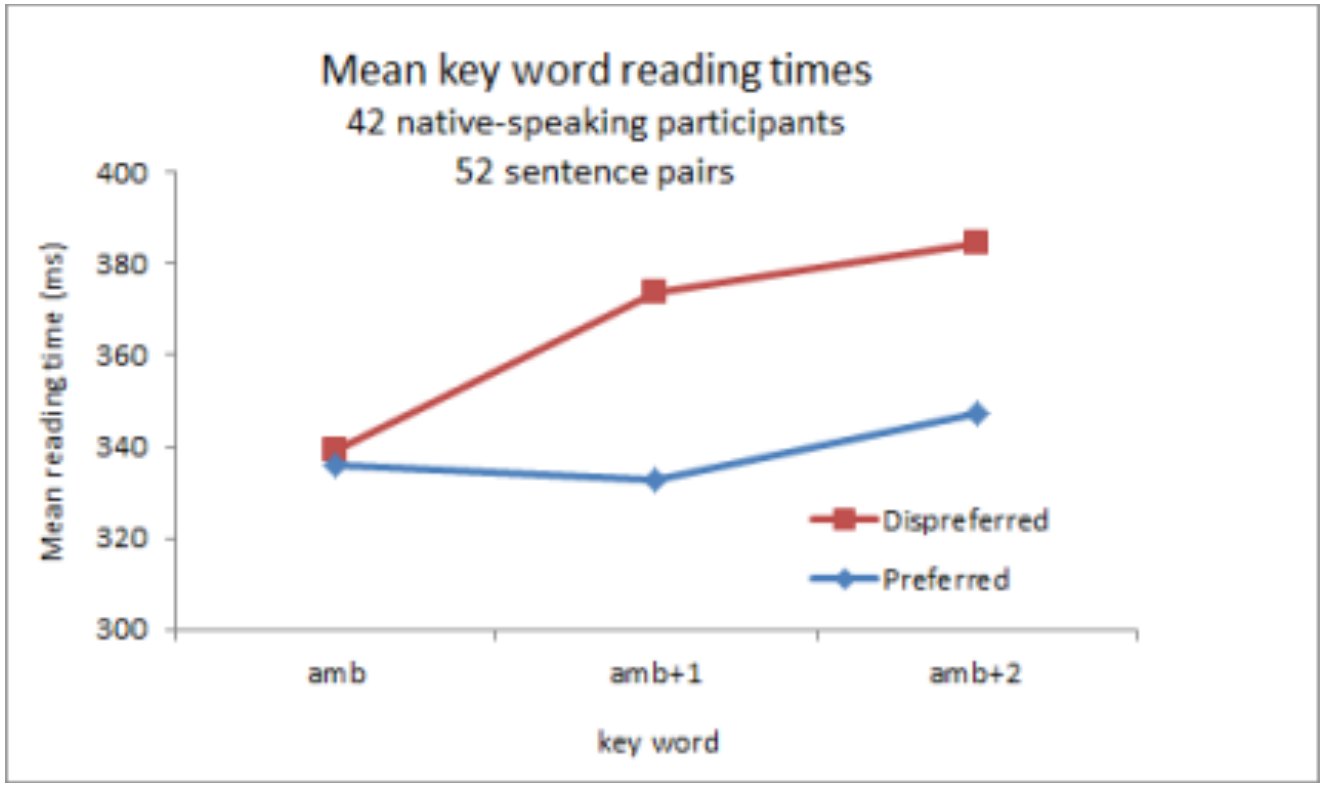
Self-paced reading

- **Stimuli:** Sentences presented word-by-word or phrase-by-phrase
- **Task:** The participant controls the rate of presentation of each word/ phrase (by pressing a button).
  - Additional tasks (off-line): comprehension questions (to check they are actually reading), plausibility judgments, etc.
- **Dependent variables**: The time between each press of the button
- **Linking hypothesis:** Longer RTs at particular positions in a sentence are thought to reflect processing difficulties.

Moving-window technique

- Most commonly used version of self-paced reading
- A sentence appears with all the words dashed out and the participant presses the space bar to see the first word/phrase.
- Another space bar press turns that word to dashes and reveals the second word, and so on.
- http://www.intro2psycholing.net/experiments/sentence_processing/self_paced/selfpaced_index.php

Results



….kids / **like Hannah** / **enjoy** / **playing**….
….kids / **like Hannah** / **because** / **she enjoys** …

Tracking eye-movements

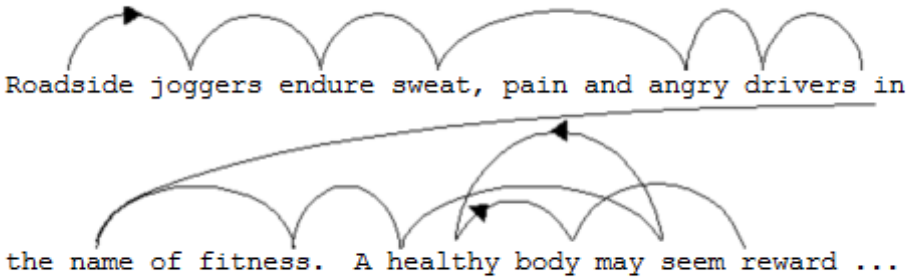
- Eye-tracking systems use video-cameras and an infra-red light source to record eye-movements and pupil dilatation with high temporal resolution (250Hz/500Hz)

- Using the movements of one's pupil and cornea reflection, the eye-tracker tracks the movement of one's eyes, which is then mapped into locations on the screen by calibration and adjustments for head movements.

- Eye-tracking provides detailed information about where people look and for how long

Eye-movements in reading

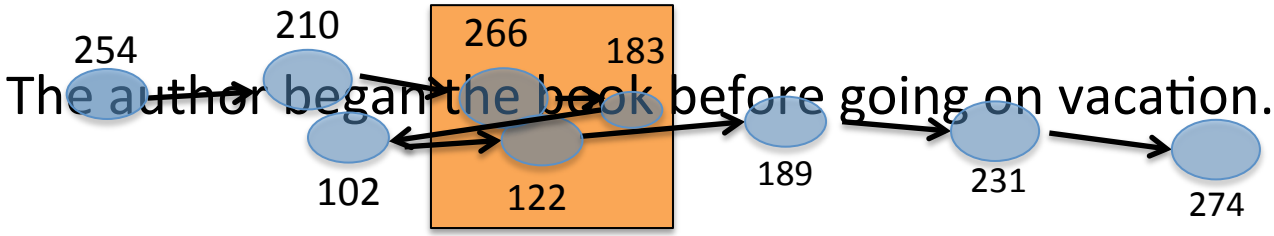
- We don't continuously move our eyes while reading. Eye-movements consist of:
  - Saccades (quick jumps, duration 25 to 45ms, 7-9 character spaces forward, vision suppressed)
  - Fixations (information extraction, mean duration 225-250ms)
  - Regressions → 10-20% of saccades



Eye-tracking in reading

- **Stimuli:** Whole sentences/texts
- **Task:** Just reading
  - Additional (offline) tasks: comprehension questions (to make sure they are reading), plausibility judgments, etc.
- **Dependent variables**: eye-movement measures

Reading measures



- First fixation duration = 266 ms
- First pass duration = 266 + 183 ms
- Regression path duration = 266 + 183 + 102 + 122 ms
- Second pass duration = 122 ms
- Total time = 266 + 183 + 122 ms
- Regressions out = 1 regression

Eye-movement measures

- First fixation duration
  - duration of first fixation in a region
- First-pass duration
  - time spent in a region before moving on or looking back
- Regression path duration
  - time from first entering a region until moving the eyes beyond that region, includes regression time
- Second-pass duration
  - duration of re-fixations
- Total time
  - sum of all fixations in a region
- Regressions out
  - proportion of regressions from a region following first-pass fixations

Linking hypothesis 1

- There is a close relationship between what the eyes are fixating and what the brain is processing
- Eye-mind hypothesis (Just & Carpenter, 1980)
  - There is no appreciable lag between what is fixated and what is processed → Readers retain fixation on a word until processing is completed
- Problem: do we perform word recognition, syntactic parsing, semantic integration, referential integration before moving eyes to the next word?

Eye-mind assumption?

- The effects of a manipulation are often visible after the critical word or region (spill-over effects)
- This suggests that processing of a word X continues while fixating word X + 1 (and possibly while fixating word X + 2 etc.)
- The eye-mind assumption is too strong

Linking hypothesis 2

Boland's (2004) linking hypothesis:

- The eyes do not leave a word until it has been structurally integrated (tree building)
  - Lexical access + constraints that control structure-building influence 'early measures' (first-fixation, first-pass reading time, first-pass regressions out)
  - Other measures (e.g., regression path duration, total reading times) are sensitive to higher level processes (semantic integration, discourse processes)

Eye-tracking vs self-paced reading

Eye-tracking

- Advantages
  - High temporal resolution
  - Less artificial
- Disadvantages
  - Interpretation of the different reading measures

Self-paced reading

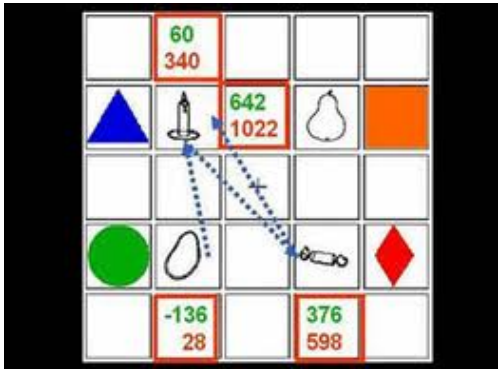
- Advantages
  - No skipped words
  - Blinking not problematic
- Disadvantages
  - Moving-window: development of expectations/predictions about incoming words
  - RTs include perception of the target + processing and programming the button press (slow RTs)

The visual world paradigm

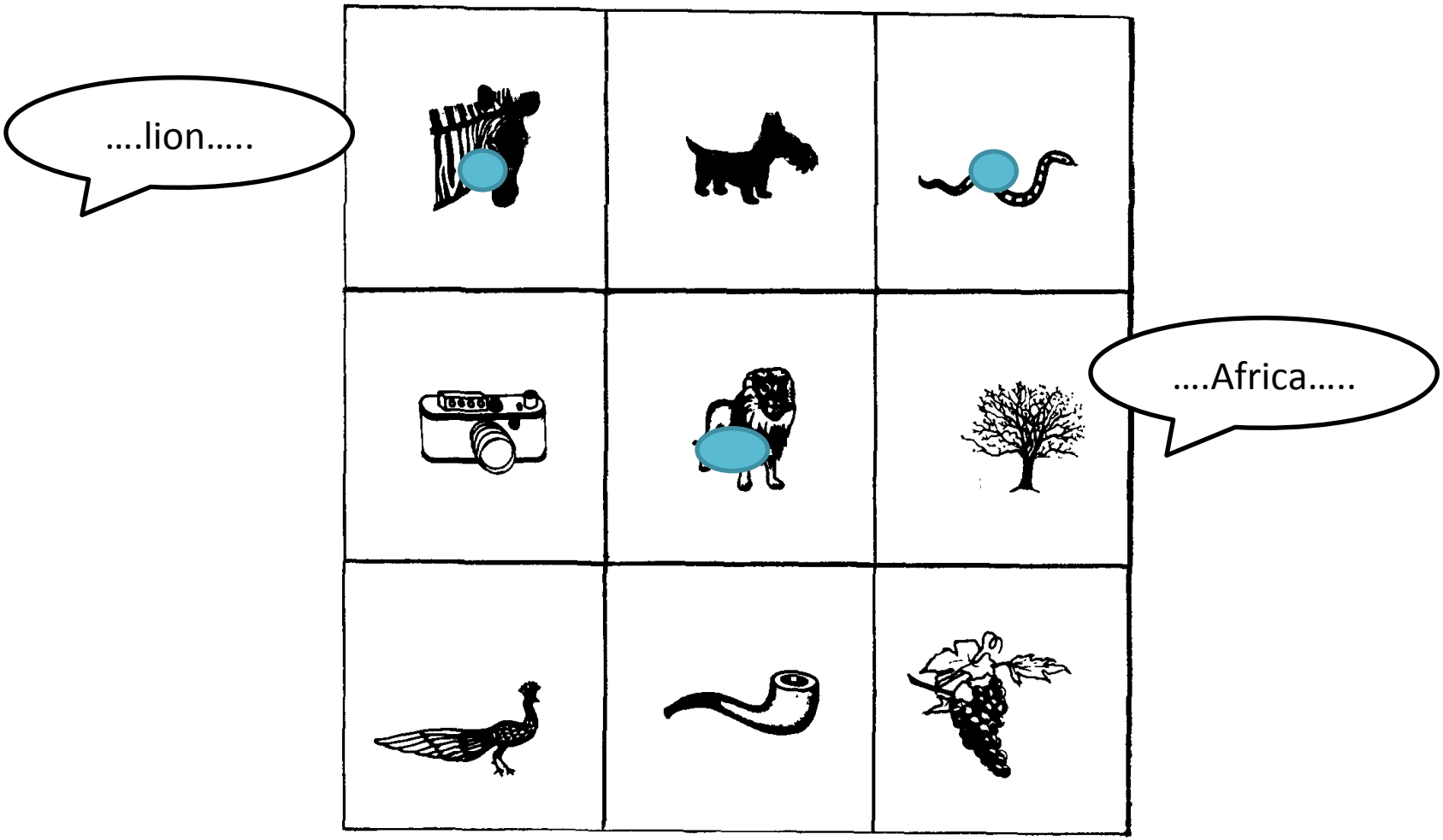
- **Stimuli**: objects or realistic scenes on the screen and spoken utterances/instructions played shortly after

- **Task**: looking at or manipulating objects in the visual scene

- **Dependent measure**: proportion of fixations on the objects in the scene



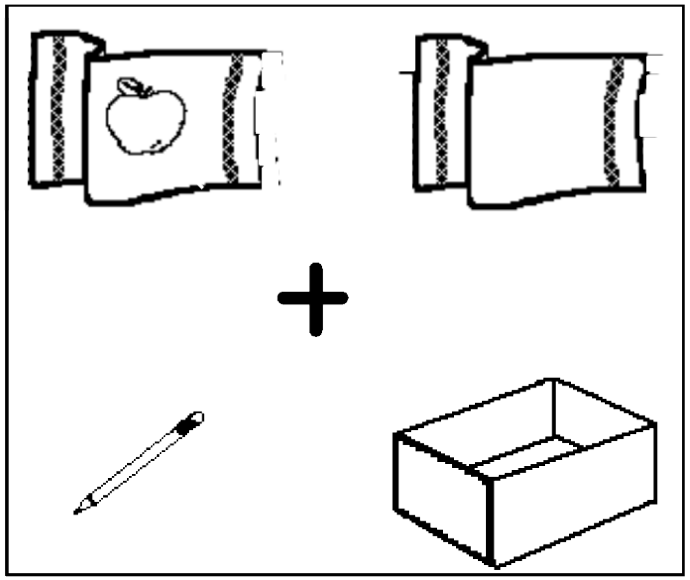
The first VW study: Cooper (1974)

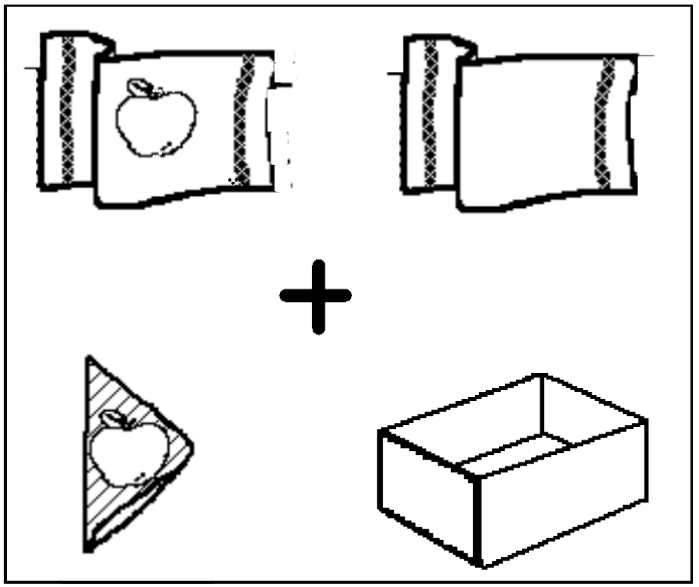


Cooper (1974)

- Around 55% of fixations were initiated *prior to word termination* (in a number of instances on the initial phonemes)
- Nearly 40% of post-word fixations occurred within 200ms following word termination
- Anticipatory looks to targets during adjectival modifiers, verbs, function words, etc…
- People spontaneously map language to the elements in the visual field most closely related to what they hear
- The visual world paradigm became “popular” only in the 90s

Tanenhaus at al. (1995)

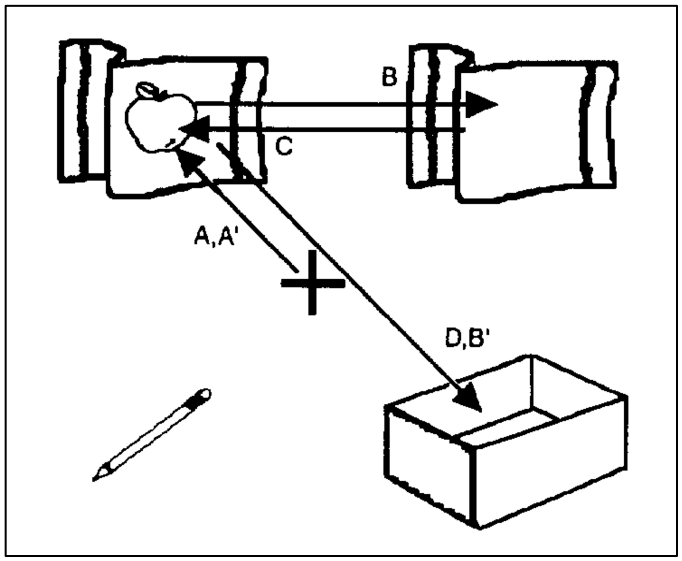


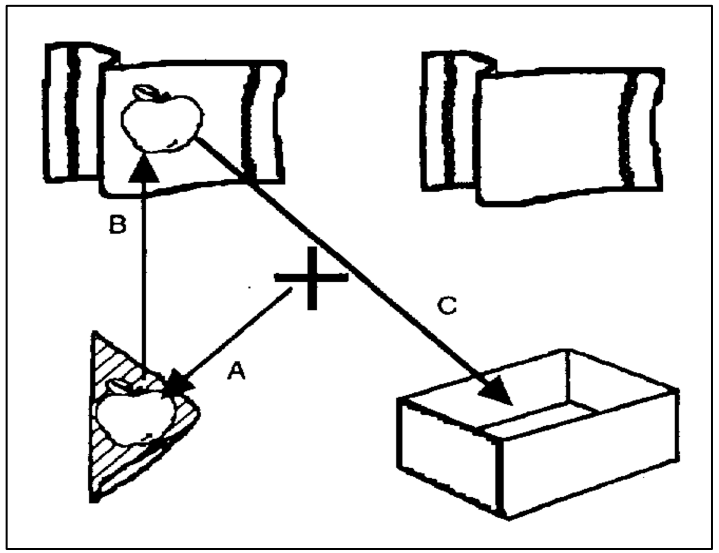


Put the apple on the towel in the box.

Tanenhaus et al. (1995)

Put the apple on the towel in the box.



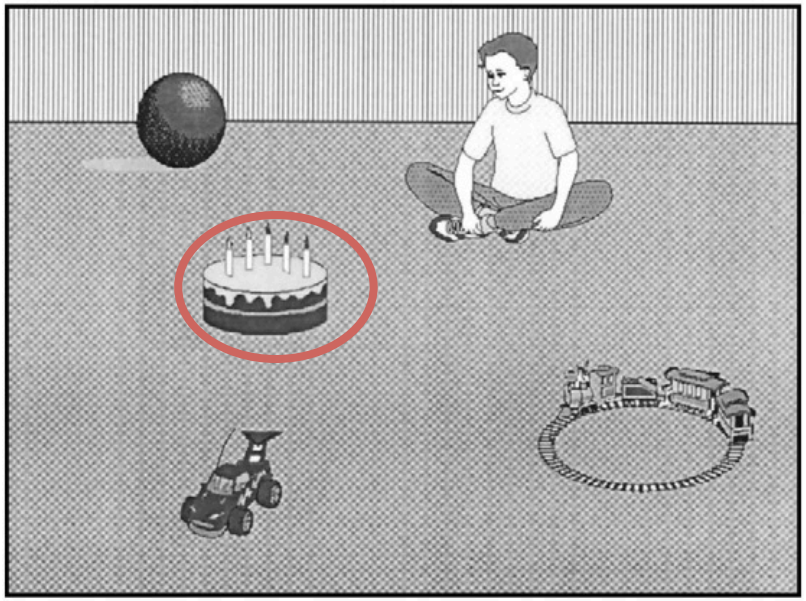


- PP interpreted as destination
- Garden path
- Structurally simplest analysis (consistent with serial models)

- PP interpreted as a modifier
- No garden path
- Extra-linguistic/visual information used during first stages → Consistent with constraint-based models

Altmann & Kamide, 1999

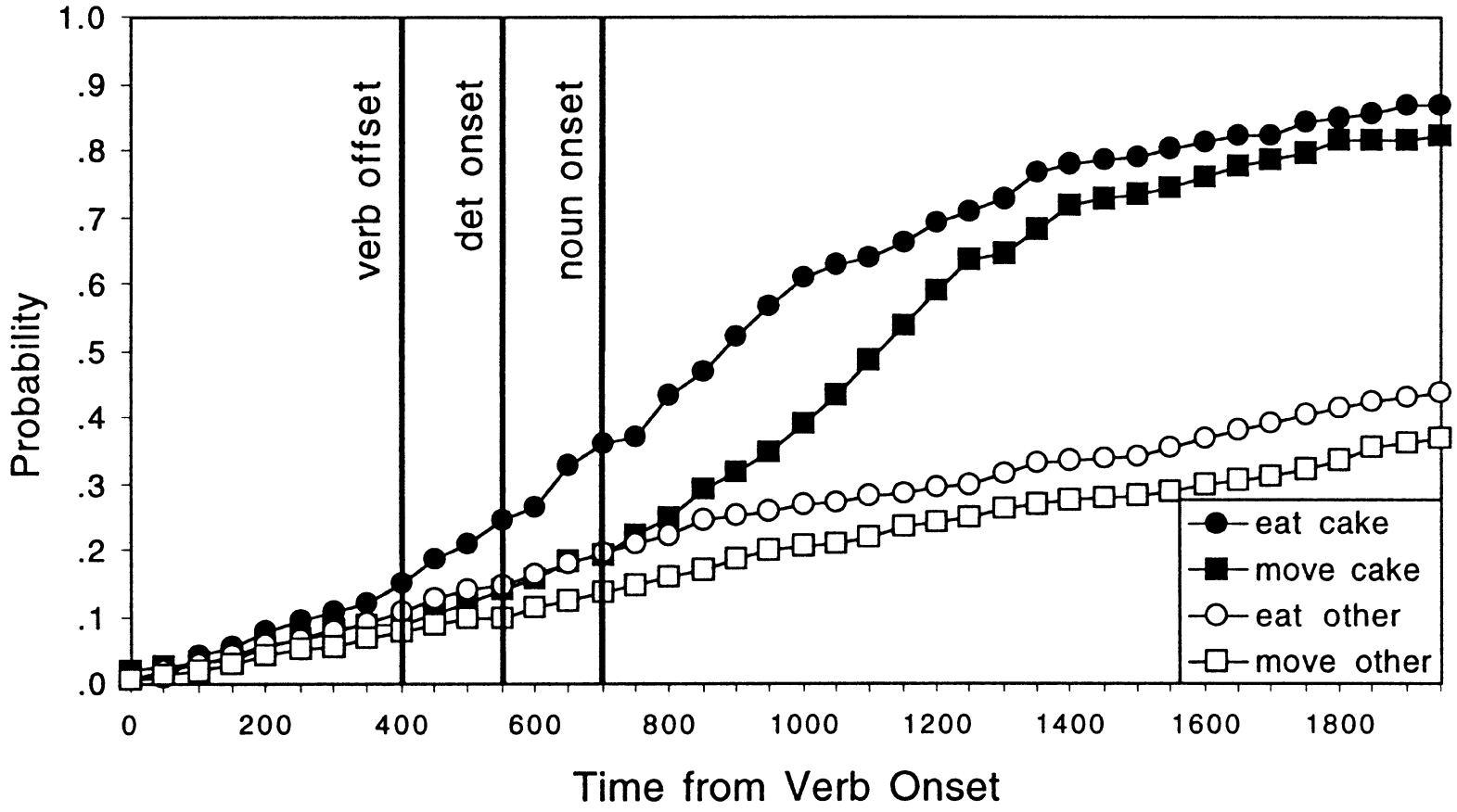
The boy will **move** / **eat** the cake



- People anticipate upcoming themes based on verb selectional restrictions

results

Probability of fixating the target object (cake) or a distractor object (other)



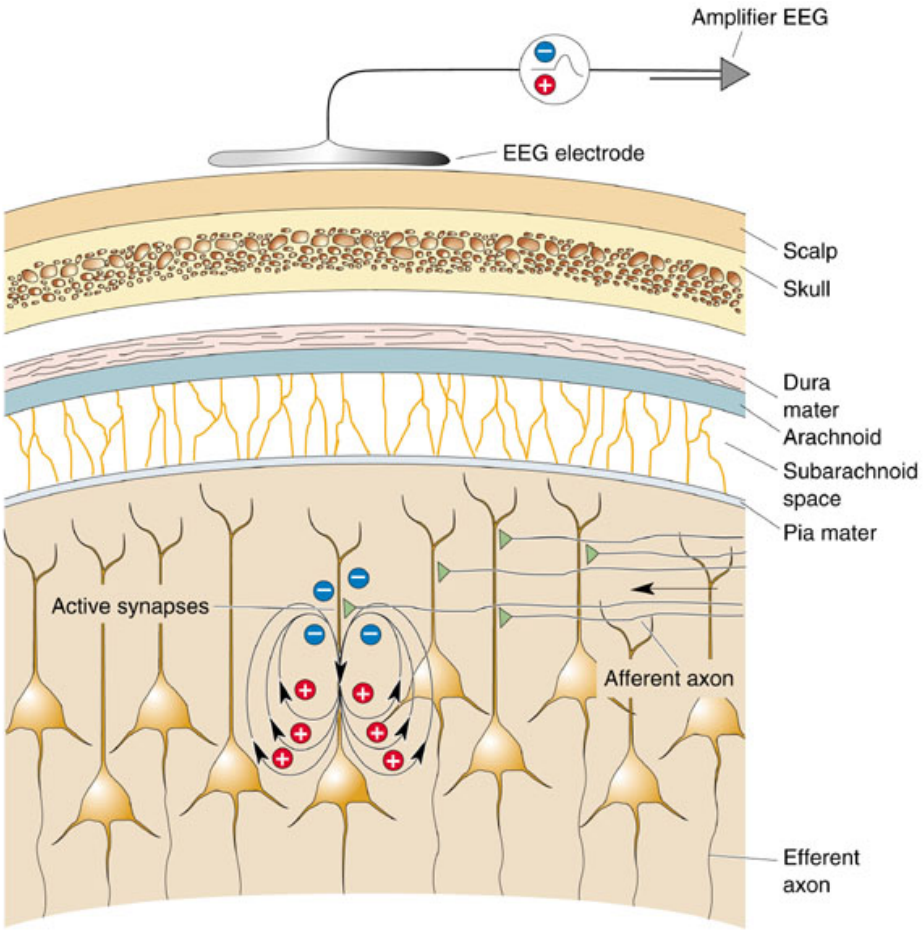
Linking hypothesis (Altmann & Kamide)

- Standard assumption: a shift in visual attention is followed by a saccadic eye movement to the attended region → Eye-movement is a measure of visual attention
- Language-mediated eye-movements reflect the interaction between visual and linguistic representations
- Language and vision are (partially) independent systems: we build a representation of the visual scene and a representation of the linguistic input
- When the two representations (partially) overlap, visual-linguistic interactions arise that are revealed by eye-movements patterns

Online methods

- Behavioral methods
  - Lexical decision, priming, eye-tracking, self-paced reading, picture naming, etc.
- Electrophysiological
  - EEG (ERPs), MEG
- Neuroimaging
  - fMRI, Pet

The neural origins of the EEG signal

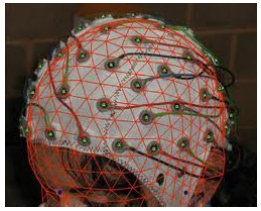


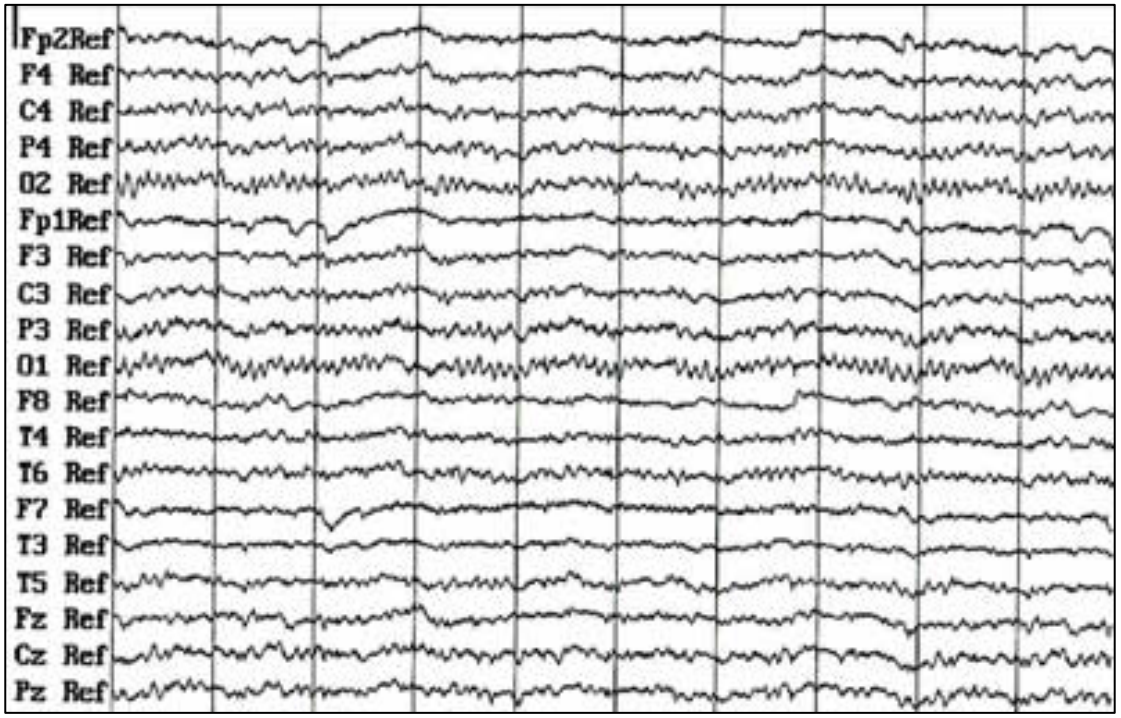
The electrical activity of neurons produces currents spreading through the head

These currents reach the surface of the scalp, in the form of voltage changes which can be measured non-invasively, using electrodes.

The voltage changes measured at the scalp are called the *Electroencephalogram* (EEG).

The EEG

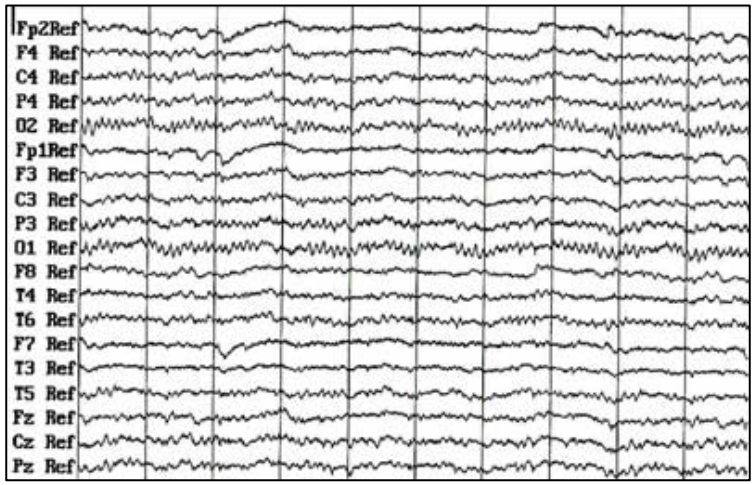




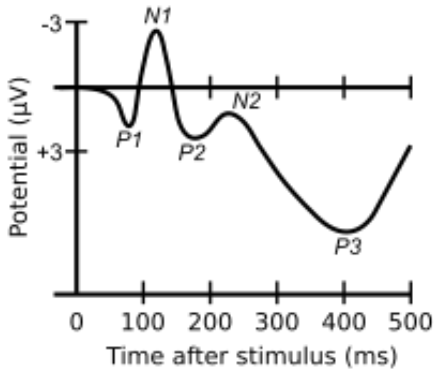
- Rapid voltage changes over time reflecting the electrical activity of large populations of neurons that fire simultaneously

From EEG to ERPs

- Spontaneous brain activity (EEG)

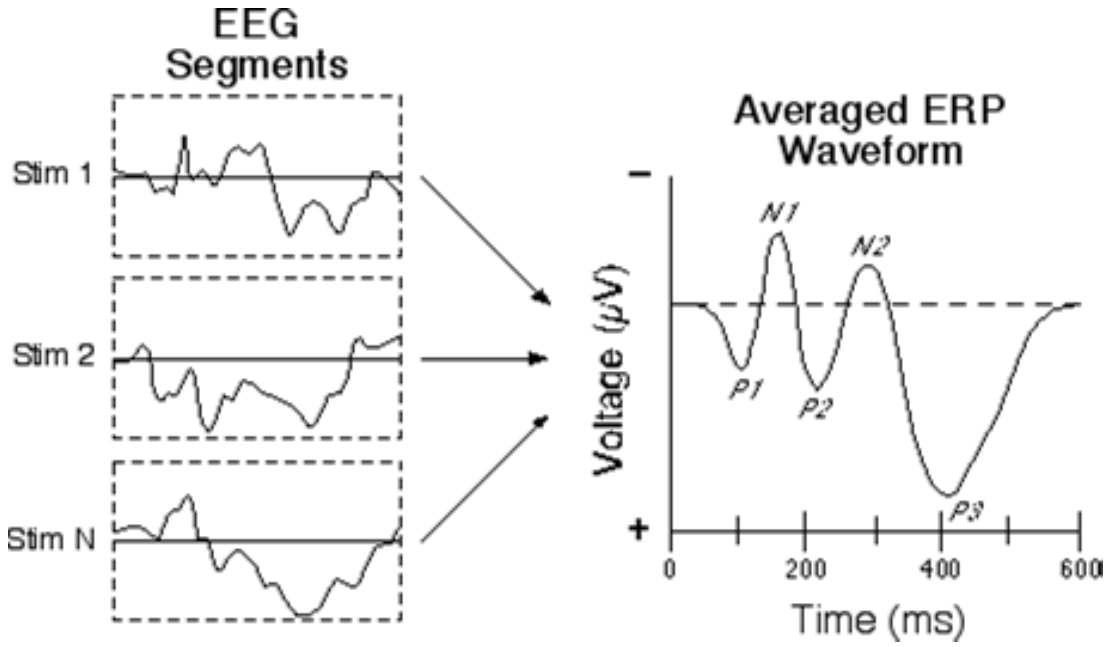


- Event-related potential (ERP)



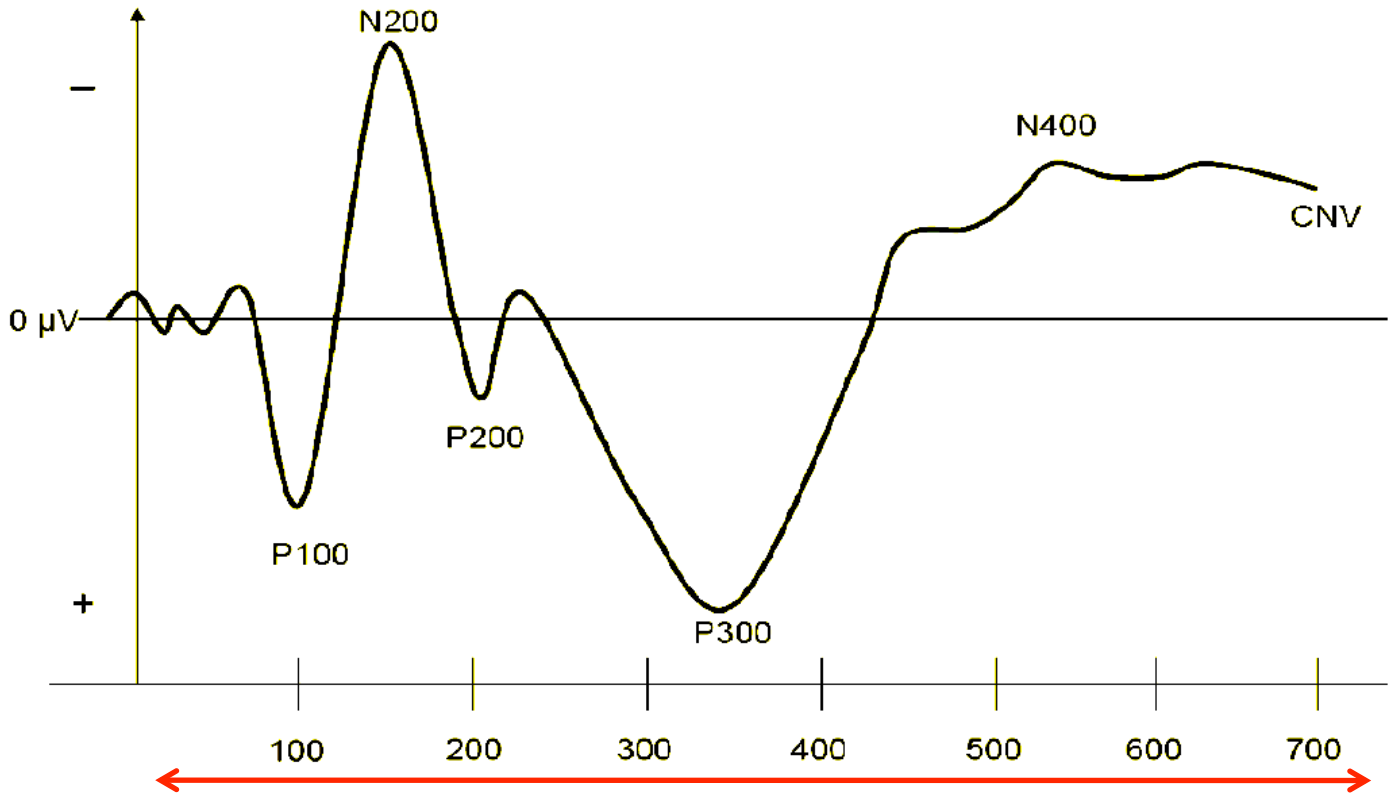
- ERPs are ‘extracted’ from EEG through an averaging technique

From EEG to ERPs



- By averaging several EEG segments time-locked to a stimulus, random background activity (noise) tends to zero and the average will approximate the signal (ERP)

ERP components

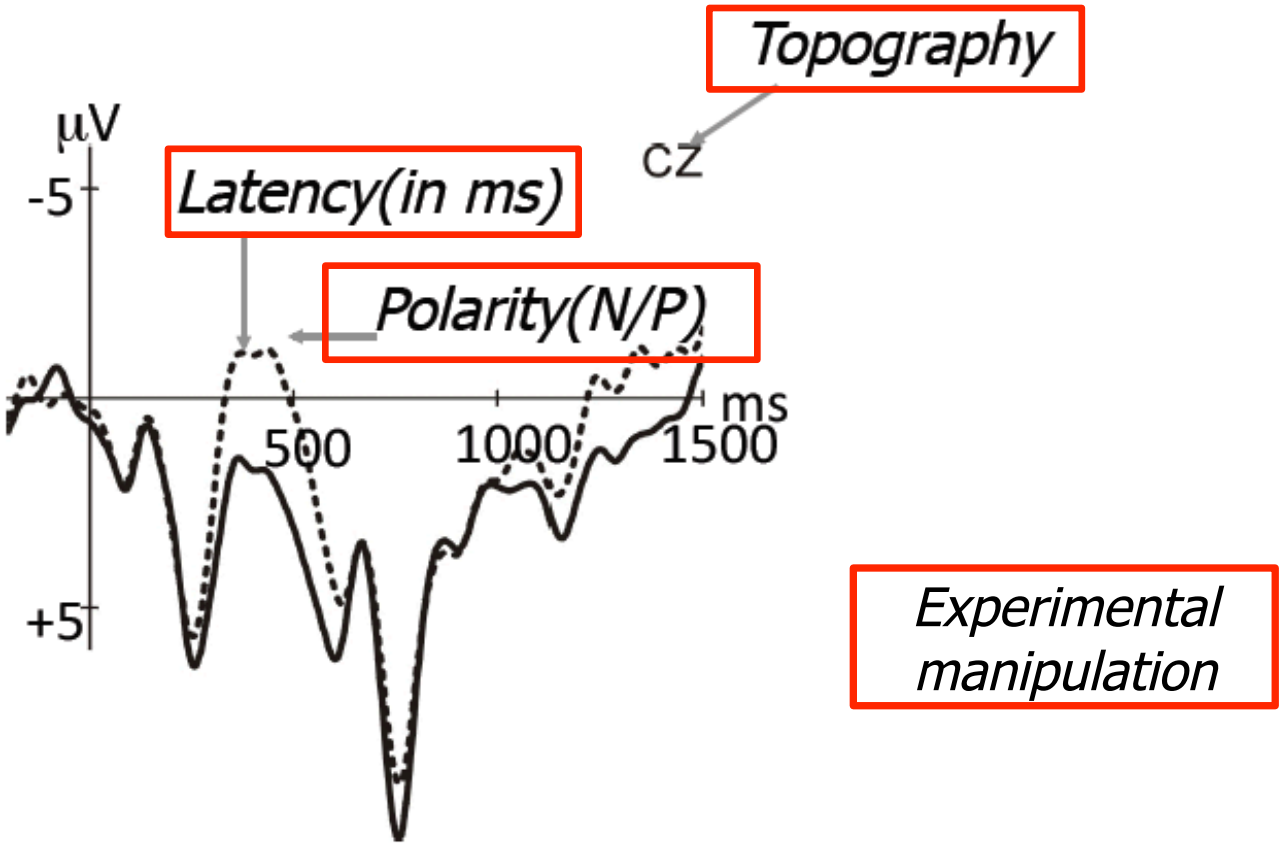


Exogenous (depending mainly on stimulus physical properties)

Endogenous (depending mainly on task and subject's state)

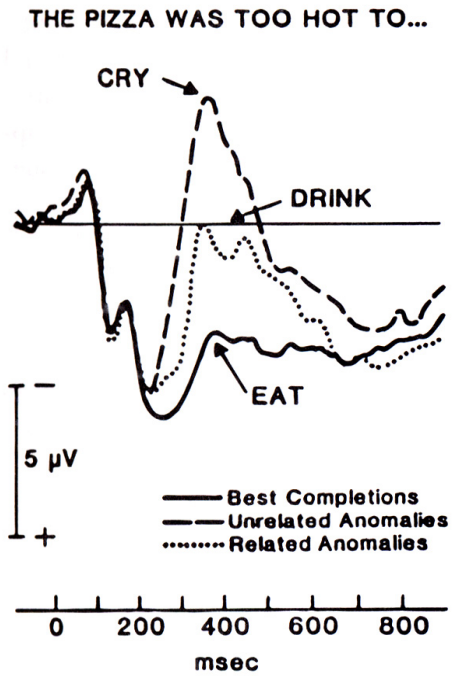
Describing ERP components

- ***P100, N200, N400, P600, …***



The N400

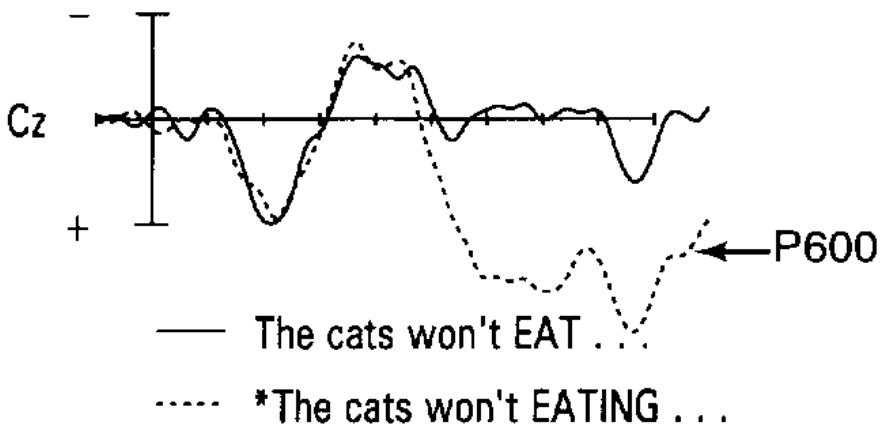
- Negative component peaking around 400ms post-stimulus onset, maximal over centro-parietal sites



- Thought to reflect aspects of semantic processing.
- Larger for semantically anomalous / unexpected words, etc.

The P600

- A positive component starting around 500ms post-stimulus onset, with a centro-parietal distribution.



- Thought to reflect aspects of syntactic processing (but 'semantic' P600s have been recently observed).
- Elicited by ungrammatical words / garden-path sentences…

What can be inferred?

- Different amplitudes suggest the same process (mental operation) is engaged at different degrees
  - The complexity of the operation

- Different components or distributions across the scalp suggest distinct neural patterns are engaged and possibly distinct cognitive processes performed

  - Information on ‘what’ is happening
  - ‘when’ is happening (high temporal resolution)

EEG Pros and Cons

☺ Temporal Resolution

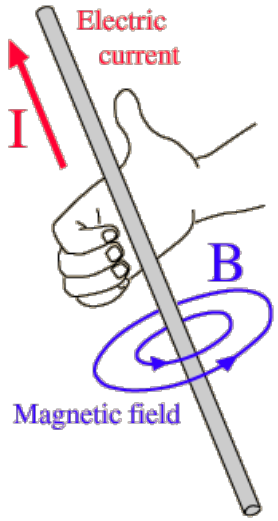
- Electrical signals travel at nearly the speed of light
- The voltages recorded at the scalp reflect what is happening in the brain at the same moment in time
- ~ 1 ms

☹ Spatial resolution

- Cerebrospinal fluid, skull and scalp smear the voltages recorded at the scalp
- It is difficult to localize the generator of the signal
- ~ 1 cm

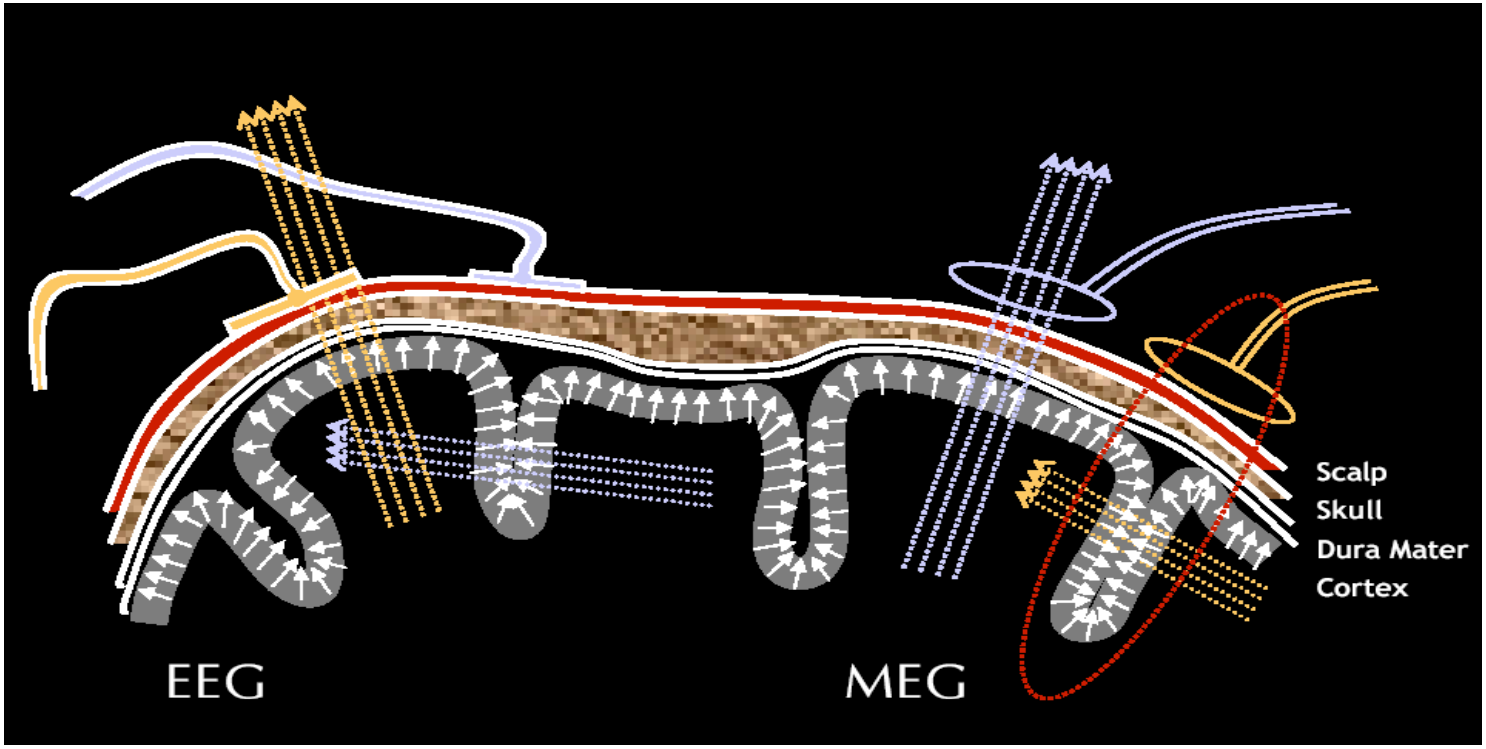
EEG & MEG

- **EEG** and **MEG** (Magnetoencephalography) are complementary techniques:
  - EEG measures electrical activity of the brain
  - MEG measures magnetic fields naturally generated by electrical activity
  - Magnetic fields form concentric circles around a straight current-carrying conductor



  - To find the direction of the magnetic field point the thumb in the direction of the current: the fingers will curl in the direction of the magnetic field (right-hand rule)

EEG vs. MEG



MEG

- Magnetic fields are measured by arrays of SQUIDs (superconducting quantum interference devices)
- SQUIDs are very sensitive magnetometers, able to detect extremely subtle magnetic fields
- The spatial distribution of magnetic fields is used to localize the neural sources

MEG - Spatial resolution

- The scalp and skull, which distort the electric potentials, are transparent for magnetic fields
- Spatial resolution is in the order of mm for cortical sources (less accurate for deep sources)
- However, given a magnetic field, estimating the current source that generates it has no unique solution (inverse problem)
  - Sophisticated source modeling techniques

EEG vs. MEG

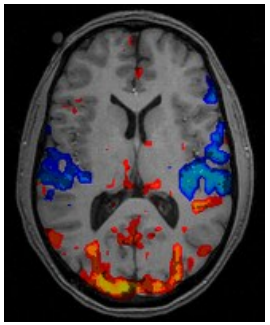
	EEG	MEG
Signal magnitude	Large signal (10 mV), easy to detect	Tiny signal (10 fT), difficult to detect
Cost	Cheap	Expensive
Signal purity	Affected by skull, scalp, etc.	Unaffected by skull, scalp, etc.
Temporal Resolution	~ 1 ms	~ 1 ms
Spatial Localization	~ 1 cm	~ 1 mm
Experimental design	Requires lots of trials	Requires lots of trials
Experimental Flexibility	Allows some movement	Requires complete stillness
Dipole Orientation	Sensitive to tangential and radial dipoles	Sensitive only to tangential dipoles

Online methods

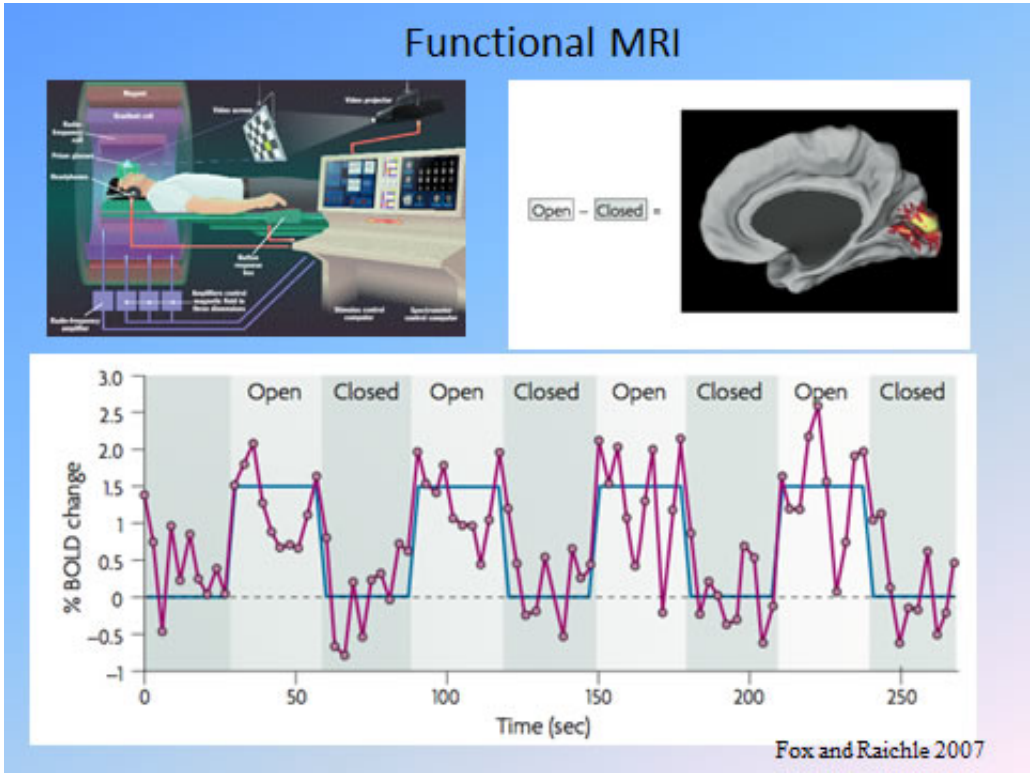
- Behavioral methods
  - Lexical decision, priming, eye-tracking, self-paced reading, picture naming, etc.
- Electrophysiological
  - EEG (ERPs), MEG
- Neuroimaging
  - fMRI, PET, etc.

fMRI

- Functional Magnetic Resonance Imaging (fMRI): uses MRI technology to measure brain activity
- Relies on the fact that neural activity requires O_2 which is carried by the blood
- When an area of the brain is in use, blood flow to that region also increases
- Measures changes in blood oxygenation (Blood Oxygenation Level Dependent (BOLD) signal) to determine which parts of the brain are most active



BOLD signal



- When a brain area is more active it consumes more oxygen
- To meet this increased demand blood flow increases to the active area
- The MRI scanner can measure this change in blood flow (the BOLD signal) and show precisely where the oxygenated blood is going

- fMRI can be used to produce activation maps showing which parts of the brain are involved in a particular mental process

fMRI Pros and Cons

☹ Temporal resolution

- BOLD response takes 2-3 seconds to rise above baseline and 4-6 seconds to peak
- Most FMRI studies have temporal resolution of the order of a few seconds

☺ Spatial Resolution

- Determined by voxels: Anatomical voxel= $(1.5mm)^3$; Typical functional voxel = $(4mm)^3$.
- Voxel is a small rectangular prism that is the basic sampling unit of fMRI.

Summary

Online methods seek to answer three questions:

- When is something happening?
  - Behavioral, EEG and MEG
- What is happening?
  - Behavioral, EEG, MEG
- Where in the brain is it happening?
  - MEG, fMRI