Lecture 8:
Sentence Processing

COGS 153

Terminology

- **Sentence processing**: the study of the processes by which readers / listeners understand the meaning of sentences.
- **Syntax:** the study of how sentences are constructed from words and phrases / how expressions can combine to form larger expressions
  - **Syntactic structure**: underlying structure of a sentence
  - The processes involved in constructing syntactic structures during language comprehension are commonly referred to as **parsing** (or syntactic processing)

Early models of sentence processing

- **Buffering**
  - Elements of a sentence are temporarily *stored* in a “memory buffer” for *later integration* at phrasal, clausal, or sentence boundaries
  - But there’s little empirical support backing up this idea

Kutas, DeLong & Smith, 2011

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- **Incremental processing**
  - Words are incorporated successively into the context of the sentence, as they are received and identified, with gradual buildup of meaning in the mind of the comprehender

Kutas, DeLong & Smith, 2011

The horse raced past the barn

The horse raced past the barn fell

“that” / “that was”

The horse raced past the barn fell

re-analysis!

“Garden Path” Sentences

lead (someone) down/up the garden path

idiom

informal

: to deceive (someone) **:** to cause (someone) to go, think, or proceed wrongly

> He believes the average consumer is being *led down the garden path* by the promises in advertisements.

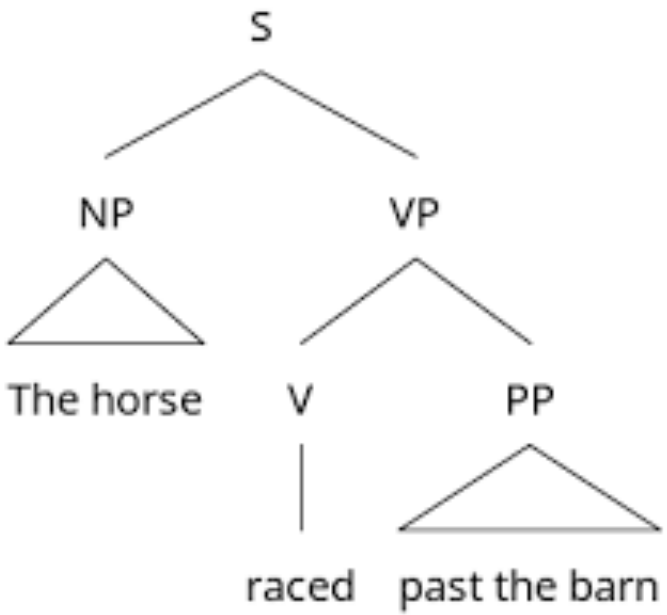
“Garden Path” Sentences

“The horse raced past the barn fell.”

- “Raced” is ambiguous until you get the word ”fell”
- main verb → incorrect parse
  - Committing to this interpretation will cause a problem when you get to the end of the sentence
- beginning of a reduced relative clause → correct parse

- (But garden path sentences are relatively rare)

The horse raced past the barn... fell



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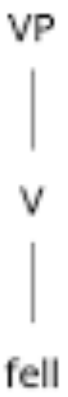
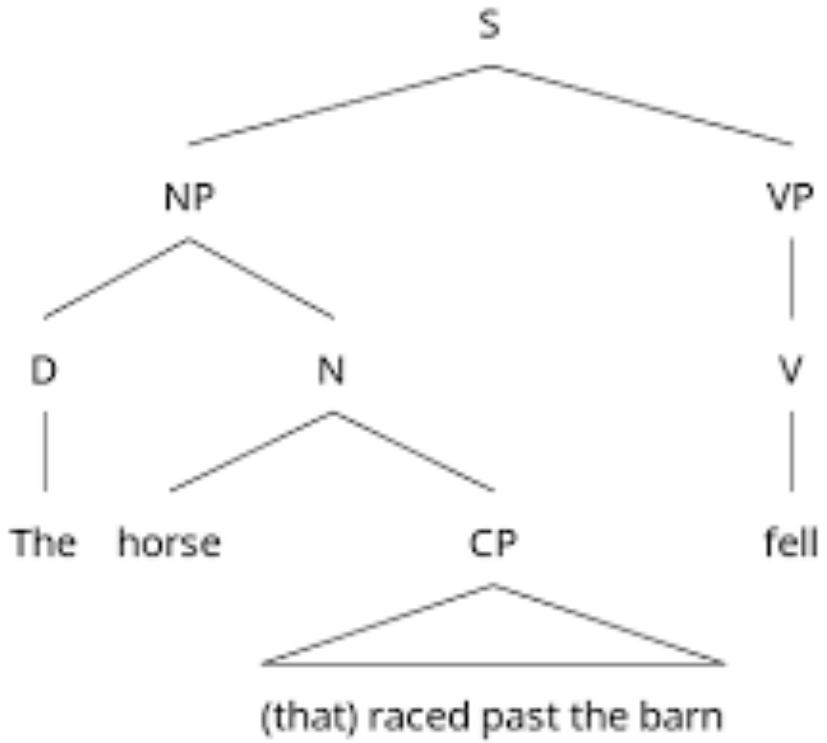




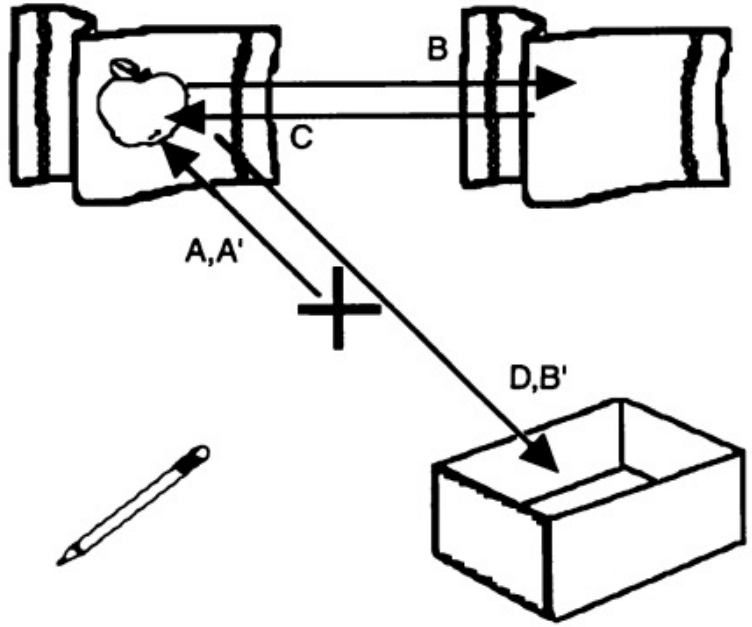
Models of sentence processing

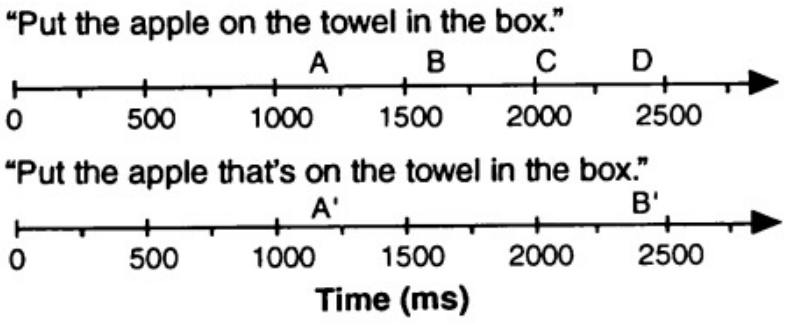
- **Garden path model**
- Proposes that the parser (your brain) constructs one parse (interpretation) and it's the simplest possible structure
  - Contextual and semantic factors influence processing *at a later stage,* which can lead to *re-analysis* of the syntactic parse
  - That re-analysis is costly and could explain the slowdown we see in garden path sentences
- Features of the model that try to explain what happens with ambiguous sentences:
  - **Late closure:** new words or phrases will be attached to the current clause
  - **Minimal attachment:** the parser builds the simplest syntactic structure possible

Frazier (1987)

Incrementality & online processing

- **Method**: eye tracking + *visual world paradigm*
  - Measure eye movements to see what participants look at when hearing language (real time/online measure of processing)
- **Procedure**:
  - Present syntactically ambiguous (or unambiguous) sentences
- **Results**:
  - "Put the apple on the towel in the box"
  - → looks to A B C D
  - "Put the apple that's on the towel in the box" -> looks to A' B'





Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995

Incremental processing at the syllable level

- **Method**: eye tracking + visual world paradigm
- **Procedure**:
  - Sentence participants hear: "Pick up the candle"
  - Independent Variable: *phonological competitor* present or absent in array
    - e.g., candle & candy or just candle
  - Dependent Variable: time it takes to look to target word
- **Results**:
  - No competitor: looked to the correct target 55ms before word ended
  - With competitor: looked to correct target 30ms *after* word ended

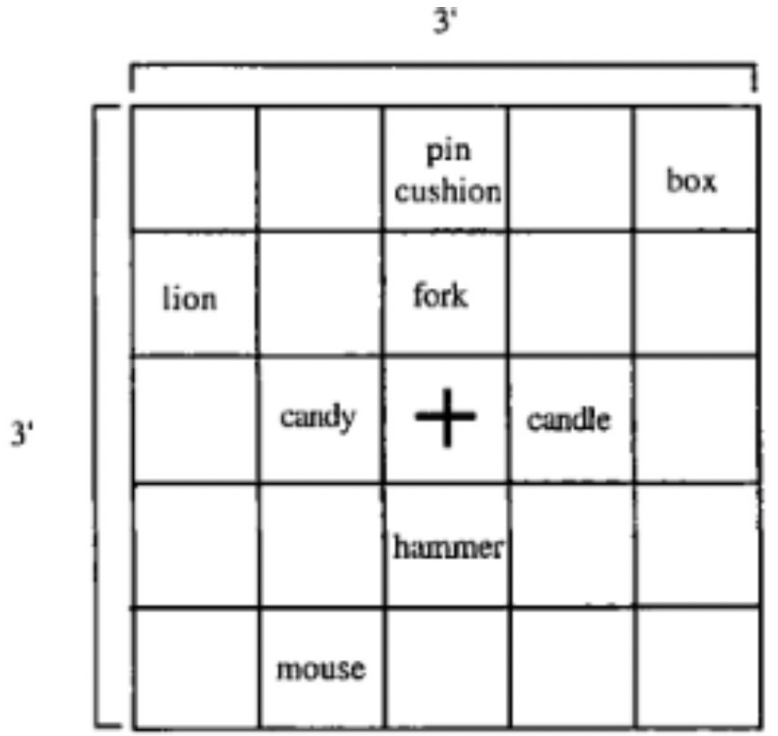
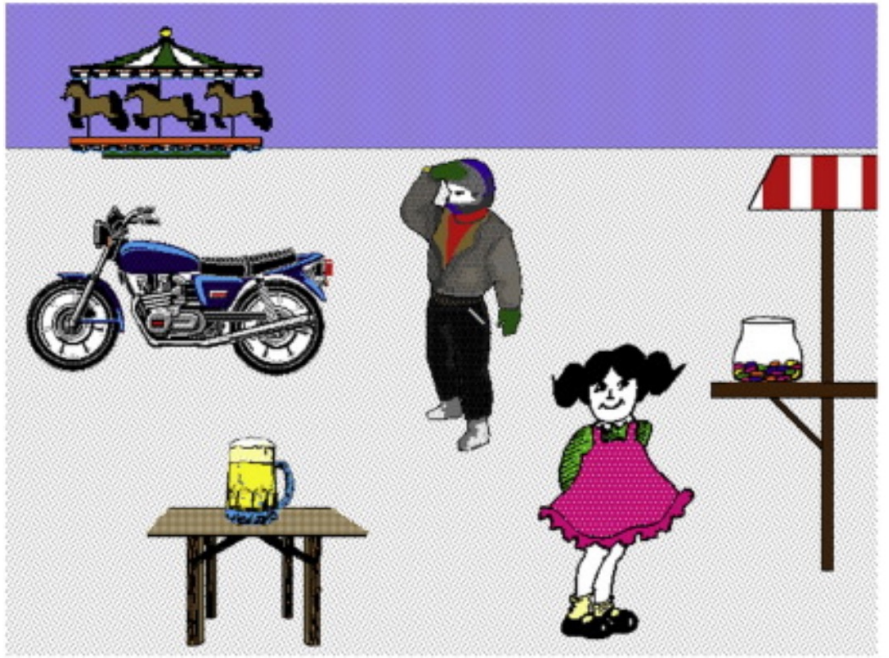


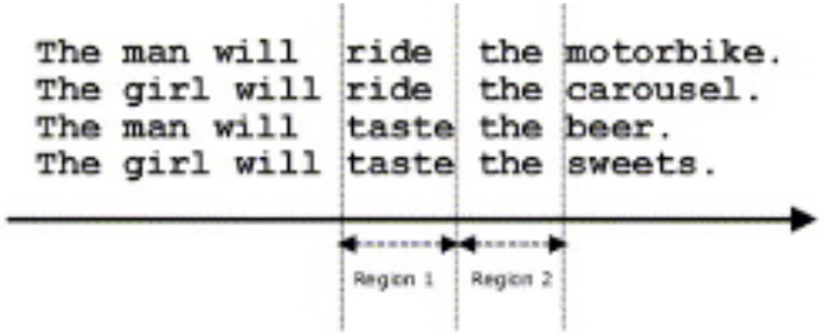
Fig. 11. Example display representing the competitor-present condition in Experiment 4. The critical instruction was "Pick up the candle."

Eberhard et al., 1995

Pre-activation of semantic information

- **Method**: eye tracking + visual world paradigm
- **Procedure**:
  - Participants hear a sentence like:
    - “The man will ride the motorbike”
  - Measure when participants look to the object of the sentence
- **Results**:
  - People tend to begin looking at the object *before* it is mentioned
    - e.g., Upon hearing “ride” in “The man will ride”, participant will look to the motorbike (not the carousel)
  - Verb conveys information that is used to anticipate/pre-activate an upcoming theme
  - Suggests we use different sources of information early and incrementally in parsing



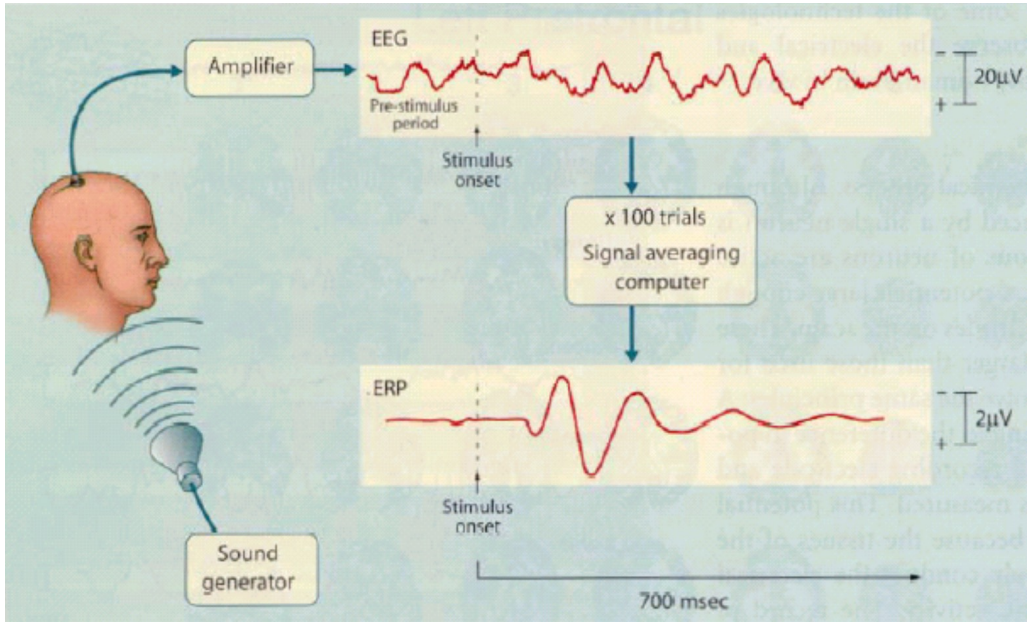


Kamide, Altmann & Haywood, 2003

Real-time language processing in the brain – a methods detour!

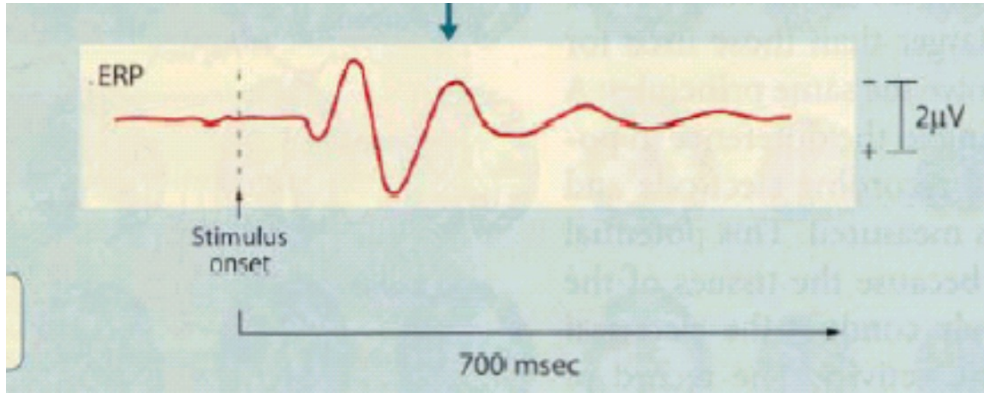
Electroencephalography (EEG)

- EEG is an oscillating voltage recorded on the surface of the scalp.
  - Reflects synchronous activity of large populations of neurons engaged in some processing
  - Very small! Measured in microvolts (mV)
- **Event-related brain potentials** (ERPs) are a signal we derive from EEG by averaging across trials
  - Reflect brain activity that is synchronized to the start of a stimulus



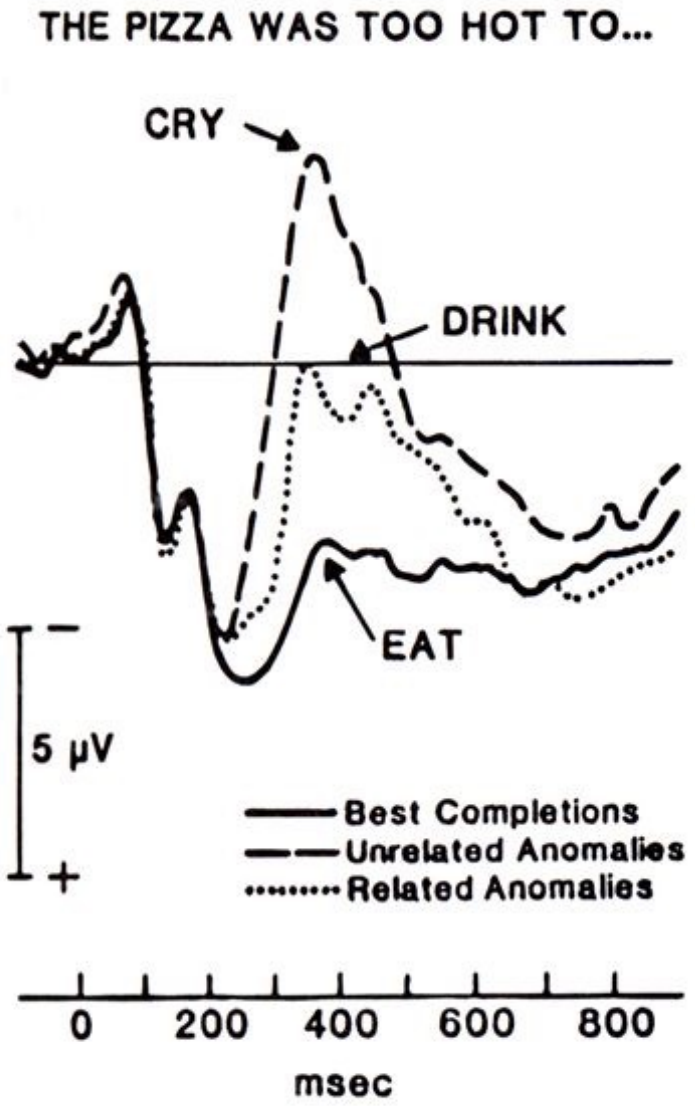
Event-related Potential (ERP)

- Event-related brain potentials (ERPs) are a signal we derive from EEG using averaging and reflect brain activity that is synchronized to the start of a stimulus
  - ERPs represent electrical activity associated with the processing of the stimuli
  - ERPs can be related to different kinds of cognitive tasks (e.g., attention, memory, & language comprehension)
- Though we can't directly observe neuron-level events in the brain in real-time, we can make inferences about neural processing by measuring electrical activity at the scalp



Real-time language processing in the brain

- **Method**: EEG
  - Manipulate relatedness of final word in sentence
  - Record EEG & compute average ERPs time-locked to onset of final word
- Procedure:
  - Participants read sentences appearing word by word on a screen & the final word is manipulated wrt semantic relatedness/appropriateness
  - Example sentences:
    - The pizza was too hot to cry.
    - The pizza was too hot to eat.
- Results:
  - Found an ERP component sensitive to manipulations relating to meaning:
    - The N400 shows a graded sensitivity to predictability of words in context
    - Measures relative ease of semantic processing
      - Smaller deflection → more ease

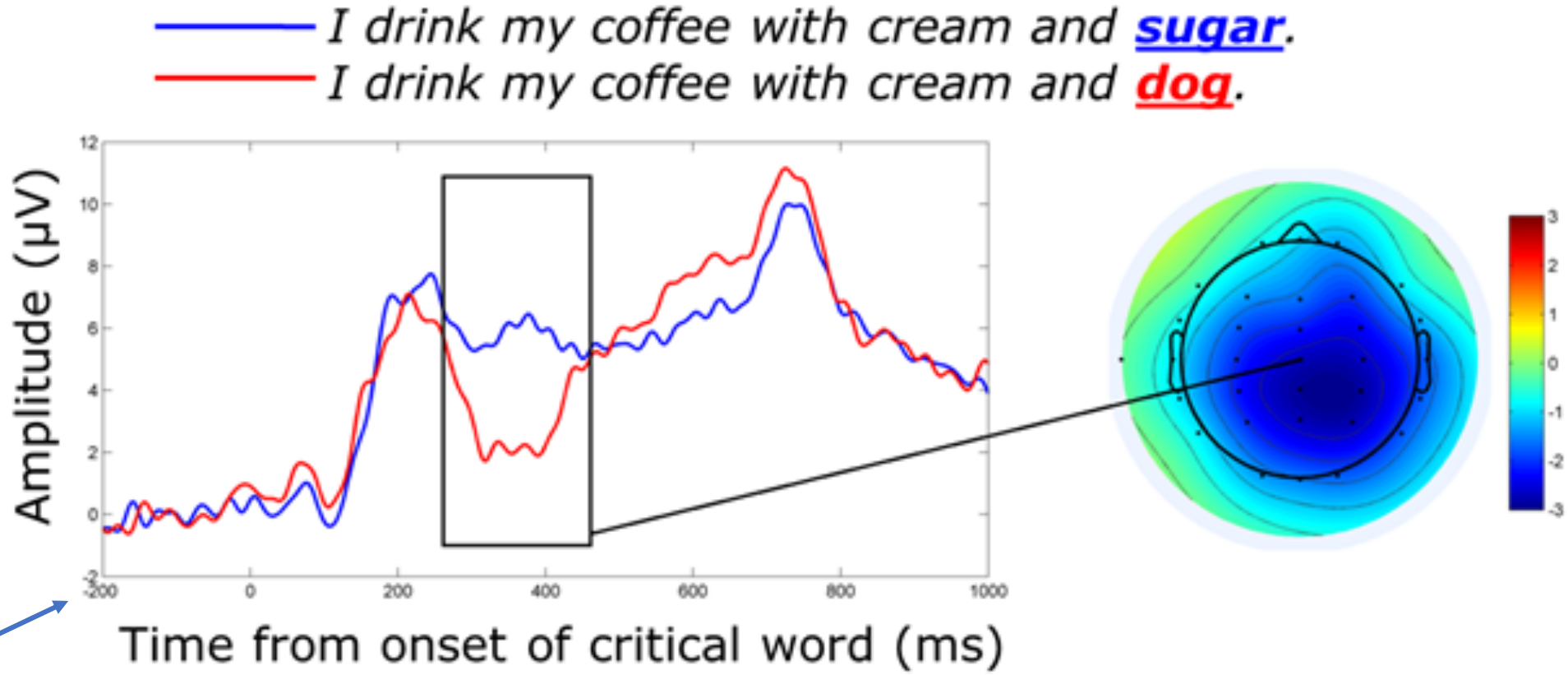


Kutas & Hillyard, 1980

Characteristics of ERPs

- Polarity
  - Is it a positive or negative going?
- Latency
  - How long after stimulus presentation does it peak?
- Functional Significance
  - What cognitive (or perceptual) activity is it sensitive to?
  - What makes it bigger or smaller?

  - “N400” → negative-going deflection in the brainwave 400 ms after the onset of the stimulus, it is sensitive to manipulations of meaning, and it’s smaller when something easier to semantically process



Negative is plotted down in this graph! Always double check!

Figure adapted from Hunt, Politzer-Ahles, Gibson, Minai, & Fiorentino (2013)

- **N400 effect**: Difference between the ERP elicited by the incongruent stimulus and the one elicited by the congruent stimulus

Models of sentence processing

- **Constraint-based model**
- Comprehenders have one interpretation over another during the comprehension of an ambiguous sentence by rapidly integrating probabilistic information
  - We may be using statistical learning on the probabilistic information available in the linguistic signal (we pick up on the frequencies and distribution of events in linguistic environments)

    1. **The horse raced past the barn fell.**
    2. **The landmine buried in the sand exploded.**

- These sentences have the same structure, but one is harder to interpret than the other...
  - The “constraints” are different!
  - People have real-world knowledge that horses are often raced, and that landmines can’t do the act of burying
  - Frequency: “raced” is usually a past tense verb, and “buried” is usually a passive participle

How many animals of each sort did Moses put on the ark?

Studies related to *depth* of processing

- How thoroughly is a stimulus processed for meaning?
- Are we always processing stimuli at 100%?

- The Moses Illusion
  - How many animals of each sort did Moses put on the ark?
  - The authorities had to decide where to bury the survivors. (Barton & Sanford, 1993)

Studies related to *depth* of processing

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- Garden-paths
  - Read: “While Anna bathed the baby played in the crib.” (Christiansen et al, 2001)
    - Ask: Did the baby play in the crib?
    - Ask: Did Anna bathe the baby?
    - People tend to say ‘yes’ to both questions!

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- Passive sentence processing + recognizing errors
  - Plausibility judgment task (Ferriera & Stacey, 2000)
    - The man bit the dog. → “No”
    - The man was bitten by the dog. → “Yes”
    - The dog bit the man. → “Yes”
    - *The dog was bitten by the man. → “Yes”*

Models of sentence processing

- **“Good enough” theory of language processing**
  - Comprehenders do not always process linguistic information completely, instead they generate *superficial representations* when it’s ambiguous or difficult
  - Kind of combines approaches from the garden path model and the constraint-based model

Ferreiera Baily, & Ferraro (2002); Ferreiera, Engelhardt, & Jones (2007)