

Brain imaging and sentence comprehension

Ted Gibson

November 8, 2004

9.591J / 24.905

To do today:

1. Deficit-lesion analyses
2. Brain imaging methods:
 1. PET
 2. fMRI
 3. Event-related potentials (ERPs)
 4. Magneto-encephalography (MEG)
3. ERPs in detail

Language and the brain: Evidence from brain damage: **Aphasia**

Broca's aphasia

a. spontaneous production difficulty: labored speech,
missing function words

“son ... university ... smart ... boy ... good ... good”

Broca's aphasia

b. difficulty understanding more complex syntactic relations:

object-extracted relative clauses (RCs):

poor performance on picture matching or question-answering

“The lion that the tiger chased watched the leopard.”

Did the tiger chase the lion?

subject-extracted RCs: good performance

“The lion that chased the tiger watched the leopard.”

Did the tiger chase the lion?

Wernicke's aphasia

Language comprehension difficulty: patients cannot understand spoken or written language, but speak fluently, often nonsensically.

"I called my mother on the television and did not understand the door. It was not too breakfast, but they came from far to near. My mother is too old for me to be young."

These and other aphasias are diagnosed **behaviorally**: based on symptoms of speech production and comprehension.

Broca's aphasics often have deficits in Broca's area:
Left-lateralized, pre-frontal cortex

Brain diagram removed for copyright reasons.

Wernicke's aphasics often have deficits in
Wernicke's area: Left-lateralized

Brain diagram removed for copyright reasons.

Imperfect correlation between deficits and lesion sites

The **Wernicke-Geschwind model / hypothesis:**

Lexicon (word-meaning relations) is stored / accessed in Wernicke's area.
Broca's area guides word production.

But:

Some Broca's aphasics have no deficit in Broca's area.

Some Wernicke's aphasics have no deficits in Wernicke's area.

Some patients with damage to Broca's area don't have Broca's aphasia.

Some patients with damage to Wernicke's area don't have Wernicke's aphasia.

We are a long way yet from a functional neuroanatomy of language.

Issues:

(1) People's brains are different: (slightly?) functional architectures.

(2) All deficits are different.

Language and the Brain: Language is left-lateralized

From the reading (Bear et al. text):

- The **Wada procedure** (developed by John Wada):
 - A fast-acting barbiturate is injected into the carotid artery on one side of the neck. The drug is preferentially carried to the ipsilateral hemisphere, acting as an anesthetic for ~10 minutes.
 - 96% of right-handed people have left hemisphere control of speech
 - 70% of left-handed people have left hemisphere control of speech
 - 93% overall have left hemisphere control of speech
- Language processing in **split-brain patients**
 - Surgeons severed the corpus callosum in patients suffering from severe epilepsy
 - Visual stimuli presented in the right visual field cannot be named by these patients. "I see nothing."

Neuroimaging and language

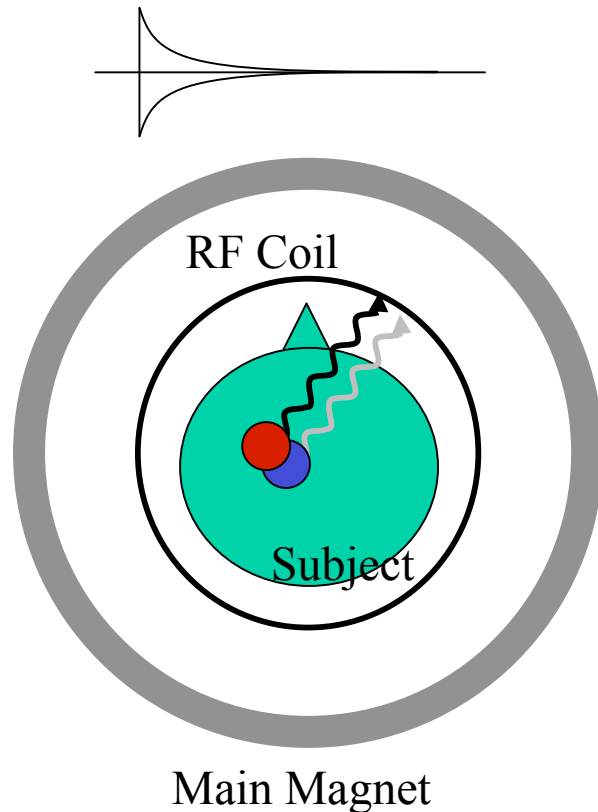
- Techniques

- Positron Emission Tomography (PET)
- Functional Magnetic Resonance Imaging (fMRI)
- Event-Related Potentials (ERP)
- Magnetoencephelography (MEG)

Comparison of Techniques

Graph removed for copyright reasons.

fMRI



What are we measuring?

Magnetic relaxation of H nuclei

Mean level neural activity increase \Rightarrow

Local Metabolism increase \Rightarrow

Local increase in Blood Flow (rCBF) \Rightarrow

Local decrease in deoxy-Hb concentration
(BOLD = blood oxygen level dependent)

Spatial resolution: mm

Temporal resolution: 1 second

Block & event-related design

ERP & MEG

- What are we measuring?
 - Summed electrical potential (ERP) or magnetic fields (MEG) of neural activity (action potential firing)
- Resolution
 - Spatial: 10 cm
 - Temporal: msec
- Event-related design

Linguistic issues that can be addressed using brain imaging

Speech recognition and production

Word recognition and production

Sentence recognition and production (our focus)

General design of brain imaging experiments

Subtraction of a control condition from the target condition.

4 general comparison types in experiments so far:

1. complex vs. simple

2. Syntactic violations vs. grammatical sentences

3. sentences vs. word lists (problematic to interpret)

4. Jabberwocky and syntactic prose (problematic to interpret)

Complex – simple: fMRI and PET results

Object-extracted RC:

The juice that the child spilled stained the rug.

Subject-extracted RC:

The child spilled the juice that stained the rug.

Object- minus subject-extracted RCs:

Activation in Broca's area, and sometimes other areas (Stromswold, Caplan, Alpert & Rauch, 1996; Caplan & Waters et al. 1999; Just & Carpenter et al. 1998)

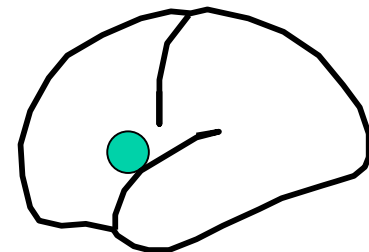
mostly left-lateralized, but sometimes some right area activation

Stromswold et al. (1996)

Diagram removed for copyright reasons.

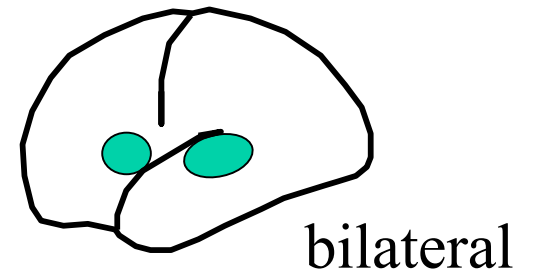
Stromswold et al (1996) & Caplan et al (1998, 1999, 2000)

- PET (rCBF)
- Stimuli
 - Object-extracted RC:
The juice_i [that the child spilled t_i]stained the rug.
 - Subject-extracted RC:
The child spilled the juice_i [that t_i stained the rug].
- Results
 - Pars opercularis (BA44)
 - Pars triangularis (BA45)



Just et al (1996)

- fMRI (rCBF)
- Stimuli
 - SO, CE-O:
The reporter_i [who the photographer admired t_j] appreciated the award.
 - SS, CE-S:
The reporter_i [who t_j admired the photographer] appreciated the award.
- Results
 - Broca's Area (BA44 & 45)
 - Wernicke's Area (BA22, 42 & 21)
 - Bilaterally



Summary of imaging localization of resource components of sentence complexity

- Most studies have found some part of Broca's area for resource complexity subtractions
- But some have not: why not?
- Many possible reasons: (We don't know why right now)
 - Small numbers of subjects makes many hypotheses plausible: maybe (1) different subject populations: good vs. poor comprehenders (Caplan et al.)
- Another issue: Breaking down resources into multiple components: Storage vs. integration
 - We don't know if the activity in Broca's area is due to storage or integration or both: The comparisons are confounded. Future work is needed here.

Syntax and the brain

Major result from neuro-imaging (event-related potentials, ERPs):

There are distinct neural responses to:

(1) violations of syntactic expectations; vs.

(2) violations of expectations due to world knowledge

Event-Related Potentials (ERPs)

Electro-encephalogram (EEG): measure the voltage changes on the scalp

Positive features of ERPs:

- 1) no auxiliary task needed (e.g., extra motor activity);
- 2) can be used auditorily as well as visually;
- 3) continuous;
- 4) on-line;
- 5) multidimensional data is returned.

Event-Related Potentials (ERPs)

Negative features of ERPs:

- 1) very noisy: lots of irrelevant brain activity, so it's hard to find the signal that you're interested in. Practically, this means many items per condition, and then the possibility that participants know what the experiment is about, because of fewer fillers;
- 2) long, complex set-up time for each experiment;
- 3) difficult to localize the signals.

Magnetoencephelography (MEG)

MEG measure the same neural activity as EEG by means of their magnetic fields, so there should be MEG correlates of all EEG phenomena.

But as yet no MEG correlates of N400 or P600 ERP waveforms (see below)

The N400 (Kutas & Hillyard, 1980)

Big jump in negativity
peaking about 400 msec
after processing a
semantically implausible
word

Graph removed for copyright reasons.

May or may not be
language-specific;
But it only occurs for certain
kinds of unexpected events.

E.g. P300 effect for
unexpected tones, pictures.

The locus of the N400

- The source of an ERP is hard to localize because (1) the signal distorts through water and skull material; and (2) the mathematical problem is difficult.
- N400s are usually visible all over the scalp, stronger on the left and centrally.

What does the N400 reflect?

- Lexical access. Semantic integration of a word: semantic memory (Kutas & Federmeier, 2000)
- All words have an N400 component: Stronger in null context, weaker in appropriate context
- The strength of an N400 varies according to the word's predictability in context: cloze probability.

Using the N400: How are null NPs processed? Garnsey, Tanenhaus & Chapman (1989)

Hypothesis 1: First resort: associate a filler (wh-phrase) with a thematic position as soon as possible.

Hypothesis 2: Last resort: associate a filler (wh-phrase) with a thematic position when there is no other grammatical possibility.

The businessman knew which **customer/article** the secretary **called** at home.

Result: N400 at “called” for “article” indicates a first-resort processor (e.g., via the DLT).

Syntactic anomaly: P600 / Syntactic Positive Shift (SPS)

(Osterhout & Holcomb, 1992; Hagoort & Brown, 1993)

Positive going wave
peaking 600 msec after
onset of stimulus.

Graph removed for copyright reasons.

The P600 is strongest at
the back of the head.

Every Monday he *mow / mows the lawn.

What does the P600 reflect?

Three possible interpretations:

1. Syntactic ungrammaticality
2. Syntactic reanalysis
3. Syntactic integration difficulty

(Maybe one, two or all three are correct.)

What does the P600 reflect?

Another interpretation (variation of the ungrammaticality detection, but not language specific):

The P600 is a "surprise" effect, an instantiation of the P300 (Coulson, King & Kutas, 1998)

It occurs later because language materials are more complex than other materials.

P600 in ambiguity resolution: Garden-path effects

Graph removed for copyright reasons.

The broker hoped / persuaded to sell the stock was sent to jail.

Binding violations: Syntactic or semantic?

The hungry guests helped themselves / *himself to
...

Binding violations: Syntactic or semantic?

The hungry guests helped themselves / *himself to
...

If syntactic then P600;

If plausibility/semantic: N400

Binding violations: Syntactic or semantic?

The hungry guests helped themselves / *himself to
...

If syntactic then P600;

If plausibility/semantic: N400

Result: P600

Auditory ERPs: Patel et al. (1998)

Some of the senators had promoted **an old idea of justice.**

Some of the senators endorsed promoted **an old idea of justice.**

* Some of the senators endorsed the promoted **an old idea of justice.**

Graph removed for copyright reasons.

Results:

1. same P600 effects in auditory stimuli (naturally presented)
2. stronger violation leads to stronger P600

ERPs to music as well as linguistic stimuli (Patel et al., 1998)

Three music conditions:

An initial sequence of chords followed by a chord which sounds:

1. good
2. odd
3. bad

In Western music (using the circle of fifths).

Graph removed for copyright reasons.

Result:
Similar P600 effect in music as in language

ERPs to music as well as linguistic stimuli (Patel et al., 1998)

Is the P600 reflecting reanalysis?

Probably not, because it is hard to interpret the music data in terms of reanalysis: There is no target structure to reanalyze to.

Evidence for the integration interpretation of the P600 (Kaan et al., 2000)

whether conditions: simple integration at "imitate": (plural = grammatical, singular = ungrammatical)

Emily wonders whether the performers in the concert **imitate(s)** a pop star for the audience's amusement.

who conditions: more complex integration at "imitate": (plural = grammatical, singular = ungrammatical)

Emily wonders who the performers in the concert **imitate(s)** for the audience's amusement.

Evidence for the integration interpretation of the P600 (Kaan et al., 2000)

Emily wonders whether the performers in the concert **imitate** a pop star for the audience's amusement.

Graph removed for copyright reasons.

Emily wonders who the performers in the concert **imitate** for the audience's amusement.

Evidence for the integration interpretation of the P600 (Kaan et al., 2000)

Graph removed for copyright reasons.

Kaan et al. (2000)

Is the P600 in Kaan et al.'s work the same P600 as in local ungrammaticality? It seems like there are some overlaps, in location.

The suggestion of an interaction at some positions is also suggestive.

Kaan et al. (2000)

Open questions:

Does Kaan et al.'s P600 reflect the number of integrations, or the difficulty of a single integration?

Is there an ERP wave-form corresponding to syntactic storage in the DLT?

An ERP waveform corresponding to syntactic storage?

King & Kutas (1995): Left Anterior Negativity (LAN)

Subject-extracted RC:

The reporter who the senator harshly attacked admitted the error.

Object-extracted RC:

The reporter who the senator harshly attacked admitted the error.

King & Kutas (1995)

Graph removed for copyright reasons.

Harris (1998):
LAN for syntactic storage

Low storage:

Tammy told the plumber that **the unionists had called** from their shop that morning.

High storage:

Tammy told the plumber whom **the unionists had called** that her fixtures were new.

Harris (1998): LAN for syntactic storage

Graph removed for copyright reasons.

Harris (1998):
LAN for syntactic storage

Low storage: NP complement:

The candidate **liked the woman who the press photographed** with him on his boat.

High storage: Clausal complement:

The candidate **hoped that the woman who the press photographed** was friendly.

Harris (1998): LAN for syntactic storage

Graph removed for copyright reasons.

ERP summary

- N400: semantic and discourse integration difficulty
- P600: syntactic resource integration difficulty (perhaps)
- LAN (left anterior negativity): syntactic storage (perhaps)

- In general, ERPs allow us a way to break reaction time data down into separable components, each of which is associated with complexity