Neurolinguistics

language in/and the brain

Psycholinguistics

LING/PSYC 27010

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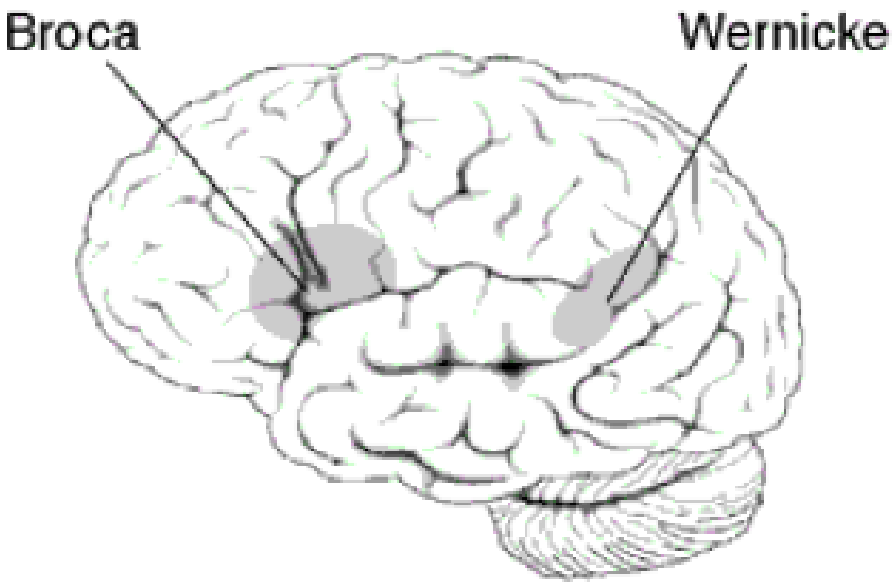
traditional beliefs about language & brain

two main "language centers"

(based on lesion studies – very crude)

- **Broca's area:** area in left frontal lobe, Paul Broca noticed language defecits in patients w damage to this region
- **Wernicke's area:** area in left temporal lobe, Carl Wernicke noticed a different kind of language defecit in patients w damage to this region



traditional beliefs about language & brain

early research on neurolinguistics based largely on studies of people suffering from **aphasia** – a linguistic defecit resulting from a stroke or traumatic brain injury

the idea that Broca's area and Wernicke's area are the brain's language centers comes from observations about two different kinds of aphasia:

Broca's aphasia; [example] (agrammatism; non-fluency)
associated w/ slow, halting, non-fluent speech; problems w/ syntax; short utterance lengths

Wernicke's aphasia [example] [example] (anomia; fluency)
associated w/ fluent speech; grammatically intact but incoherent sentences; problems w/ lexical access
phonologically possible but non-existent "words"

traditional approaches to "neuro-linguistics"

questions one can ask limited b/c lesion data only

linking components of language to broad brain regions, for example (crudely speaking)

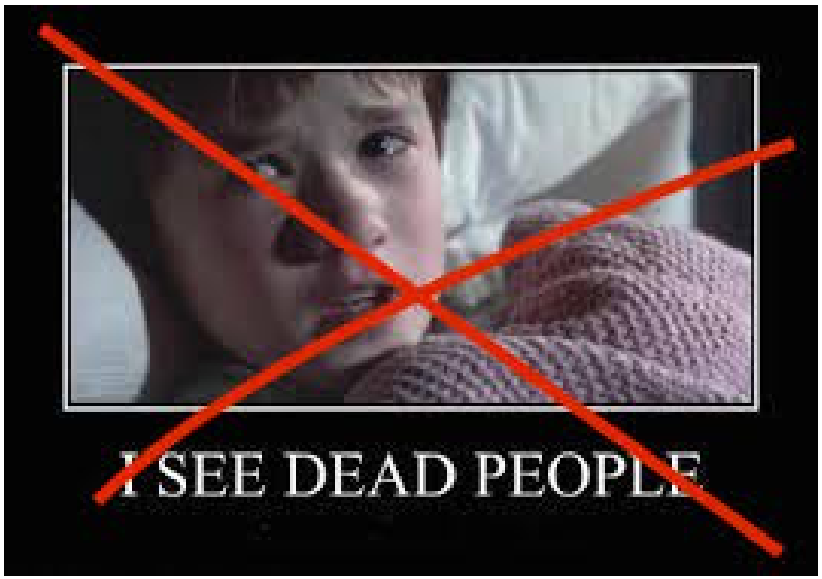
- damage to BA associated w "syntactic deficits"
- damage to WA associated w "semantic deficits"

relied on uncontrolled, isolated cases

traditional approaches to "neuro-linguistics"

problems:

- causal inference from deficits in linguistic behavior is tricky because of **co-morbidity** (stroke can do **a lot** of diverse damage)
- autopsy not useful because dead ppl don't speak!



traditional theory of language in the brain

- more of a physiological theory than a theory of language processing
- built on very thin foundations
(due to the times!)
- basically no understanding of how healthy brains store/deploy/organize linguistic knowledge

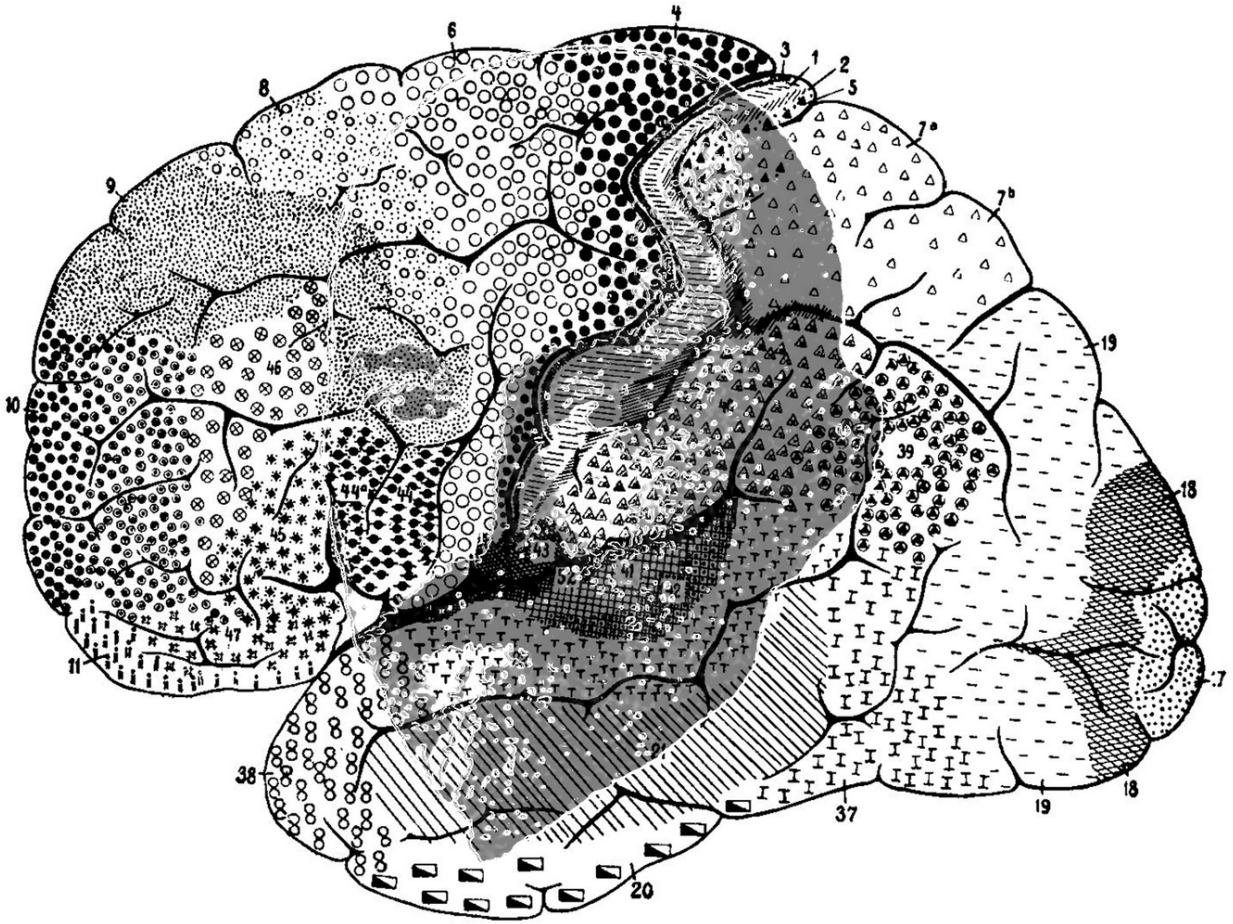
modern advances

Some important discoveries/contributions:

- no single "language center"
- neural bases of language organized in a complex network of discontinuous regions with differing specialized functions
  (not all of which are purely linguistic in nature)
- not necessarily completely uniform across individuals (e.g. handedness seems to matter)

modern advances

Brodmann mapping – phrenology on steroids
(thankfully now without race-based craniology)



$\Longrightarrow$ better understanding of neuroanatomy in general

modern advances

MOST IMPORTANTLY

technological advances allow for insight into neural bases of language for living patients without brain damage

$\Longrightarrow$ allows us to use neural signals as a dependent measure in controlled experimental settings!

regions of interest (ROIs)
brain regions hypothesized to be functionally related to some manipulation in expt design
(the activity of which provides dependent measure)

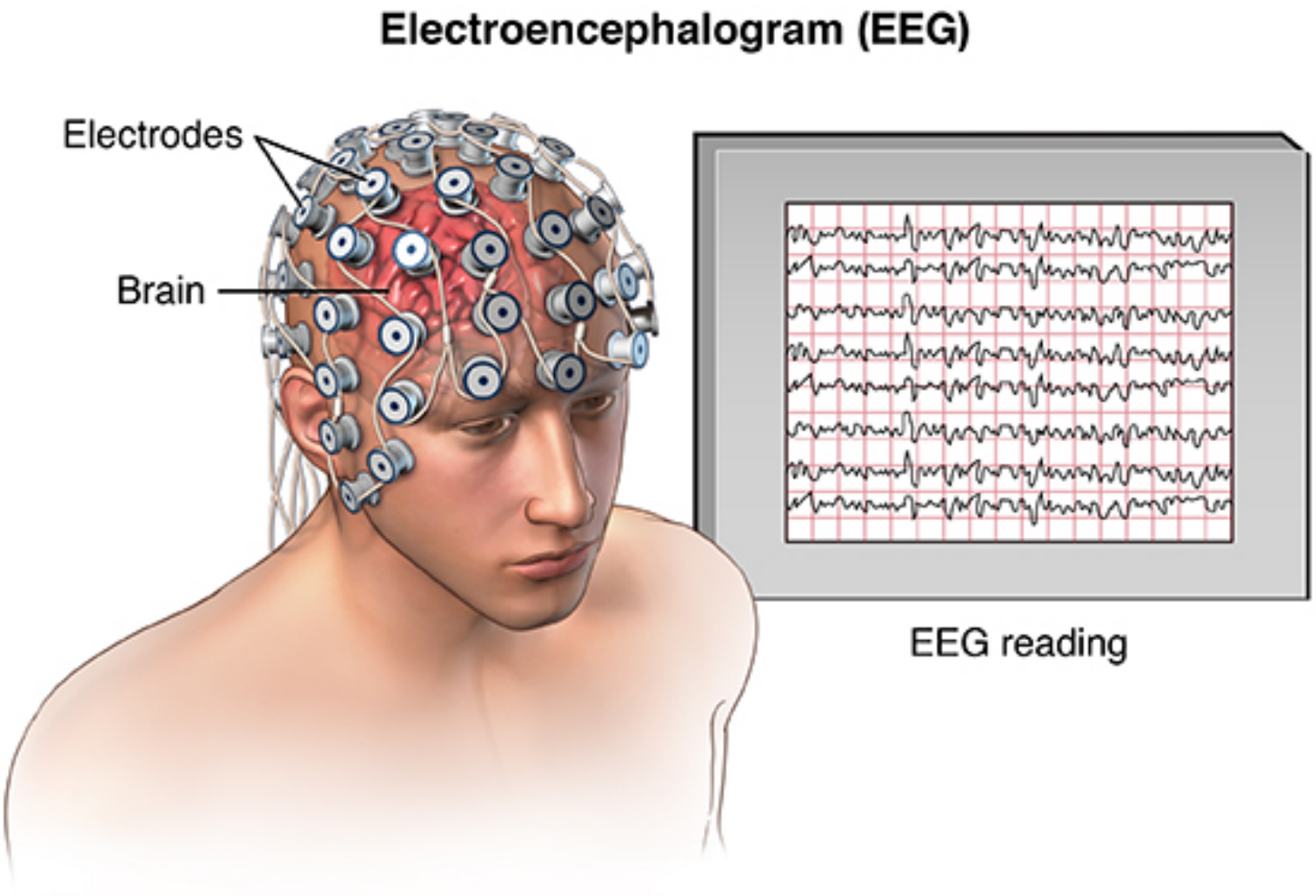
some relevant technologies

electroencephalography – aka **EEG**

- allows one to measure electric signal from different parts of brain, time locking them to events in a stimulus
  (e.g. an auditorily presented sentence)

- this technology makes the study of **event-related potentials** (**ERPs**) possible

EEG



some relevant technologies

magnetoencephalography – aka **MEG**

- allows one to measure magnetic fields emitted by neuronal activity from very specific brain regions
- brain activity operationally defined as magnetic signal, measured in femtoTeslas (10^{-15}T)

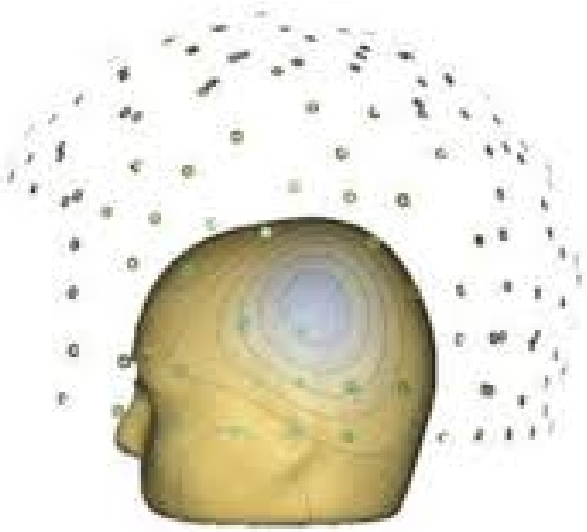
  for reference/comparison:

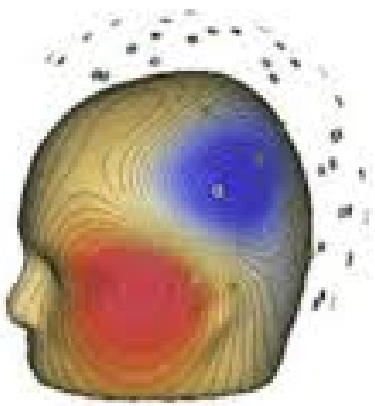
  5 milliTesla $\approx$ refrigerator magnet

  1 Tesla $\approx$ magnet in a large speaker

  16 Tesla $\approx$ amount required to levitate a frog

MEG





comparison of EEG and MEG

EEG

- good temporal resolution
- not as good spatial resolution
- relatively cheap

MEG

- very good temporal resolution (in ms range)
- very good spatial resolution (in mm range)
- extremely expensive (requires liquid helium and SQUIDs)

Advantages of MEG: resolution quality allows

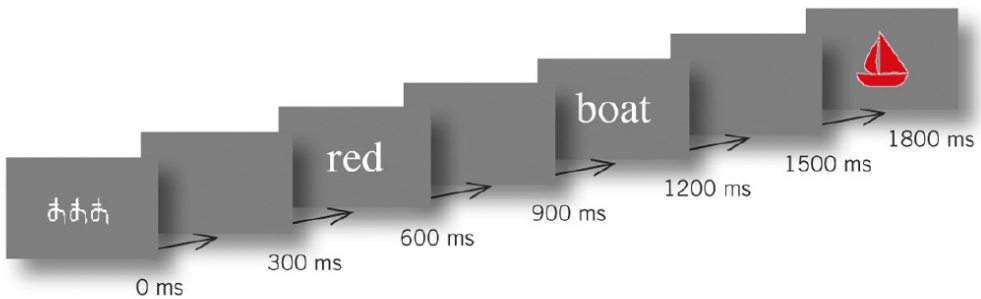
- ability to time-lock events in a linguistic stimulus to (magnetic) activity in a highly specific ROI (usually ≥ 1 contiguous brodmann area)
- used in tandem with MRI, can generate 4d brain images associated with each condition in an experiment (averaged over subjects and stimuli)

connecting ling. theory and neuroscience

- recent MEG studies have investigated the neural bases of fundamental linguistic processes
- the **anterior temporal lobes** (esp. LATL) have been repeatedly implicated in "conceptual combination" – not a sharply defined concept, but illustrated with *boy* = *male* + *child*, *blue boat* = *blue* + *boat*, etc.
- Pylkkänen and colleagues: conceptual combination plausibly involved in the compositional operation that combines a noun with an adjective that modifies it

Bemis & Pylkkänen (2011), design

investigated activity evoked in various brain regions by compositional stimuli (*red boat*), versus word-lists (*cup, boat*), versus unpronounceable string followed by target (*xfrk boat*)



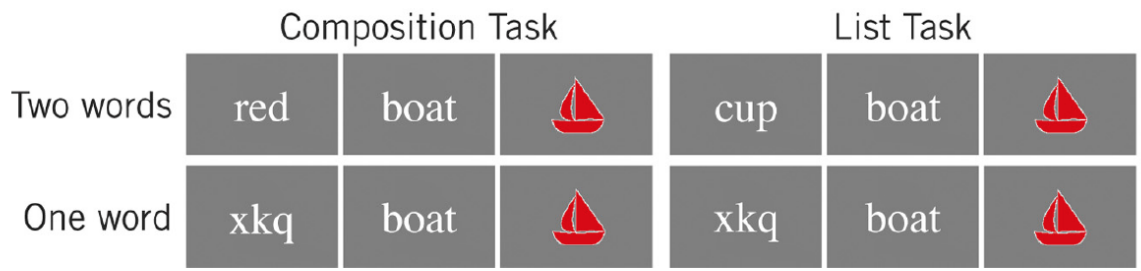
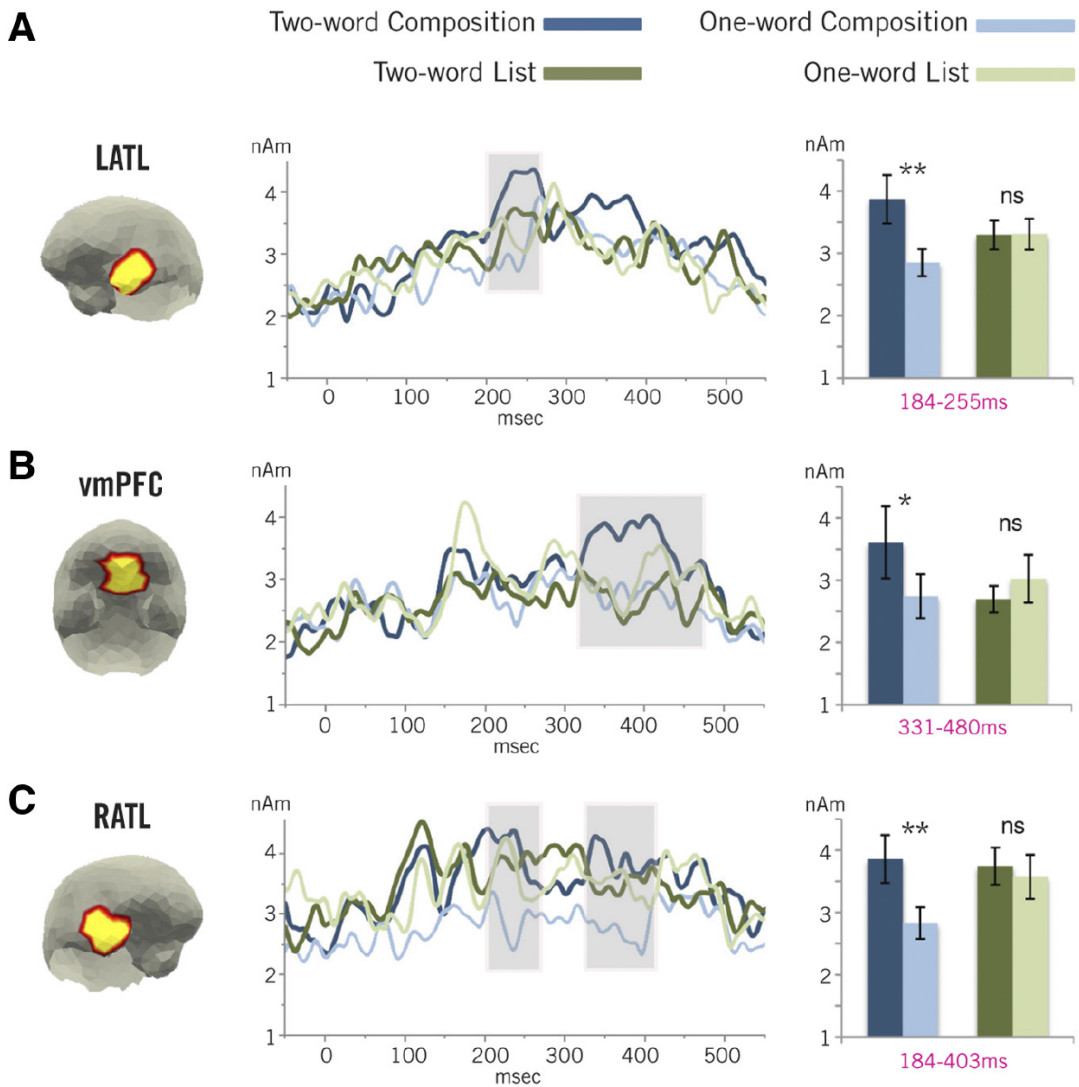


Figure 1. Experimental design. Our design crossed task (composition vs list) and number of words (two vs one). In each trial, participants indicated whether the target picture matched the preceding words. To satisfy this criterion, in the composition task, all preceding words were required to match, whereas in the list task, any matching word sufficed. A total of six colors and 25 shapes were randomly combined and used as stimuli. Half of the target pictures matched, but half did not. Only activity recorded at the matched nouns ("boat") was analyzed.

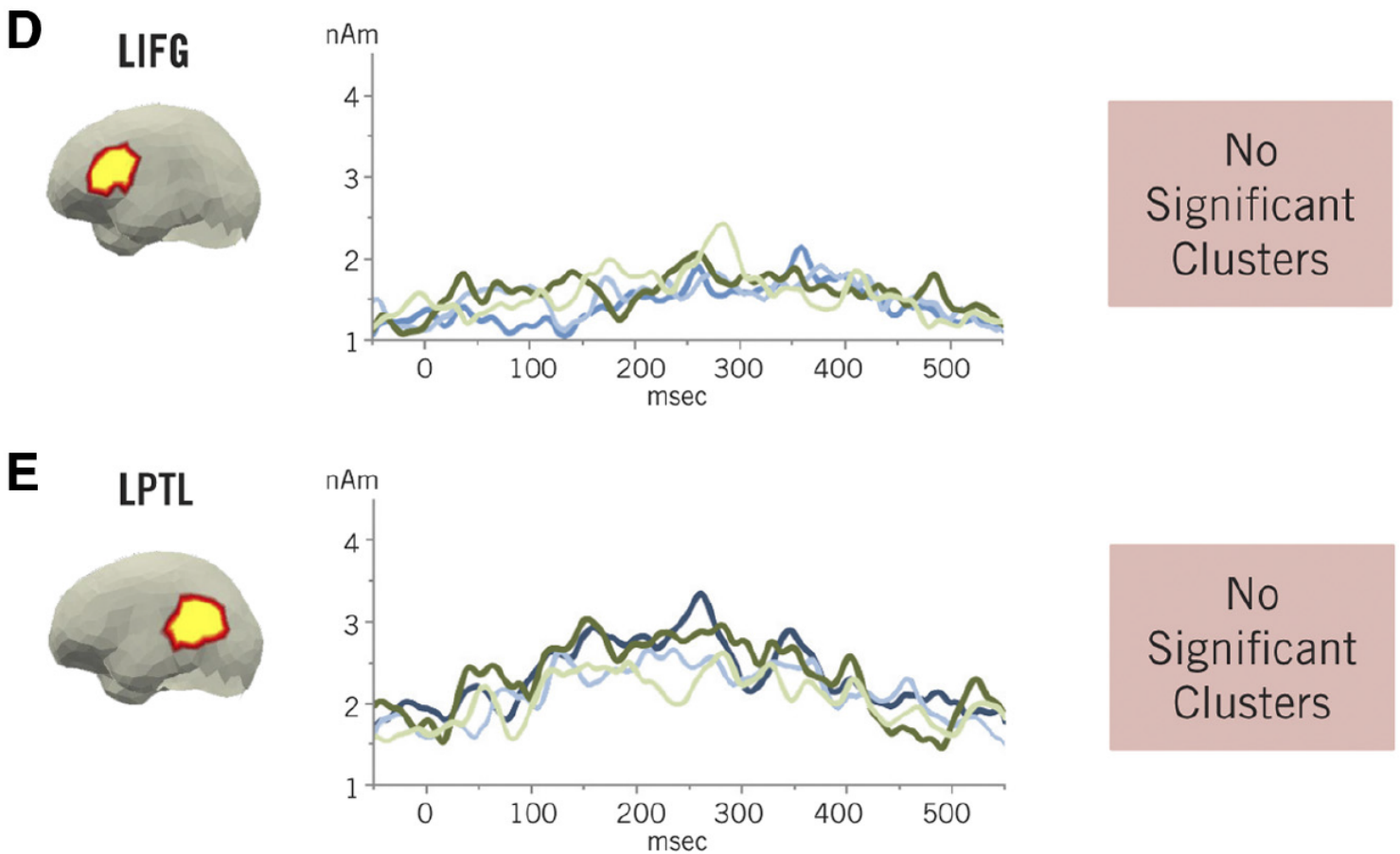
Bemis & Pylkkänen (2011), results

- higher **early** LATL and RATL activity for two-word composition condition compared to others
- higher **late** activity in vmPFC and RATL for two-word composition condition over others



Bemis & Pylkkänen (2011), results

- no reliable increases for any condition in LIFG (Broca's area)
- no reliable increases for any cond. in LPTL (Wernicke's area)



Bemis & Pylkkänen (2011), interpretation

- at the earliest stages of language processing, basic compositional operations are associated with increased activity in the **anterior temporal lobes** and the **vmPFC**
- these regions have been previously implicated in syntactic and semantic processing in a broad sense

activity in traditional language centers is not reliably associated with basic composition!

Leffel, Lauter, Westerlund, Pylkkänen (2014): motivation

- In BP11, compositional trials were presented in isolation
- underdetermines **what kind of composition** was being performed by subjects – intersective modification? function-argument saturation??
- we manipulated the "restrictiveness" of composition by introducing contextual information into the stimuli

Leffel, Lauter, Westerlund, Pylkkänen (2014): motivation

Two functions of adjectival modifiers:

- to restrict the set of possible referents (=**restrictive**)
  - *I cannot find my* **blue** *notebook (I have all the others).*
  - *The* **young** *dog doesn't play nice with the others.*
- to provide additional information about an independently identifiable object (=**nonrestrictive**)
  - *I have to take care of my* **sick** *mother.*
  - *The* **vicious** *tiger should be kept in its cage.*

question:
how would you classify the modifiers we saw in visual world studies??

LLWP14, conditions

2×2 design:

- factor 1: **category** (levels: `Adj`/`Det`)
- factor 2: **restriction** (levels: `Restr`/`NonRestr`)

		Question	Answer
Adj	restrictive	Which chicken should the farmer slaughter next?	His fat **chicken**.
	non-restr	Will the farmer slaughter his chicken or his lamb?	His fat **chicken**.
Det	restrictive	Will the farmer slaughter his chicken or Mary's chicken?	His **chicken**.
	non-restr	Will the farmer slaughter his chicken or his lamb?	His **chicken**.
Anomalous Filler		Will the farmer slaughter his chicken or his lamb?	#His (fat) pig.

important: unique pragmatics associated with `NonRestrAdj` condition and non-restrictive modifiers generally

LLWP14, hypothesis space

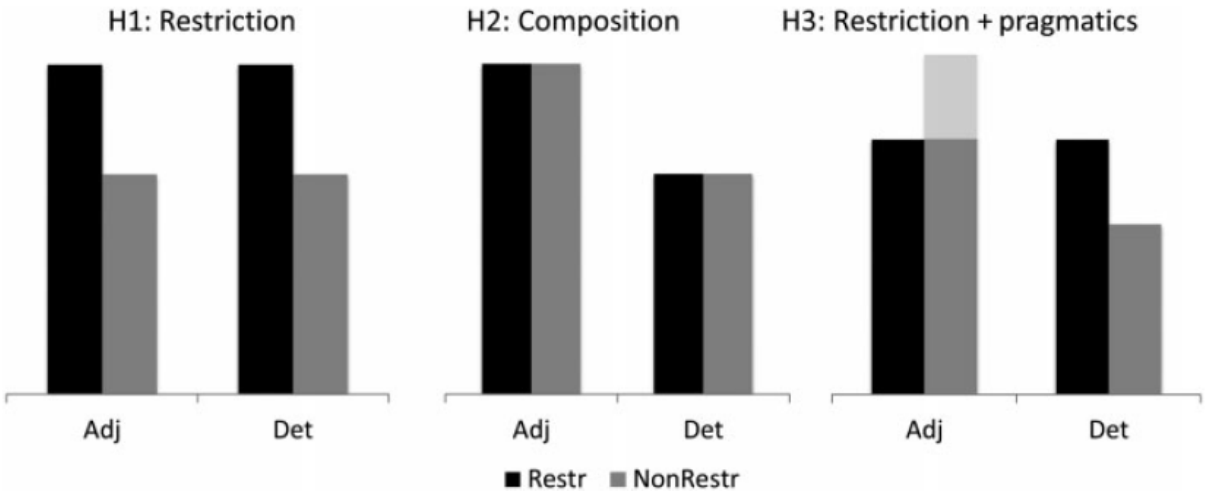
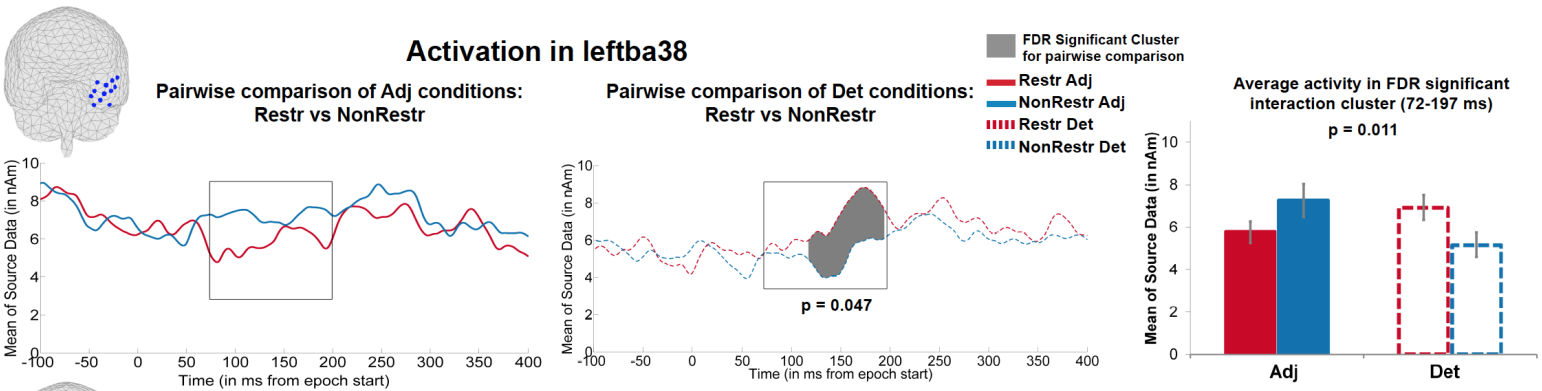


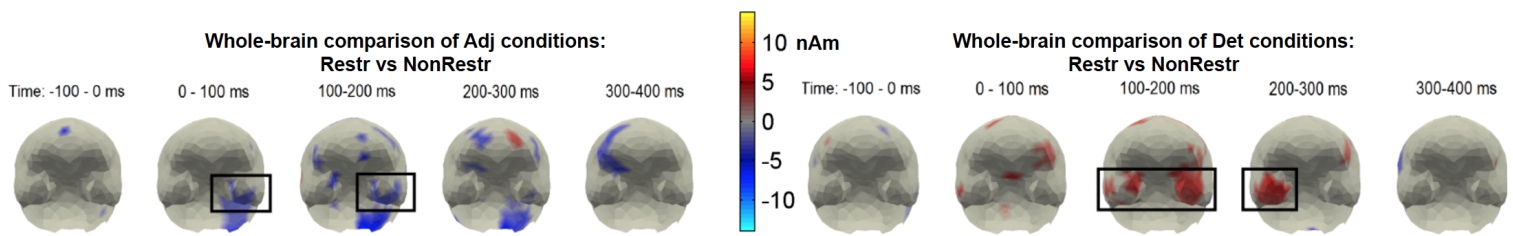
Figure 1. Hypothesised LATL activity profiles. If the LATL only computes restrictive composition, both restrictive conditions should elicit increased amplitudes (Hypothesis 1). In contrast, an increase for both adjectivally modified conditions would suggest a more general role for the LATL in composition (Hypothesis 2). Finally, sensitivity to both restriction and pragmatic inferencing predicts an increase for restriction for the Determiner cases (with no specially interpreted adjectives) and a potential increase for the non-restrictive adjectives over the restrictive ones, driven by pragmatics (Hypothesis 3).

LLWP14, analysis/results

2×2 ANOVA over averaged sources in L/R ba38 (LATL, RATL) from 0 to 300ms after onset of target noun

FDR correction and lots of data cleaning to eliminate noise





LLWP14: interpretation

the results are compatible with a number of possible explanations, but of H1-H3 described above, only compatible with:

H3: restriction + pragmatics

The anterior temporal lobes are associated with restrictive composition specifically, but also are recruited in the pragmatic reasoning required to interpret a modifier non-restrictively.

According to **H3**, `NonRestrAdj` over `RestrAdj` in LATL is due to the pragmatic function of LATL; `RestrDet` over `NonRestrDet` in LATL is due to the restrictive function of LATL.

general conclusions

- biologically speaking, the language processing system is a complex network of small, functionally independent(?!) regions, each of which likely contributes very domain-specific information.
- We can use modern imaging techniques like MEG to reveal facts about some of these regions' plausible functions.

HOWEVER

Severe methodological limitations/questions:

- huuuuuuge hypothesis space
- how to generate expectations about particular regions' functional roles to begin with?! (the brain is a big place)
- what is the nature of neural "activation"?! ("when we do this, that thing lights up...")
- how much across-individual variation is there?! (e.g. most MEG studies use exclusively right-handed subjects)