More thought, less 'words':
reframing the questions in neurobiology of syntax and semantics

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Miscarving in language comprehension

- (1) We forget that thought is distinct from language

'language comprehension'

Miscarving in language comprehension

- (1) We forget that thought is distinct from language

conceptual system   language system

Miscarving in language comprehension

- (2) We imagine that 'words' are distinct from syntax

words/lexicon   syntax

Miscarving in language comprehension

- (2) We imagine that 'words' are distinct from syntax

syntactic units and syntactic relations

Ways Forward: More thought, less words

conceptual system

language system

syntactic units and syntactic relations

Today

- Proposal for understanding inferior parietal (angular gyrus) responses during language comprehension: **referential indexes**
  - It was *visual* working memory that we should have been learning about!

- New insights gained (Fedorenko; Matchin & Hickok) when we get rid of 'words' in our theories of comprehension

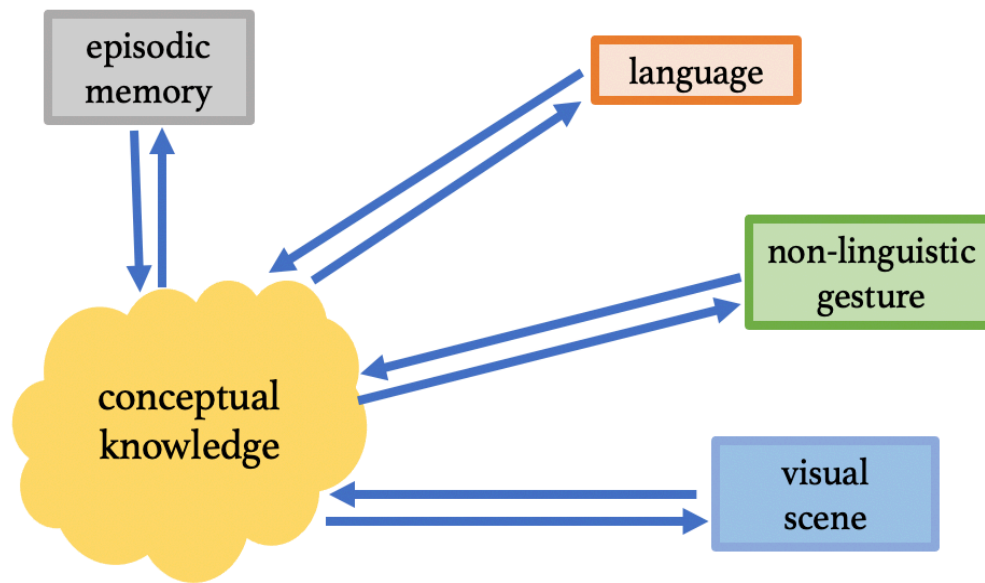Language comprehension is not a unique venue for conceptual combination

Language comprehension is not a unique venue for conceptual combination

Language comprehension is not a unique venue for conceptual combination

'That boy has a cicada on his cheek'

Language comprehension is not a unique venue for conceptual combination

A cortical network for semantics: (de)constructing the N400

Ellen F. Lau*, Colin Phillips*‡ and David Poeppel*‡§||

The evidence that we have just reviewed suggests that storage of lexico-semantic information is specific to the middle part of the posterior temporal cortex.

Dissociating N400 Effects of Prediction from Association in Single-word Contexts

Ellen F. Lau[1,2,3], Phillip J. Holcomb[2], and Gina R. Kuperberg[1,2]

the target. Although the word pair paradigm is far from a typical language comprehension situation, these findings provide proof in principle that specific lexical–conceptual predictions can affect N400 amplitude over and above
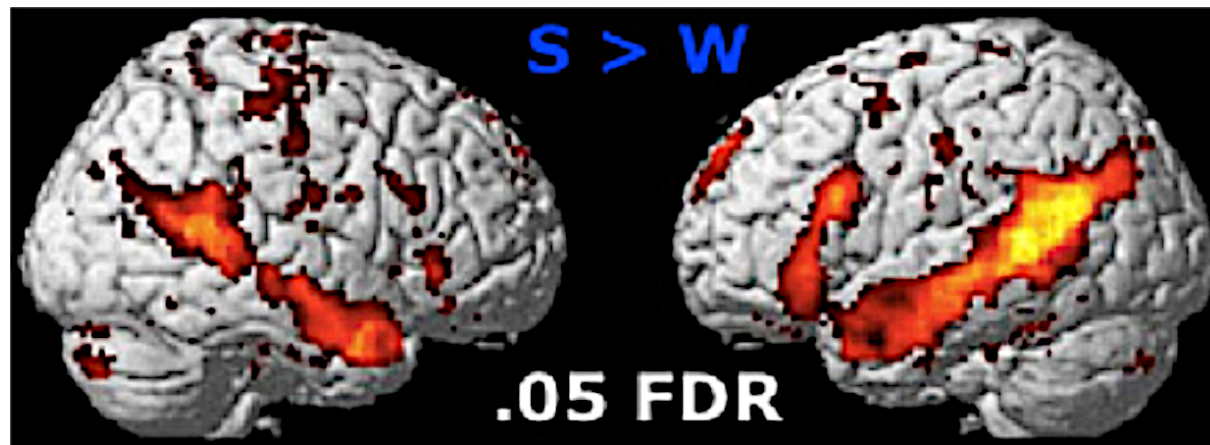
Language comprehension isn't just language
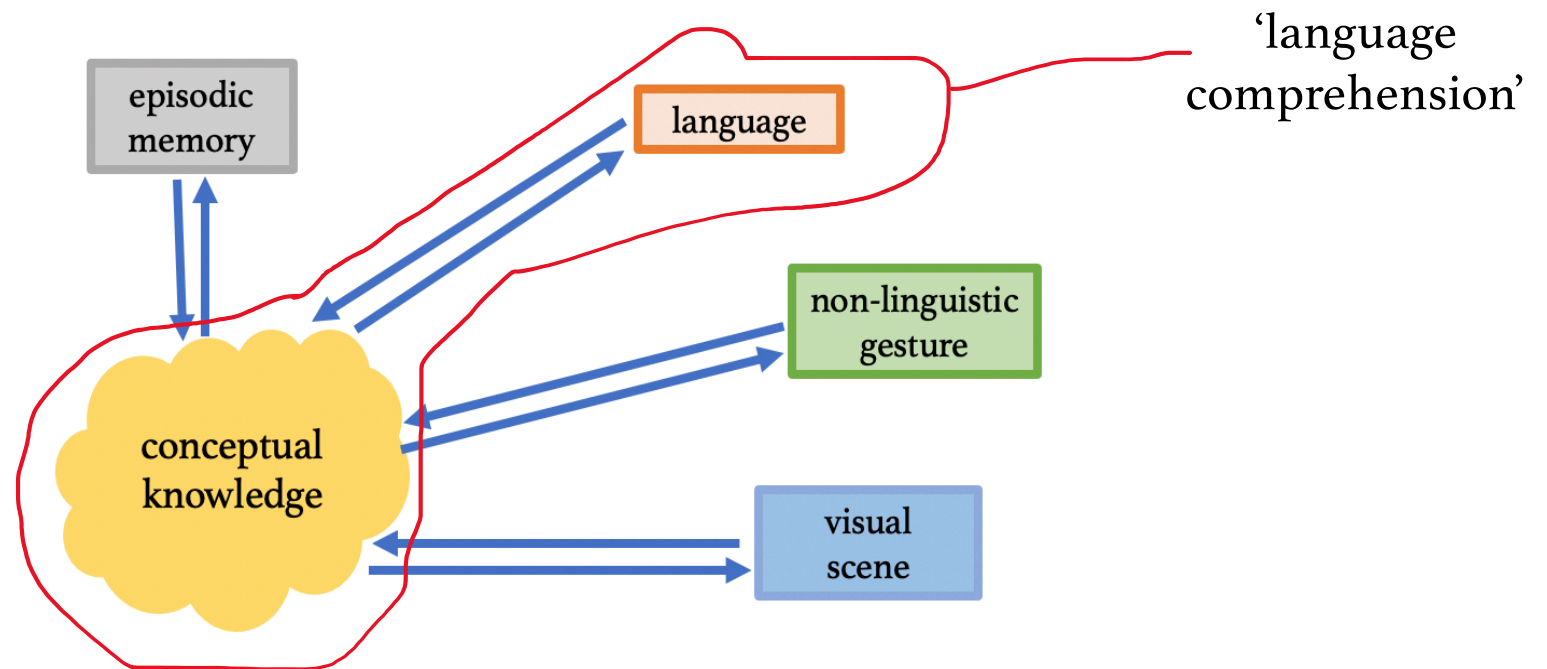
Language comprehension isn't just language

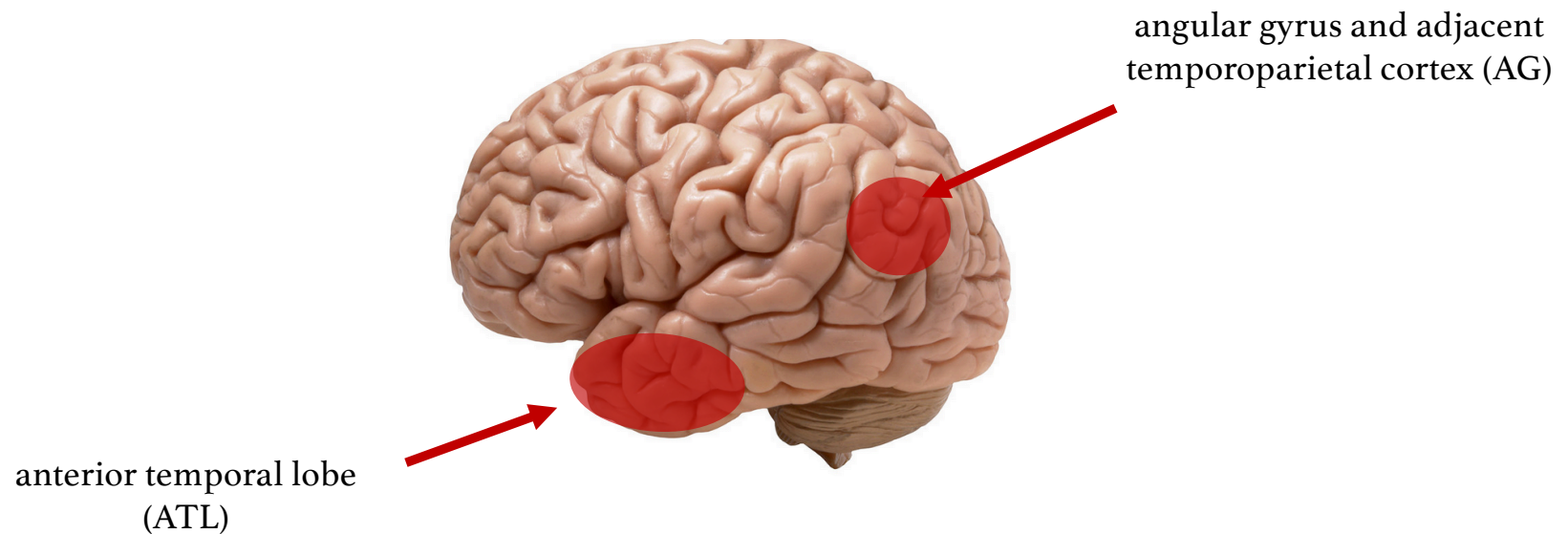**Structured:** two clients examine this nice couch
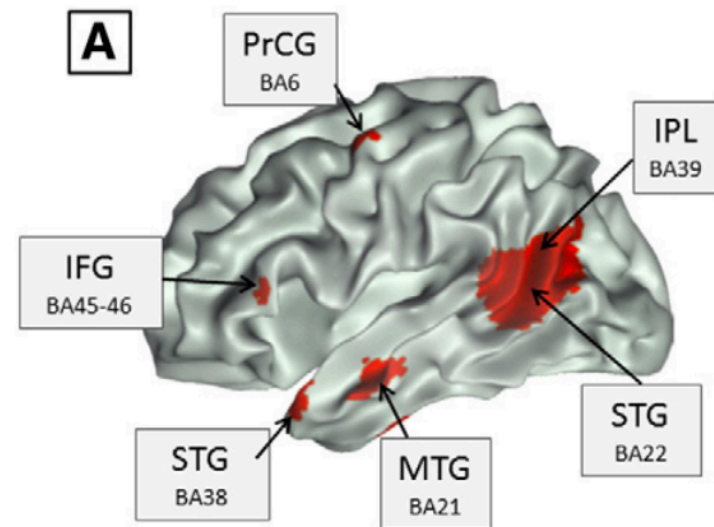**Unstructured:** couch clients two this nice examine

'Conceptual' regions in language comprehension: ATL and AG

angular gyrus and adjacent temporoparietal cortex (AG)

anterior temporal lobe (ATL)

'Conceptual' regions in language comprehension: ATL and AG
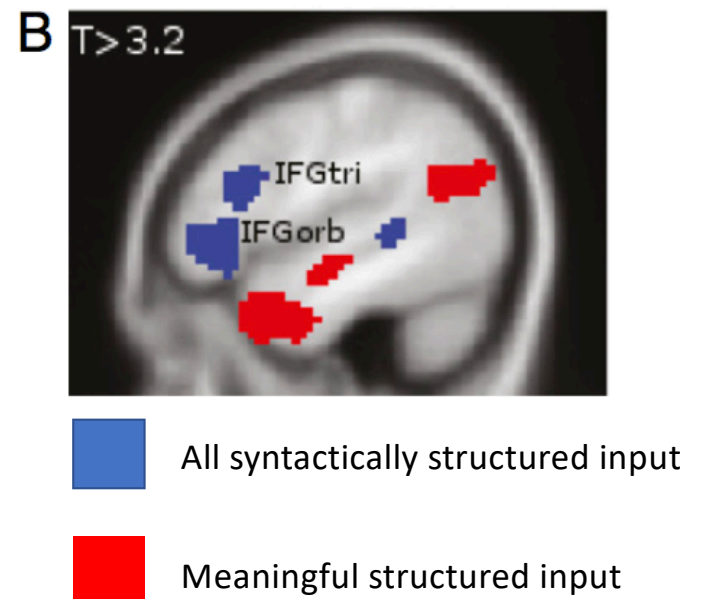
Beyond the word and image:

Jouen et al., 2015

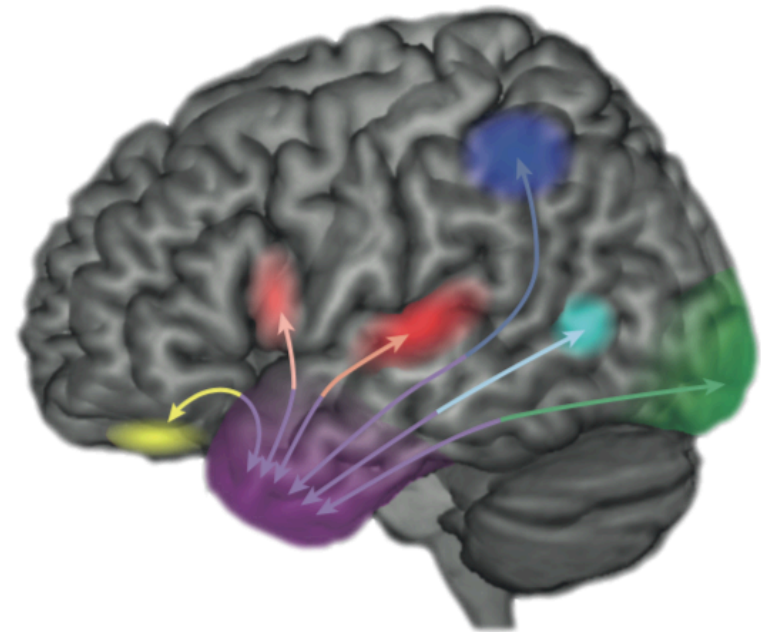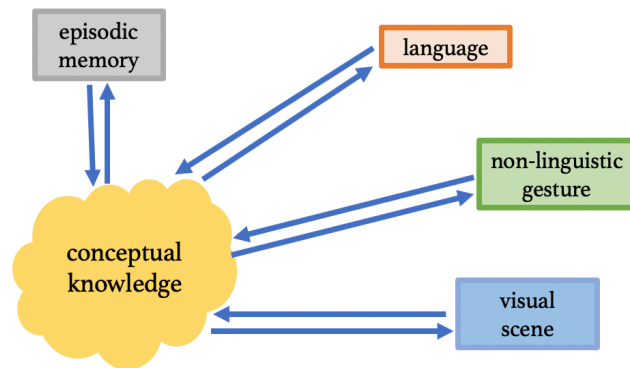# 'Conceptual' regions in language comprehension: ATL and AG

- Jabberwocky manipulations

*I toseive that you should begept the tropufal of your lew viroate*

All syntactically structured input

Meaningful structured input

Pallier, Devauchelle, & Dehaene (2011)

ATL is a 'hub' for conceptual knowledge

episodic memory

language

non-linguistic gesture

conceptual knowledge

visual scene

Patterson et al. 2007; Lambon Ralph, Jefferies et al. 2016
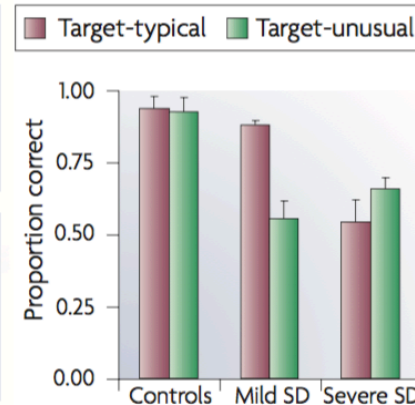
Semantic dementia
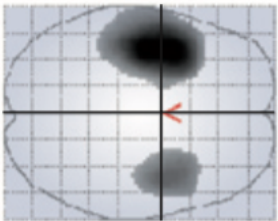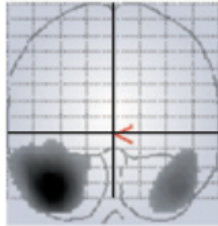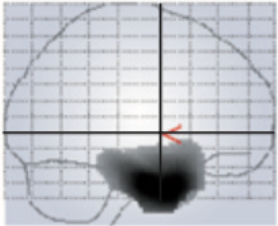
- Severe, non-linguistic conceptual deficits in semantic dementia

c Colour and object recognition
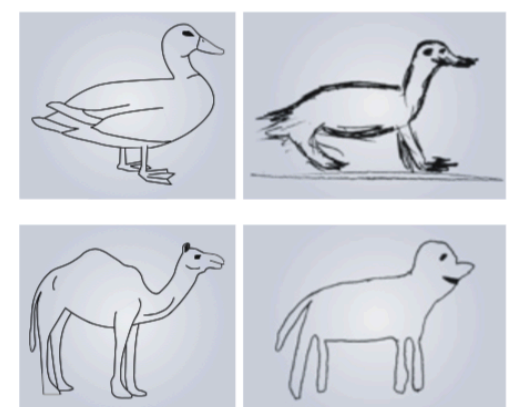
Task one stimulus: Which is coloured correctly?

Task one performance
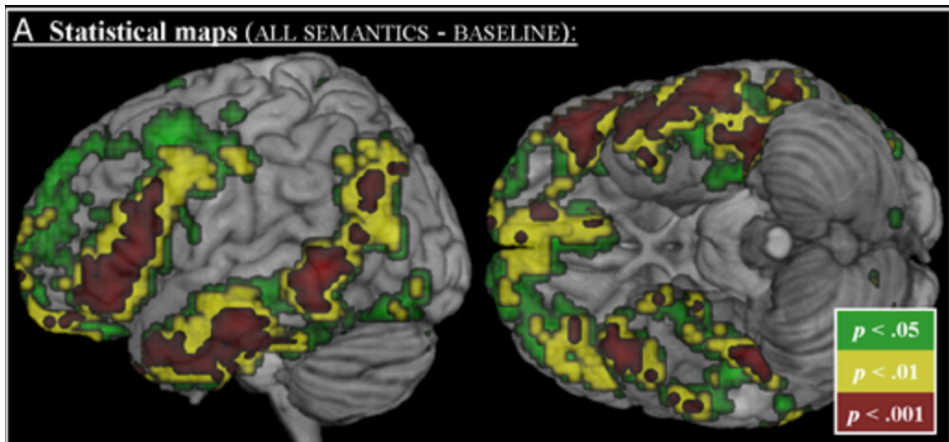

d Delayed-copy drawing
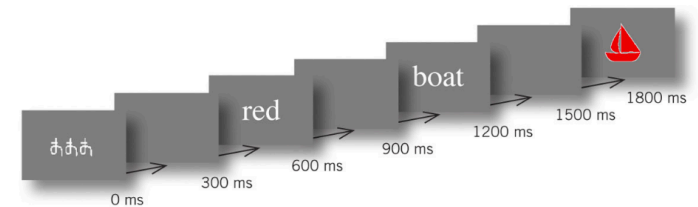
Model · Delayed copy

Patterson et al. 2007; Lambon Ralph, Jefferies et al. 2016

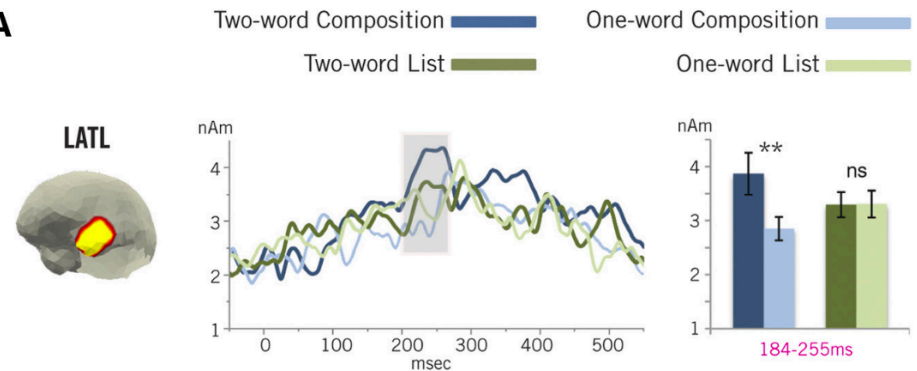- fMRI and MEG responses in ATL for conceptual access and conceptual combination

Visser, Jefferies, Embleton & Lambon Ralph, 2012

Bemis & Pylkkanen, 2011

ATL is a 'hub' for conceptual knowledge

- At the 'end' of the visual identification pathway, in which representations get progressively more abstract as you move 'forward' from occipital cortex

- Broad connectivity throughout cortex

- Great expansion of this area in humans

- Conveniently located next to medial temporal episodic memory regions
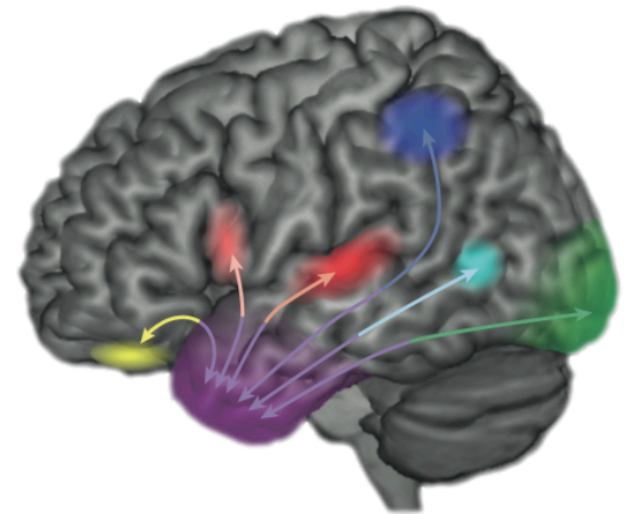
Patterson et al. 2007; Lambon Ralph, Jefferies et al. 2016

ATL is a 'hub' for conceptual knowledge

- Sensible spatial arrangement for hooking up speech to concepts
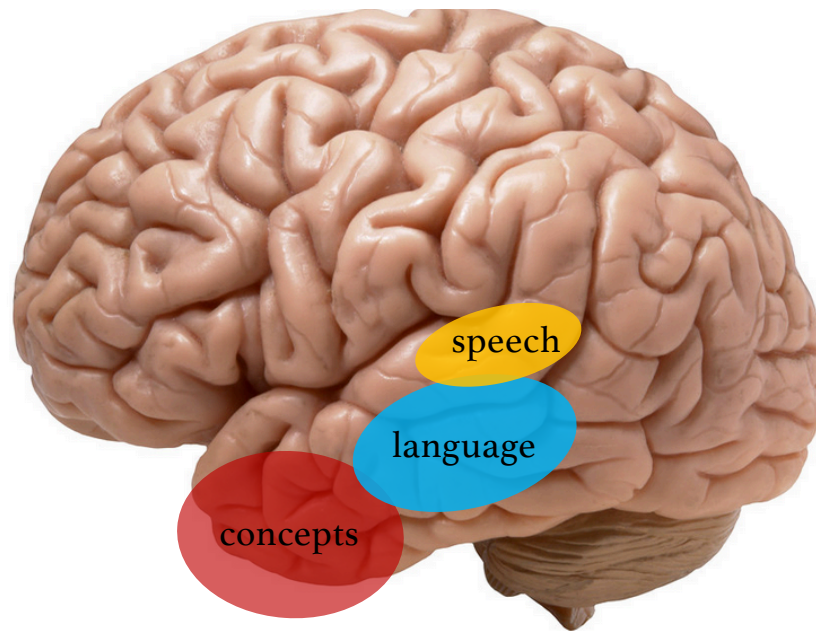
What happens in sentence comprehension?

- Identifying phonological and syntactic units and relations
- Putting together concepts or functions to concepts in particular ways indicated by the syntax

Angular gyrus

- What is left for AG to do?

angular gyrus and adjacent
temporoparietal cortex (AG)

speech
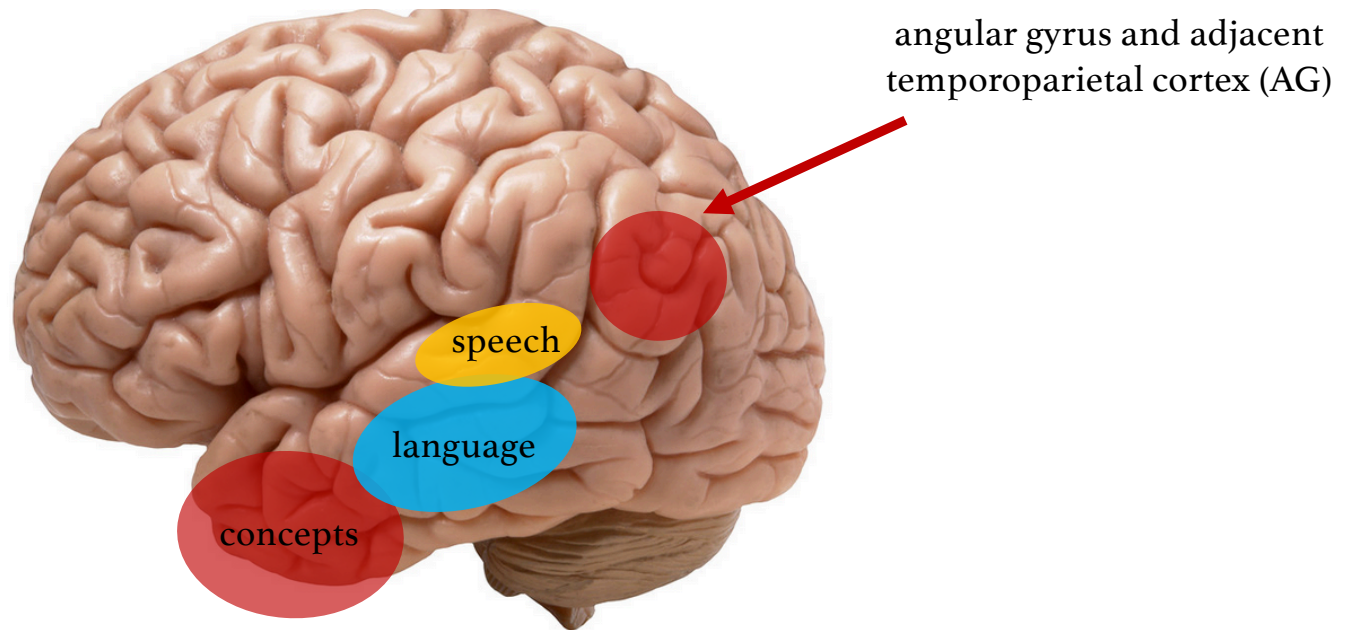
language

concepts

Humphries et al. 2006; Humphreys et al. 2021

Visual scene processing

- Known to depend on temporal and inferior parietal regions
- Drives conceptual combination and memory update, just like language
- Requires binding a bunch of visual properties to indexes: **reference**

Object files and reference

- We often think about visual objects being *defined* by their properties (blue square)

- But if you look at visual behavior, looks like viewers create visual object pointers that, once 'baptized', have a life of their own **independent of their properties**
    - 'It's a bird—no, it's a plane—no, it's Superman!'

- Kahneman and Treisman called these 'object files'

Object files

- Pointers to collection of visual properties, but not determined by them
- Adults seem to be able to keep **maximum 4** of these at a time (VWM)
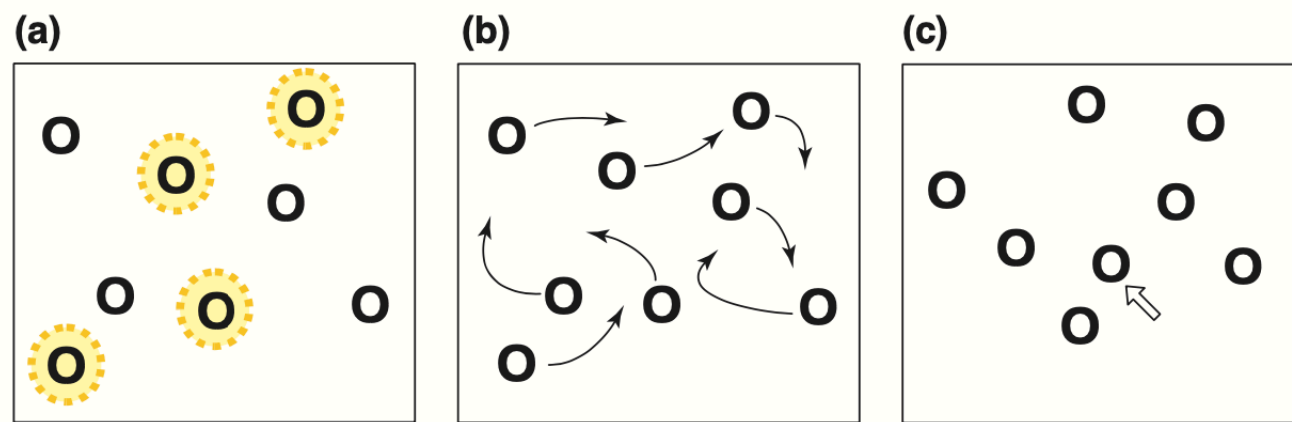
Multiple Object Tracking

Treisman, Pylyshyn, Kanwisher, Scholl, Spelke, Carey

Individuation, novel feature binding

- How do you avoid duplicating entities to be encoded to memory (today I saw a bird and I saw Superman)? Individuation through object files

- How do you do probe *novel combinations* (does this red thing have an X shape), where conjunction coding can't work? Temporary, instantaneous bindings provided by object files

Feature Search   **Conjunction Search**

Treisman
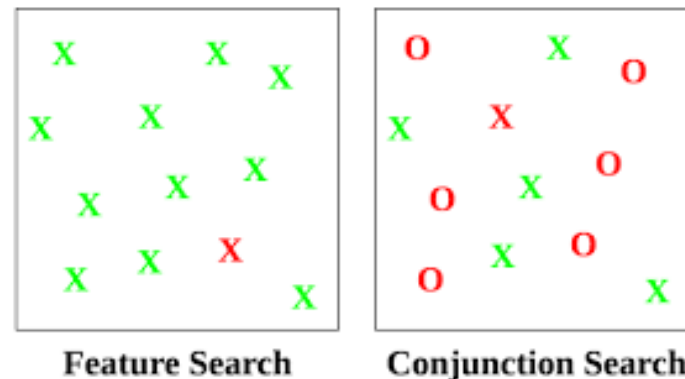
Inferior parietal: binding to indexes

- Inferior temporal visual cortex **estimates visual properties** like color and shape, independent of task, loosely grouped into proto-objects
- Intraparietal sulcus provides **temporary bindings** from properties to object files
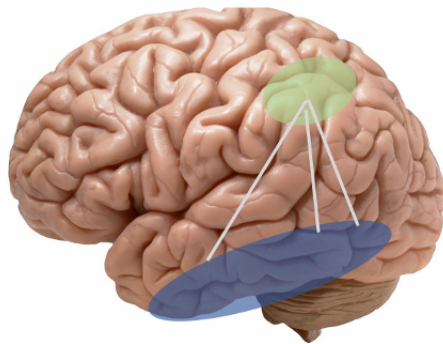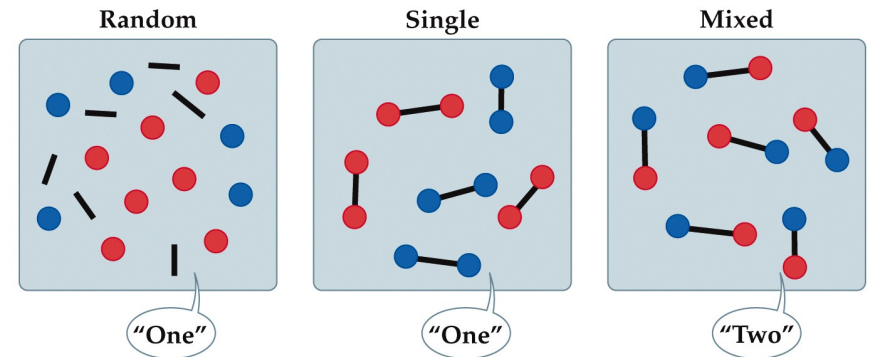
Yaoda Xu, 2017; Xu & Chun, 2006

Inferior parietal: binding to indexes

- Simultagnosia/Balint's syndrome: bilateral damage to parietal cortex
- Awareness of one object at a time; can't comprehend overall meaning of a visual scene; binding errors

Lateral views

(A) "How many colors do you see?"

Random   Single   Mixed

"One"   "One"   "Two"
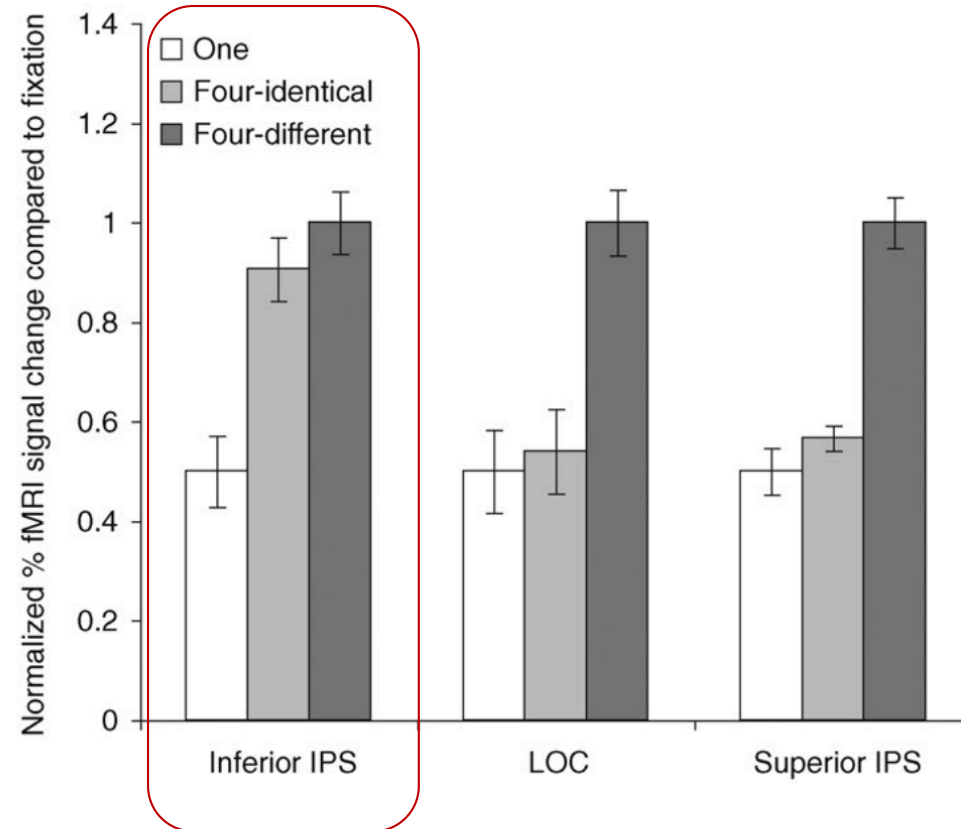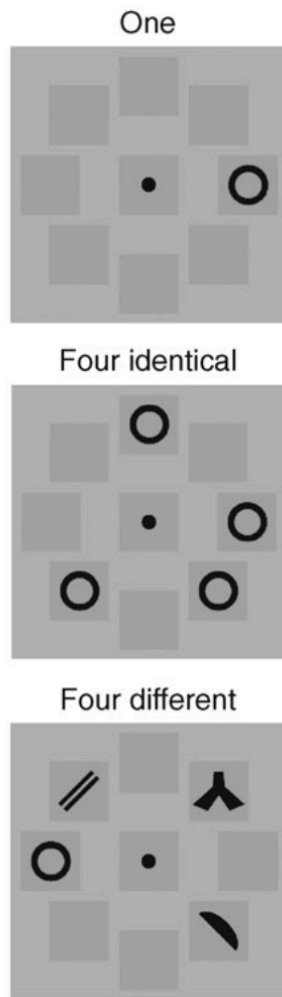
PRINCIPLES OF COGNITIVE NEUROSCIENCE 2e, Figure 7.2 (Part 1)
© 2013 Sinauer Associates, Inc.

Inferior parietal: binding to indexes

- Response in intraparietal sulcus is modulated as a function of the **number of object files**, not the amount of features bound to them

Todd & Marois, 2004; Xu & Chun, 2006; Xu, 2007

One

Four identical

Four different

Normalized % fMRI signal change compared to fixation

☐ One
▨ Four-identical
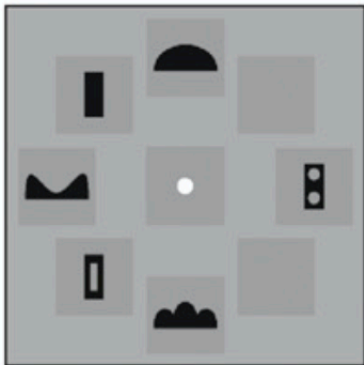▨ Four-different

Inferior IPS   LOC   Superior IPS

TRENDS in Cognitive Sciences

Xu (2009)
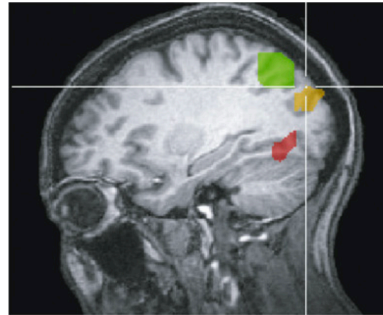
'simple' objects

'complex' objects

Behavioral performance

Behavioral VSTM capacity estimate K

Inferior IPS

- Simple
- Complex

- Simple
- Complex
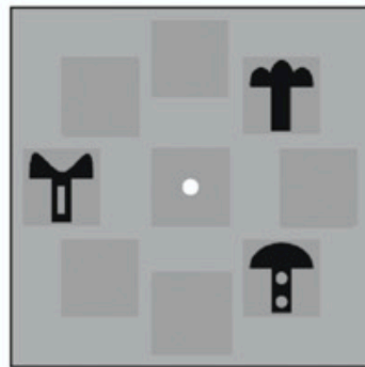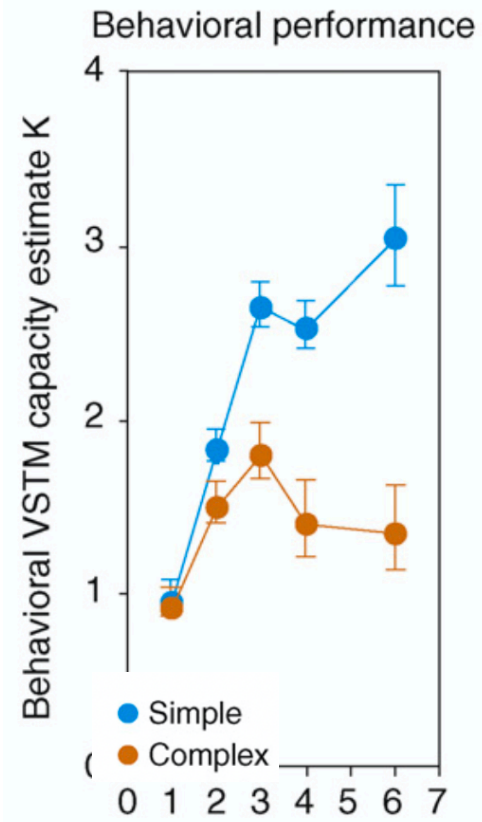
Number of items to remember

Xu & Chun, 2006
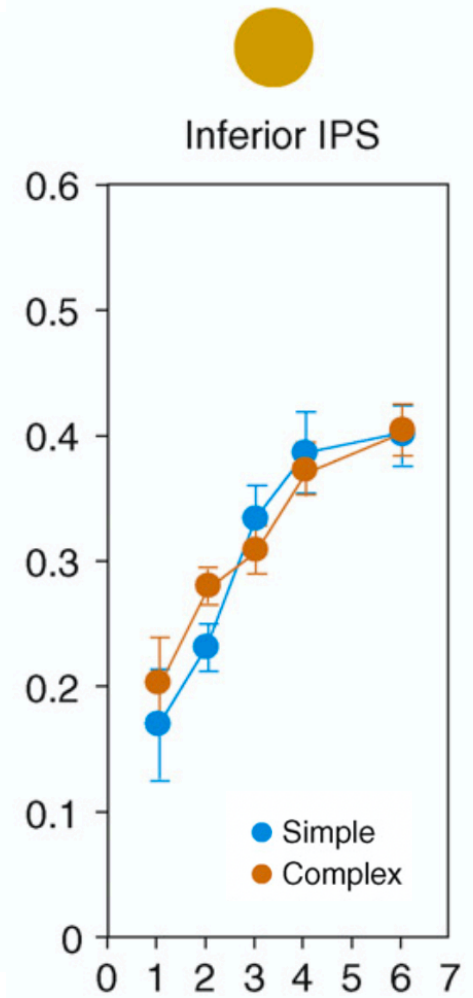
Inferior parietal: binding to indexes

- ERPs show sustained responses for visual WM tasks where amplitude tracks the **number of items** being encoded; MEG shows responses largely driven by inferior parietal cortex (Becke, Hopf et al. 2015)
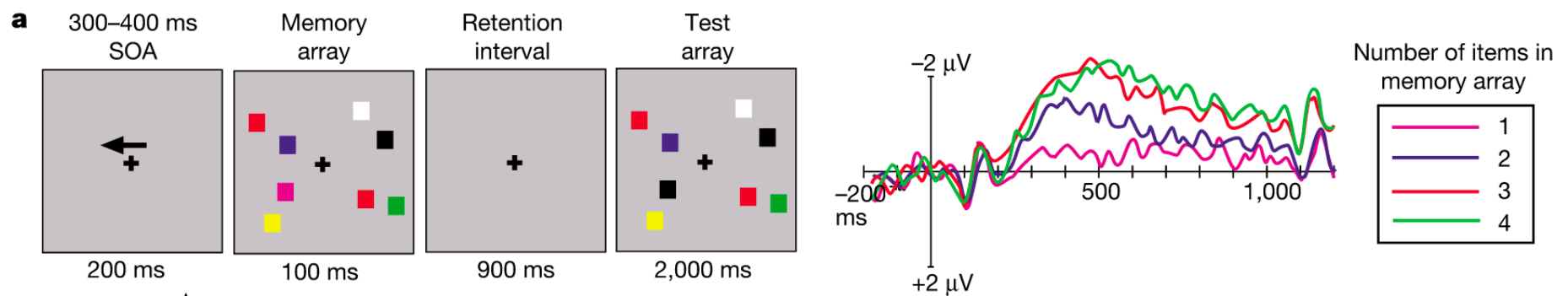
Vogel & Machizawa, 2004

Inferior parietal: binding to indexes

- In vision, inferior parietal cortex supports **a limited set of pointers** to properties represented in inferior temporal cortex

- These act as 'indexes' for individual entities and events in the world

- The indexes enter into working memory computations, and allow appropriate episodic memory update
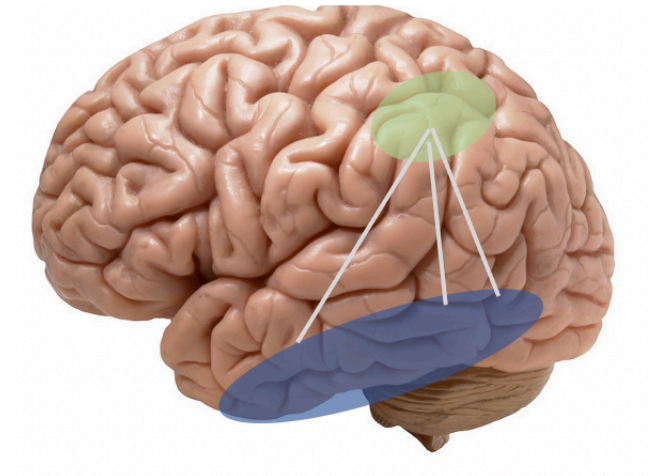
From object files to 'discourse files'

- Once we remember that language comprehension, like scene perception, ends in manipulation of non-linguistic concepts, natural extension of this 'vision' theory accounts for inferior parietal activity during language experiments
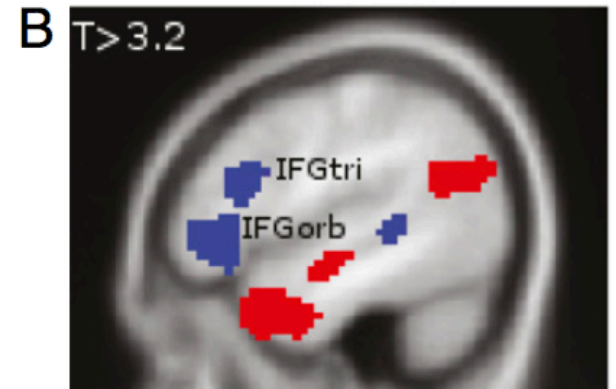
Reference

A woman saw a dancing peanut who had a big smile on his face.

Nieuwland & Van Berkum, 2006

Reference

*A woman saw a dancing peanut who had a big smile on his face. The peanut was singing about a girl he had just met. And judging from the song, the peanut was totally crazy about her. The woman thought it was really cute to see the peanut singing and dancing like that. The peanut <u>was in love,</u> and by the sound of it, this was definitely mutual.*

Nieuwland & Van Berkum, 2006

What happens in sentence comprehension?

- Identifying phonological and syntactic units and relations
- Putting together concepts or functions to concepts in particular ways indicated by the syntax
- **Creating indexes for individuals and events described by the sentence, and binding new conceptual properties to them**   **angular gyrus**

Angular gyrus: referential indexing

- Since we think there is continuity between the thoughts we encode based on visual scenes and language, just add that
  - Indexes can be created based on linguistic cues, not just spatiotemporal visual contiguity
  - Amodal conceptual properties can be bound to files, not just visual properties
  - May be slightly different parietal sub-regions?
  - Note not literally 'objects'; events can be referents too
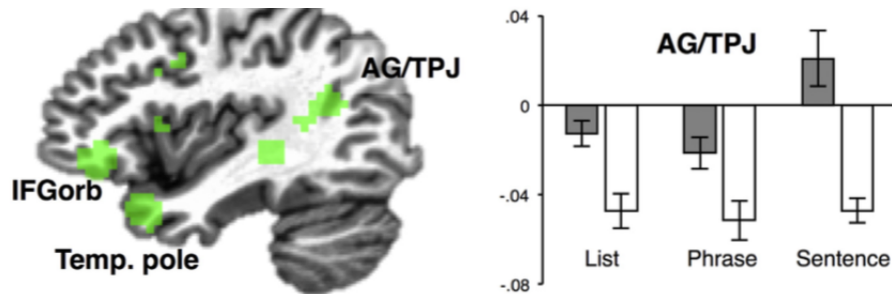 - Input to 'mental model' WM operations (Johnson-Laird)
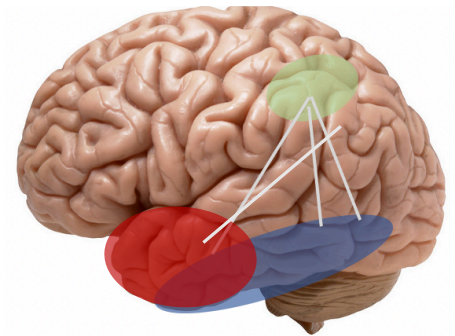
Angular gyrus: referential indexing

- More response to sentences than word lists (independent of task) because you're not getting clear instructions to create individuals in lists
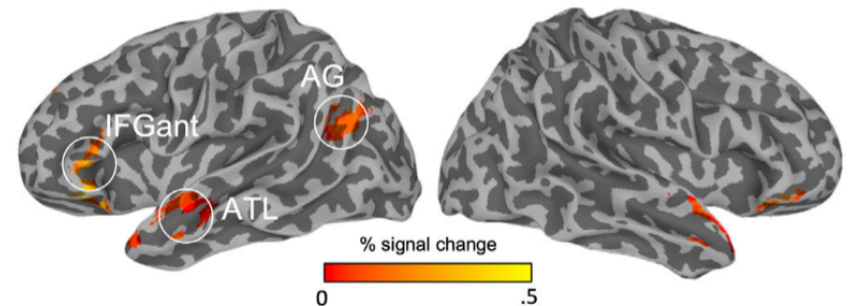
couch clients two this nice examine

Sentence > List; memory probe
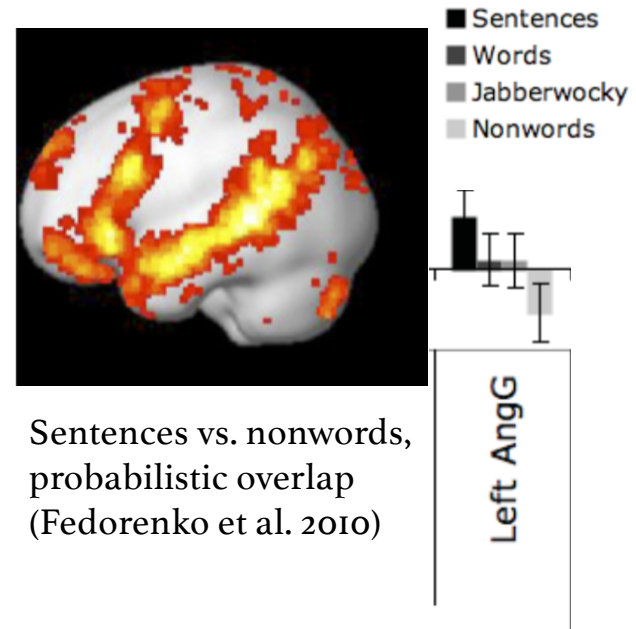
Sentence > List; semantic judgment

Matchin et al., 2017

Matchin et al., 2019

Angular gyrus: referential indexing

- Angular gyrus does not respond to jabberwocky sentences; no conceptual properties to bind to indexes

I toseive that you should begept the tropufal of your lew viroate

Pallier et al. 2011

Sentences vs. nonwords, probabilistic overlap (Fedorenko et al. 2010)
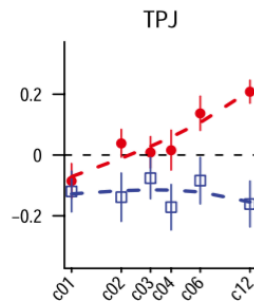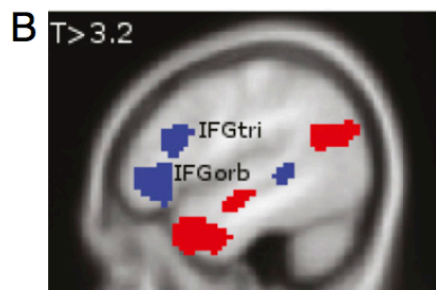
Angular gyrus: referential indexing
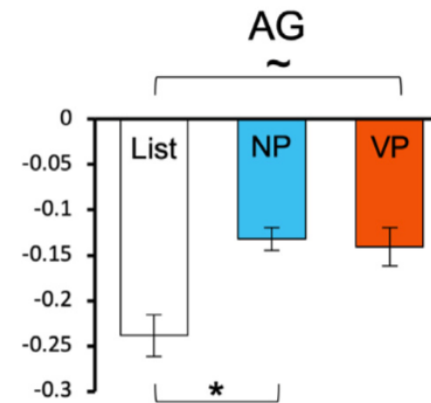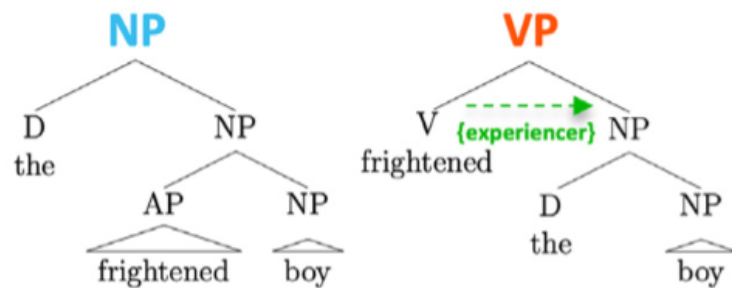
- Equal response to NPs and VPs above word lists in a semantic memory task; in both you can bind properties to indexes
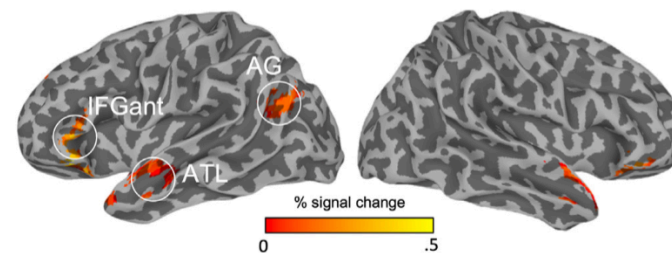
Matchin, Liao, Gaston & Lau 2019

Angular gyrus: referential indexing
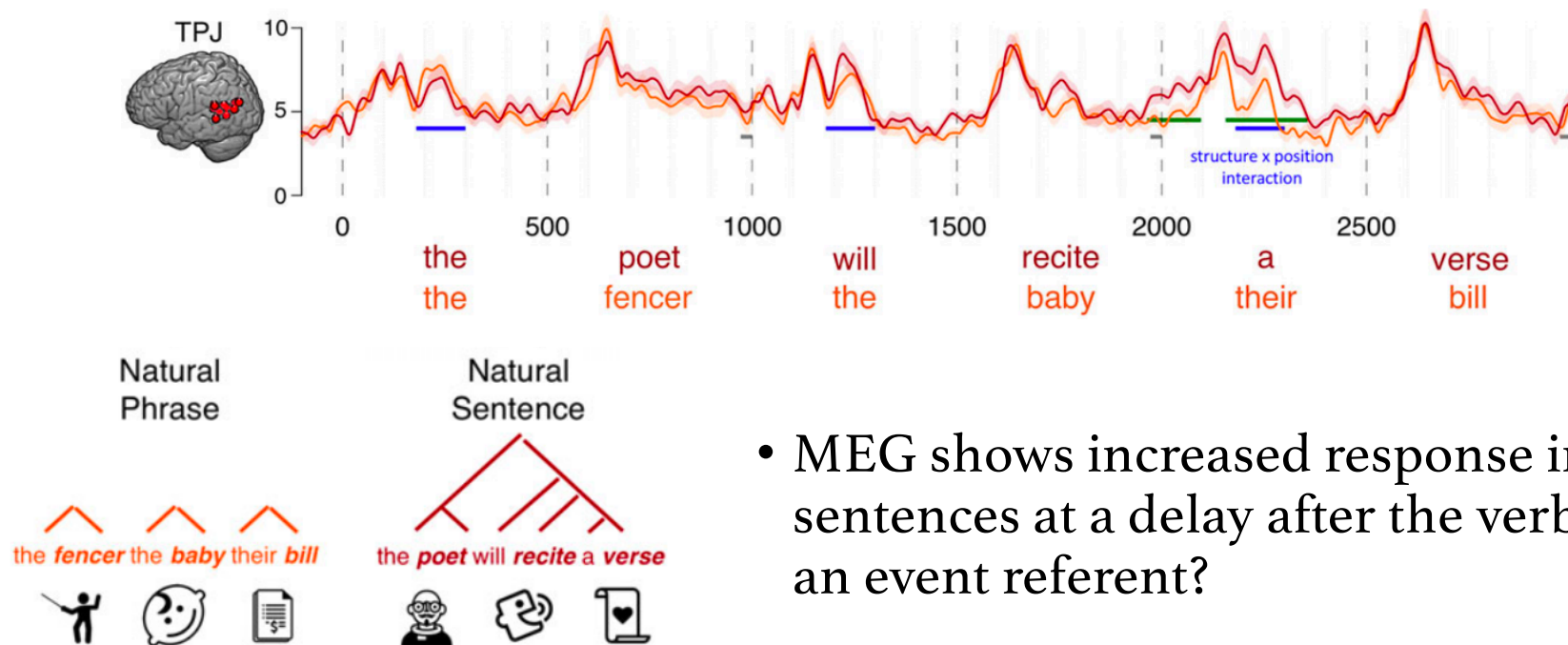
- MEG shows increased response in AG in sentences at a delay after the verb; adding an event referent?

Matchin, Brodbeck, Hammerly & Lau, 2018

Angular gyrus: referential indexing

- One alternative kind of theory argues instead that angular gyrus might be a second hub for conceptual **knowledge**, where ATL and AG split according to the kinds of property knowledge they store
  - Taxonomic vs. thematic knowledge (Schwartz et al. 2011)
  - Object vs. event knowledge (Binder & Desai, 2011)
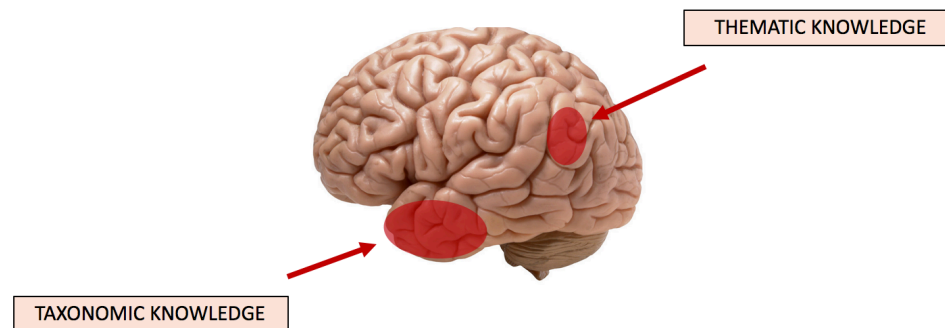
Angular gyrus: referential indexing

- However, semantic dementia patients appear to be just as impaired on event concepts (what constitutes 'jumping' vs. 'tumbling') as on entity concepts (Bonner et al., 2009)

What happens in sentence comprehension?

- Identifying phonological and syntactic units and relations
- Putting together concepts or functions to concepts in particular ways indicated by the syntax
- Creating pointers for individuals and events described by the sentence, and binding new conceptual properties to them
- **Updating episodic memory with AG-ATL representation**   **medial temporal lobe**

Working memory to long-term memory

- The content of referent indexes are frequently synced to longer-lasting, higher capacity 'episodic' index system in the hippocampus/MTL
  - Over long-term some of these are consolidated as new ATL concepts
- Referent indexes can also be 'copied' in the other direction, from episodic memory into one of the 4 inferior parietal 'slots'
  - Default network
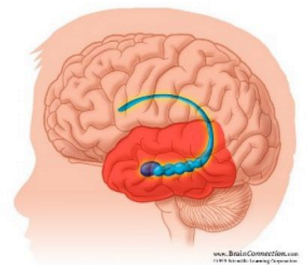
Working memory to long-term memory

- The content of referent indexes are frequently synced to longer-lasting, higher capacity 'episodic' index system in the hippocampus/MTL
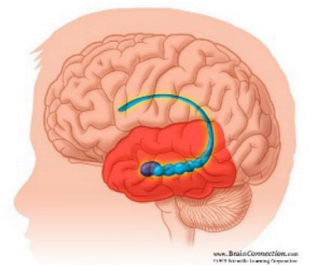 - Over long-term some of these are consolidated as new ATL concepts
- Referent indexes can also be 'copied' in the other direction, from episodic memory into one of the 4 inferior parietal 'slots'
- Perhaps N400 reflects not lexical or conceptual 'access', but regular 'syncing' of the referent files to episodic memory—less new featural content to sync = smaller N400

Angular gyrus: referential indexing
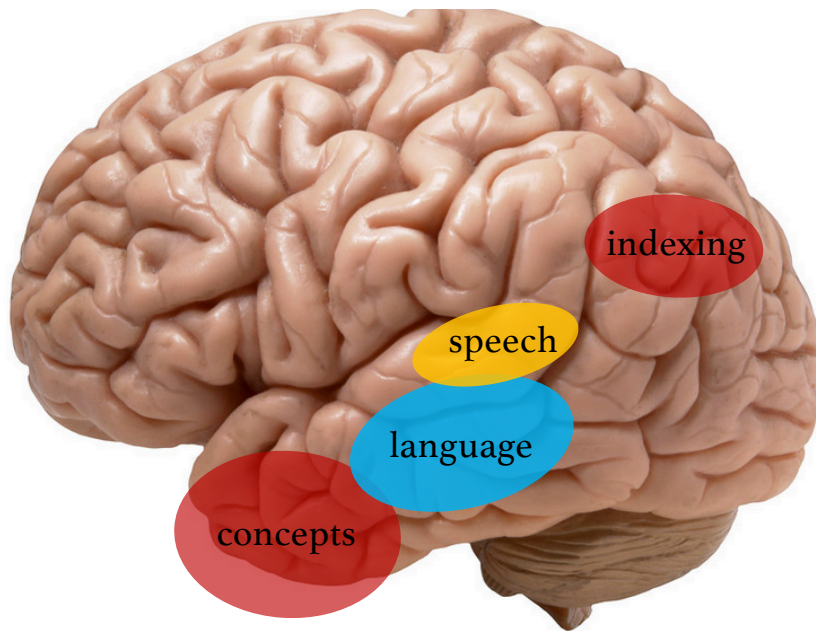
- Coordinating linguistic and non-linguistic representations across time: incrementality and revisability

- Sustained negativities for 'syntactic' WM or for referential indexes in WM?

- Sentence-picture matching deficits sometimes due to damage to index system, not syntactic system?

Less words

- Where are they anyway? Why don't we agree on that by now???
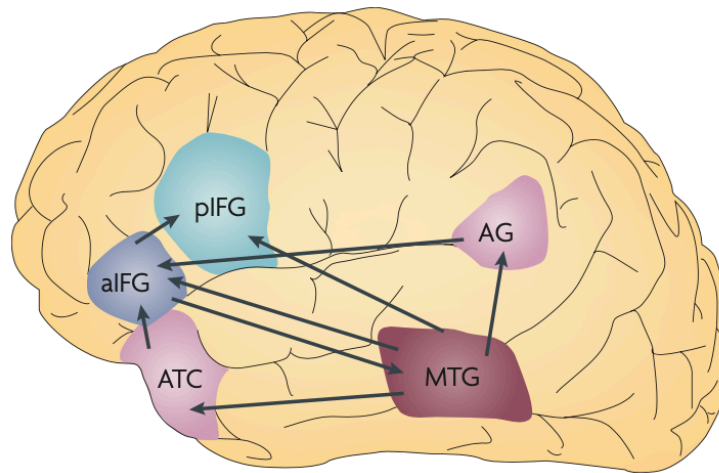
Figure 5 | **A functional neuroanatomic model for semantic processing of words in context.** Lexical

Lau, Phillips & Poeppel, 2008

There's no such thing as 'words'

- Colloquial term, with no precise usage
  - sometimes used for, whatever occurs between white spaces when typed out (in languages that have that)
  - sometimes used for something approximately phonological 'That word has two meanings'
  - sometimes for a form-meaning pair 'Do you know the word *blicket*?' 'No, but I've heard it before'

There's no such thing as 'words'

- What about 'lexical item', where we have in mind a 1-1-1 pairing between a sound unit, a syntactic unit, and a conceptual unit?

/kaet/

unit3327 +noun

{cat}
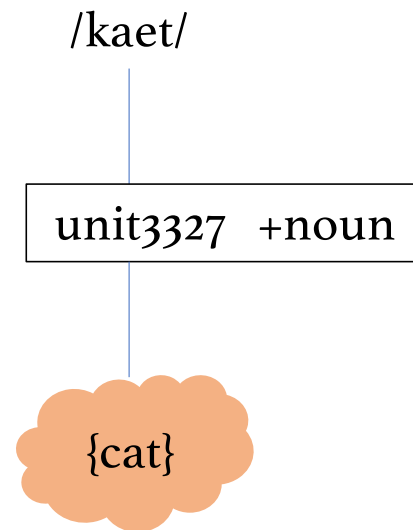
There's no such thing as 'words'

- For one thing, as a field the _variability_ in our usage of terms like 'lexical item' and 'lexical access' is horrendous—no chances of making progress when some of us use 'lexical access' to mean recognizing a common sound form and others to mean making contact with a non-linguistic concept

There's no such thing as 'words'

- What about 'lexical item', where we have in mind a 1-1-1 pairing between a sound unit, a syntactic unit, and a conceptual unit?
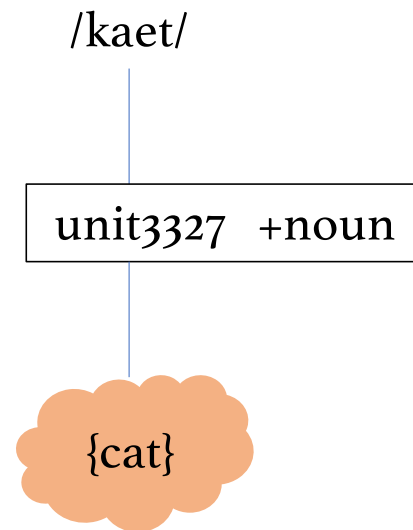
/kaet/

| unit3327 +noun |

{cat}

There's no such thing as 'words'

- Many, many cases of non 1-1-1 mappings
  - Things that look like single phonological words map to multi-unit syntax—'Djwannabet?'
  - Things that look like single conceptual units map to multi-unit syntax and phonology—'kick the bucket', 'go off'
  - Even the canonical examples of 1-1-1 mappings ('dog') are not—e.g. unsystematic meaning changes conditioned on syntactic category and context are common ('concerns dogged the project')

Noyer, Marantz, Embick, Harley, Goldberg, Preminger, Carston

There's no such thing as 'words'
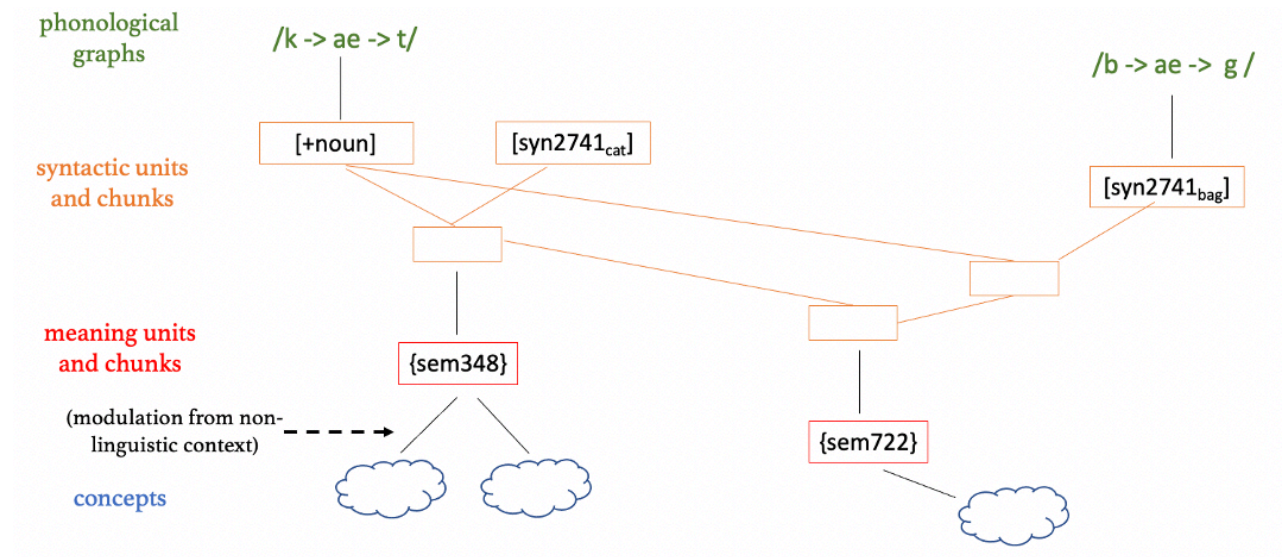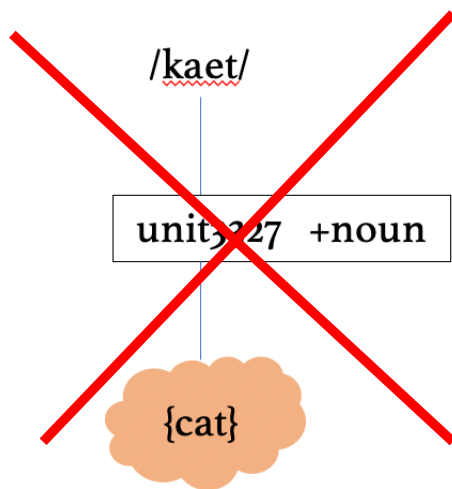
There's no such thing as 'words'

- Does it really matter for psycholinguists and neurolinguists?

- If speakers store mappings between meanings and syntactic structures, not just single lexical units, that should nudge us towards different neuroanatomical theories of syntactic analysis

Lexicon and syntax

- Classic theories suggested that lexicon is in temporal cortex, and you need circuits in Broca's area to manage the combination operations
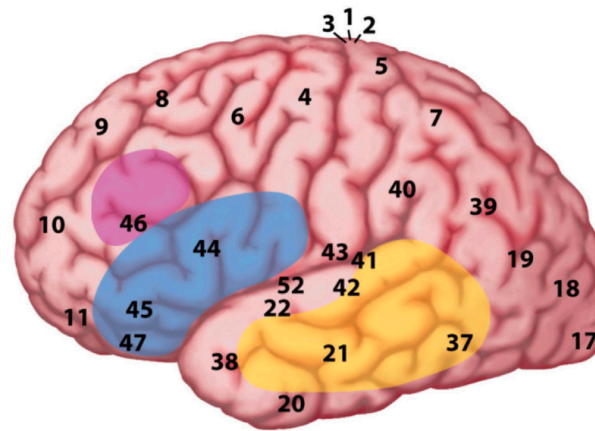
Hagoort (2017): MUC – Memory, Unification, Control

Lexicon and syntax

Lack of selectivity for syntax relative to word meanings throughout the language network

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[b] McGovern Institute for Brain Research, MIT, Cambridge, MA 02139, USA
[c] Department of Psychology, UCLA, Los Angeles, CA 90095, USA
[d] Department of Psychology, Columbia University, New York, NY 10027, USA
[e] Eberly Center for Teaching Excellence & Educational Innovation, CMU, Pittsburgh, PA 15213, USA

- But across many fMRI studies, Fedorenko observes that it's hard to find areas that distinguish lexical access from syntactic combination

Lexicon and syntax

- Matchin and Hickok (2020): temporal cortex 'does it all'
  - **Stored mappings from syntactic units and relations** to sound and meaning
  - Generative model for estimating **new syntactic relations** between existing units
  - IFG only does syntactic production stuff needed for syllabification and articulation
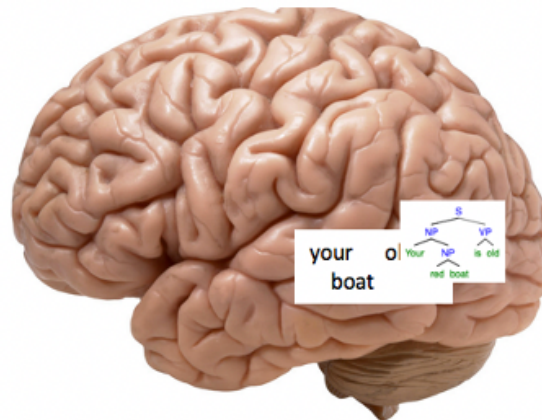
No more words

- Instead of identifying a set of discrete lexical items and then figuring out how they relate to each other

- ....think about solving for both syntactic units and syntactic relations at the same time, 'mapping through syntax'

- Mid-temporal cortex is the heart of the true 'language network', where you solve for the syntactic units and their relations simultaneously
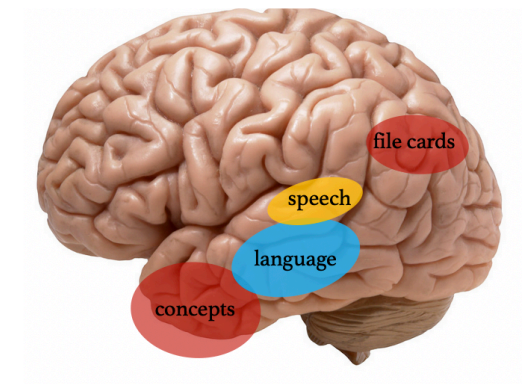
Decomposing the Mind-Brain: A Long-Term Pursuit

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Abstract. This paper defends cognitive neuroscience's project of developing mechanistic explanations of cognitive processes through decomposition and localization against objections raised by William Uttal in *The New Phrenology*. The key issue between Uttal and researchers pursuing cognitive neuroscience is that Uttal bets against the possibility of decomposing mental operations into component elementary operations which are localized in distinct brain regions. The paper argues that it is through advancing and revising what are likely to be overly simplistic and incorrect decompositions that the goals of cognitive neuroscience are likely to be achieved.
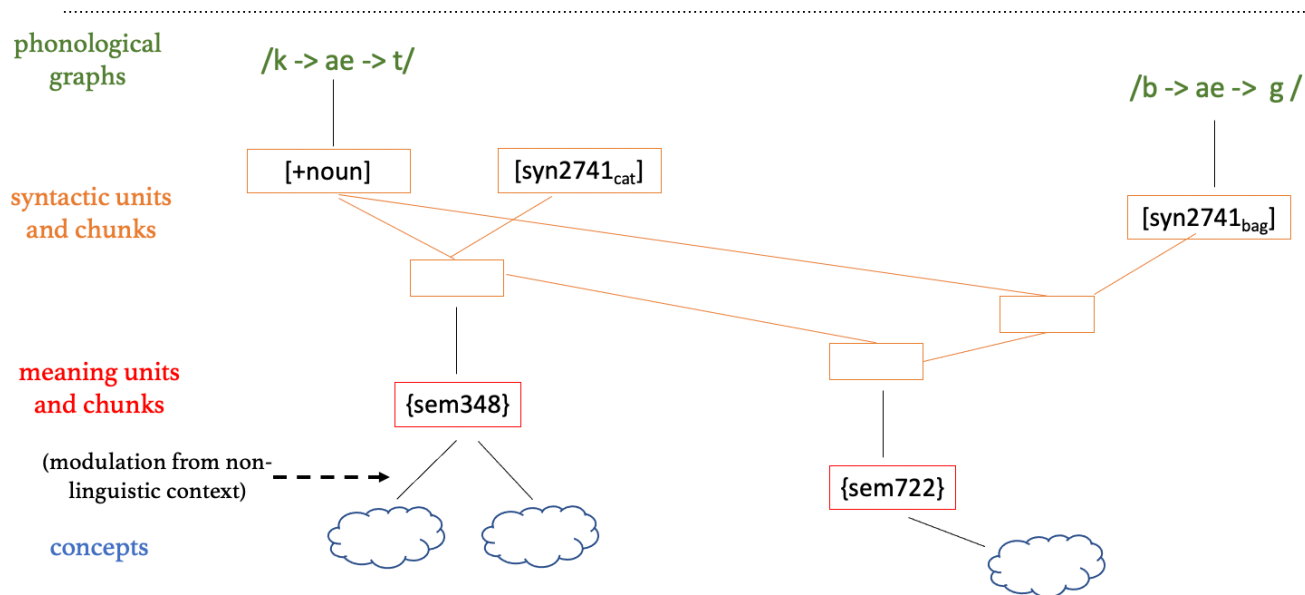
Ways Forward: More thought, less words

conceptual system

language system

syntactic units and syntactic relations

Explicit assumptions

- If we're gonna use words like 'word' or 'lexical item' or 'lexical access', we should start clearly defining them in our papers

Phrases, not single words

- Experiments on isolated single words out of context are like trying to learn about face perception by running lots of experiments on noses!

Which Is Larry's Nose?

Which Is Larry?

Tanaka & Farah
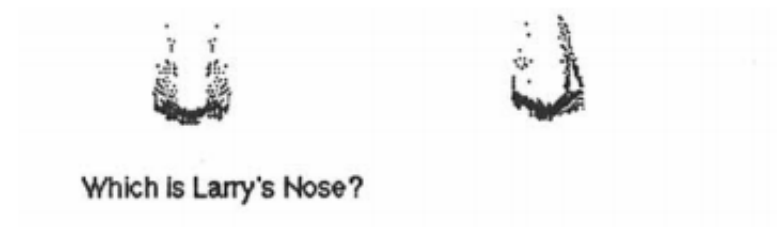
Working memory and sentence comprehension

- All along, it was *visual* working memory we should have been paying attention to, because that's about binding properties to referents

- If no 'words', then 'verbal' working memory for word lists may have little to do with the language decoding pathway

More thought, less words

Thanks

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