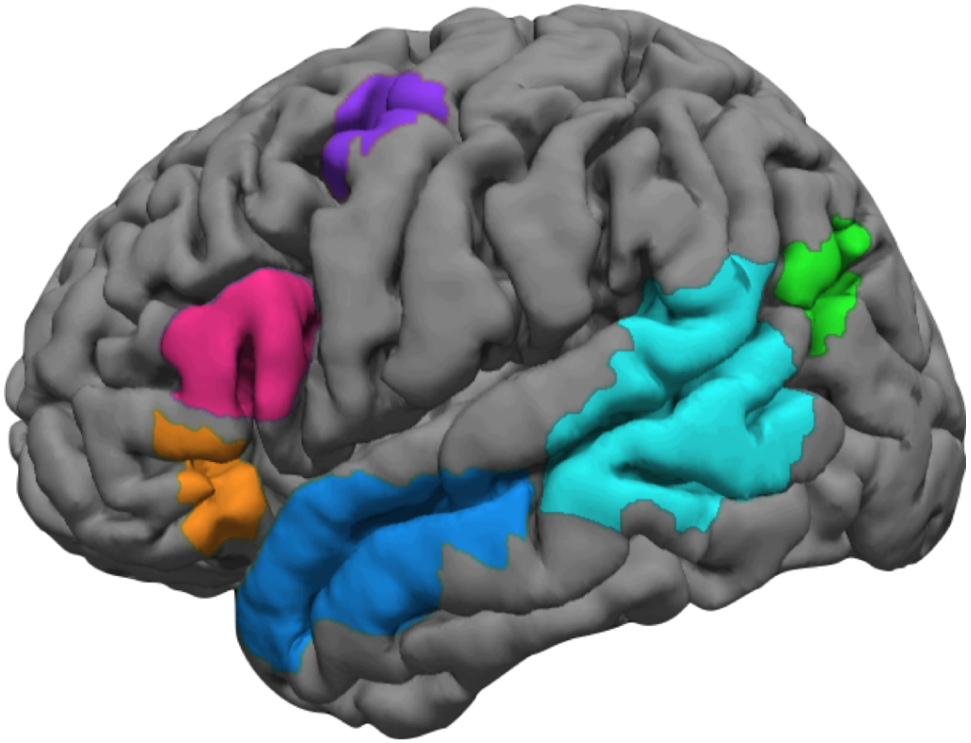
The internal architecture of the language network



Ev Fedorenko
HMS/MGH; MIT

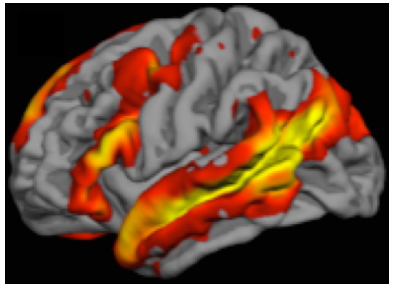
University of Gothenburg
September 13, 2016

Outline

1. The language network is **a functionally integrated system**.
2. The language brain regions **closely track linguistic input**.
3. Hypotheses about **possible organizing principles** of the language network.

The language network is a functionally integrated system

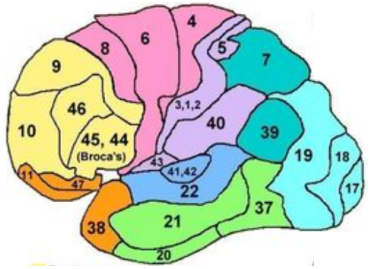
Language system



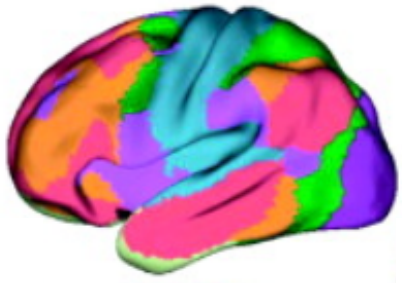
Idan Blank

General approach:

- functional correlations

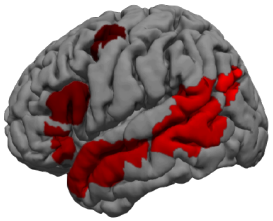


Brodmann (1909)



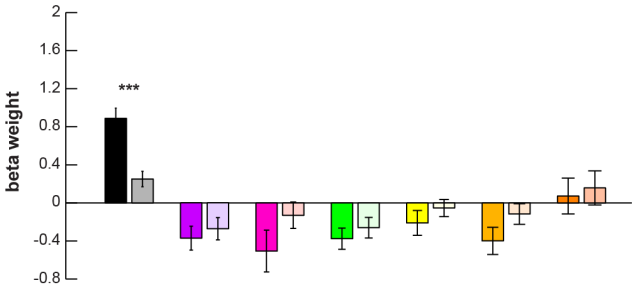
e.g., Yeo et al. (2011)

Language

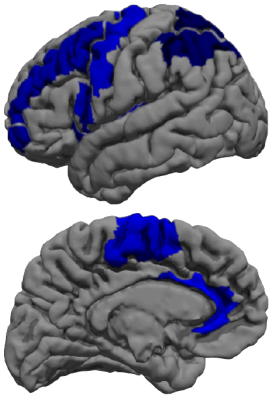


(b)

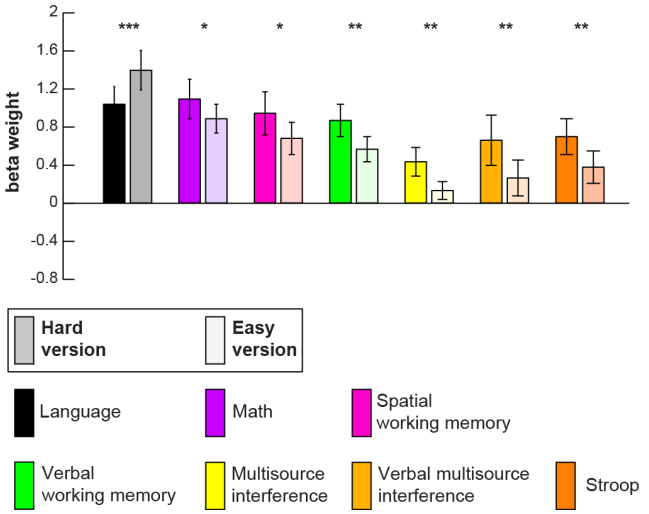
Sample language fROI (infterior frontal gyrus, orbital)



MD



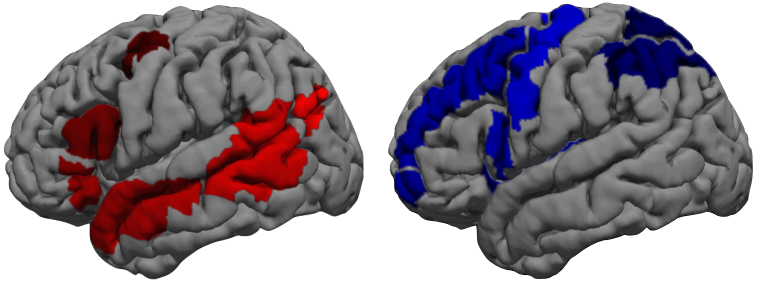
Sample MD fROI (infterior frontal gyrus, opercular)

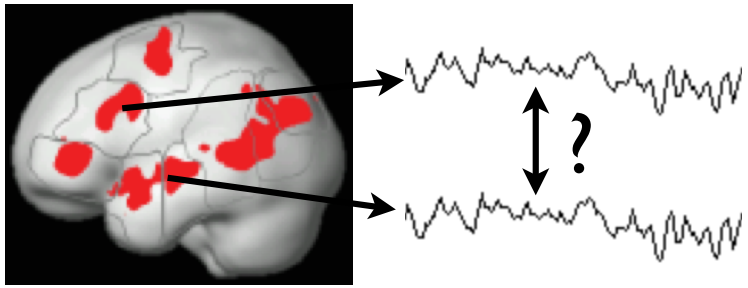


Fedorenko et al. (2011, PNAS); Fedorenko et al. (2012, Curr Biol); Fedorenko et al. (2013, PNAS)

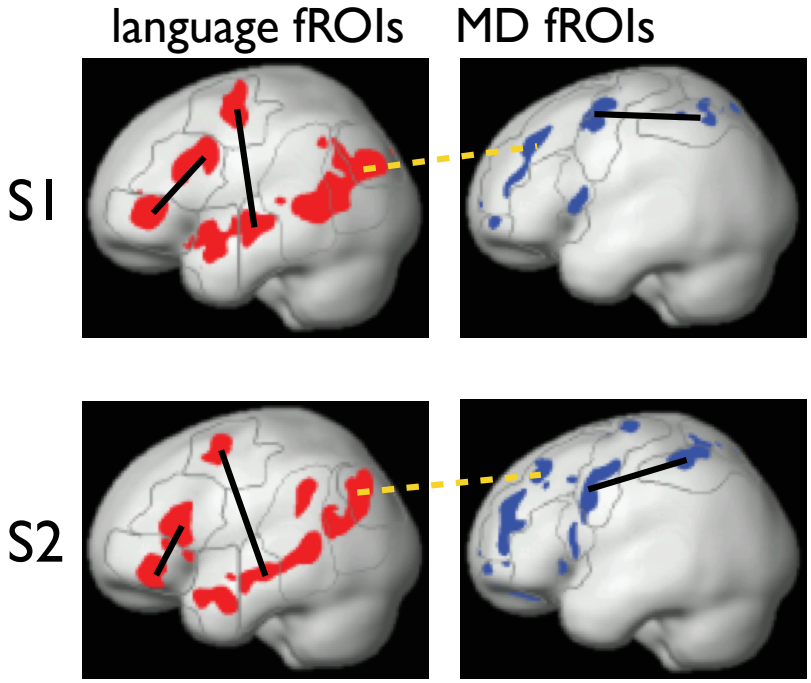
The language network is a functionally integrated system

Idan Blank





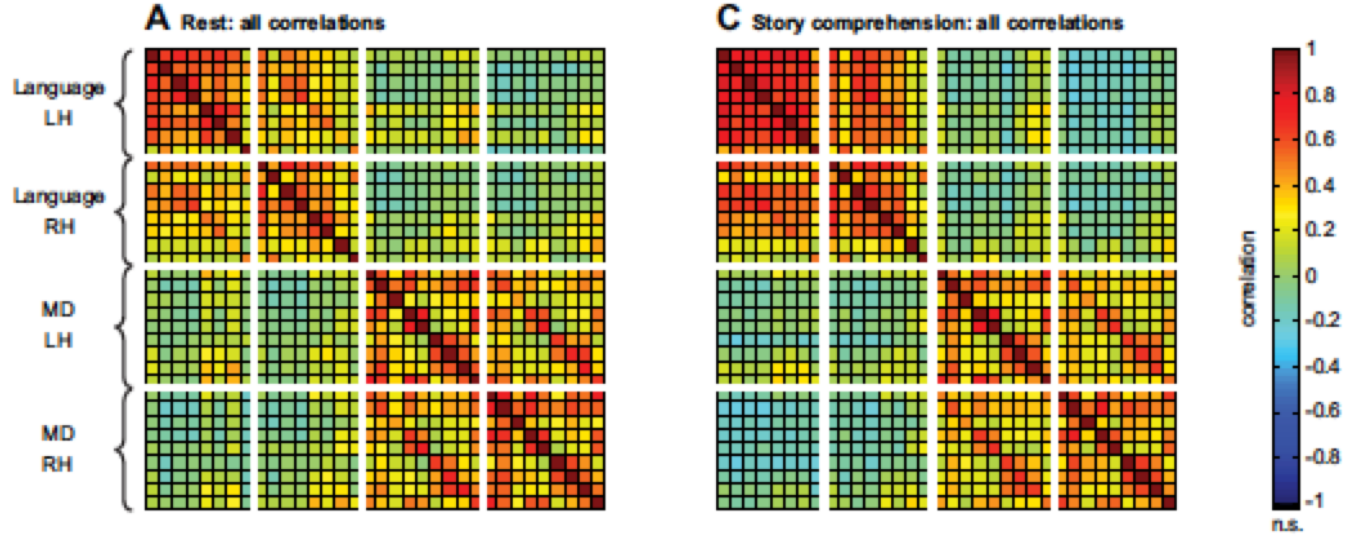
(correlations across regions within an individual)

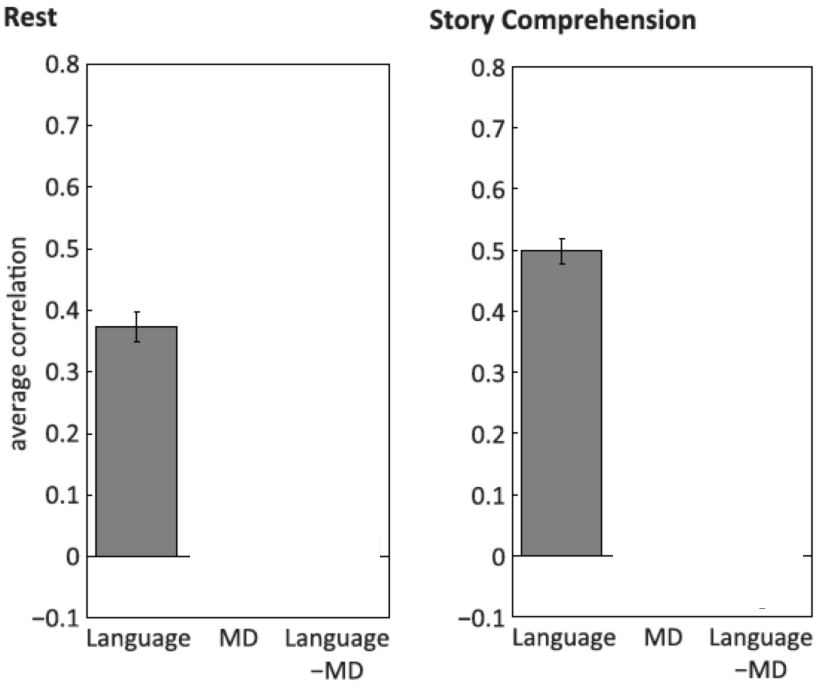


Blank, Kanwisher & Fedorenko (2014)

The language network is a functionally integrated system

Idan Blank





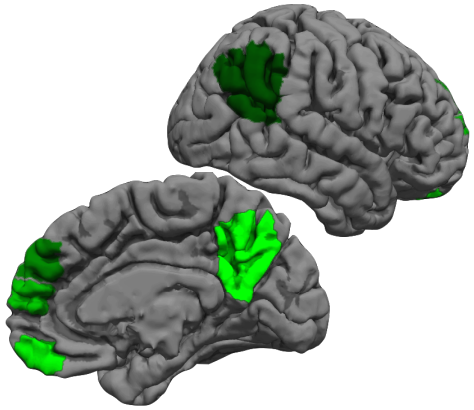
1. Language regions form a functionally integrated system.
2. MD regions form a functionally integrated system.
3. Language and MD regions are functionally dissociable.

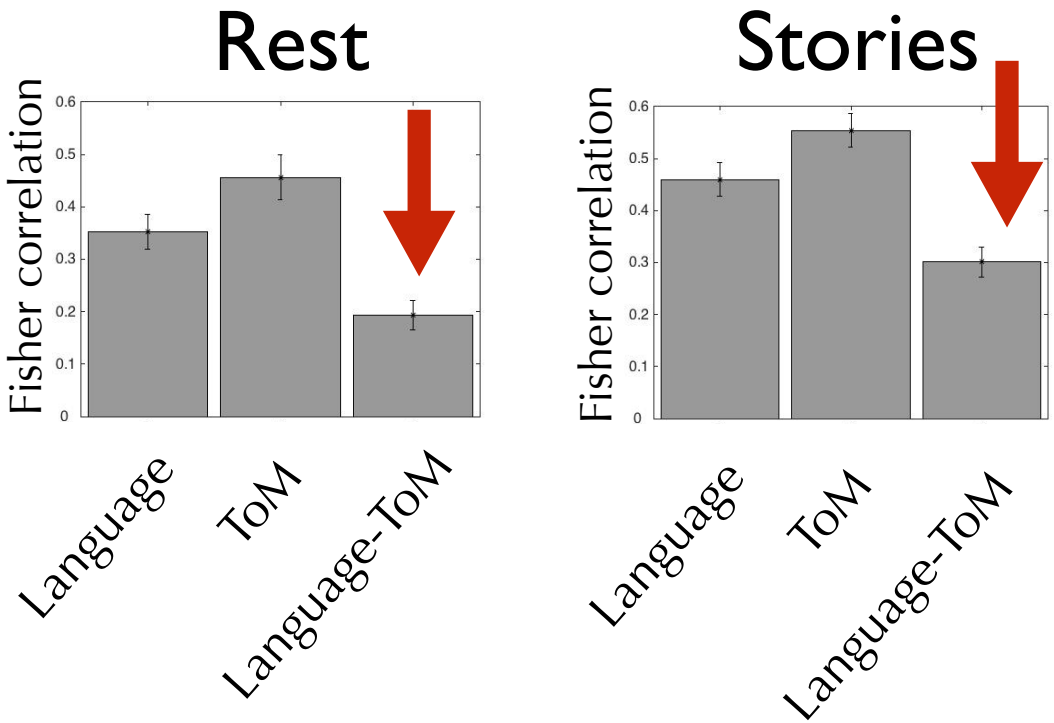
Blank, Kanwisher & Fedorenko (2014)

The language network is a functionally integrated system

Alex Paunov Idan Blank

Network supporting social cognition





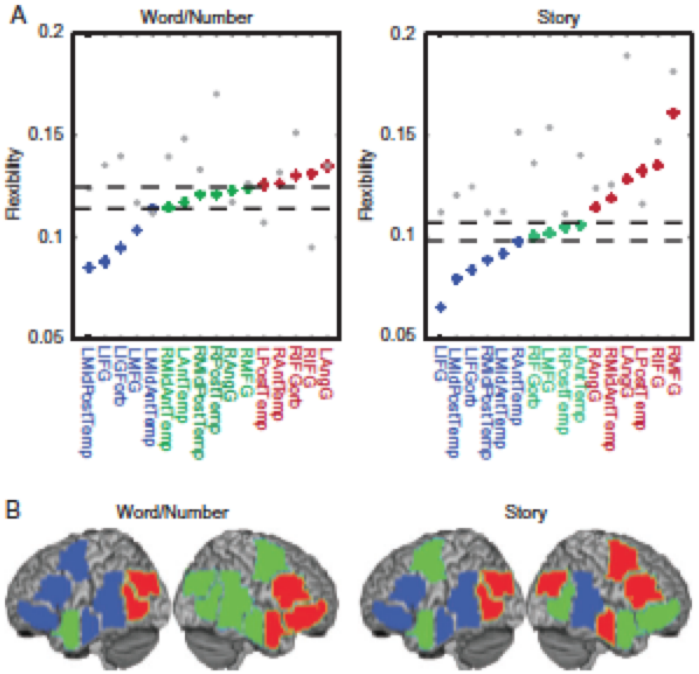
Language and social regions are functionally dissociable, BUT: there is a substantial correlation between the two networks.

Paunov, Blank & Fedorenko (in prep.)

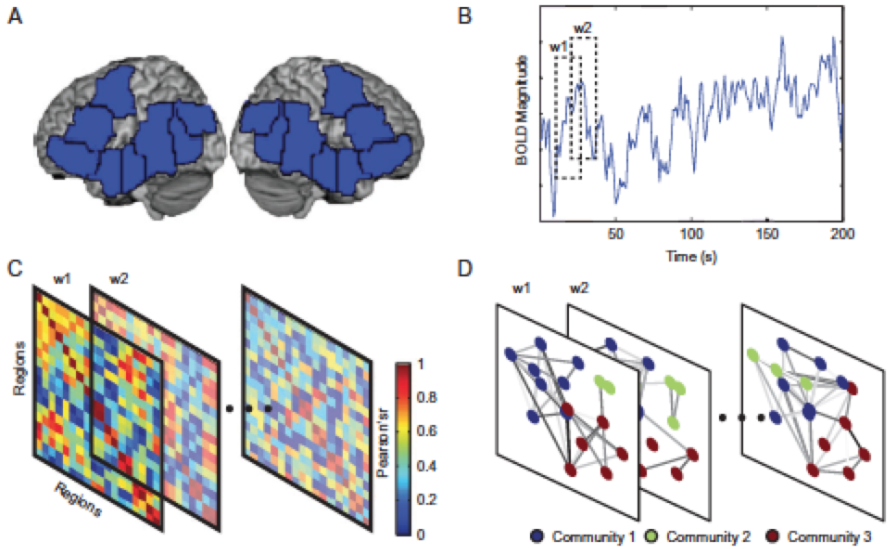
The language network is a functionally integrated system

Lucy Chai Dani Bassett

Core & periphery model



Dynamic network modeling



The language network consists of a stable core (LH regions) and a flexible periphery.

Chai et al. (2016, Cer Cortex)

Outline

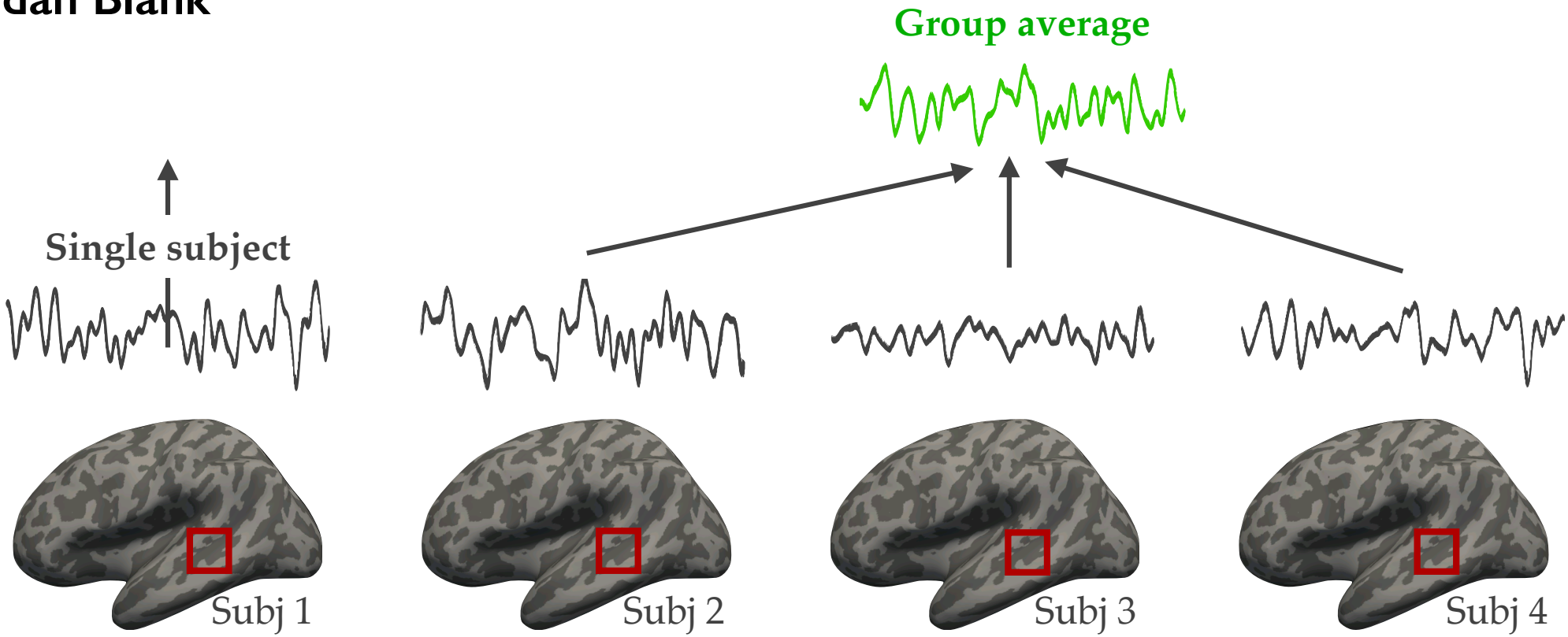
1. The language network is **a functionally integrated system**.
2. The language brain regions **closely track linguistic input**.
3. Hypotheses about **possible organizing principles** of the language network.

The language brain regions closely track linguistic input

Idan Blank

How can we estimate the degree of stimulus tracking?

Inter-subject correlations (Hasson et al.)



The language brain regions closely track linguistic input

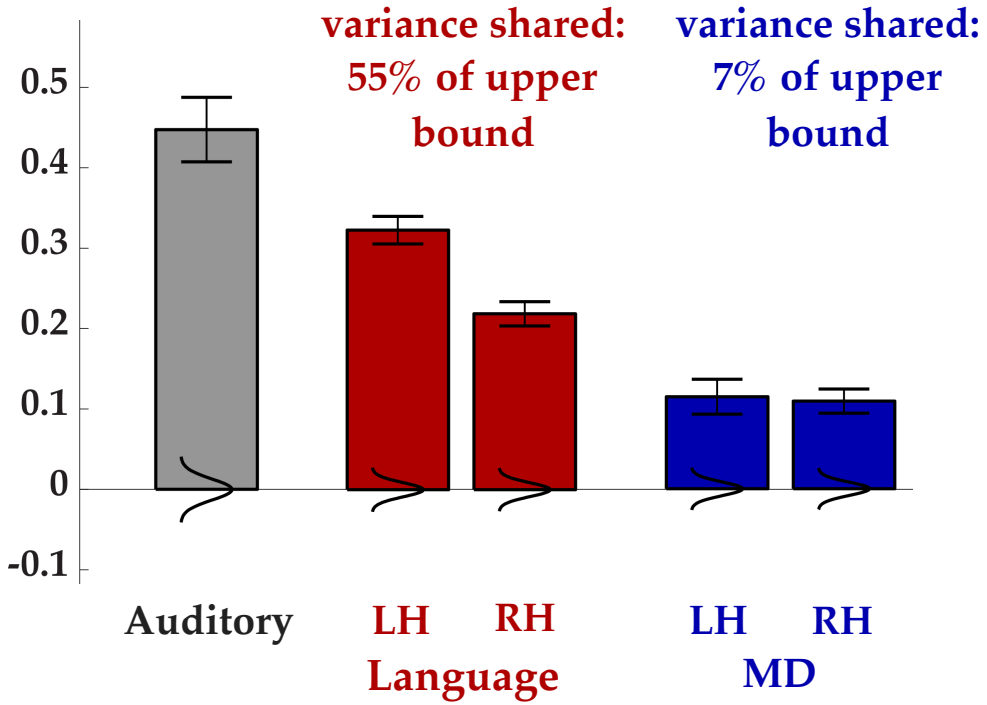
ambiguity | infrequent words | infrequent syntax | non-local dependencies

The Bradford Boar

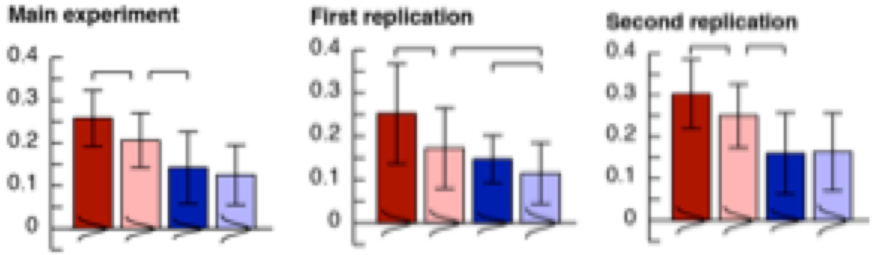
That the people of Bradford bore the brunt of the beast's ferocity was unfair in the eyes of the people of the region. Eventually, the issue reached the ears of the kindly Lord of the Manor who the people had often asked for help. The Lord saw the severity of the problem the people faced and suggested a contest could solve the problem. He said that whoever could kill the boar and bring as proof its head to the Manor House would be rewarded with land and fame. It was the people of Bradford and the people who knew them who rejoiced at this proclamation but one question remained: who would kill the boar?

The language brain regions closely track linguistic input

Inter-Subject Correlations (ISCs, $n = 17$)



Replicated twice:



(error bars here: st devs)

The language regions (but not the MD regions) closely track variations in the linguistic input.

Blank & Fedorenko (2014, submitted)

Outline

1. The language network is **a functionally integrated system**.
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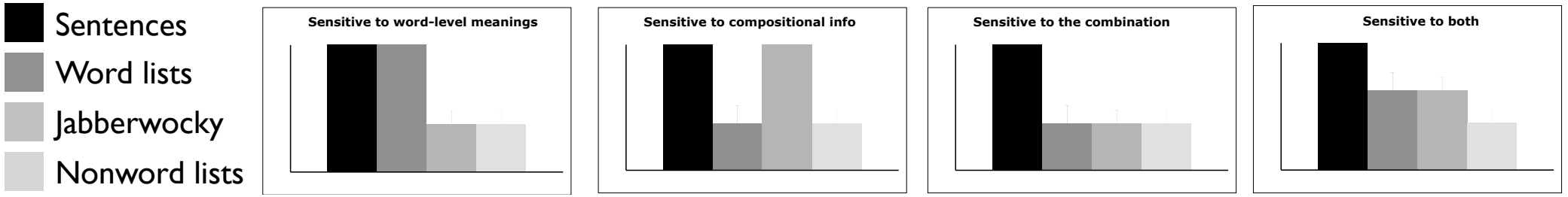
Possible organizing principles of the language network

Lexical semantics vs. syntax

Word-level meanings

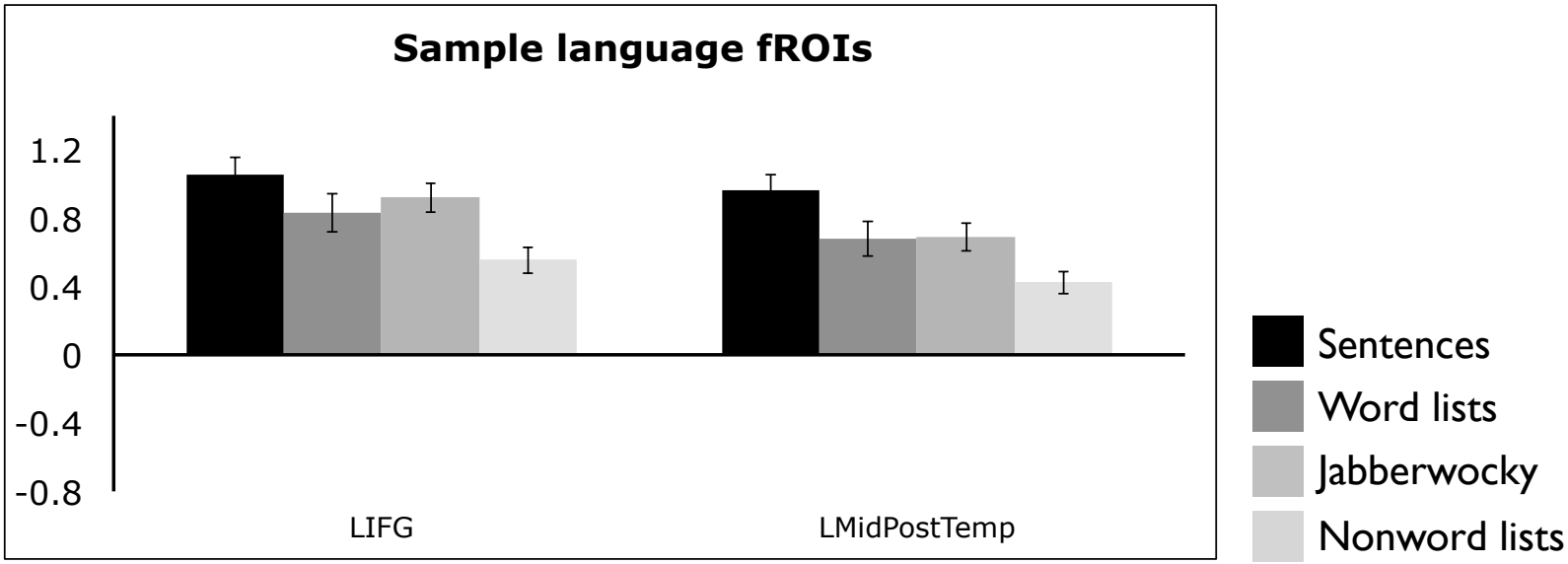
Combinatorial information	✓	✗
✓	**Sentences** THE SPEECH THAT THE POLITICIAN PREPARED WAS TOO LONG FOR THE MEETING	**Word lists** IN BECAUSE NEW ROBBERY SOON EVERY ANGRY RUN TRACY MORNING AND BATTLE
✗	**Jabberwocky sentences** AFTER THE BONTER MELLVERED THE PERLEN HE MESTED TO WEER ON COLMITION	**Nonword lists** BONTER CRE POME COLMITION PERLEN WORNETIST LAS BROO FICK PRELL CRE VILLPA

Possible profiles



Possible organizing principles of the language network

Lexical semantics vs. syntax

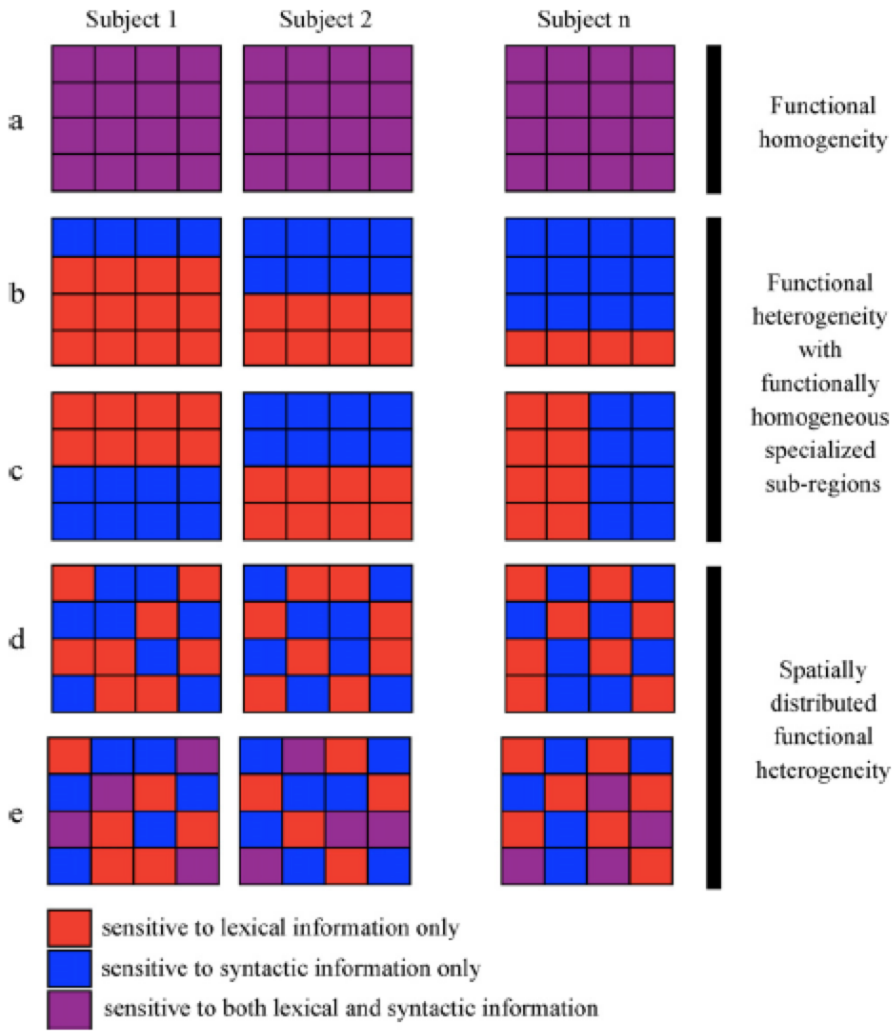


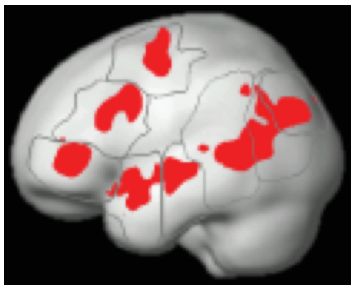
Sensitivity to the presence of both i) word-level meanings, and ii) structural/combinatorial information throughout the language network.

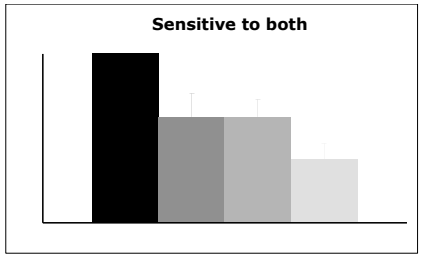
Fedorenko et al. (2010, JNeurophys)

Possible organizing principles of the language network

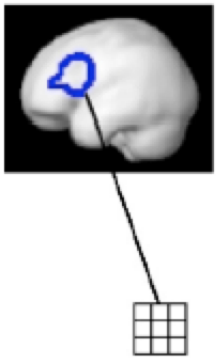
Lexical semantics vs. syntax

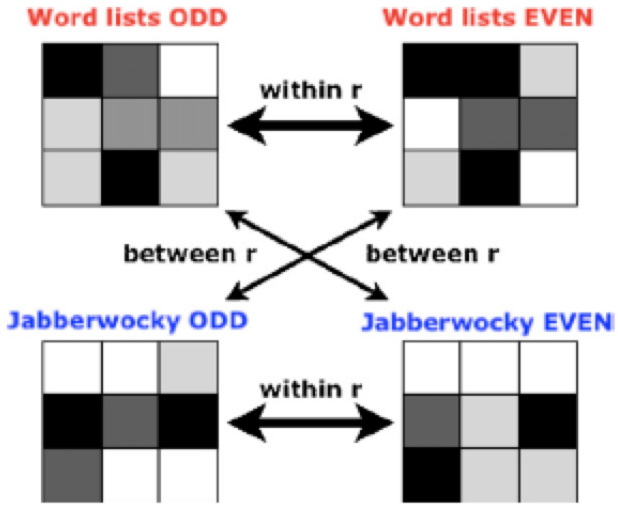






Multi-voxel pattern analysis:





Fedorenko et al. (2012, Neuropsychoplogia)

Possible organizing principles of the language network

Lexical semantics vs. syntax

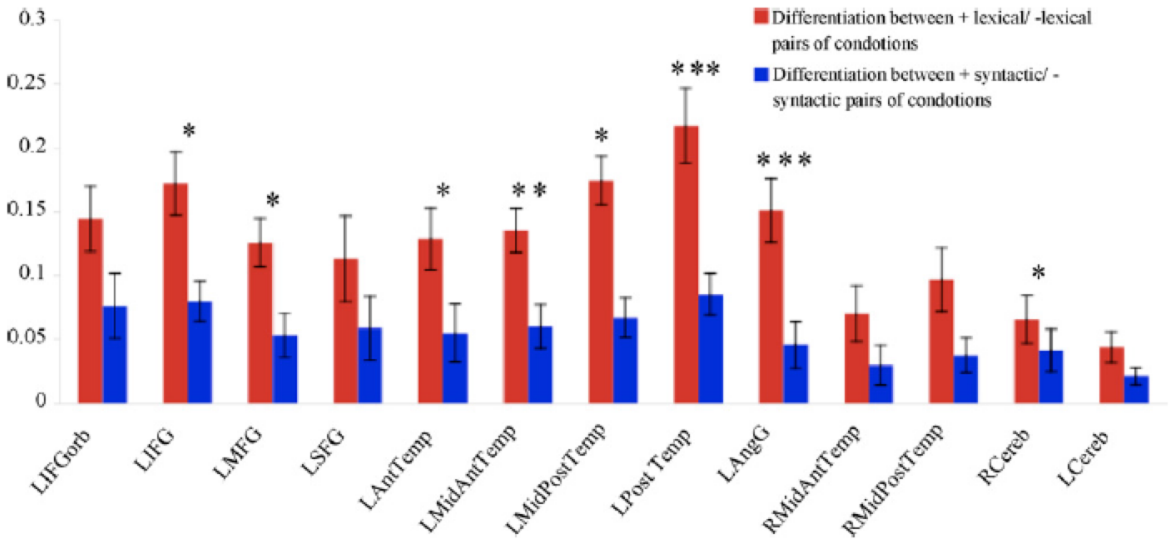
Q1: Do language regions differ in how robustly the represent lexical vs. combinatorial information?

Lexical information:

Sentences vs. Jabberwocky
Word-lists vs. Nonword-lists

Combinatorial information:

Sentences vs. Word-lists
Jabberwocky vs. Nonword-lists



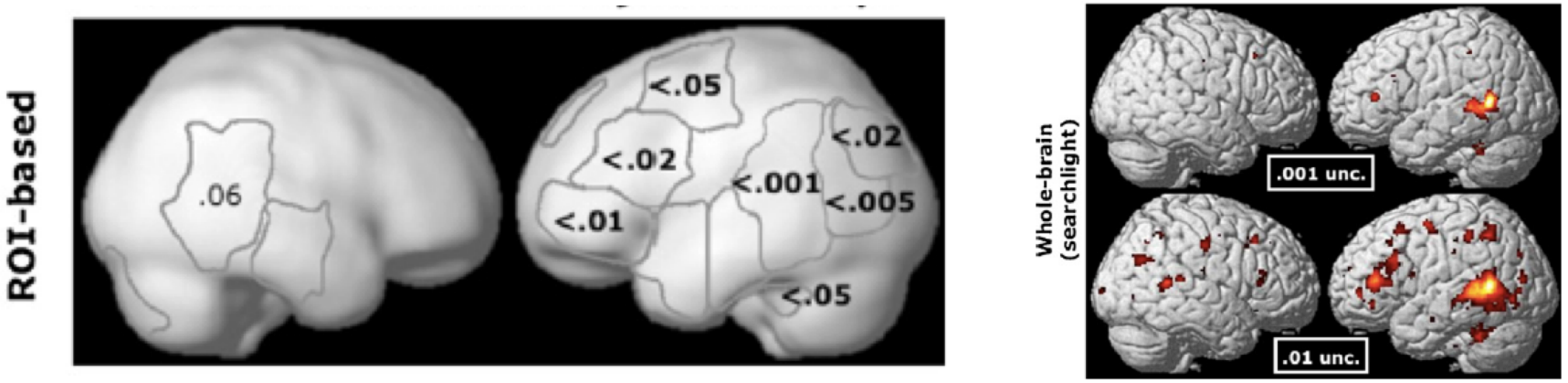
All language regions represent lexical information more robustly.

Fedorenko et al. (2012, Neuropsychoplogia)

Possible organizing principles of the language network

Lexical semantics vs. syntax

Q2: Do any language regions distinguish between the processing of "pure" lexical (Word-lists) and "pure" combinatorial (Jabberwocky) information?



Some language regions reliably discriminate between the word-list and Jabberwocky conditions.

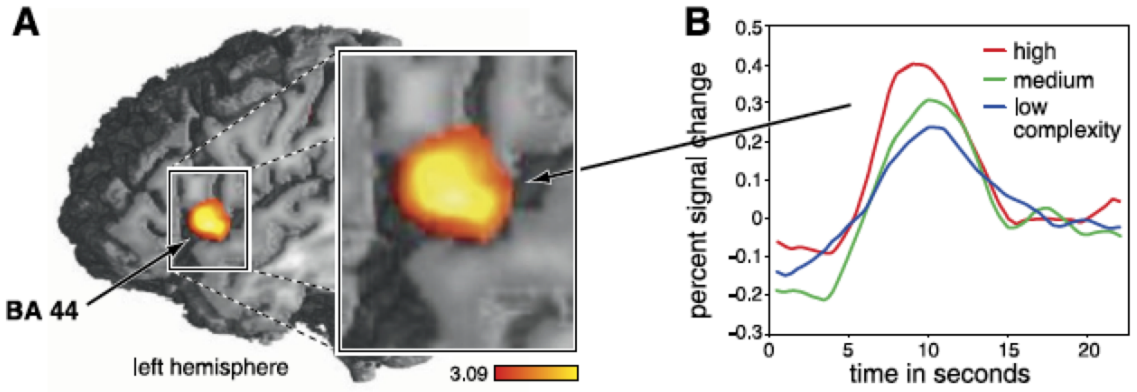
Fedorenko et al. (2012, Neuropsychoplogia)

Possible organizing principles of the language network

Lexical semantics vs. syntax

Ubiquitous sensitivity to syntax across the network.

Syntactic processing has been argued by many to be ***localized***, typically to a region within Broca's area.



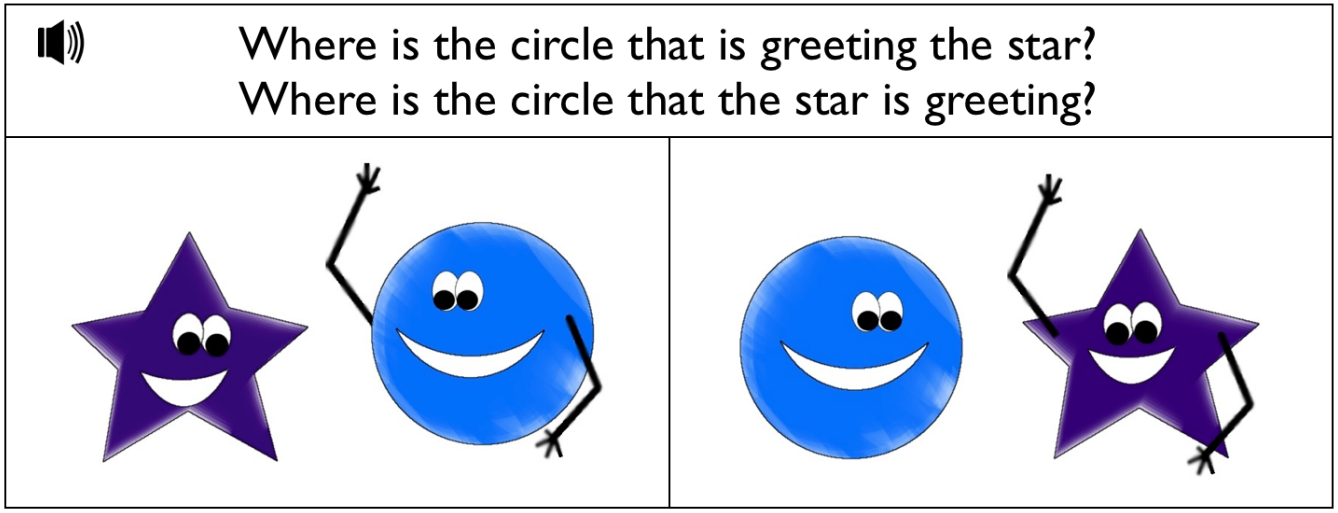
"... the processing of syntactically complex sentences recruits Broca's area" (Friederici, 2011)

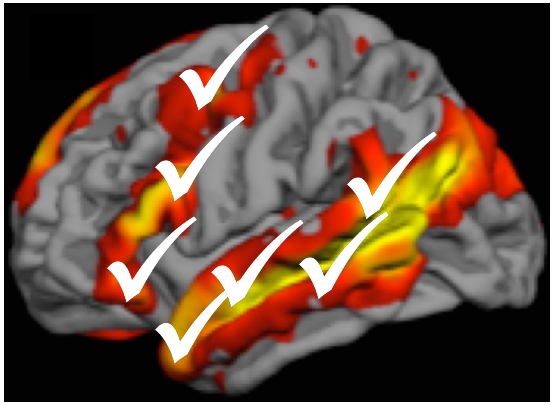
Possible organizing principles of the language network

Lexical semantics vs. syntax

Ubiquitous sensitivity to syntax across the network.

the **circle** that is **greeting** the star vs. the **circle** that the star is **greeting**



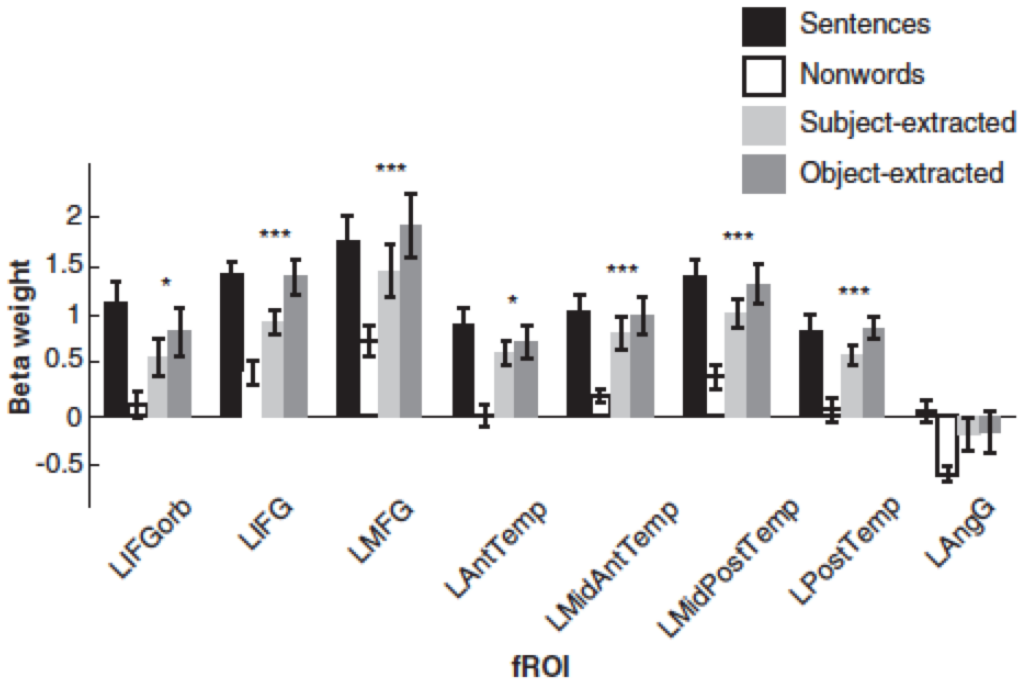


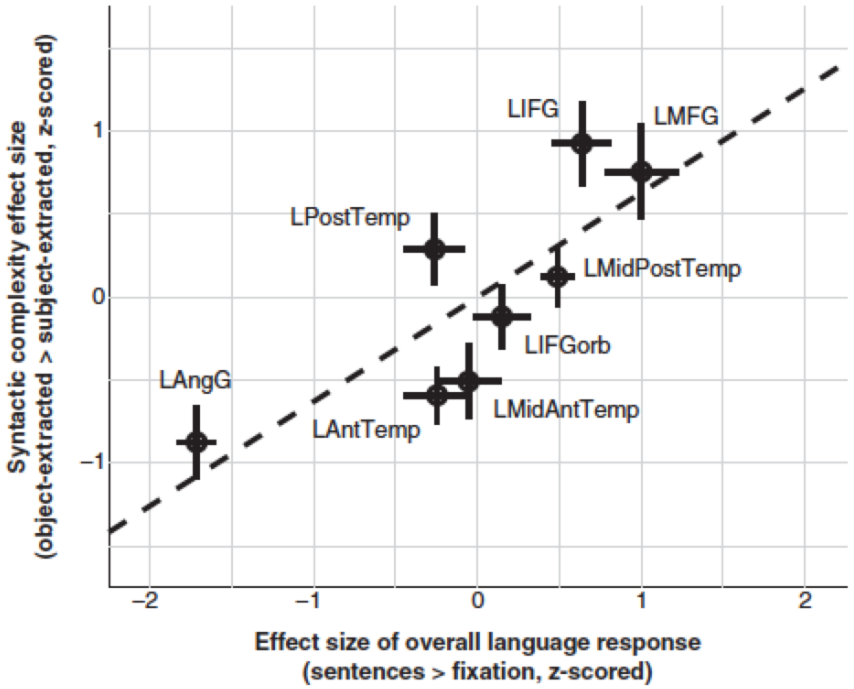
Blank et al. (2016, NI)

Possible organizing principles of the language network

Lexical semantics vs. syntax

Ubiquitous sensitivity to syntax across the network.





Blank et al. (2016, NI)

Possible organizing principles of the language network

Lexical semantics vs. syntax

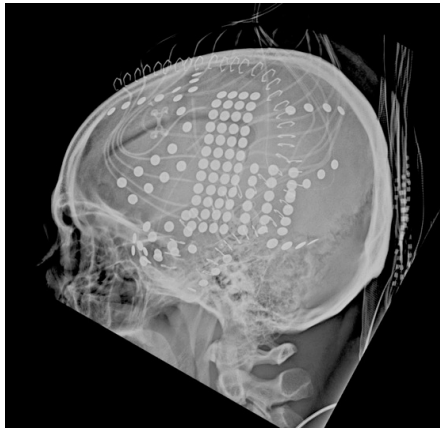
Syntactic processing is distributed across the language network.

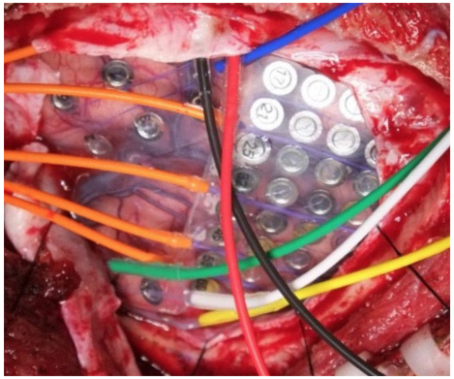
Consistent with the patient literature:
Damage to many different components of the language network leads to similar syntactic comprehension difficulties (e.g., Caplan et al., 1996; Dick et al., 2001; Wilson & Saygin, 2004).

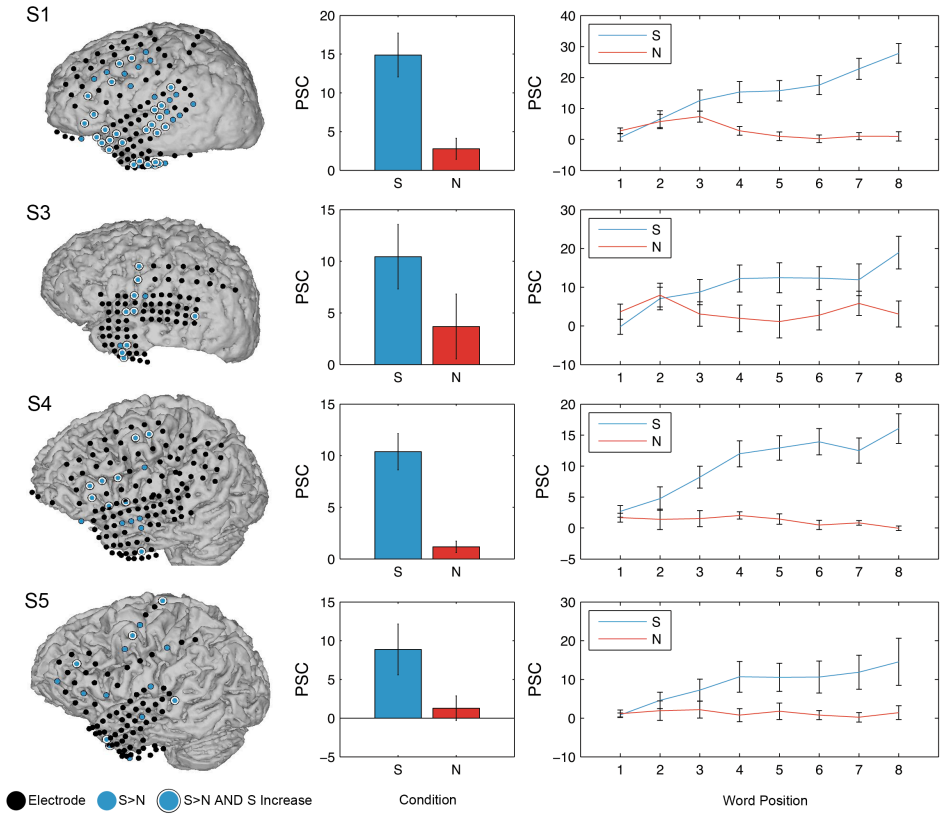
Possible organizing principles of the language network

Lexical semantics vs. syntax

Constructing complex meanings





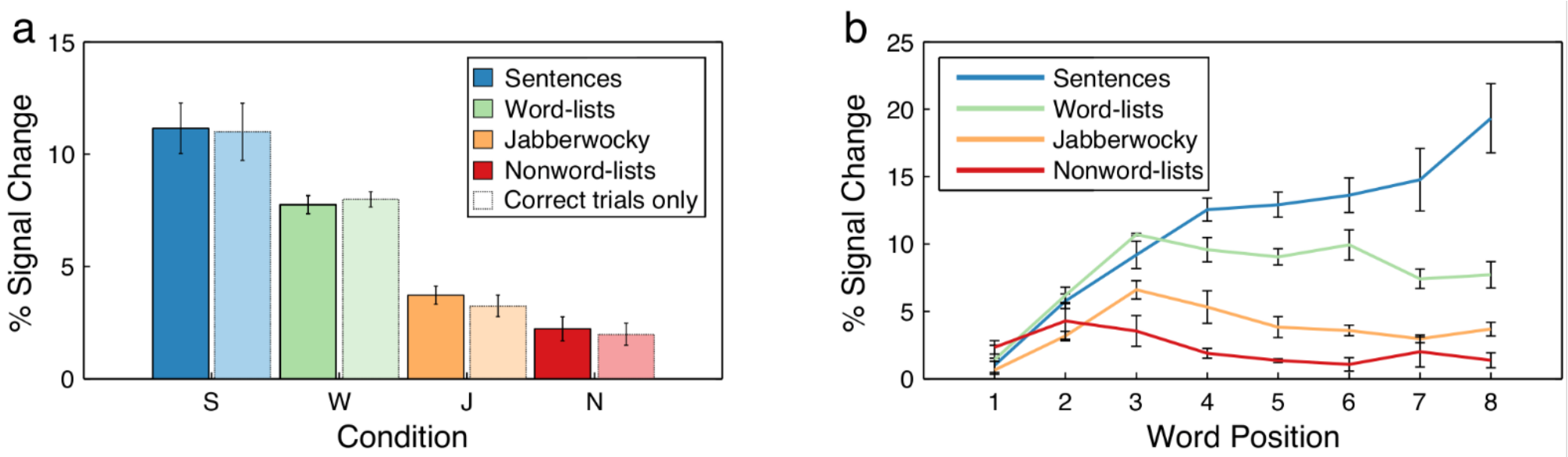


Fedorenko et al. (in press, PNAS)

Possible organizing principles of the language network

Lexical semantics vs. syntax

Constructing complex meanings



The build-up effect reflects the construction of complex meanings.

Fedorenko et al. (in press, PNAS)

Possible organizing principles of the language network

Size of the temporal integration window

Lerner et al. (2011)

Temporal integration window ≈
the scale of input incoherence which disrupts reliable processing

Method:

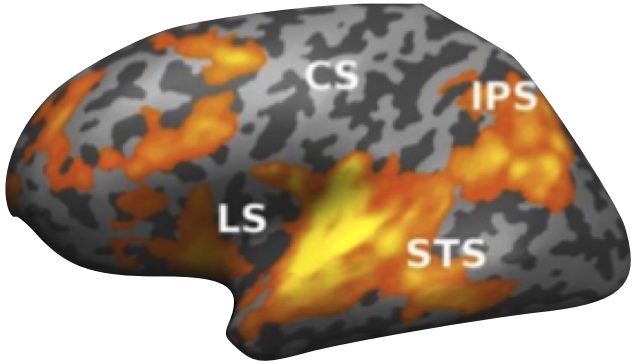
- Subjects listen to 5 versions of a story, from Lerner *et al.* (2011):

- A region with a relatively short integration window is only sensitive to input from the very recent past (local environment), not to broader context.
  → Processing is hampered when the input is locally incoherent; if it is locally well-structured, incoherence at a coarser scale is irrelevant.
- A region with a relatively long integration window is more sensitive to input from the more "distant" past (global environment).
  → Processing is hampered when the input is incoherent at a global level, even if it is locally well-structured.

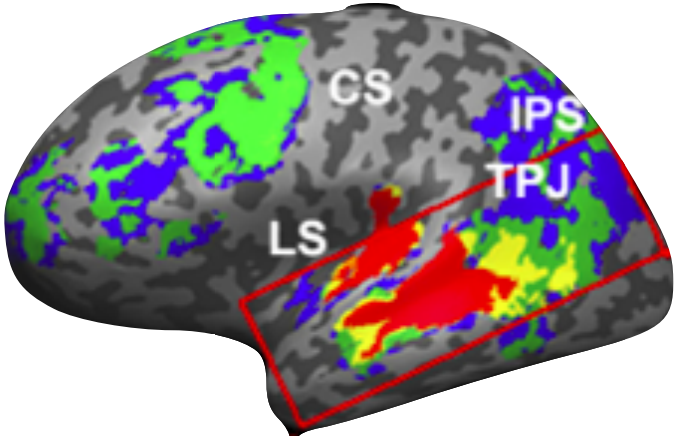
Possible organizing principles of the language network

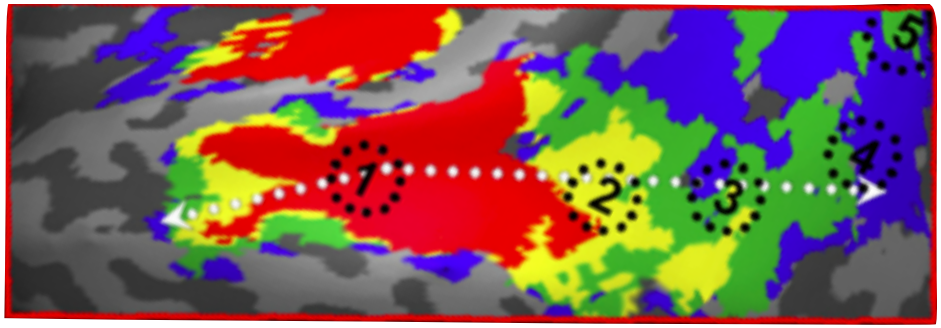
Size of the temporal integration window

Lerner et al. (2011)



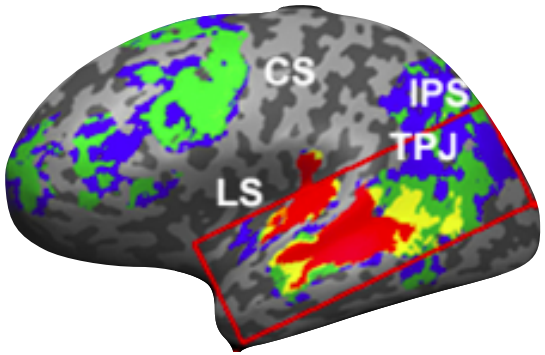
- A cortical topography of integration windows.
- This topography appears to overlap with the language network.

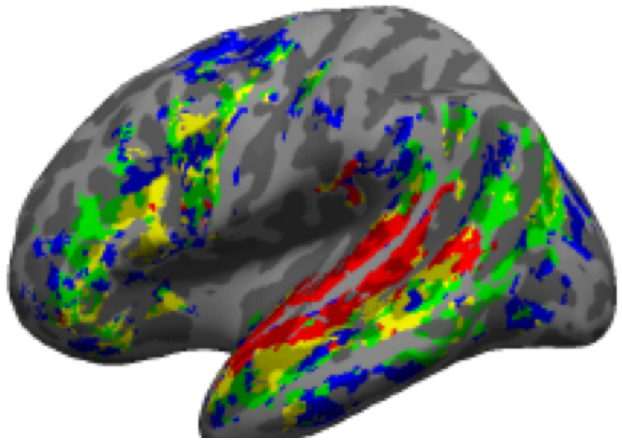


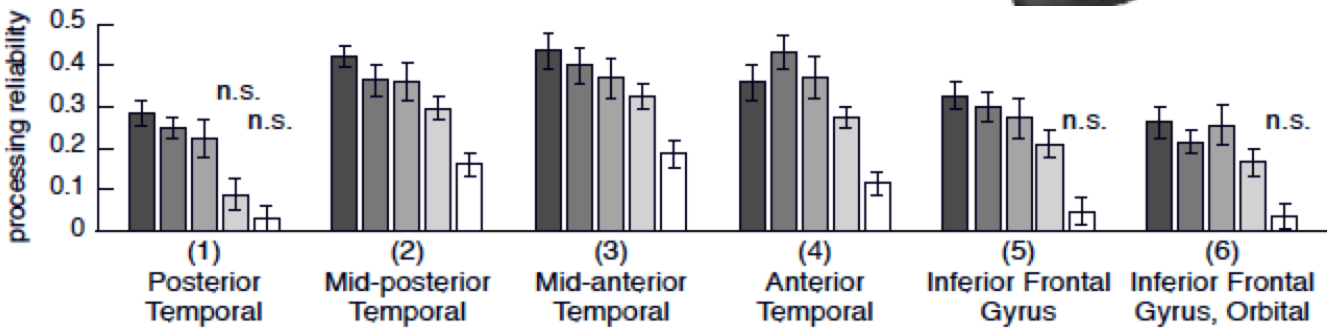


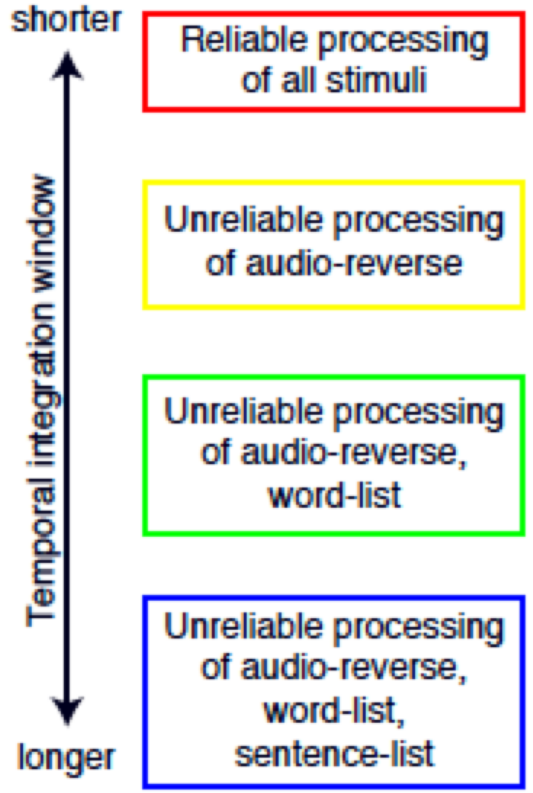
Possible organizing principles of the language network

Size of the temporal integration window







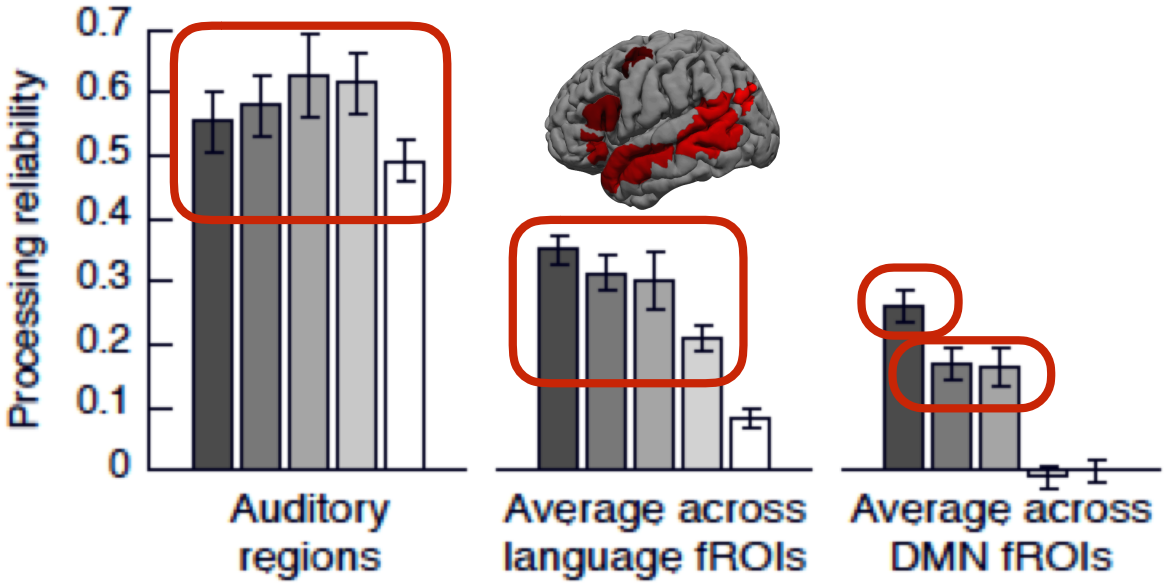


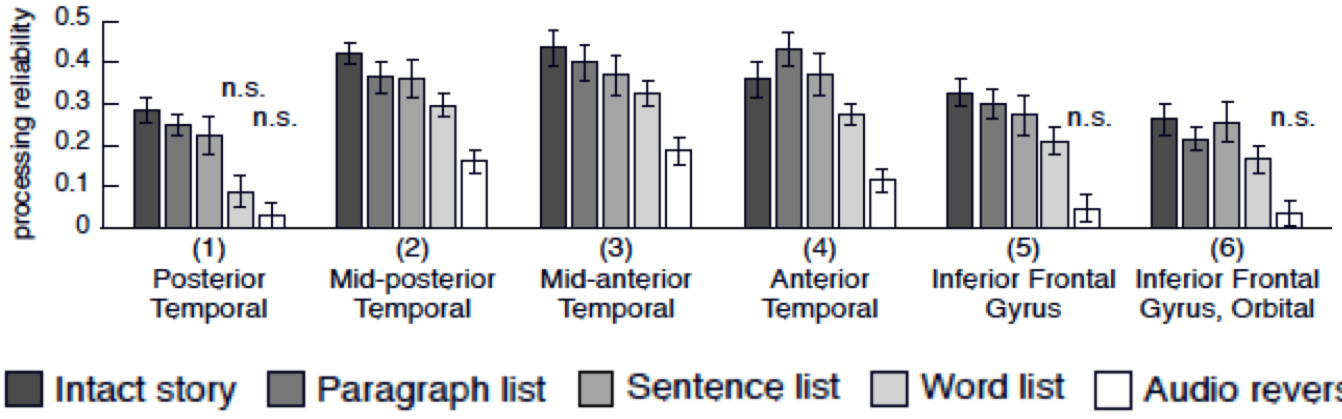
Blank & Fedorenko (in prep.)

Possible organizing principles of the language network

Size of the temporal integration window

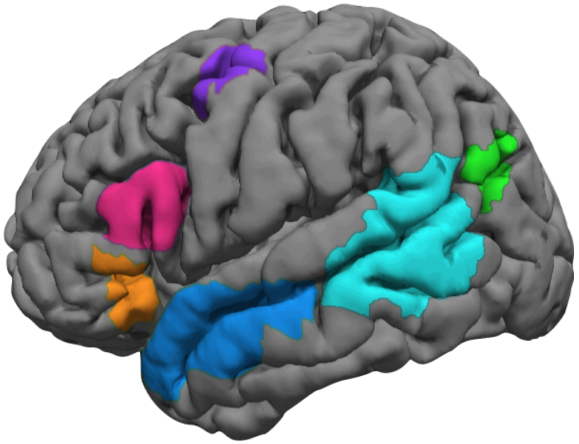
No evidence that the language network is spatially organized by representational grain size: different regions share a common integration window.





Blank & Fedorenko (in prep.)

Thank you!



EvLab members

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