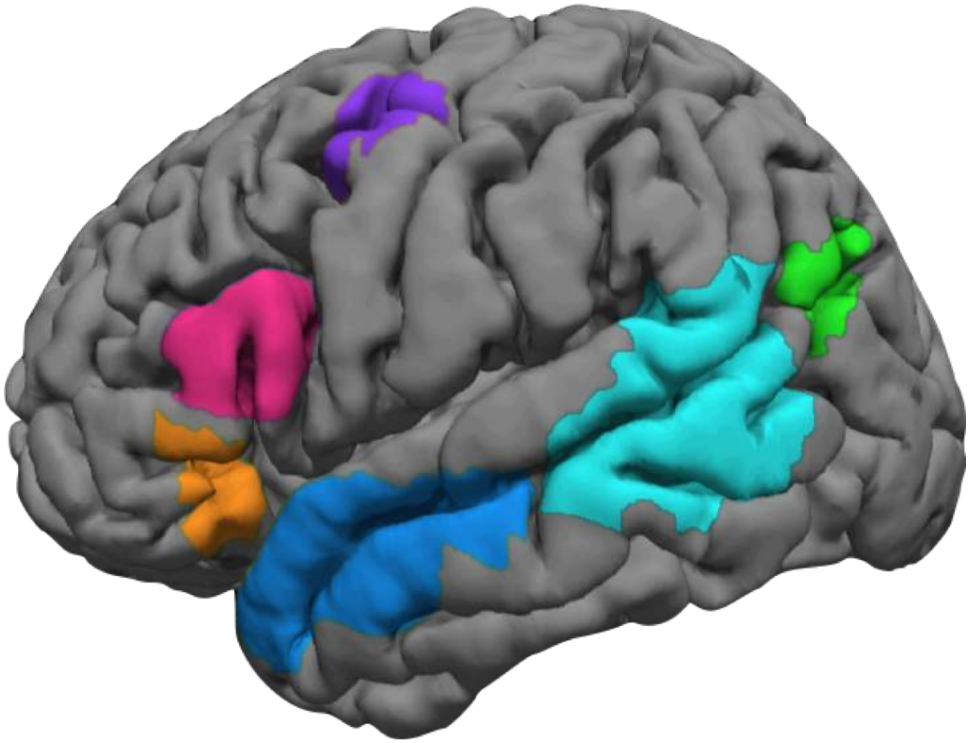
The language network within the broader architecture of the human mind and brain



Ev Fedorenko
HMS/MGH; MIT

University of Gothenburg
September 8, 2016

Outline

1. The language system / network
    - Introduction
    - Questions / goals
    - How to study it?
2. Language vs. thought.
    - fMRI evidence
    - patient evidence

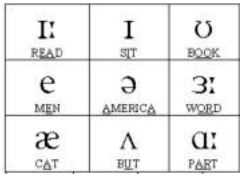
The language system / network

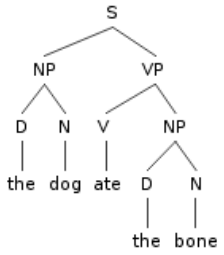
Language comprehension

Speech perception

Reading

Interpretation and generation of meaningful linguistic signals





Speech production (articulation)

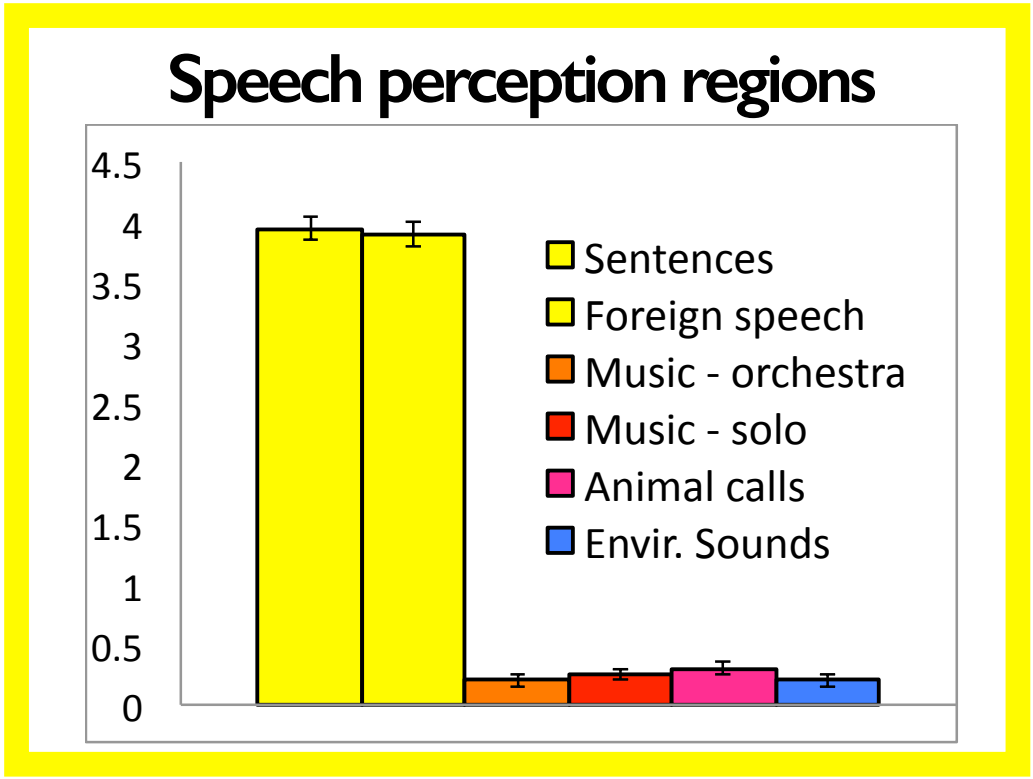
Writing / typing

Language production

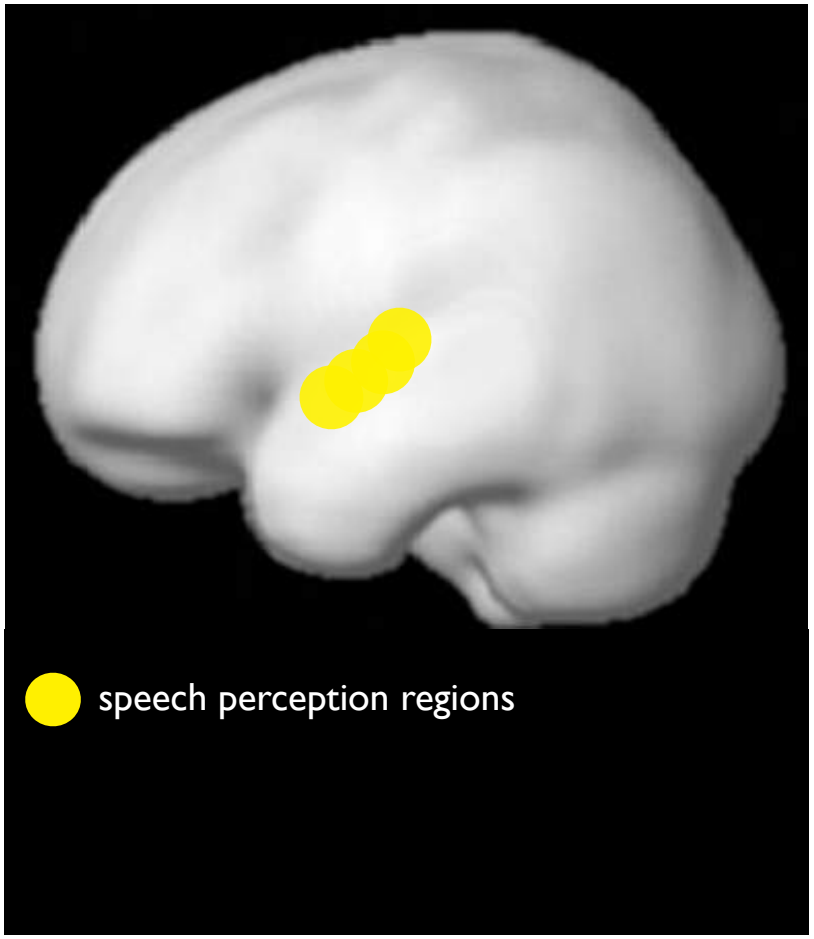
The language system / network

Speech perception

Norman-Haignere et al.
(unpublished data)



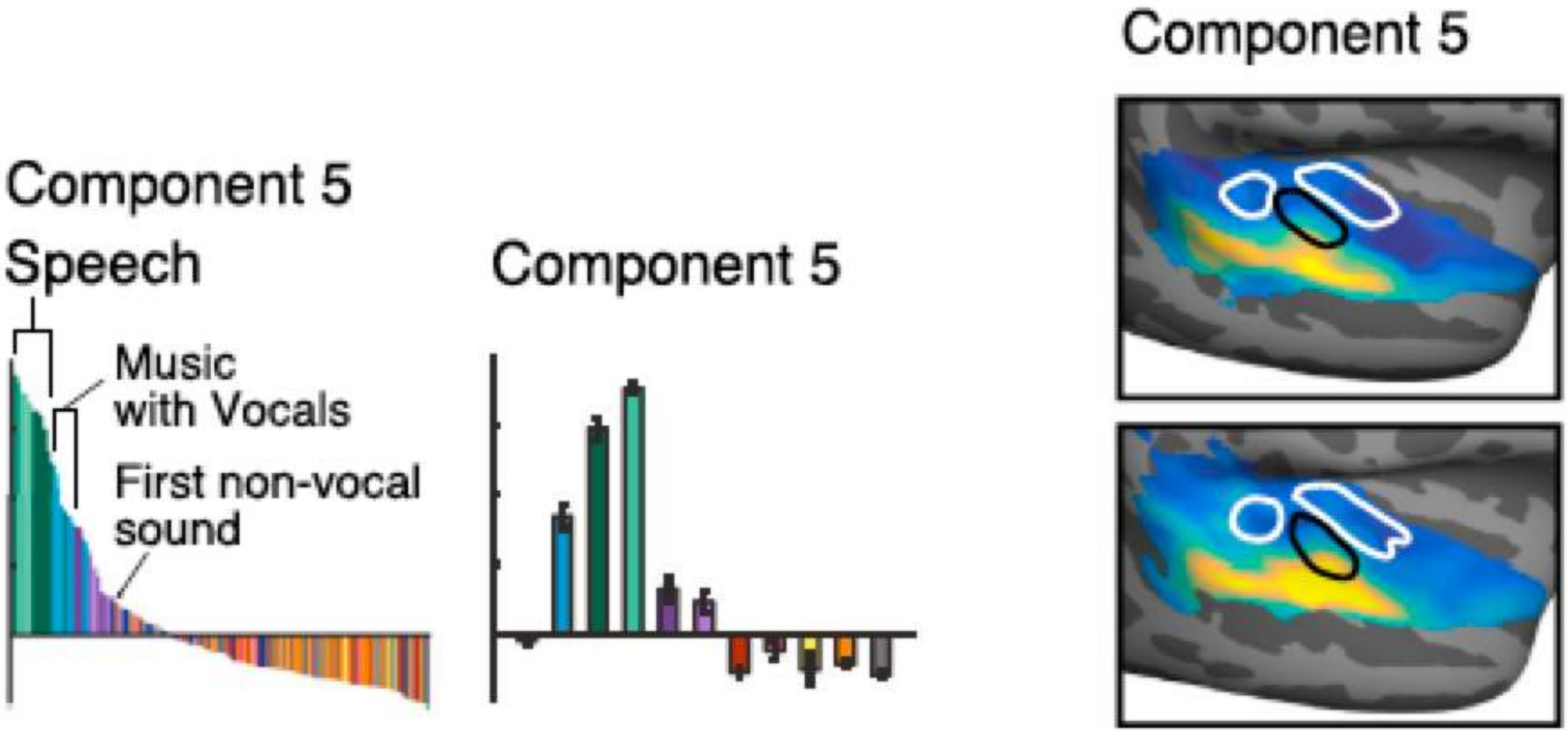
This is a cartoon!



The language system / network

Speech perception

Norman-Haignere et al. (2015)

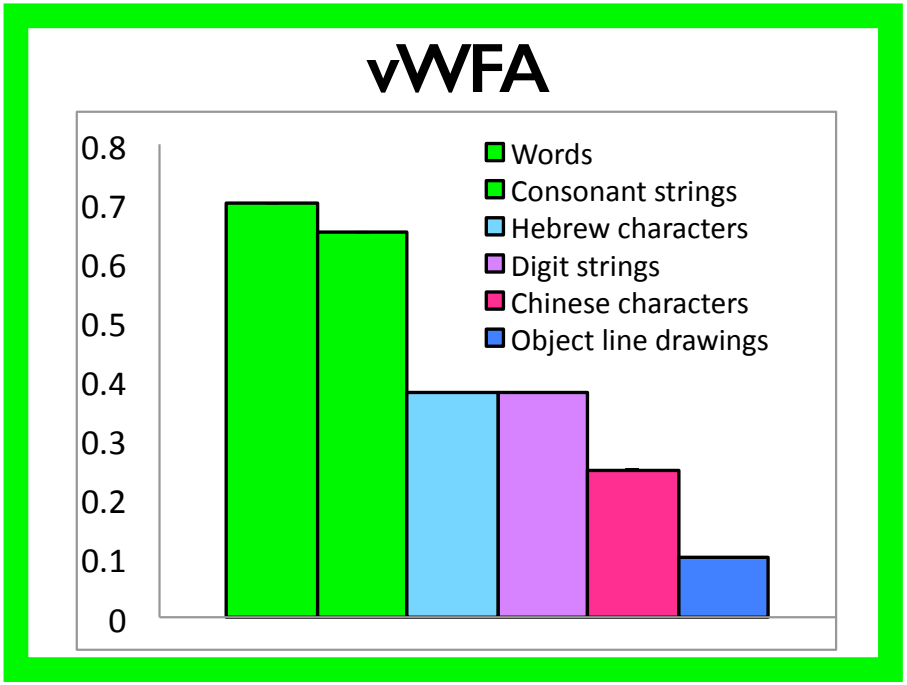


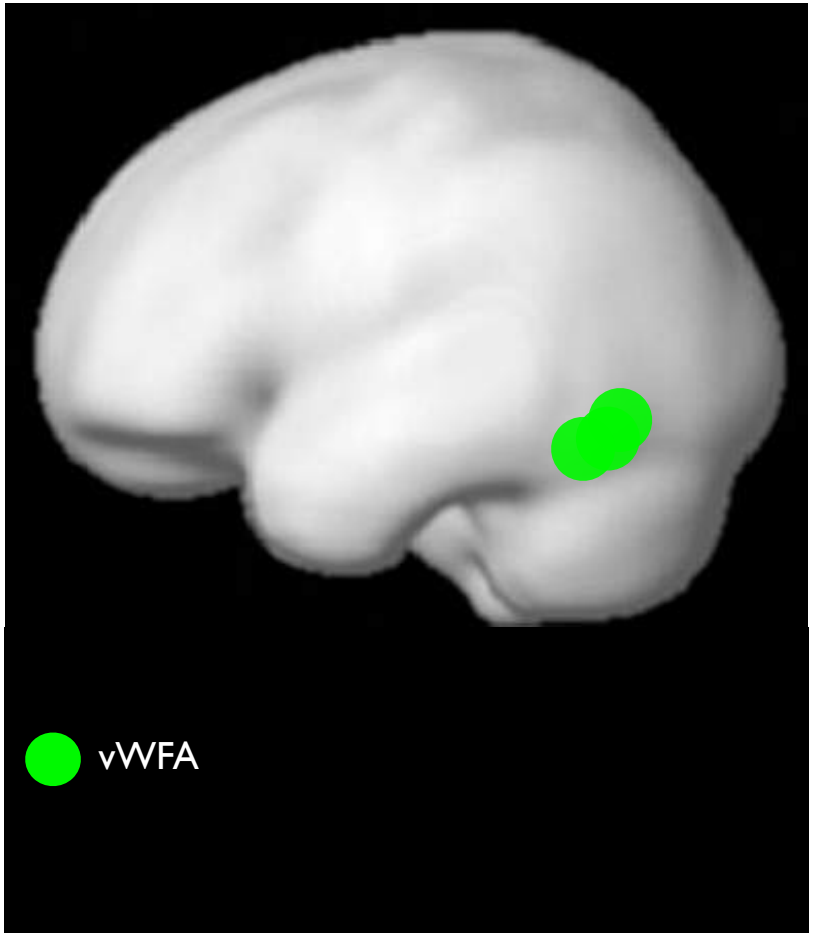
The language system / network

Visual letter/word perception

This is a cartoon!

Baker et al. (2007)



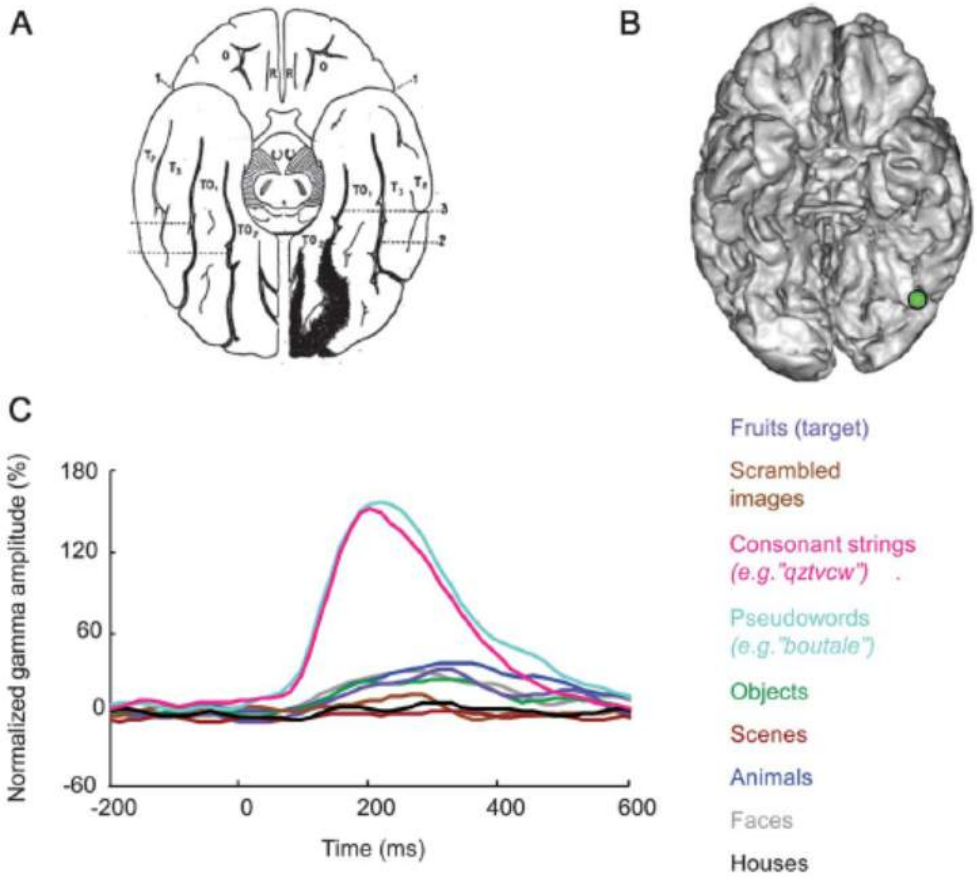


The language system / network

Visual letter/word perception

Hamame et al. (2013)

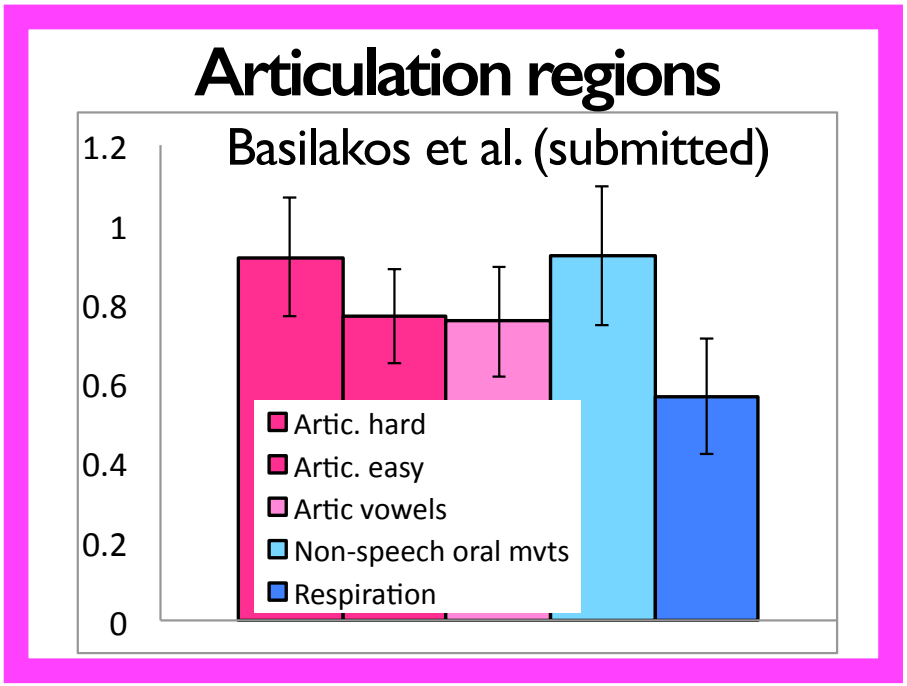
Figure 1 **Strong neural specialization for reading in the visual word form area: Recordings from depth electrodes**

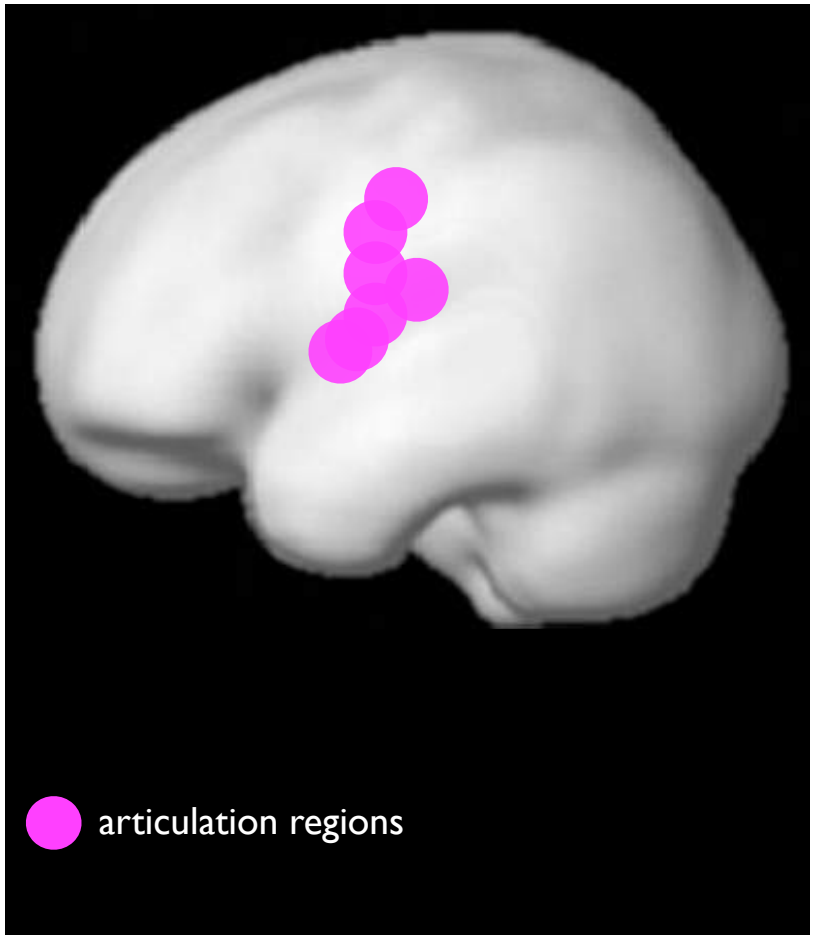


The language system / network

Articulation

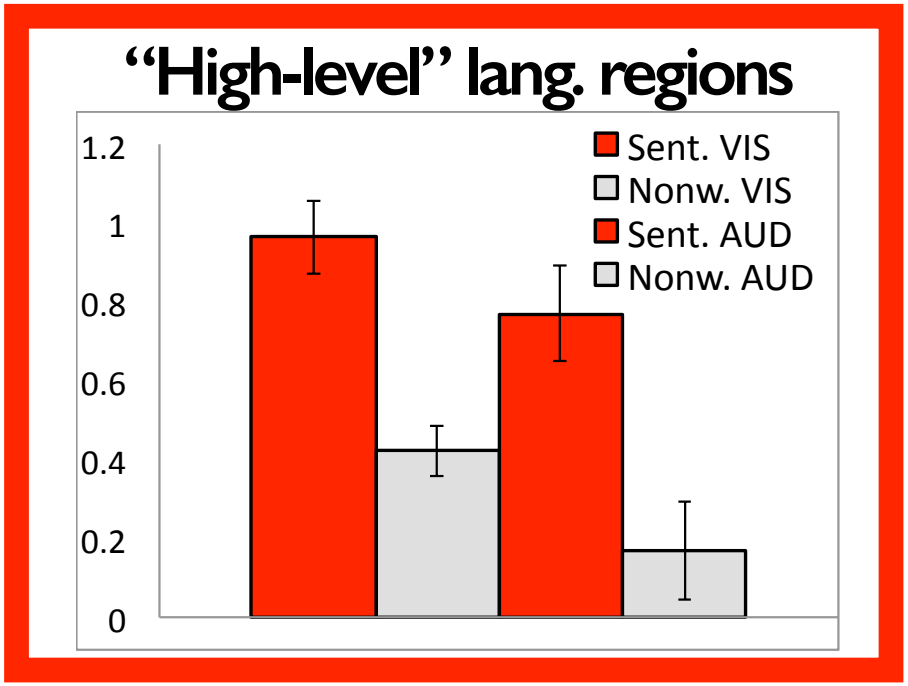
This is a cartoon!

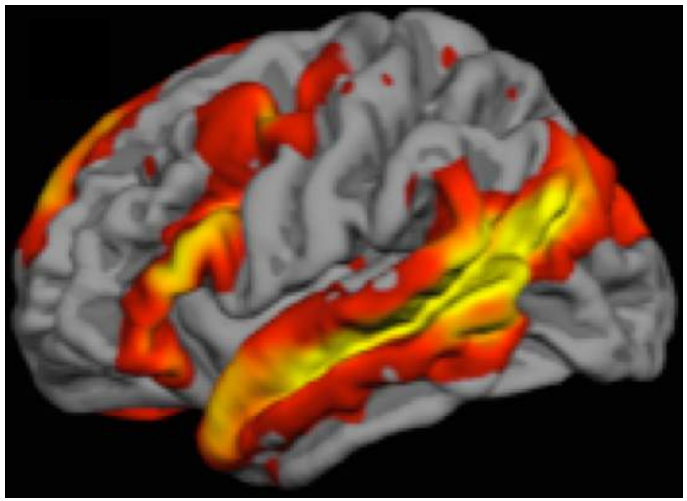




The language system / network

High-level language processing regions





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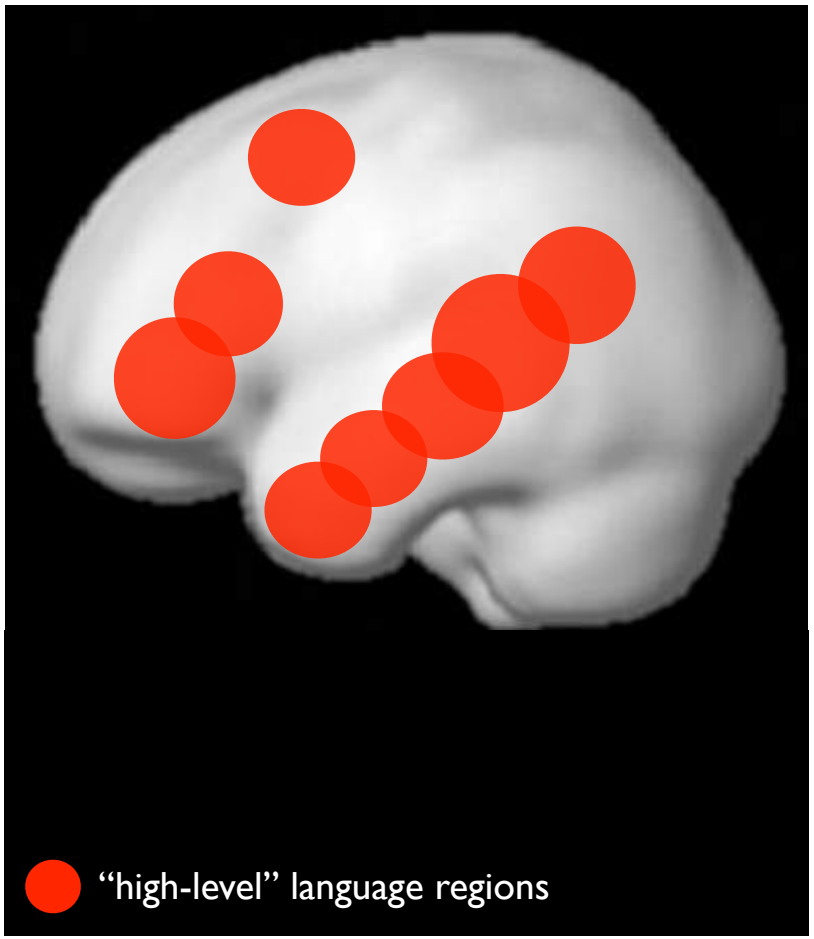
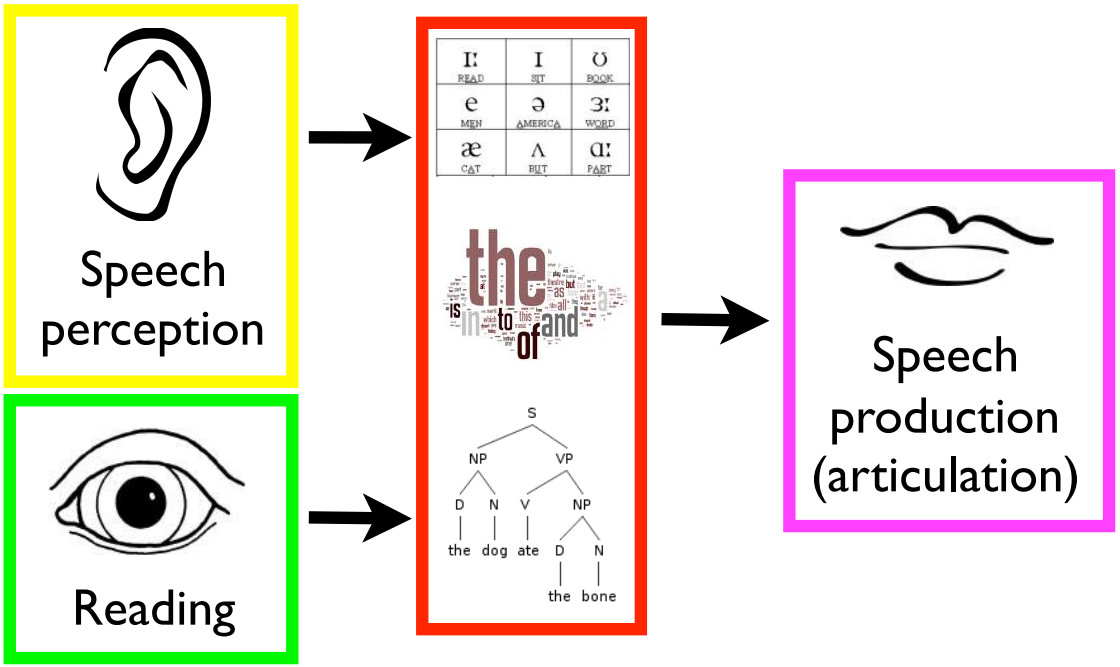
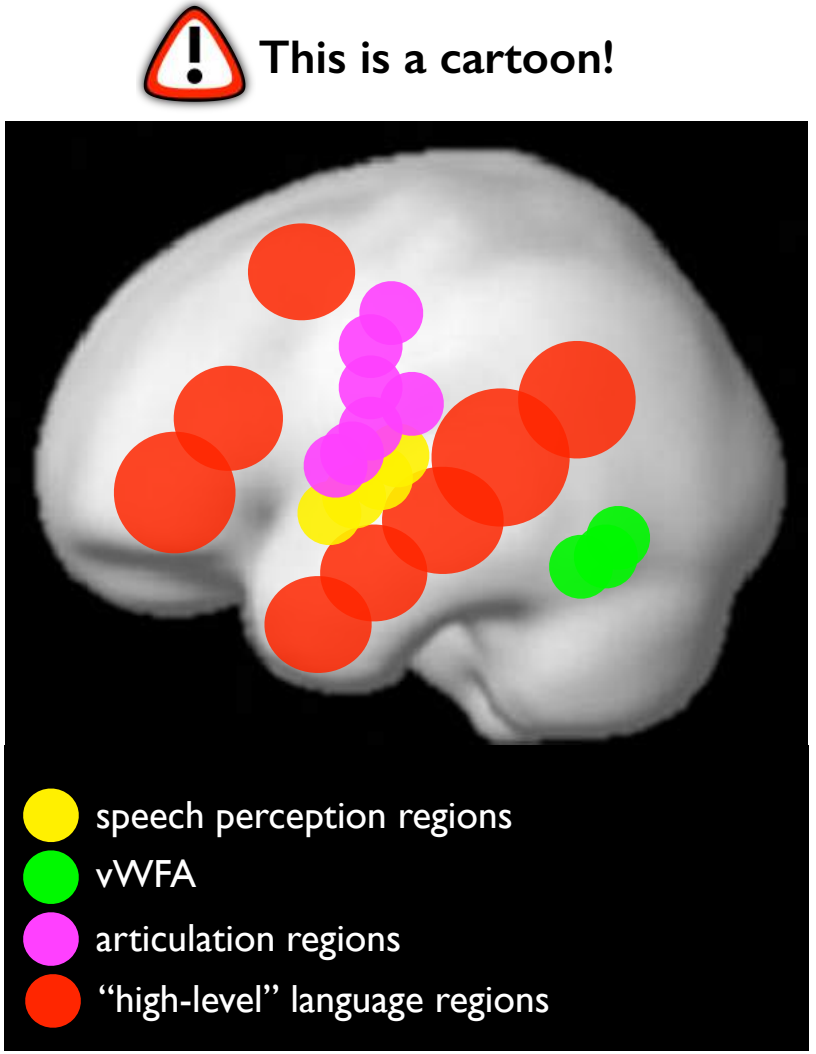


The language system / network





Fedorenko & Thompson-Schill (2014, TiCS)

Outline

1. The language system / network
    - Introduction
    - Questions / goals
    - How to study it?
2. Language vs. thought.
    - fMRI evidence
    - patient evidence

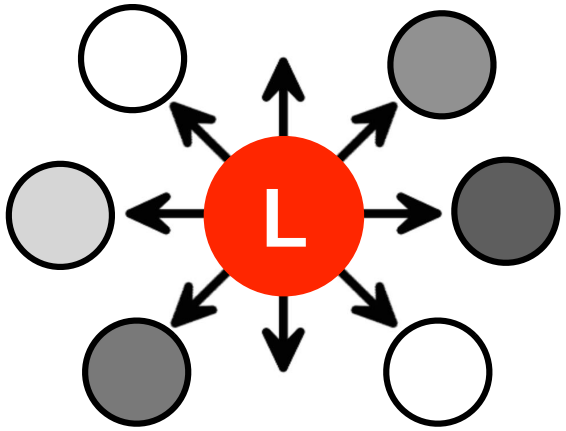
The language network

Key research questions:

The ultimate goal:
to understand the *representations* stored and the *computations* performed by the language regions

Tractable questions:

1. What is the relationship between the language system and *the rest of human cognition*?



2. What is the *internal architecture* of the language system?

Outline

1. The language system / network
    - Introduction
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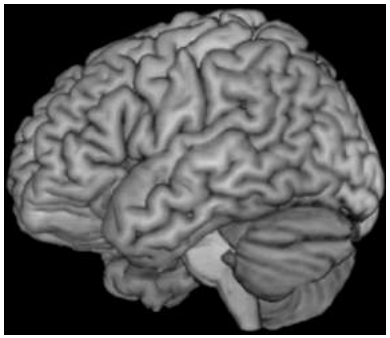
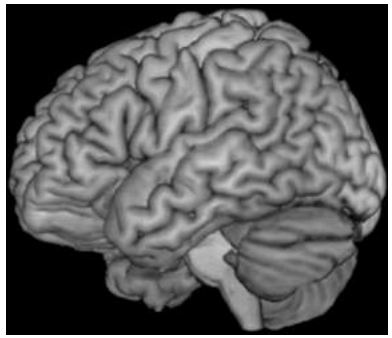
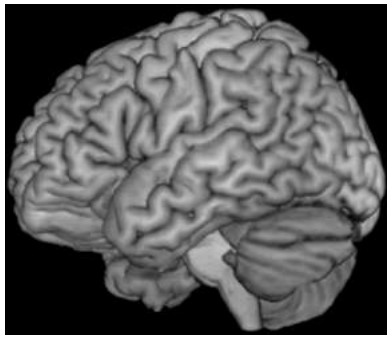
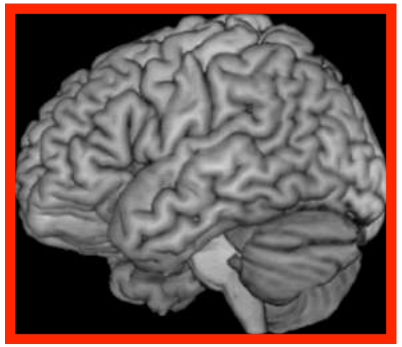
How to study the language system?

Cognitive neuroscience strives for generality.
How do we generalize across brains?


Subject 1


Subject 2


Subject 3


"Template" brain

What's the problem?
Variability across individual brains.

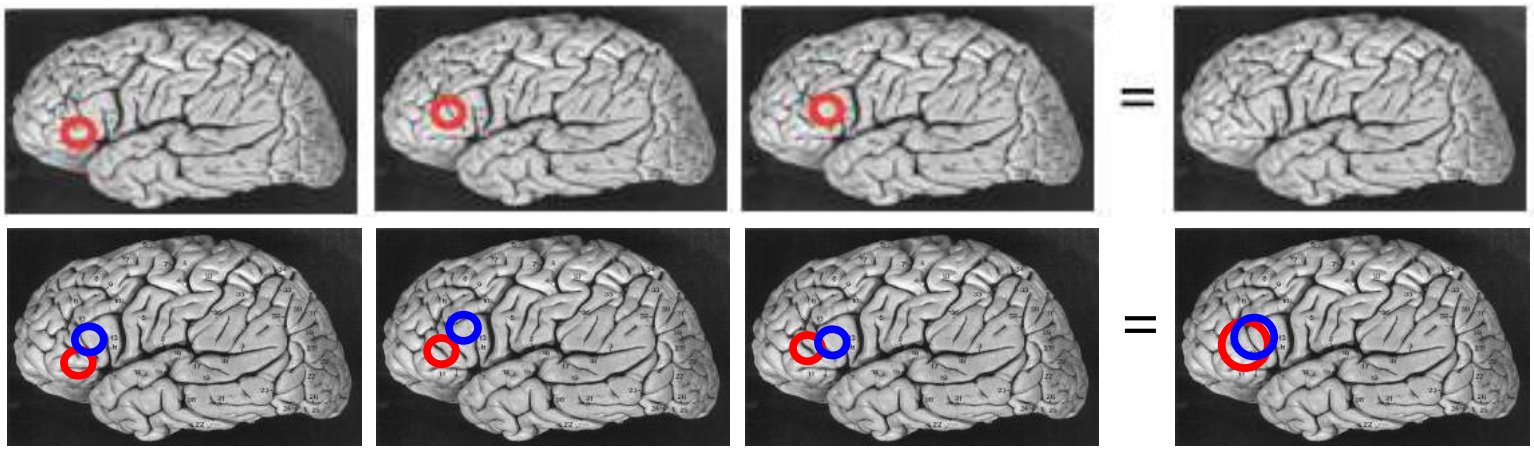
Consequence: functional activations do not line up well.

Fedorenko & Kanwisher (2009, 2011); Fedorenko et al. (2010); Nieto-Castañon & Fedorenko (2012)

How to study the language system?

Potential issues inherent in traditional group analyses:

- limited sensitivity
- limited functional resolution



Fedorenko & Kanwisher (2009, 2011); Fedorenko et al. (2010); Nieto-Castañon & Fedorenko (2012)

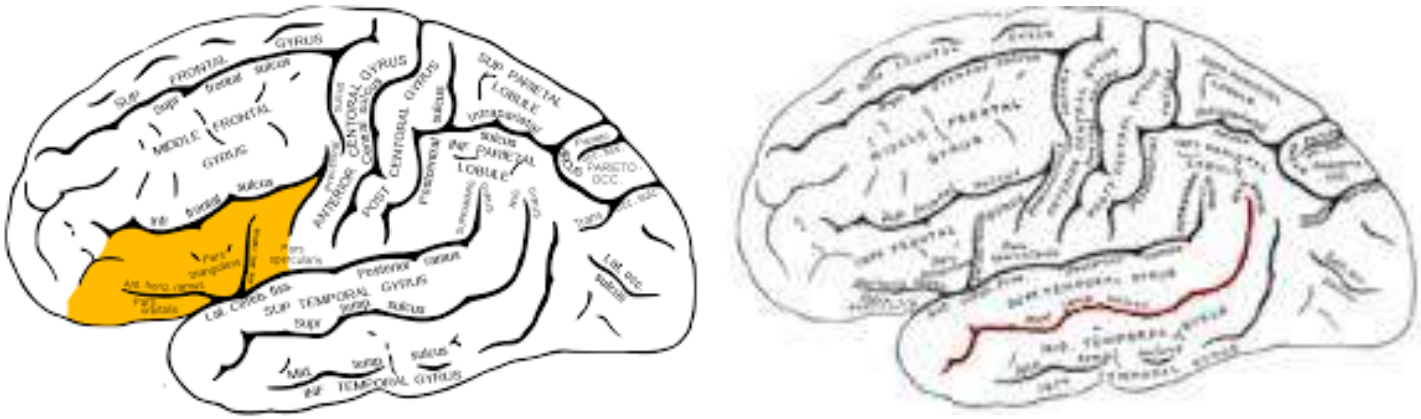
How to study the language system?

Potential issues inherent in traditional group analyses:

- limited sensitivity
- limited functional resolution
- difficulty in establishing a cumulative research enterprise

Output of traditional analyses - ?

{x,y,z}



Fedorenko & Kanwisher (2009, 2011); Fedorenko et al. (2010); Nieto-Castañon & Fedorenko (2012)

How to study the language system?

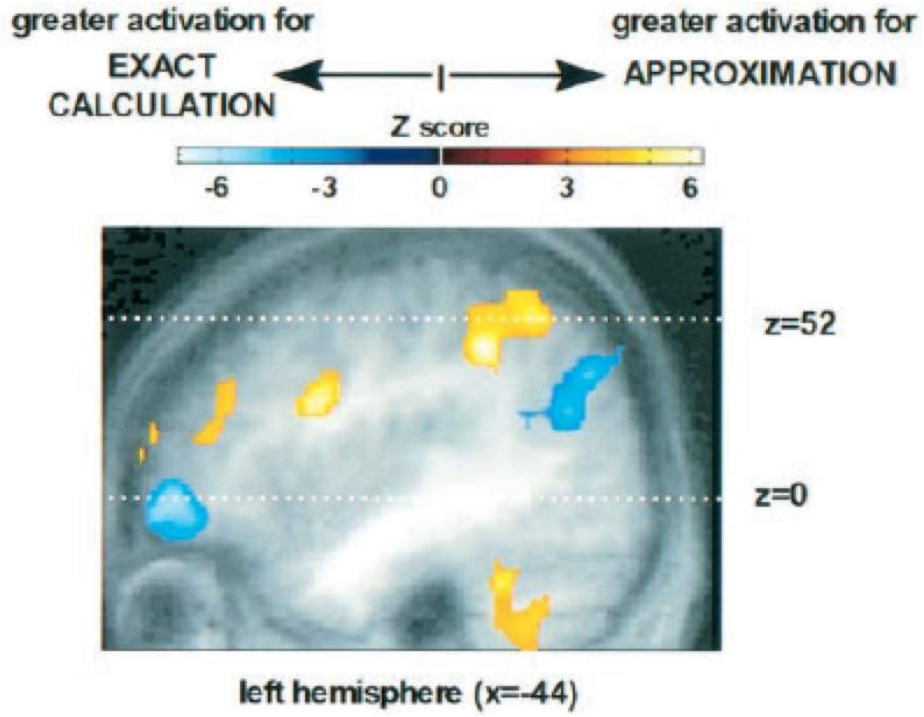
Real dangers of reaching fundamentally wrong conclusions:

Science 1999

Sources of Mathematical Thinking: Behavioral and Brain-Imaging Evidence

S. Dehaene,[1]* E. Spelke,[2] P. Pinel,[1] R. Stanescu,[1] S. Tsivkin[2]

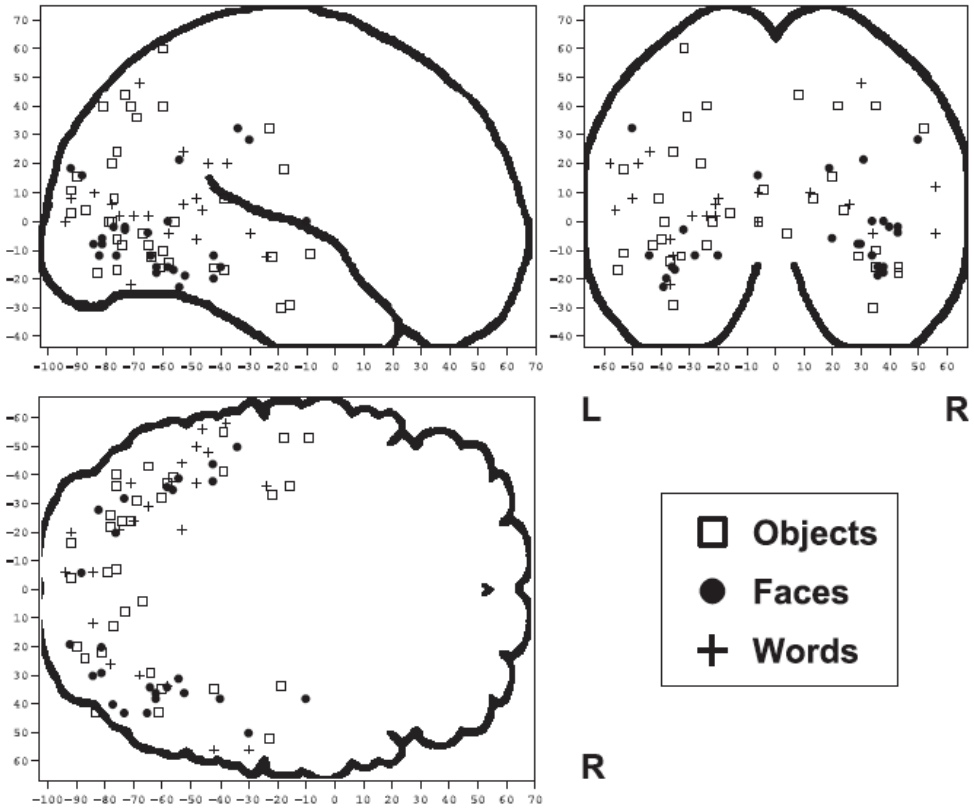
Does the human capacity for mathematical intuition depend on linguistic competence or on visuo-spatial representations? A series of behavioral and brain-imaging experiments provides evidence for both sources. Exact arithmetic is acquired in a language-specific format, transfers poorly to a different language or to novel facts, and recruits networks involved in word-association processes. In contrast, approximate arithmetic shows language independence, relies on a sense of numerical magnitudes, and recruits bilateral areas of the parietal lobes involved in visuo-spatial processing. Mathematical intuition may emerge from the interplay of these brain systems.



Fedorenko & Kanwisher (2009, 2011); Fedorenko et al. (2010); Nieto-Castañon & Fedorenko (2012)

How to study the language system?

Real dangers of reaching fundamentally wrong conclusions:



Aguirre & Farah (1998)

Conclusion reached: distributed representations of visual categories in the ventral visual stream.

Wrong conclusion!

Fedorenko & Kanwisher (2009, 2011); Fedorenko et al. (2010); Nieto-Castañon & Fedorenko (2012)

How to study the language system?

How to find it?

Language > **Linguistically degraded control**

Sentences > **Nonword sequences**

A RUSTY LOCK WAS FOUND IN THE DRAWER

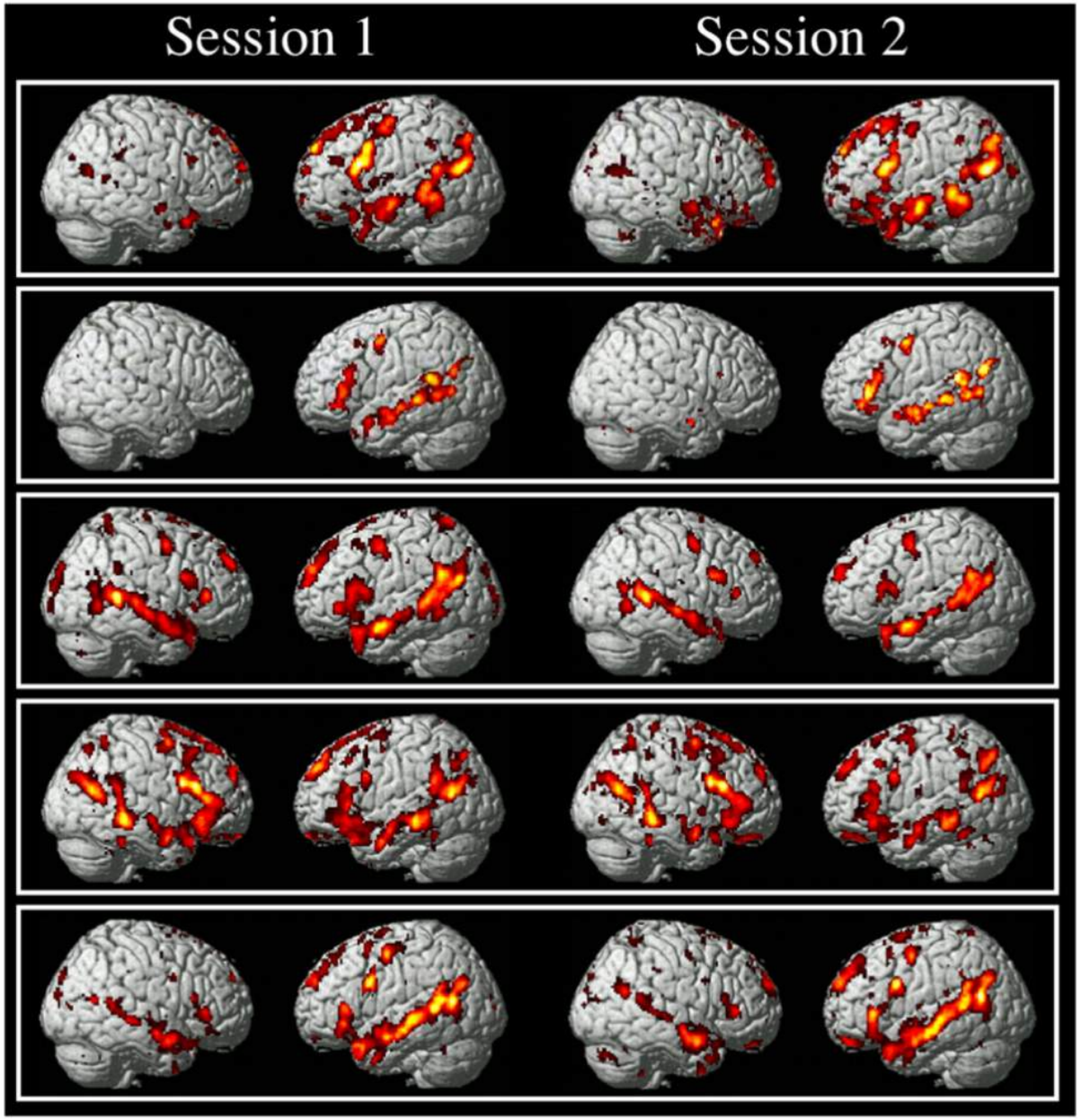
DAP DRELLO SMOP UB PLID KAV CRE REPLODE

Sample individual functional regions of interest (fROIs)

Fedorenko et al. (2010, JNeurophys); Scott et al. (2016)

How to study the language system?

K. Mahowald, E. Fedorenko / NeuroImage 139 (2016) 74–93

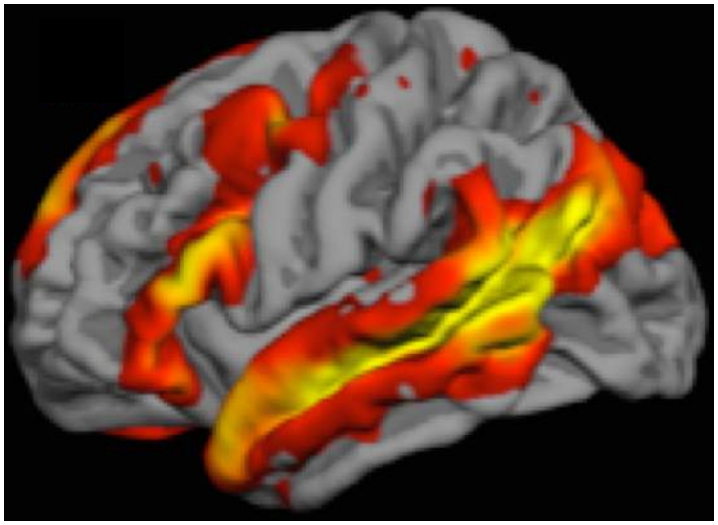


Activations are extremely stable within individuals over time!

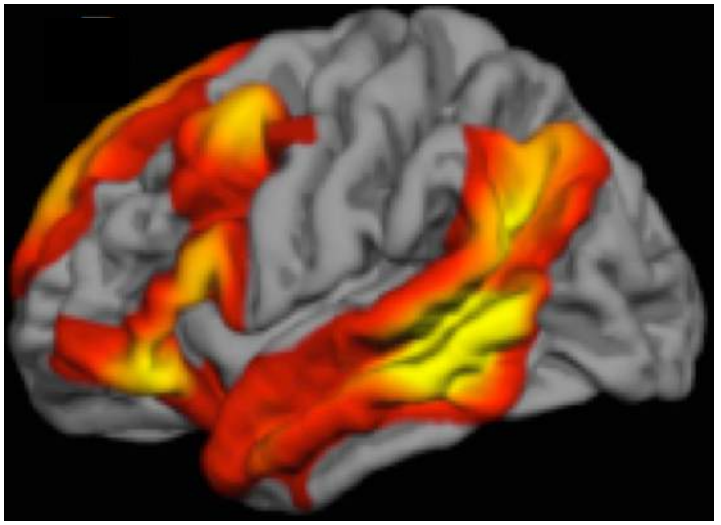
Fig. 3. Sample activation maps from the two sessions of 5 participants scanned twice on the language localizer task.

The language system/network

Sentences > **Nonwords**



Resting state correlations data



(data from Brad Dickerson's lab; seed - posterior LMTG)

Outline

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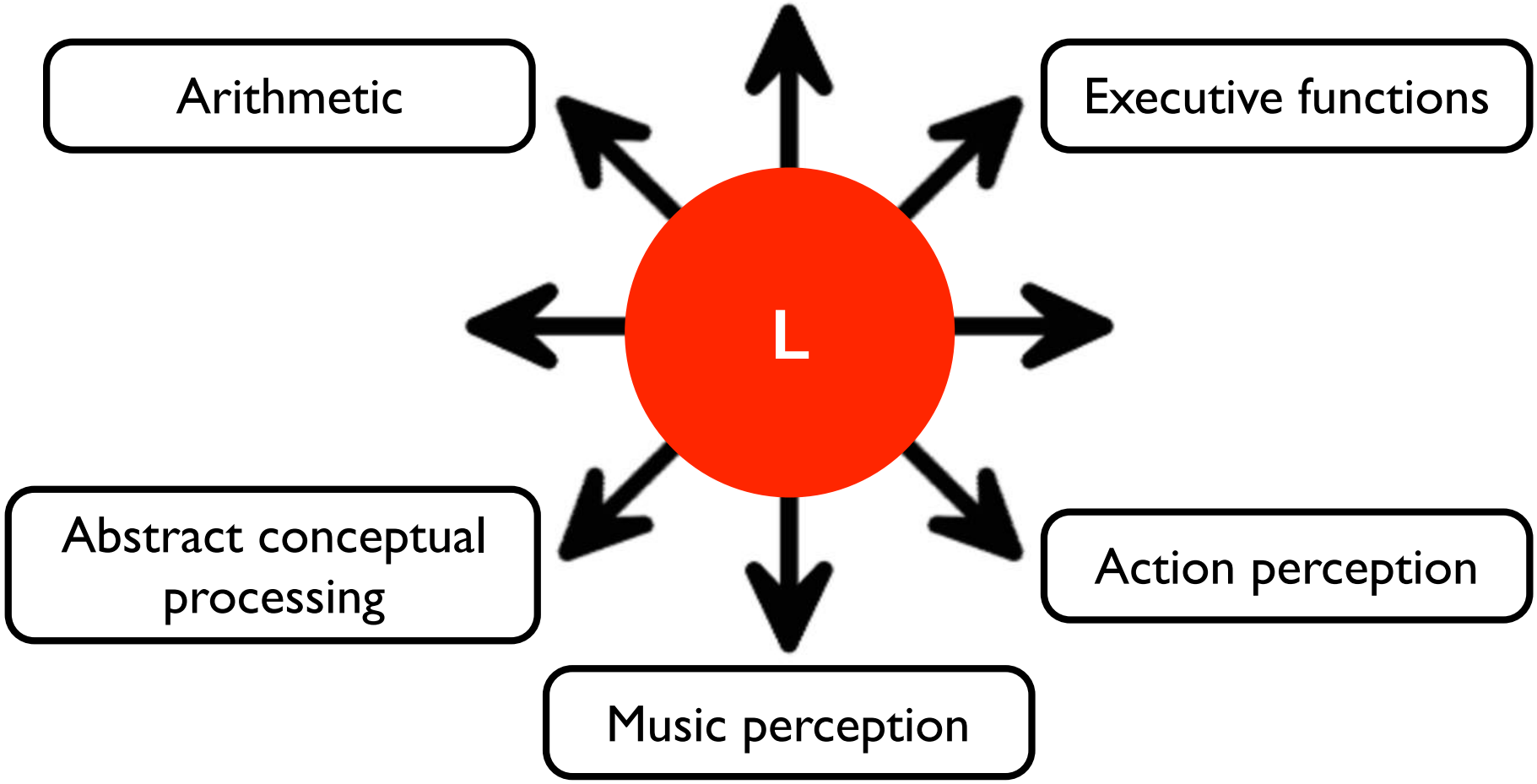
    - patient evidence

Language vs. thought

The relationship between language and the rest of the human mind and brain



Language vs. thought

The relationship between language and the rest of the human mind and brain

Two complementary approaches:

Brain imaging (fMRI)

The logic:

- examine the response of the language brain regions to non-linguistic tasks
- **low or no response** suggests that these regions do not get engaged during those non-linguistic tasks

Patient studies

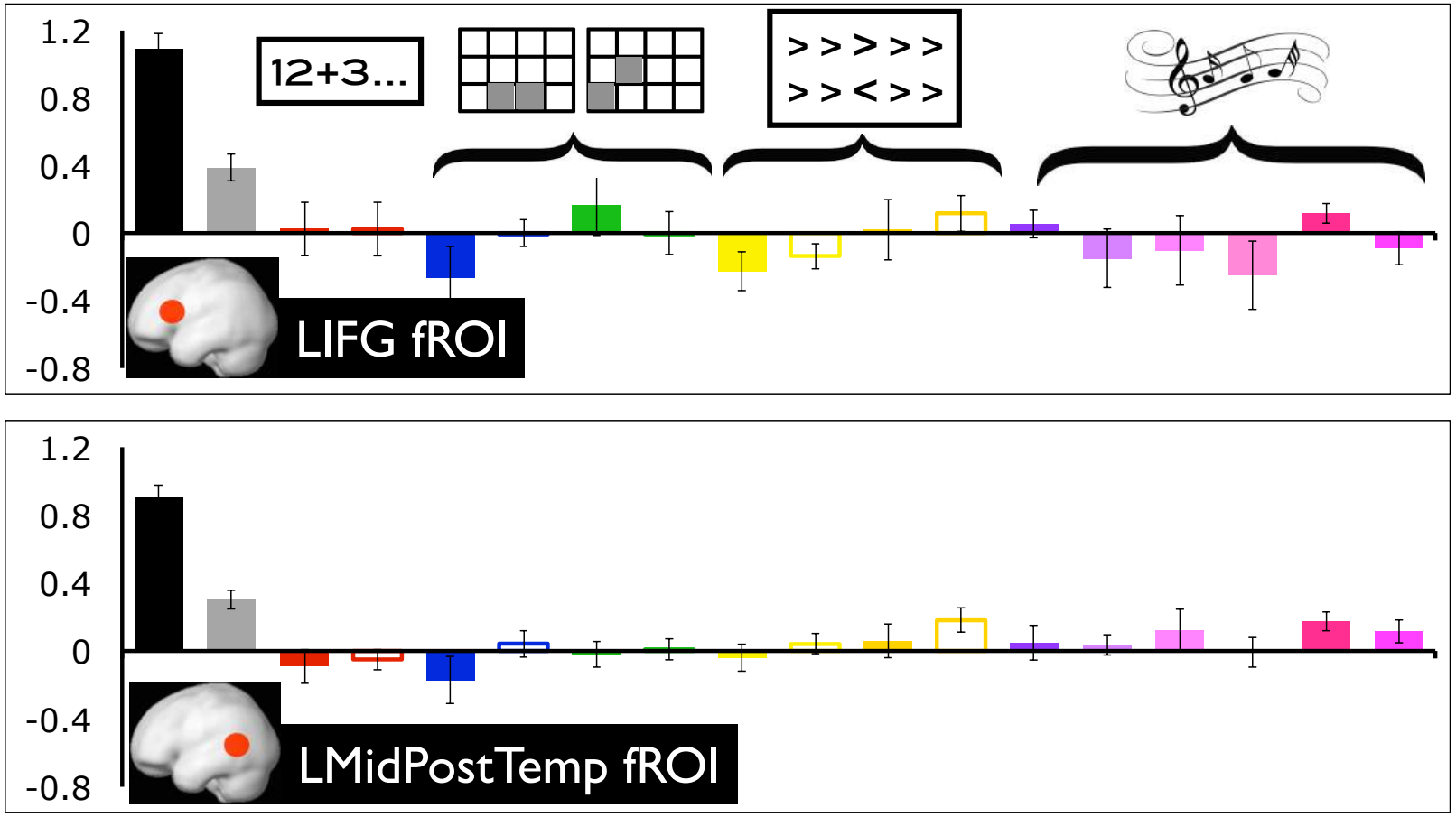
The logic:

- examine non-linguistic abilities in individuals without a functioning language system
- **success** suggests that the language system is not necessary for performing those non-linguistic tasks

Language vs. thought

fMRI evidence

Math, executive functions, music



Sentences
Nonwords
Hard Math
Easy Math
Hard Spatial WM
Easy Spatial WM
Hard Verbal WM
Easy Verbal WM
Hard MSIT
Easy MSIT
Hard vMSIT
Easy vMSIT
Intact melodies
Scrambled melodies
Intact drum tracks
Scrambled drums
Orchestral music
Solo music

NB: The responses are plotted as percent BOLD signal change relative to the fixation baseline.

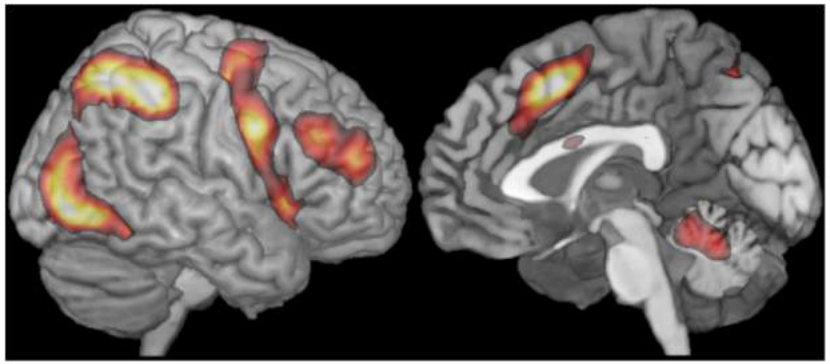
Fedorenko et al. (2011, PNAS); Fedorenko et al. (2012, Curr Biol)
Norman-Haignere et al. (in preparation)

Language vs. thought

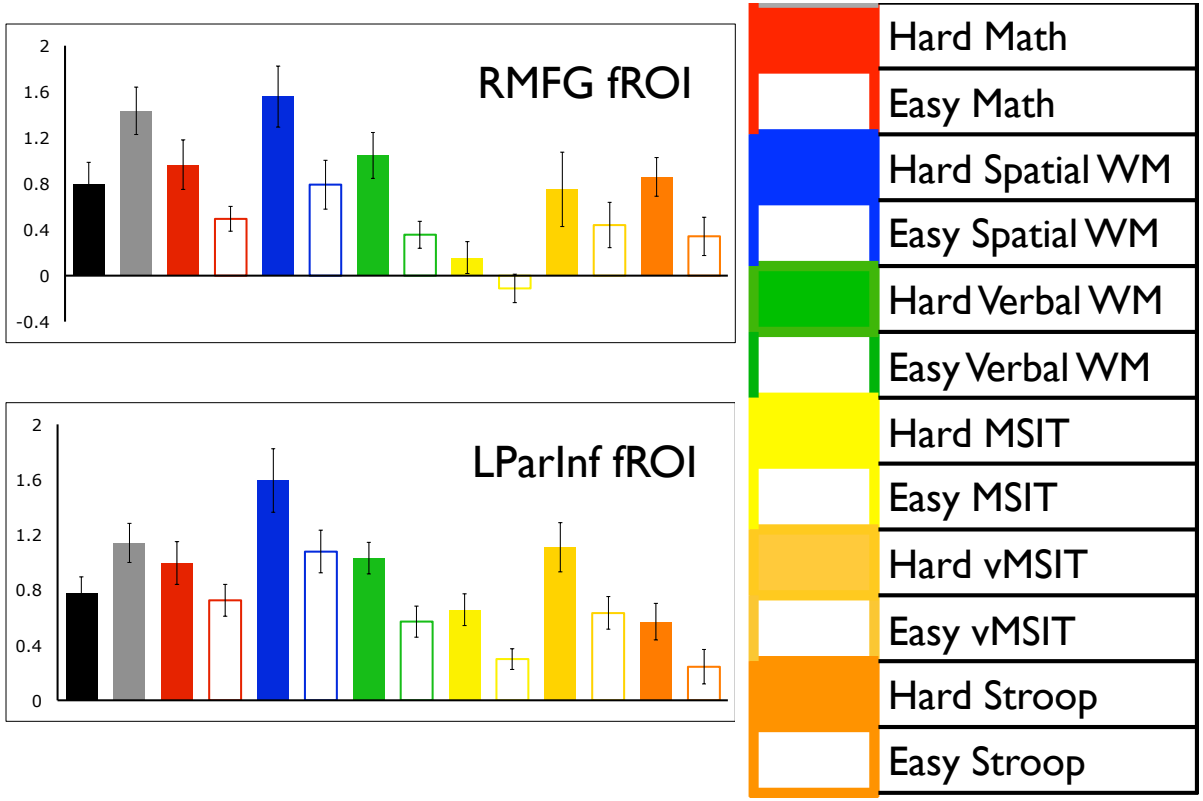
fMRI evidence

Math, executive functions, music

The cognitive control or "multiple demand (MD)" network



Duncan & Owen (2001);
Miller & Cohen (2001);
Duncan (2010)



The multiple demand network:

- **is sensitive to effort across tasks**
- **supports a wide range of goal-directed behaviors.**

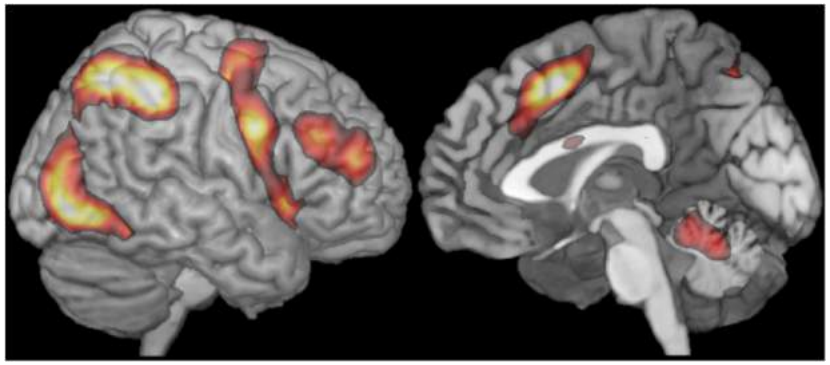
Fedorenko, Duncan & Kanwisher (2013, PNAS)

Functional specificity for language

fMRI evidence

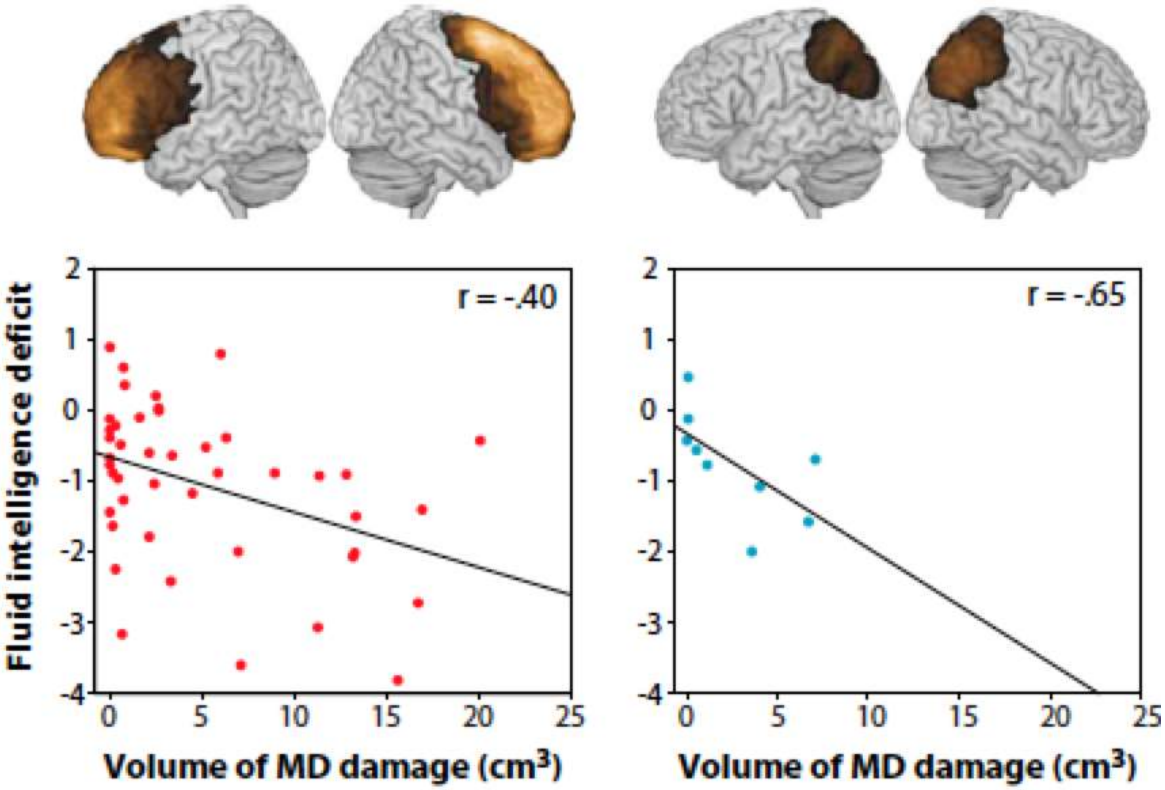
Math, executive functions, music

The cognitive control or "multiple demand (MD)" network



Duncan & Owen (2001);
Miller & Cohen (2001);
Duncan (2010)

Damage in the multiple demand network has been linked to loss of intelligence.

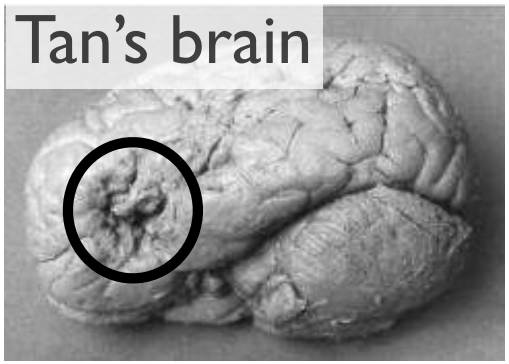


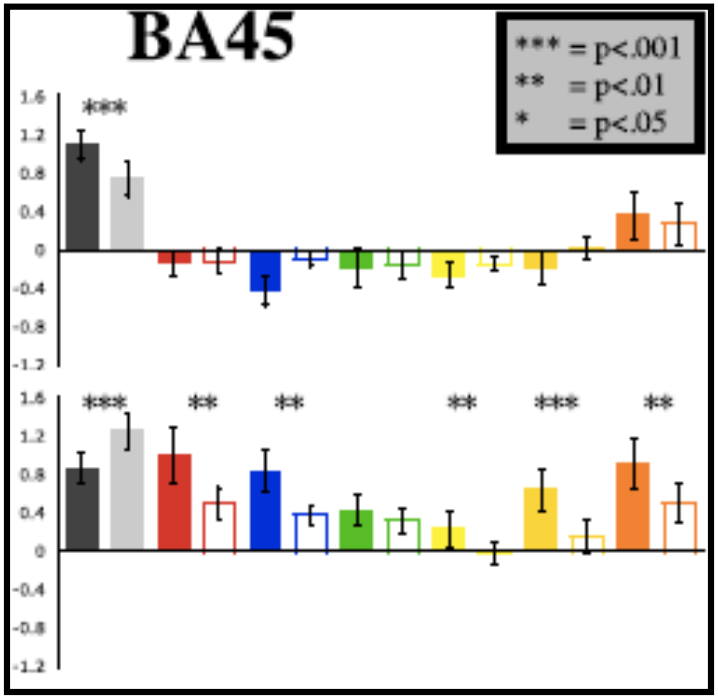
Woolgar et al. (2010)

Fedorenko, Duncan & Kanwisher (2013, PNAS)

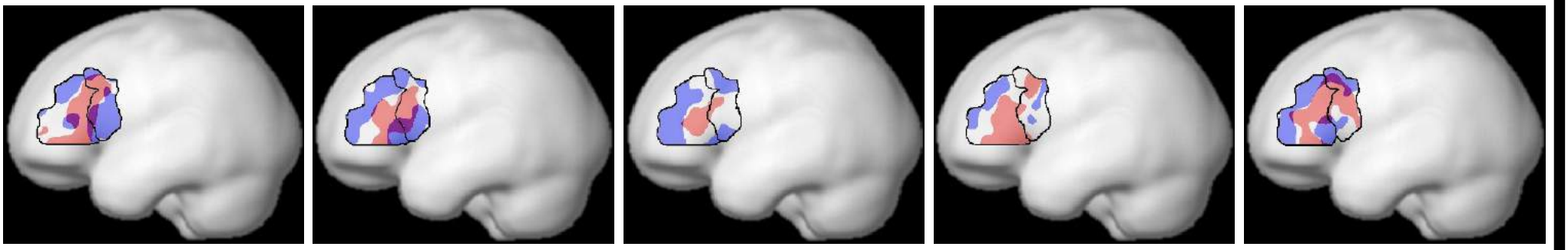
A small aside about "Broca's area"

A few words about Broca's area





Sample individual activations: Language MultipleDemand

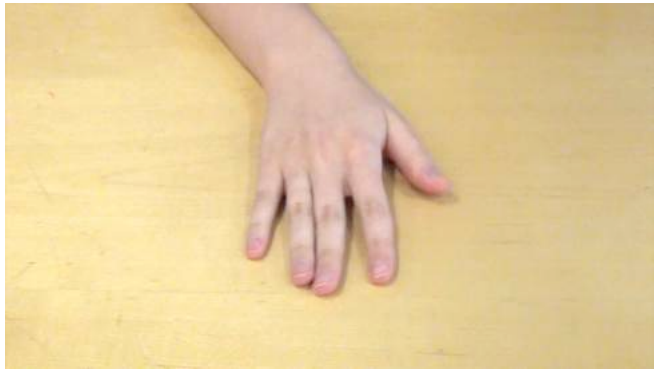


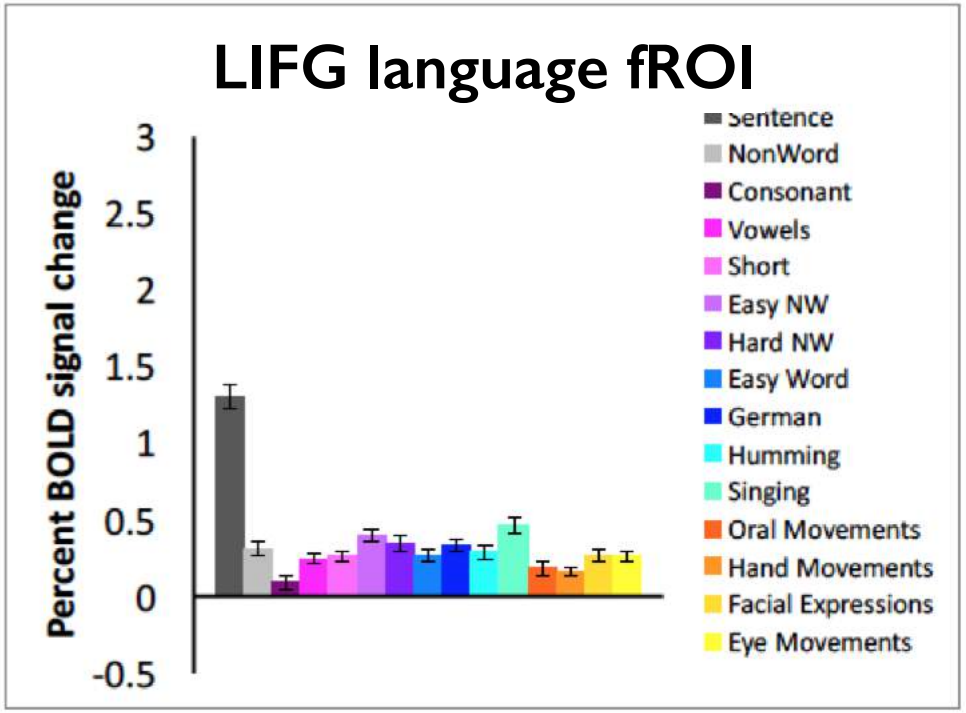
Fedorenko, Duncan & Kanwisher (2013, Curr Biol)

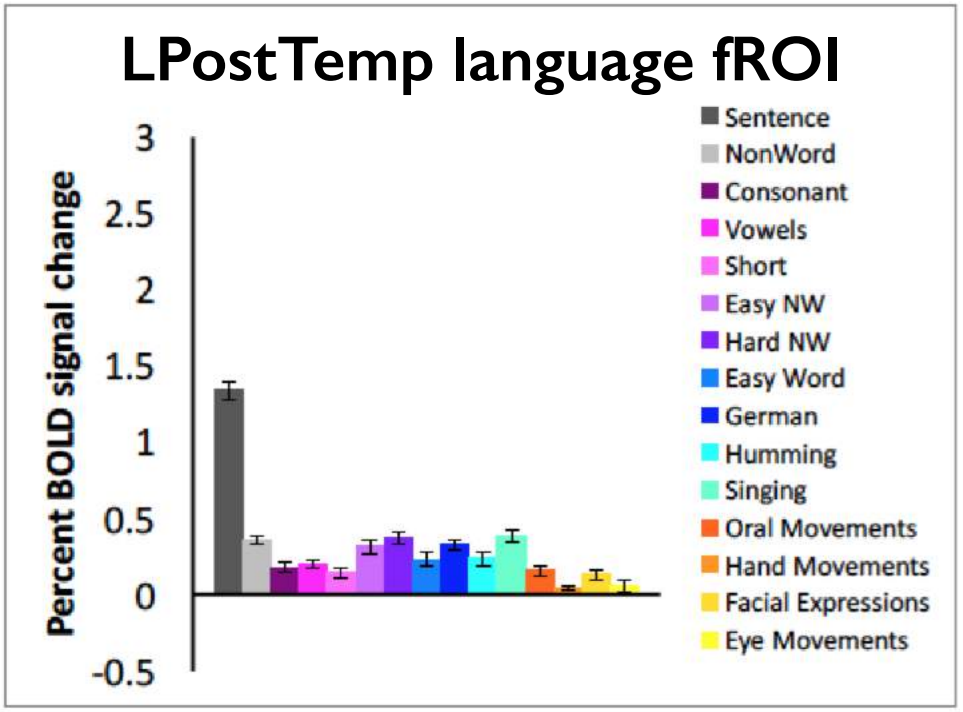
Language vs. thought

fMRI evidence

Action observation







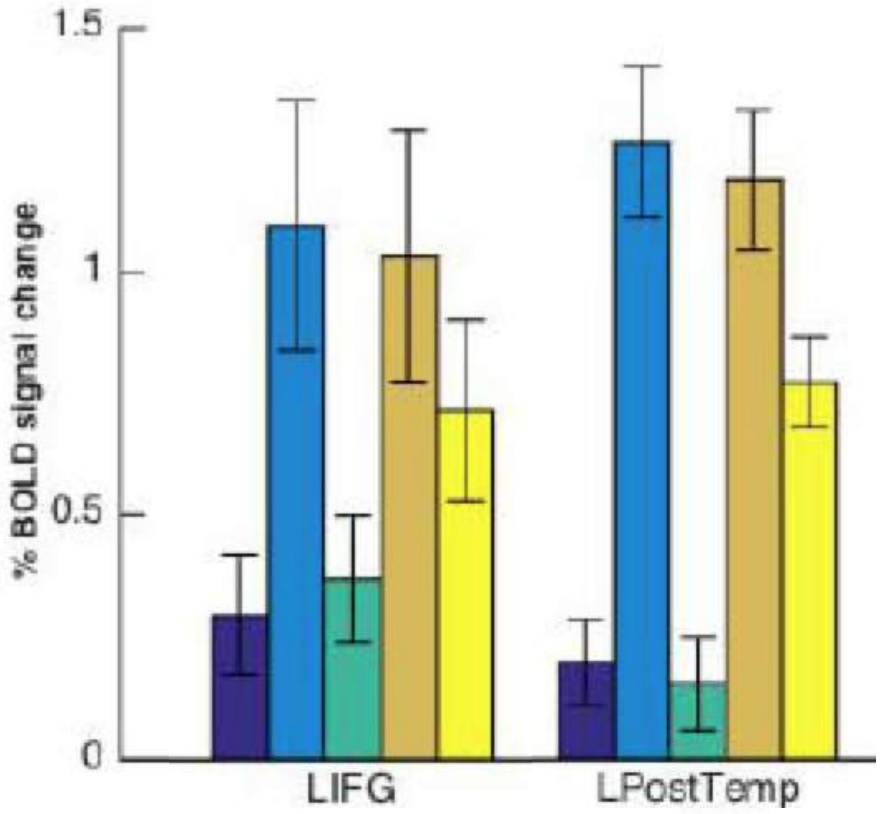
Fedorenko et al. (in preparation)

Language vs. thought

fMRI evidence

Gesture observation

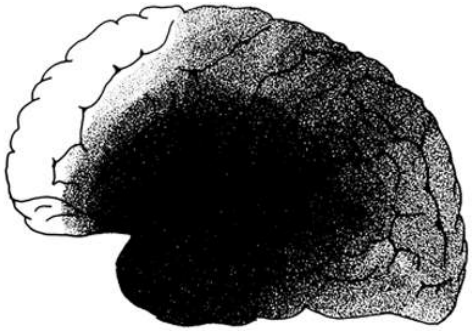
Jouravlev et al. (submitted)



Language vs. thought

Patient evidence

Rosemary Varley
(UCL)



Varley & Siegal (2000; Curr Biol)

Causal reasoning

Non-verbal social cognition

Willems et al. (2010; Nplogia)

Arithmetic

Varley et al. (2005, PNAS)

L

Spatial navigation

Bek et al. (2010; Memory & Cognition)

Music

Fedorenko, McDermott & Varley (2014, in prep.)

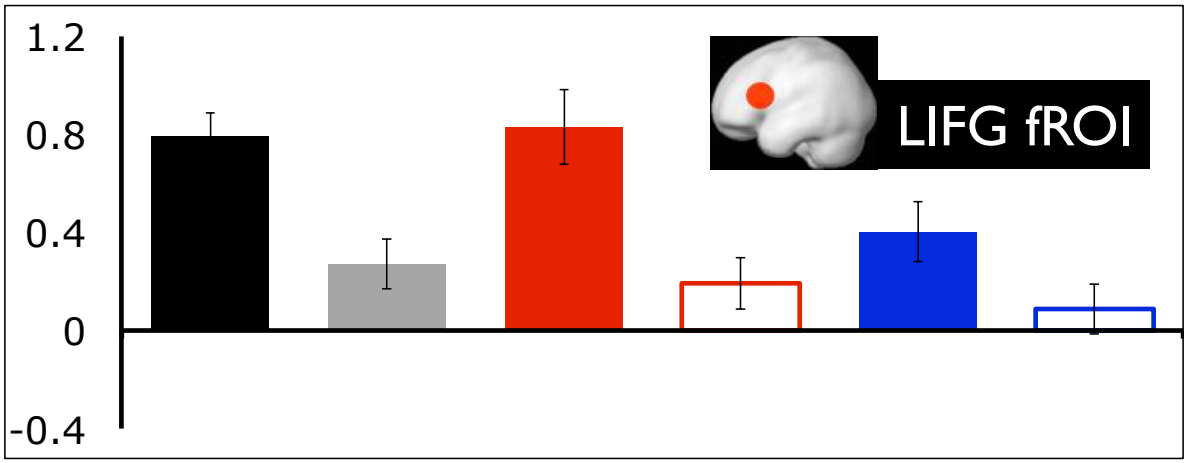
Language vs. thought

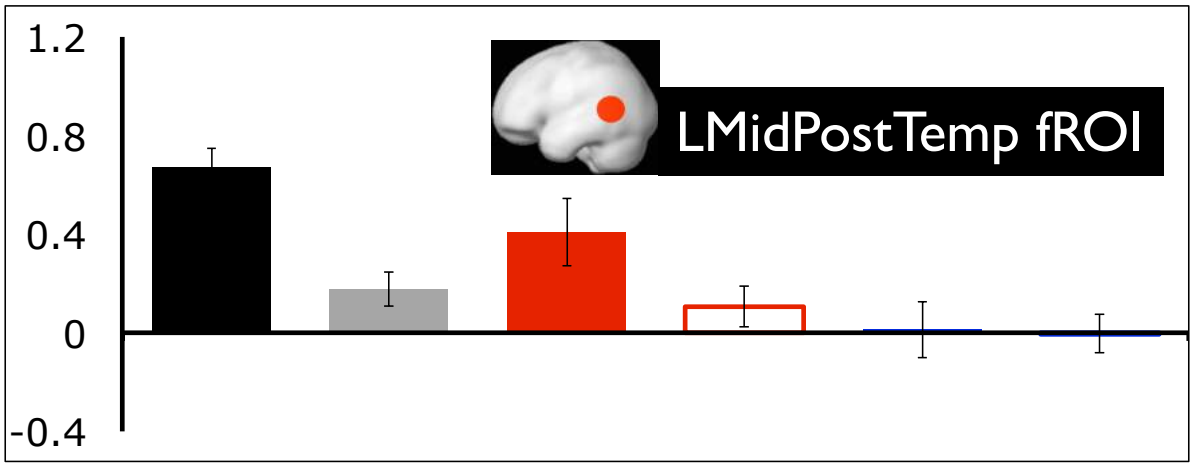
fMRI evidence

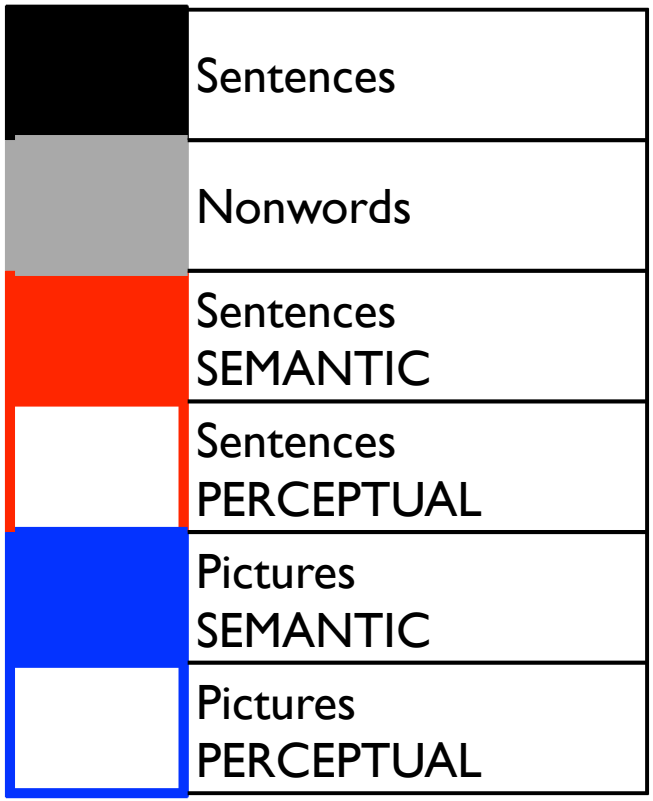
Non-verbal semantics

THE MAN IS WATERING A HOUSE PLANT.

THE MAN IS WATERING AN EGG.







Fedorenko, Goldhaber, Varley & Kanwisher (in prep.)

Language vs. thought

Patient evidence

Non-verbal semantics

Tom Lubbock,
chief art critic of *The Independent*
(1957 - 2011)

"My language to describe things in the world is very small, limited. My thoughts when I look at the world are vast, limitless and normal, same as they ever were. My experience of the world is not made less by lack of language but is essentially unchanged."

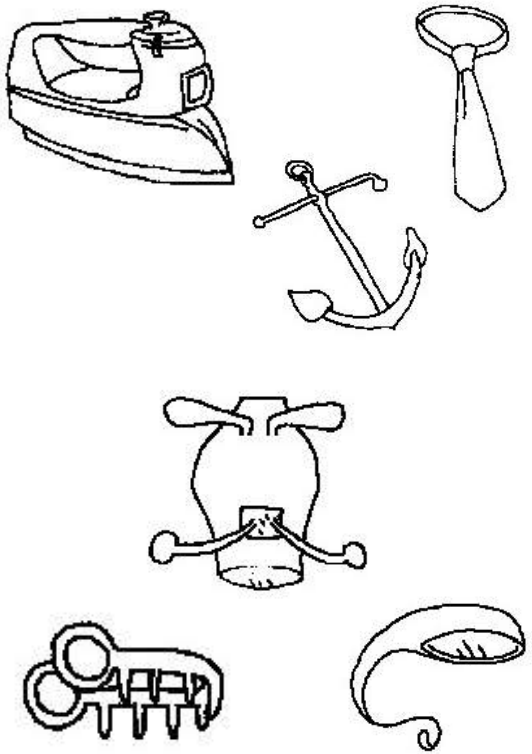
(from Tom Lubbock: A memoir of living with a brain tumor)

Language vs. thought

Patient evidence

Non-verbal semantics

Real object?



✓

Plausible event?

✓

Plausible event?

✓

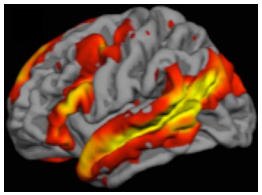
Fedorenko, Kanwisher & Varley (in prep.)

Language vs. thought

To summarize:

Brain imaging (fMRI)

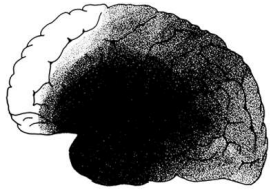
Brain regions of the language system show little or no response to



a wide range of non-linguistic tasks.

Patient studies

Individuals with no functioning language system perform well on



Brain regions of the language system are strongly *specialized* for interpreting and generating linguistic messages.

Implications for language evolution

Brain regions of the language system are strongly *specialized* for interpreting and generating linguistic messages.

What **<u>does NOT</u> follow** from it:

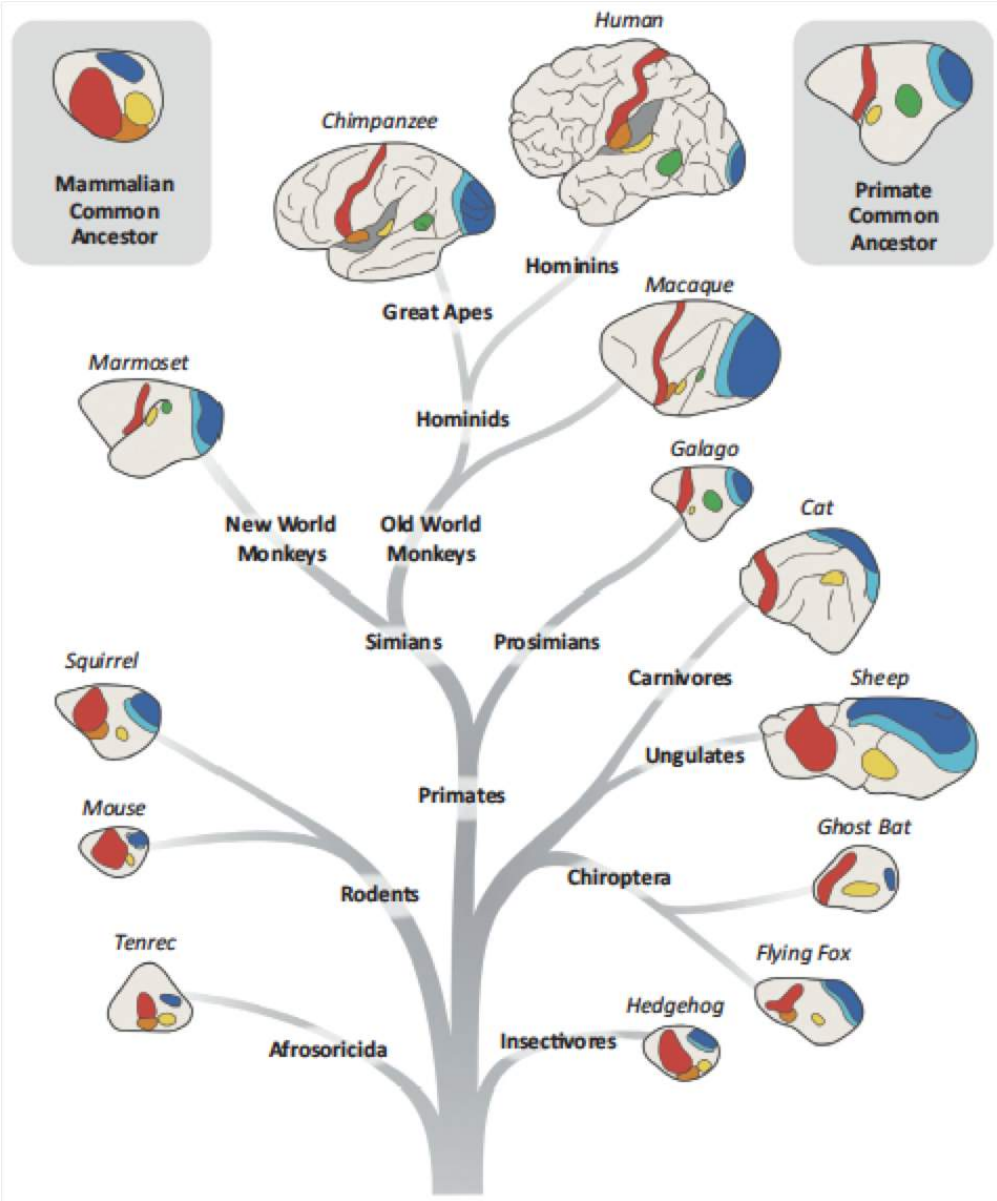
- the language system is *innate*
- the brain regions that in modern humans support linguistic processing *evolved* specifically for language
- the language system is *isolated* from (i.e., does not interact with) the rest of the brain

Implications for language evolution

Human brain evolution

How do **human brains** differ from those of other primates or mammals in general?

A key change:
association areas in frontal, temporal and parietal cortices expanded

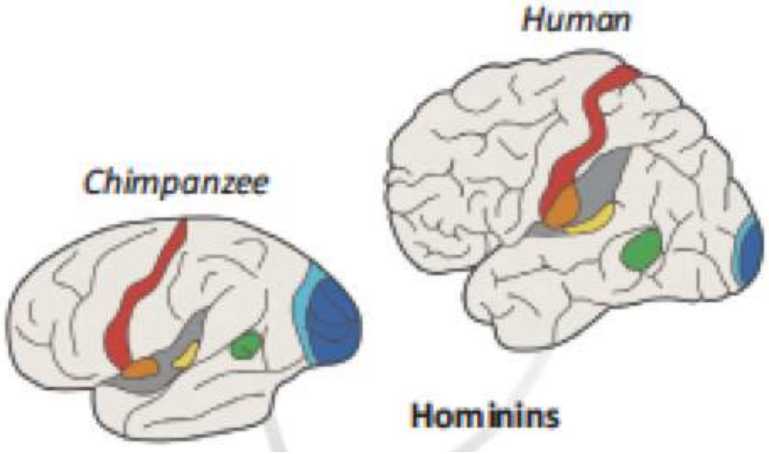


Buckner & Krienen (2014)

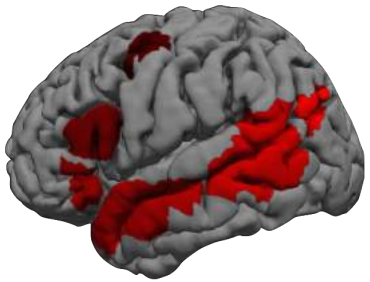
Implications for language evolution

Human brain evolution

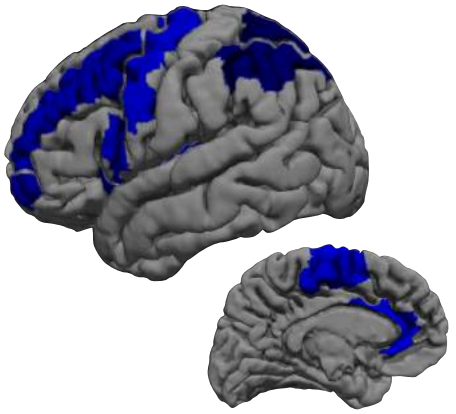
A big question:
Is something qualitatively different about the human brains, or is it just a "scaled-up primate brain" (e.g., Azevedo et al., 2009; Herculano-Houzel, 2012)?



3 high-level large-scale networks:

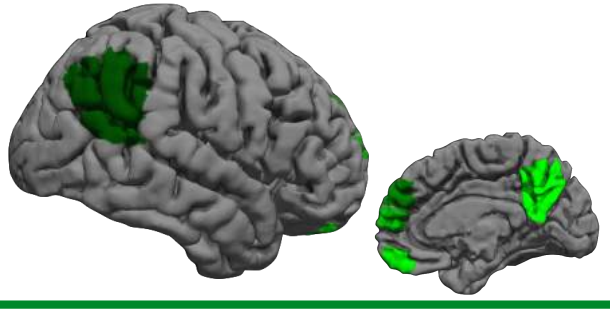


Language system



"Multiple demand (MD)" system
(e.g., Duncan, 2010, 2012)

Social cognition system
(e.g., Saxe & Powell, 2006)



Implications for language evolution

Human brain evolution

Quantitative changes

Bigger but similar brains?

Yes!

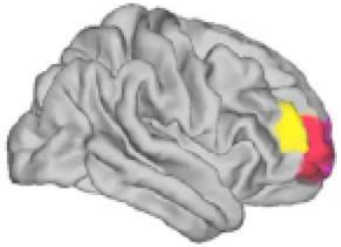
- Homologies between human neocortical brain regions and those in non-human primates, including Broca's area (e.g., Preuss & Goldman-Rakic, 1991; Petrides & Pandya, 1999, 2002)

Qualitative changes

Newly emerged brain regions?

Evidence is scarce…

- Some brain regions in the human brain may not be present in nonhuman primates (e.g., Neubert et al., 2014)



Implications for language evolution

Human brain evolution

Quantitative changes

Bigger but similar brains?

Storage
(communicative signals)



Qualitative changes

Newly emerged brain regions?

Computation
(combinatorial machinery)

BUT:

- The human **storage capacity** is under-appreciated.
- The **combinatorial machinery** is overrated.

(e.g., de Boer, 2014; Piantadosi & Fedorenko, under review)

Implications for language evolution

Human brain evolution

Quantitative changes

Different developmental time-course?

Yes!

- 3-fold (cf. only 2-fold in chimps) post-natal expansion (e.g., Harvey, 1987)

(Piantadosi & Kidd, 2016, PNAS)

Humans are exceptionally responsive to environmental influence!

Implications for language evolution

Human brain evolution

Language — a useful code for our thoughts

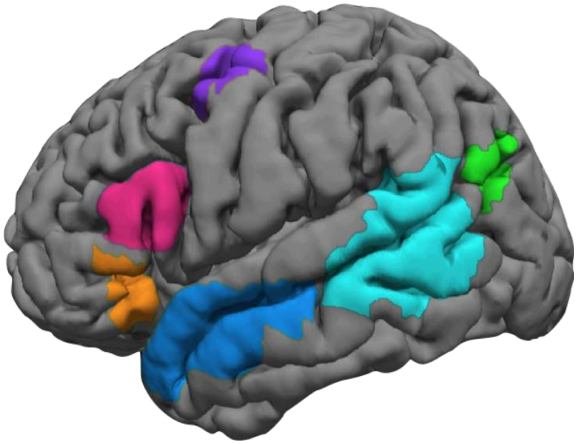
What does it "**buy**" us?

- the ability to share our thoughts with one another

(possibly leading to sophisticated mentalizing capacities)

Some evidence suggests that language provides **an important scaffold** for the development of mature Theory of Mind abilities.

Thank you!



EvLab members

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