

THE CORTICAL ORGANIZATION OF SYNTACTIC PROCESSING IN AMERICAN SIGN LANGUAGE

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Glossary of terms & brain map

- Clear version can be found at www.williammatchin.com/extras, “Language Neurobiology” button on bottom left
- Limited number of printed handouts; if already well-versed in brain & language, please share

What is language?

What is language? Two views

1. An complex form of auditory-vocal learning & communication

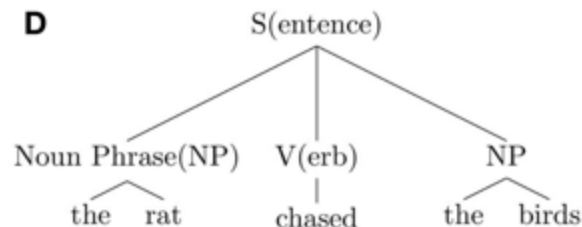
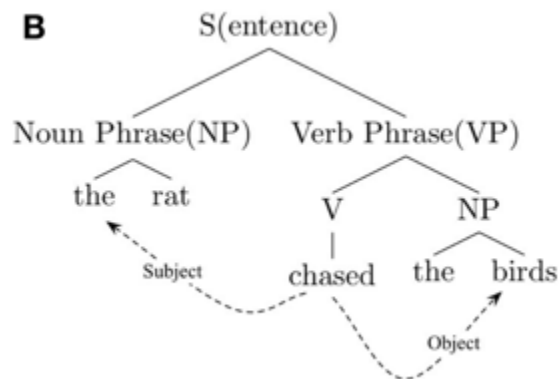
What is language? Two views

1. An complex form of auditory-vocal learning & communication

(structure)

(meaning)

2. A computational system, syntax and semantics, expressed through speech



Berwick et al., 2011

Language is modality independent



Sign vs. Pantomime

Bernard Bragg's Pantomime of "steal"



The ASL Sign STEAL



Syntax in sign languages

- Spatial agreement



a. I-GIVE-YOU

b. S/HE-GIVE-HIM/HER



c. YOU-GIVE-HIM/HER

d. I-GIVE-YOU-ALL

- Hierarchical syntactic structure

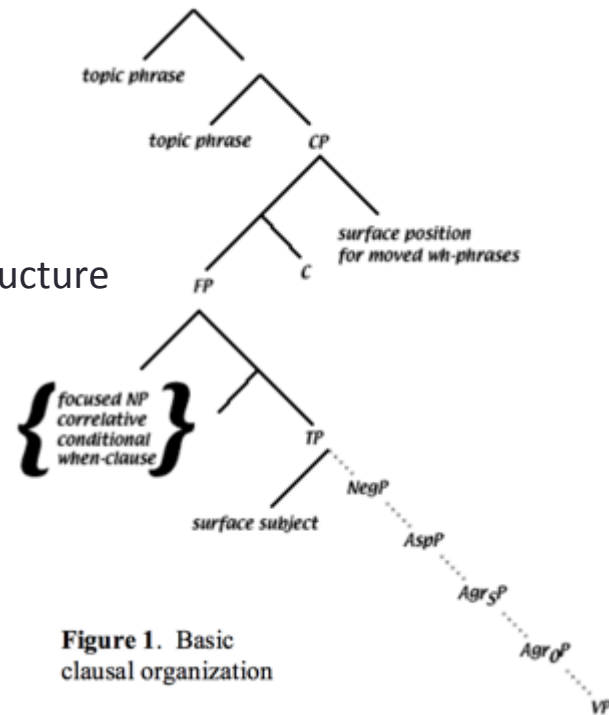


Figure 1. Basic clausal organization

- Non-manual syntactic features

$\overline{\text{foc/rc}}$
 MOUSE CHASE CAT DIE

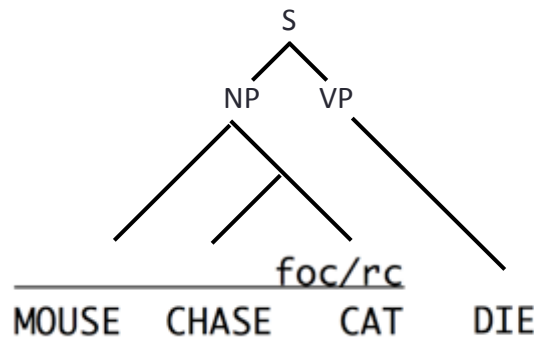
‘The mouse that chased the cat died.’

Illustration of grammatical non-manual markers

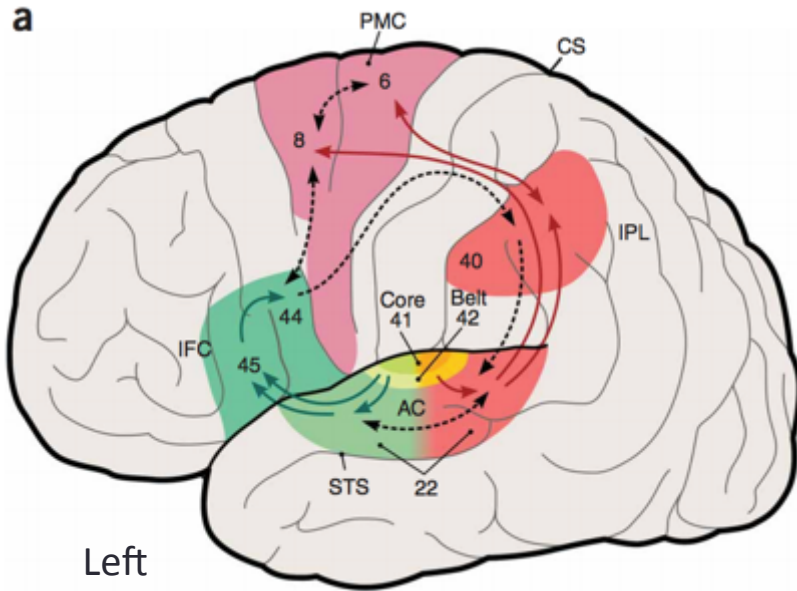


What is language? Two views

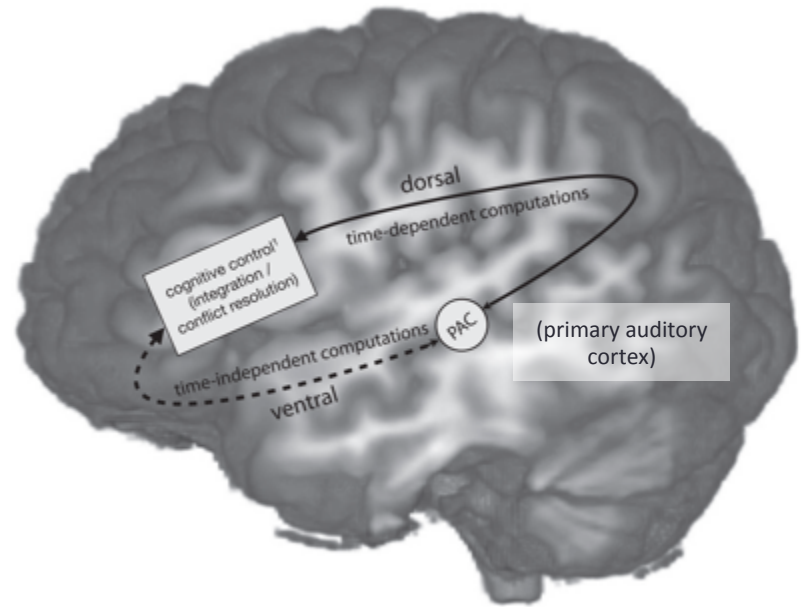
1. An complex form of **visual-manual** learning & communication
2. A computational system, syntax and semantics, expressed through **sign**



Auditory-centric models of language & brain



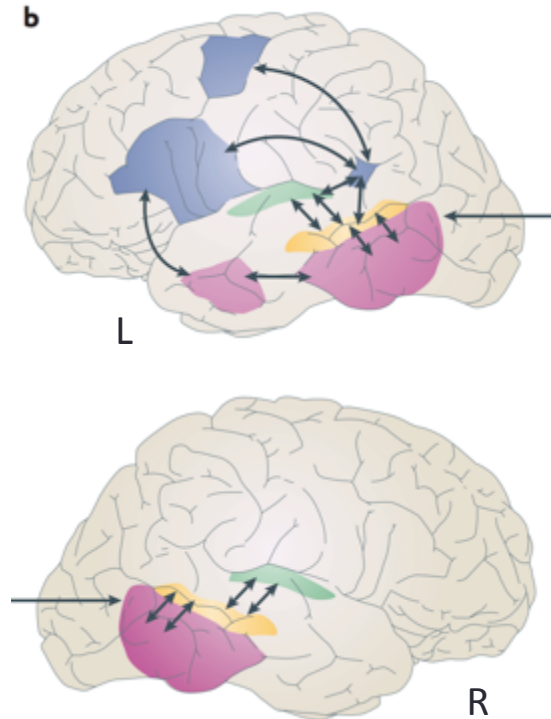
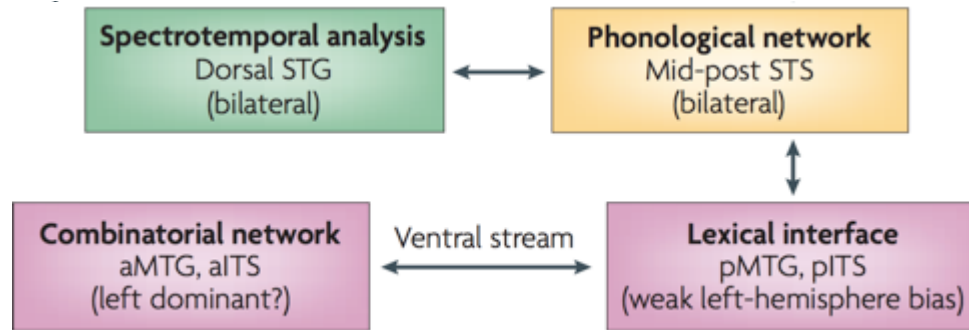
Rauschecker & Scott, 2009



Bornkessel-Schlesewsky & Schlesewsky, 2013

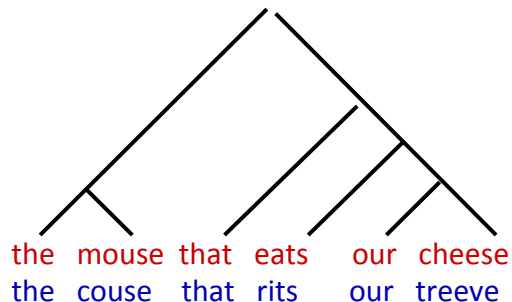
Auditory-centric models of language & brain

- Ventral stream: *sound* to meaning

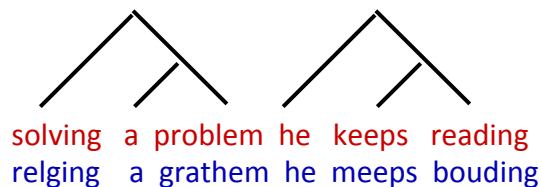


Structural sensitivity in the language network

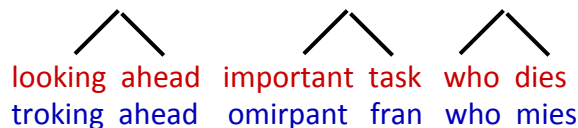
- **Natural:** all real words
- **Jabberwocky:** open-class words replaced with nonwords
- Syntax-sensitive regions should show increased activity for bigger structure
- Semantics-sensitive regions should only show this effect for **natural** stimuli



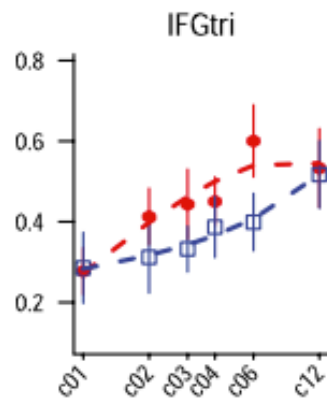
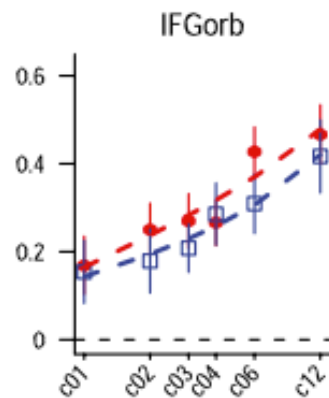
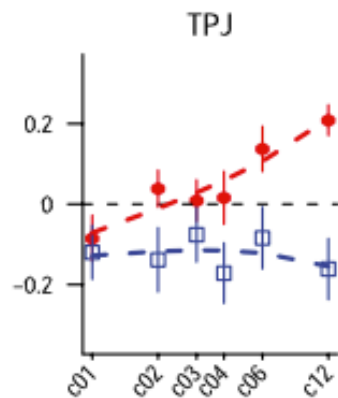
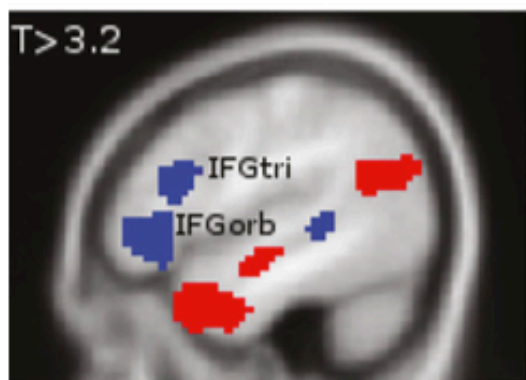
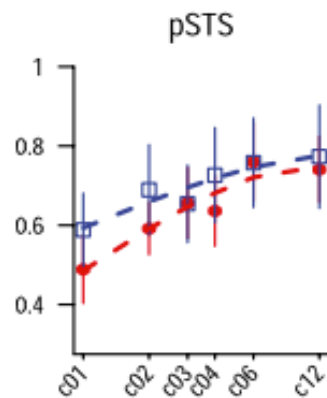
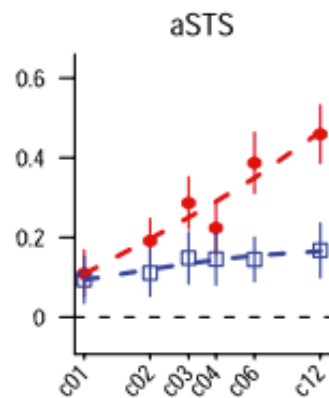
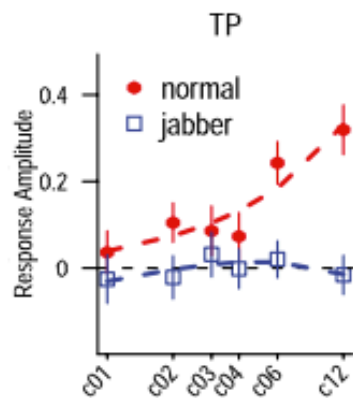
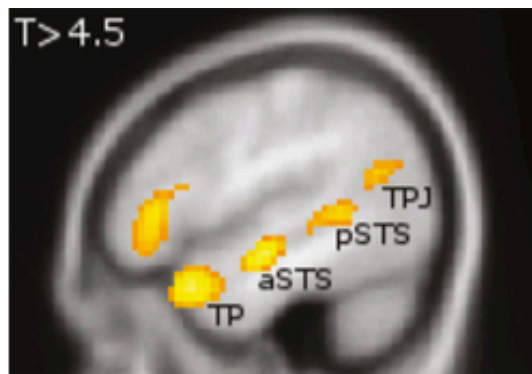
High structure



Medium structure



Low structure



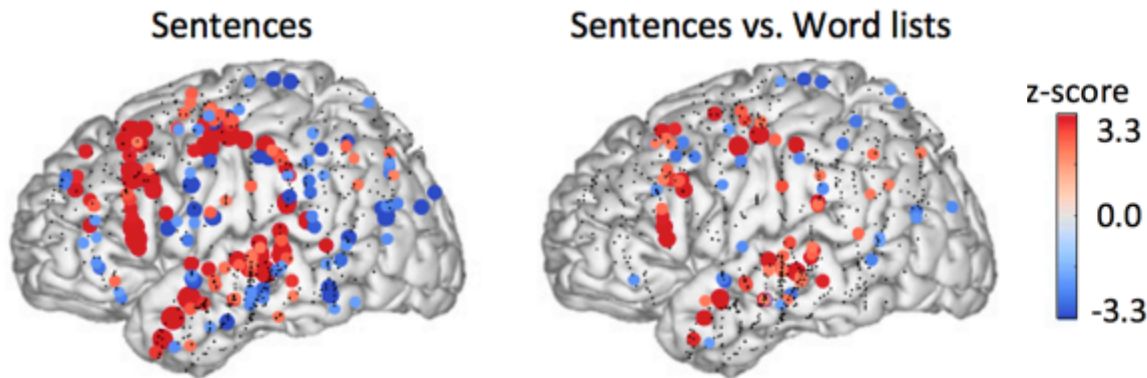
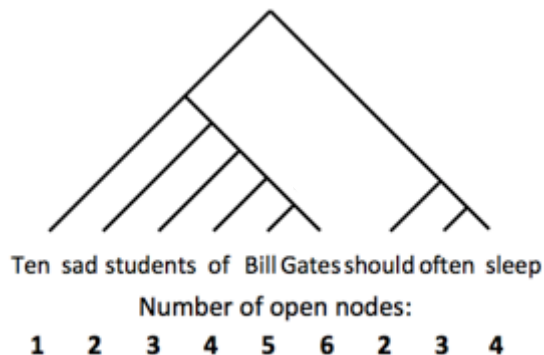
Pallier et al. (2011)

fMRI

Low structure → High structure

Real-time structural sensitivity

- Open node tracking: the bigger the structure at each word, the more brain activity



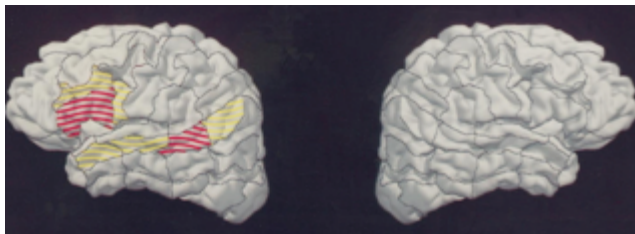
Regression model: number of open nodes at each word

Sign language & the brain

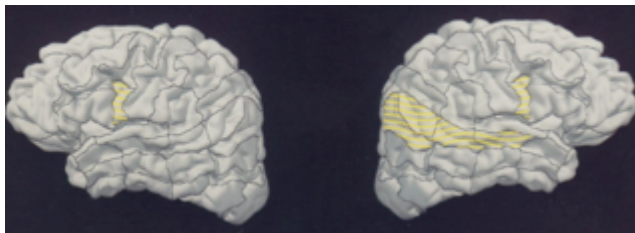
Written English sentences > sequences of consonants

- ASL generally activates similar regions as spoken/written languages
- ASL in deaf native signers: right-lateralized?
- Language laterality: syntactic processing?

Hearing native English speakers

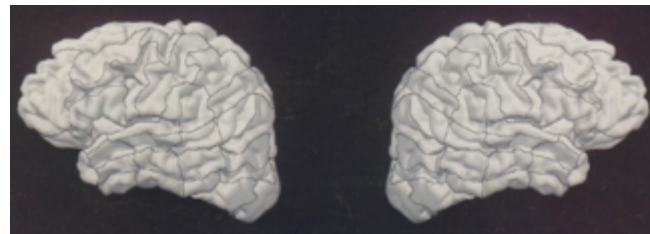


Deaf native ASL signers

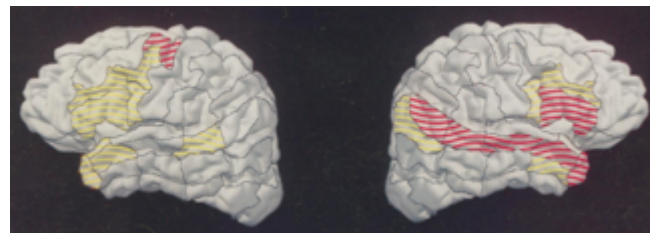


ASL sentences > nonsign gestures

Hearing native English speakers



Deaf native ASL signers



Present study

- Investigate syntactic processing in ASL in deaf native signers using fMRI
- Look for correlation between structural complexity and brain activity
- Parametric design: use multiple levels of structure,
- Compare with findings in spoken/written languages

Stimuli

6-word lists (6W)



AWARD BELT SHOVEL BOY PIG POTATO

Video duration: ~4-6 seconds

2-word sentences (2S)



FAMILY TRAVEL DESSERT ALL-GONE LETTER SAD

'the family travels', 'the dessert is all gone',
'the letter is sad'

6-word sentences (6S)



TEACHER GIVE-OUT HW TEND-TO NOT POPULAR

'a teacher who gives out homework
tends not to be popular'

Stimuli

6-word lists (6W)

Max. constituent size:
1 word

AWARD BELT SHOVEL BOY PIG POTATO

(pseudo non-manual
gestures included to help
control motion dynamics)

2-word sentences (2S)

Max. constituent size:
2 words

FAMILY TRAVEL DESSERT ALL-GONE LETTER SAD

'the family travels', 'the dessert is all gone',
'the letter is sad'

6-word sentences (6S)

Max. constituent size:
6 words

TEACHER GIVE-OUT HW TEND-TO NOT POPULAR

'a teacher who gives out homework
tends not to be popular'

Presentation/Task

- Blocks of 3 stimuli in a row (18 signs), ~20 seconds per block
- End of block: picture memory probe
 - 50% of time: picture matches one of the signs
- Control condition: watch still face of signer
 - Fixation cross every 4 seconds (press button)
- 4 scanning blocks, structural MRI acquired

Still face with cross

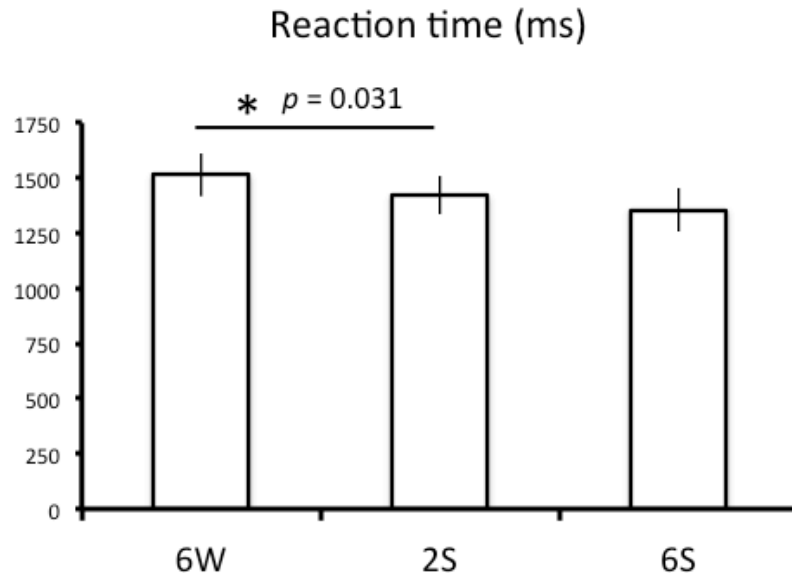
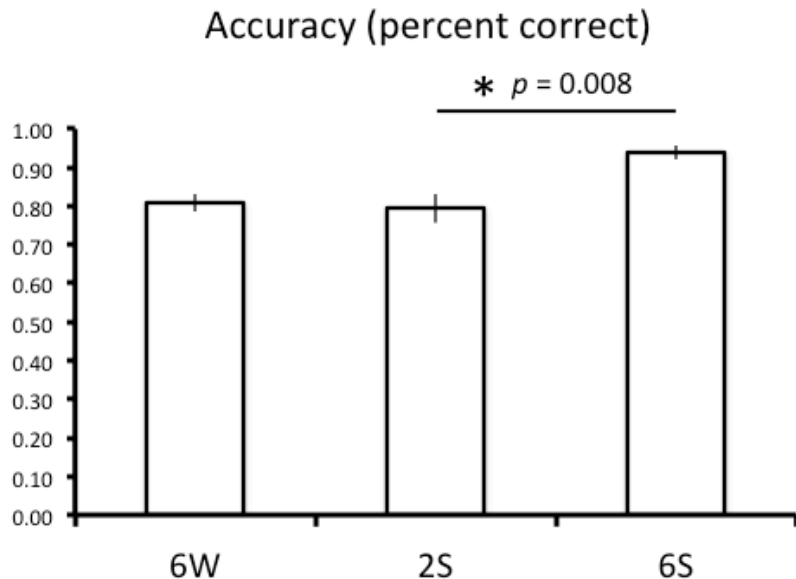


Example
memory probe

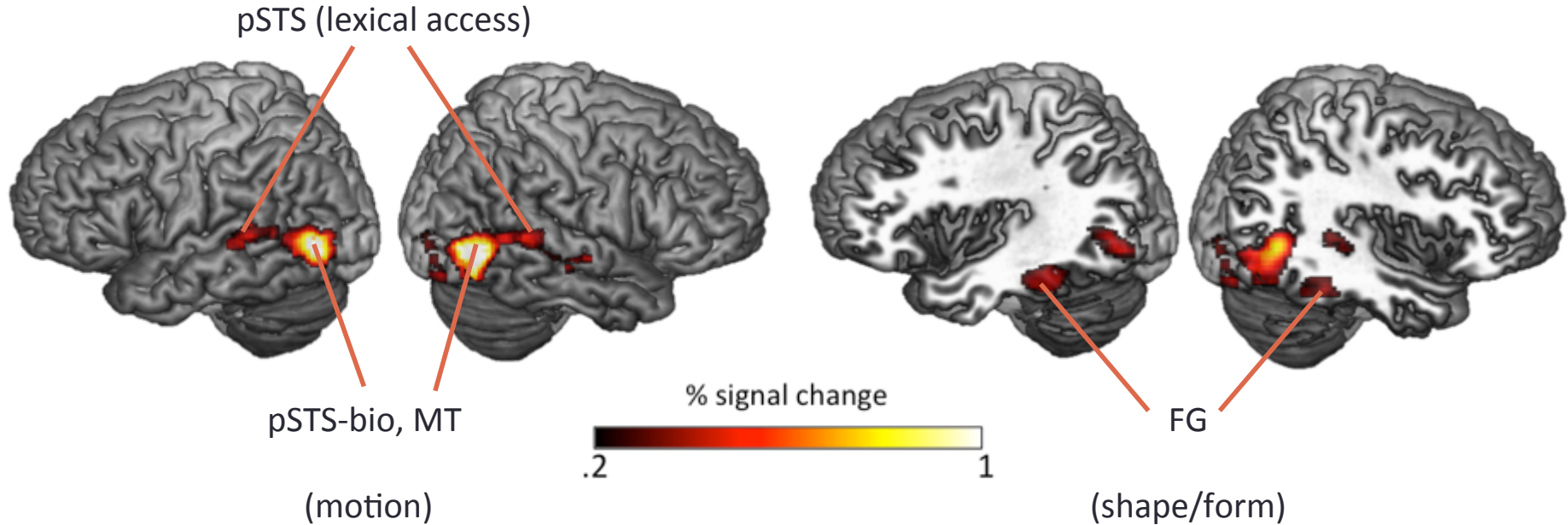


Behavioral data

- Structure enhances perception & recall
- Brener, 1940; Miller et al., 1951; Marks & Miller, 1964
- Error bars: standard error of mean, subject effects removed (Cousineau, 2005)

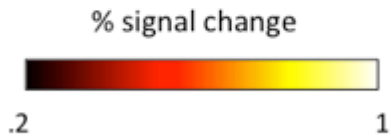
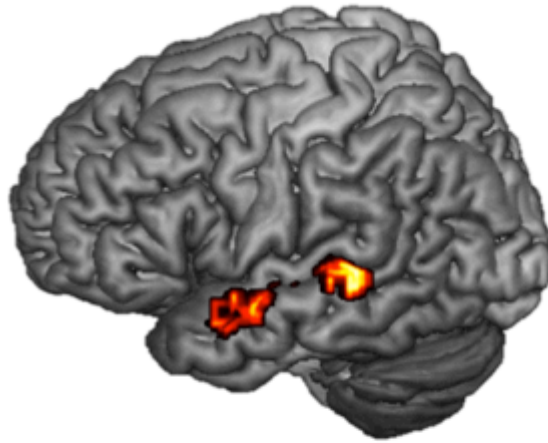


Phonological processing & lexical access: 6W > still face

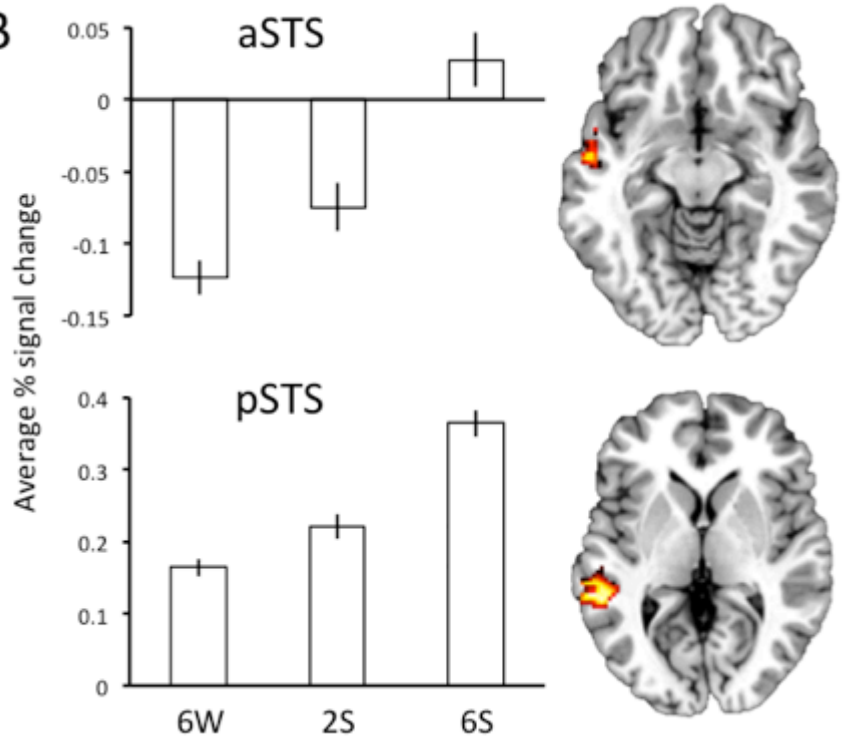


Syntactic processing: linear contrast of structure

A

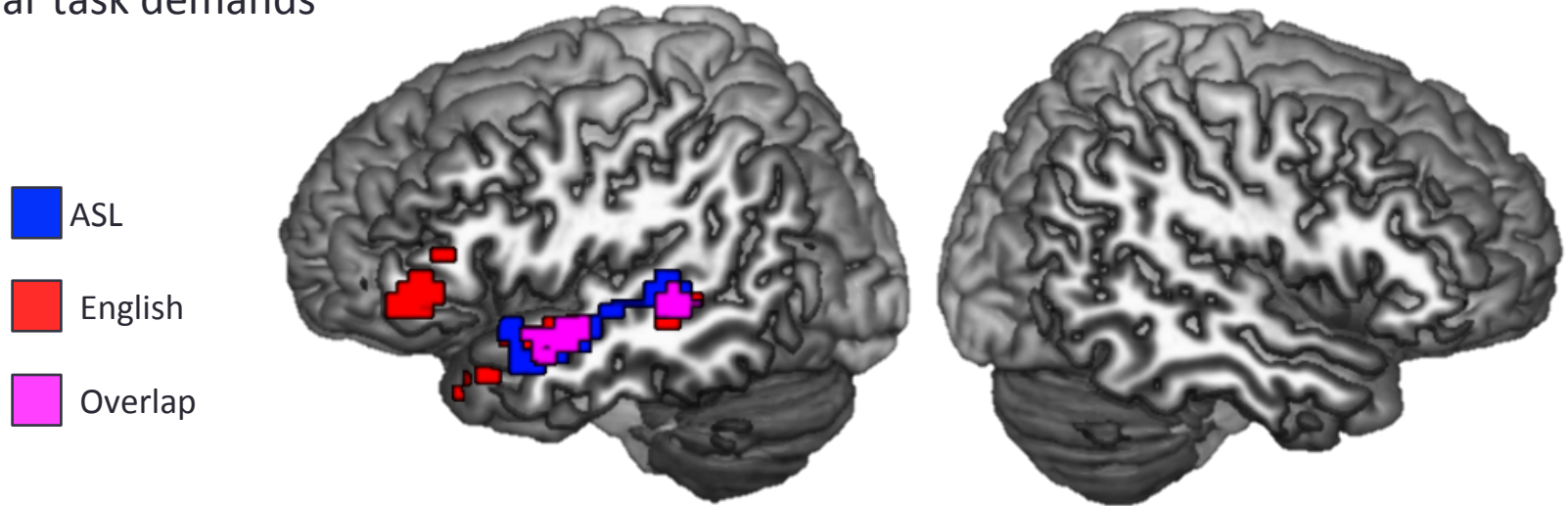


B



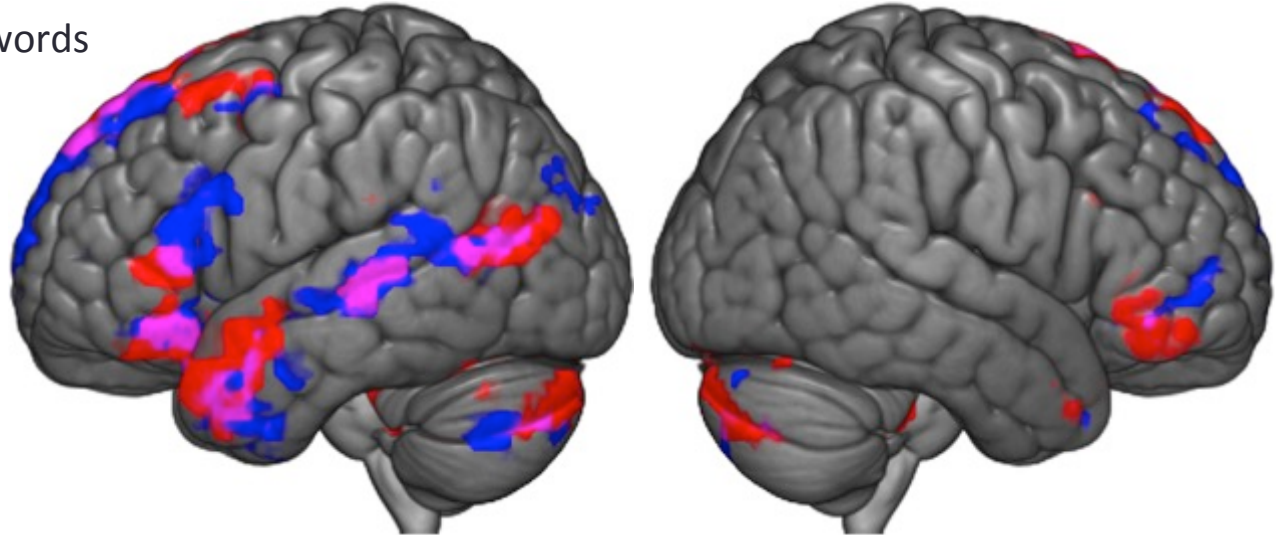
Overlap of syntactic processing in English & ASL

- Matchin et al. (2017 - fMRI): 6 word sentences > 6 word lists (written)
- Similar task demands

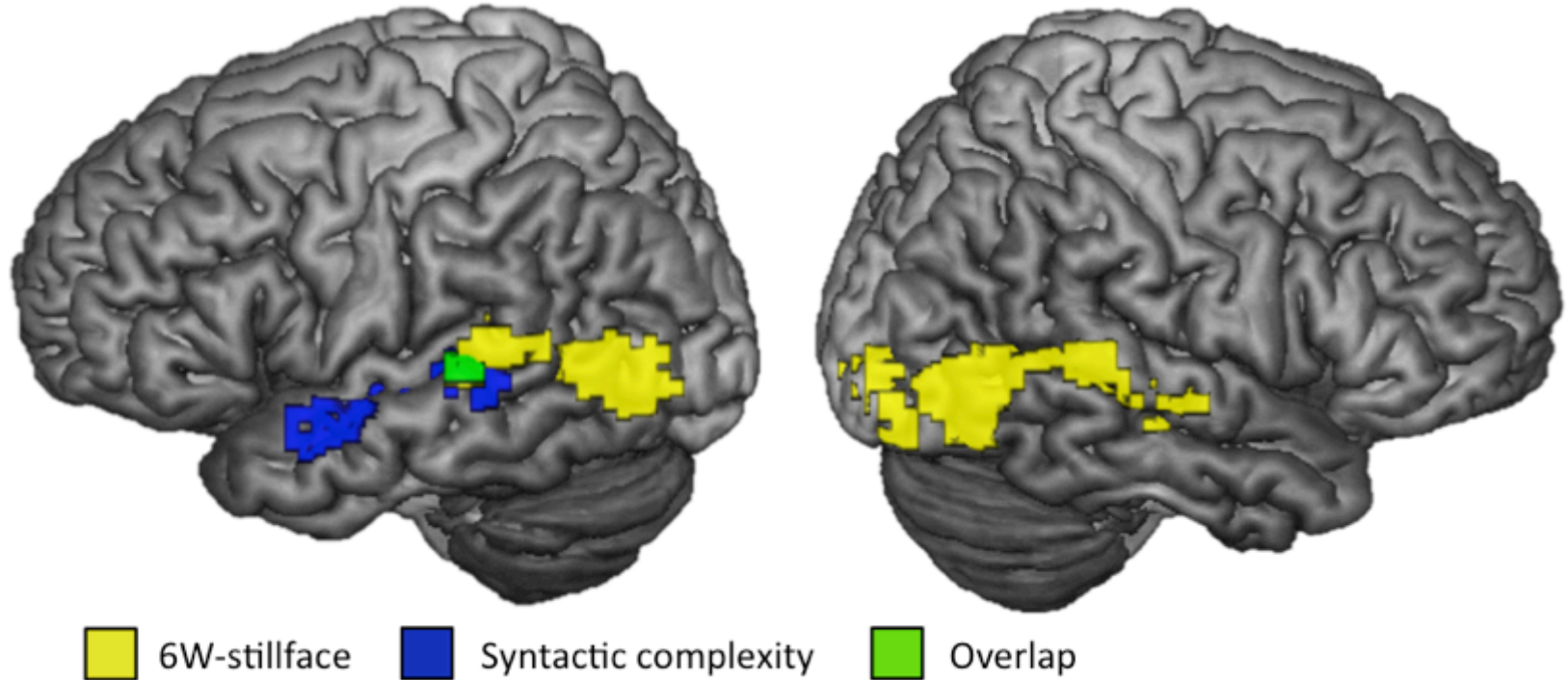


Experiment 2: native deaf and hearing L2 signers

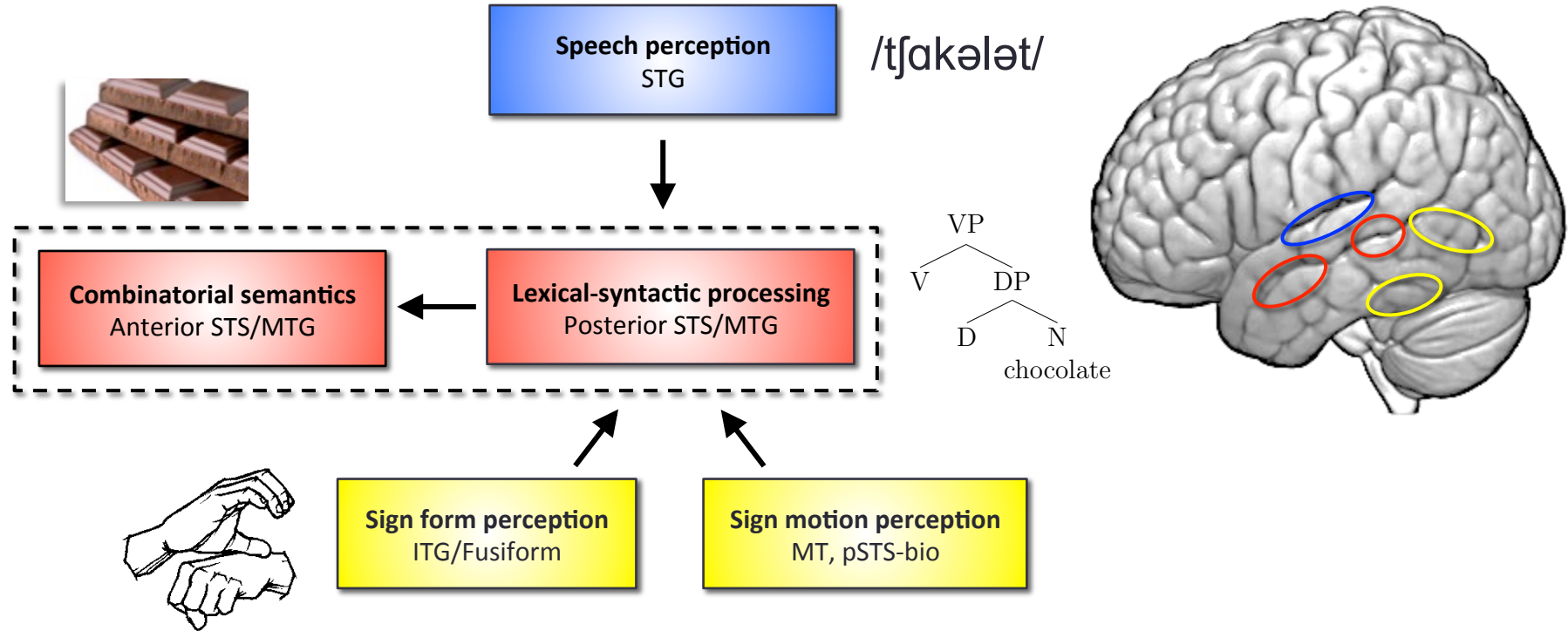
- fMRI: four-word sentences > four-word lists
- Preliminary results: voxel-wise $p < 0.05$ (one-tailed, uncorrected)
- Sentence task: semantic anomalies
- List task: detect animal words
- 5 deaf native signers
- 4 hearing L2 signers



Overlap of phonological/lexical & syntactic processing



Conclusions: the revised ventral stream



Future directions

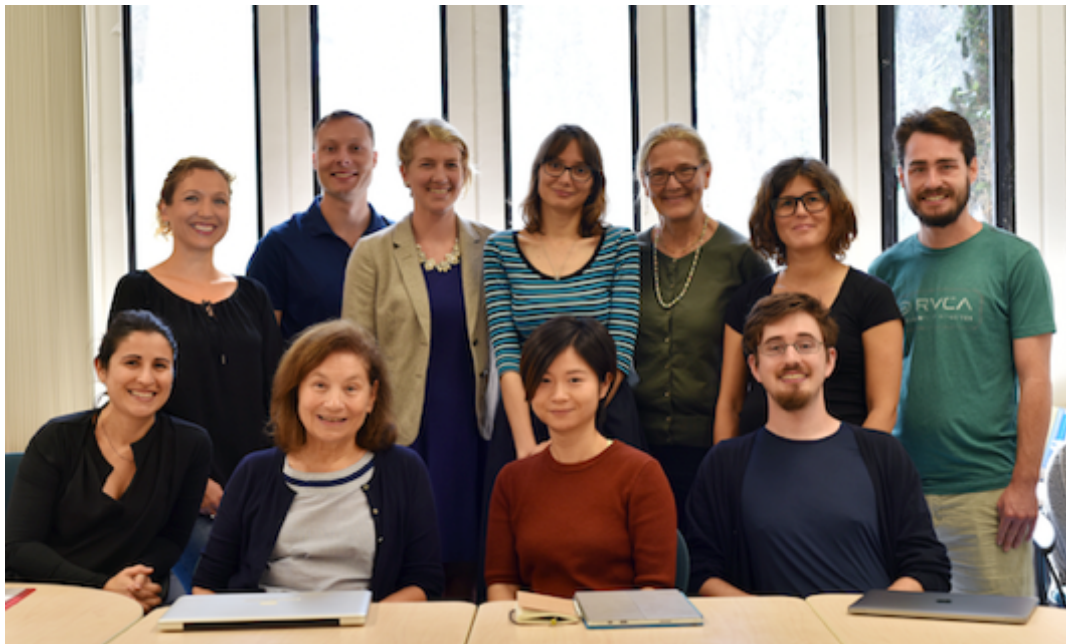
- Timecourse of combinatorial processing in ASL using MEG
- Experiments on ASL phonology (fMRI, MEG)
- Sentence production in ASL

Acknowledgements

- Mayberry lab
- Halgren lab
- Lau lab (University of Maryland)



Grant # R01DC012797



Subjects

- 13 deaf native signers of ASL
- Right-handed
- No neurological disorder

Preprocessing

- Slice-timing correction
- Motion correction
- Morphing to Talairach template
- Spatial smoothing (6mm FWHM)
- Conversion to % signal change

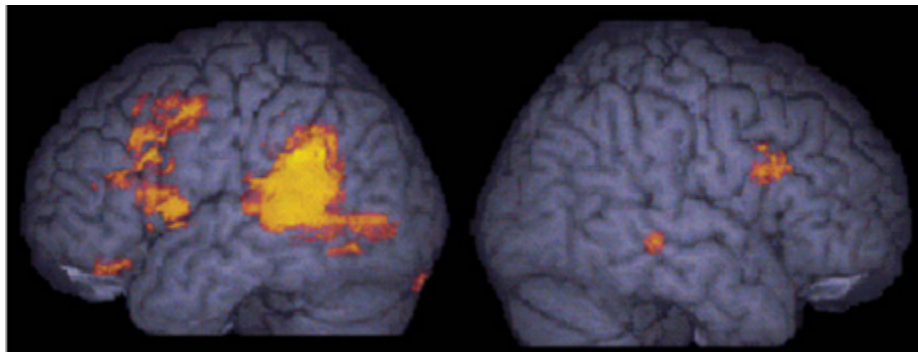
Analysis

- Single subject deconvolution regression analysis
- Group analysis using AFNI's 3dANOVA2 function
- Contrast weights for linear effect of constituent size (same as Pallier et al., 2011):
 - 6W, 2S, 6S: [-2 -1 -3]
- Voxel-wise $p < 0.005$ (one-tailed)
- Cluster-corrected for multiple comparisons ($p < 0.05$) using AFNI's 3dClustSim and `-acf` option

Syntax in sign languages

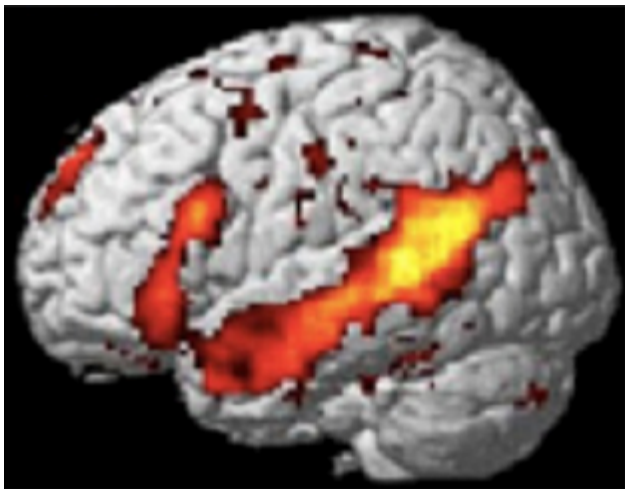
- Deaf native signers
- Activation in posterior temporal lobe & posterior IFG
- Left-lateralized effects
- No ATL activity
- Unbalanced stimulus materials

- Sentences > sign lists



Language selectivity in the language network

Sentences > word lists



Sentences:

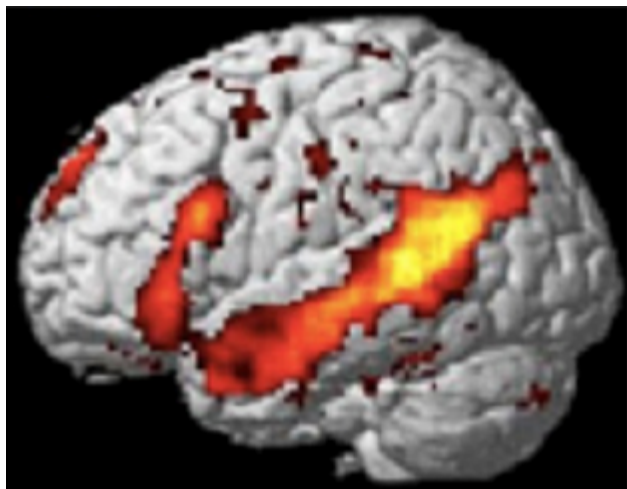
- THE DOG CHASED THE CAT ALL DAY LONG

Word lists:

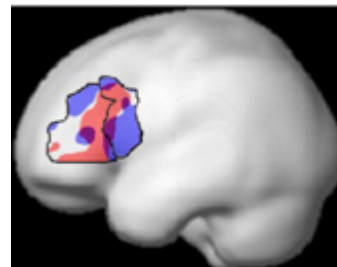
- BECKY STOP HE THE LEAVES BED LIVE MAXIME'S

Language selectivity in the language network

Sentences > word lists

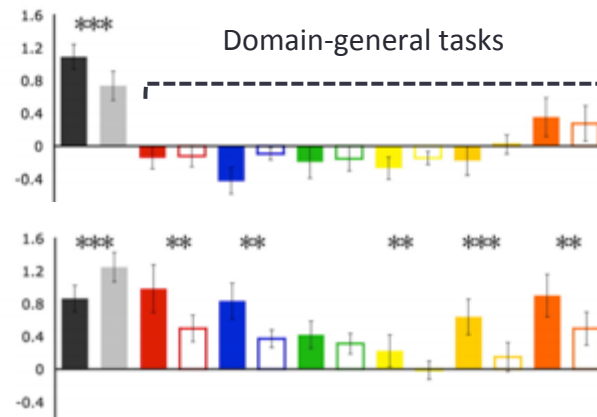


■ Sentences
□ Nonwords



Language-selective
(red areas)

Domain-general
(blue areas)



Phonology in sign languages

- Phonological parameters
 - Minimal pairs
- Phonotactic constraints
- Syllable and prosodic structure

Handshape



1a. DANGEROUS



1b. INTERESTING

Location



1c. SCOLD



1d. SEND

Movement

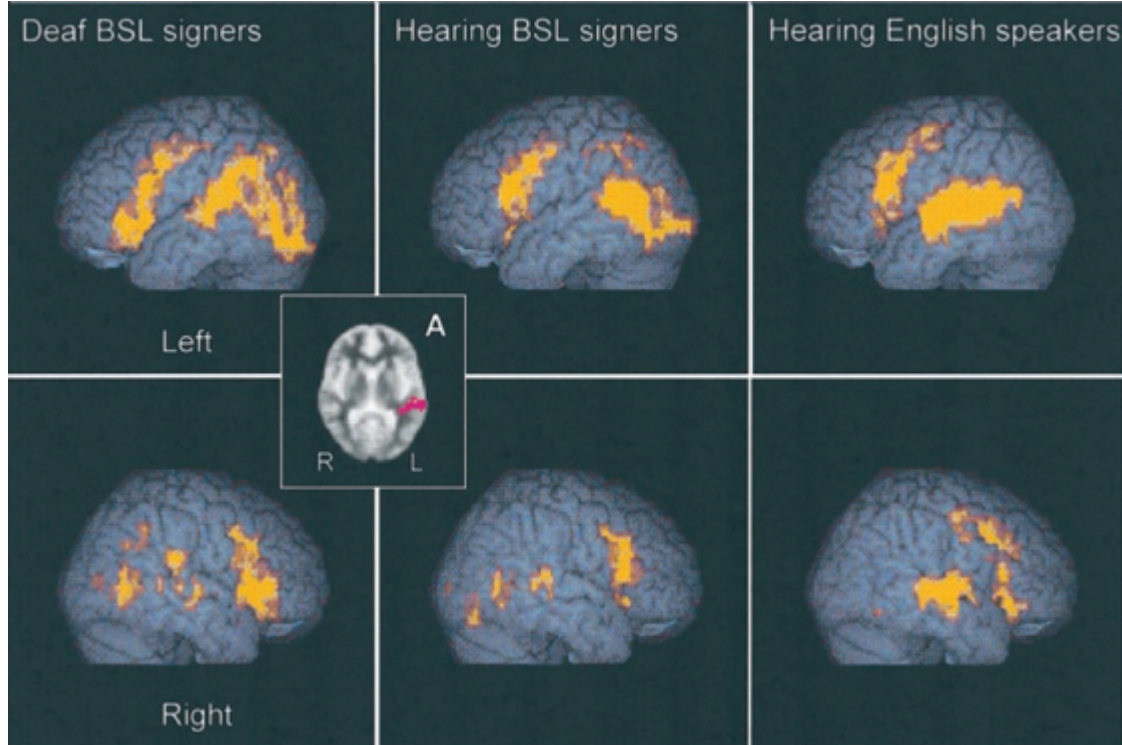


1d. ESCAPE

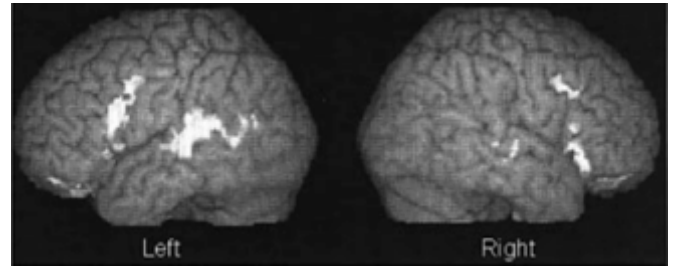


1e. BETRAY

Neuroimaging of sign language

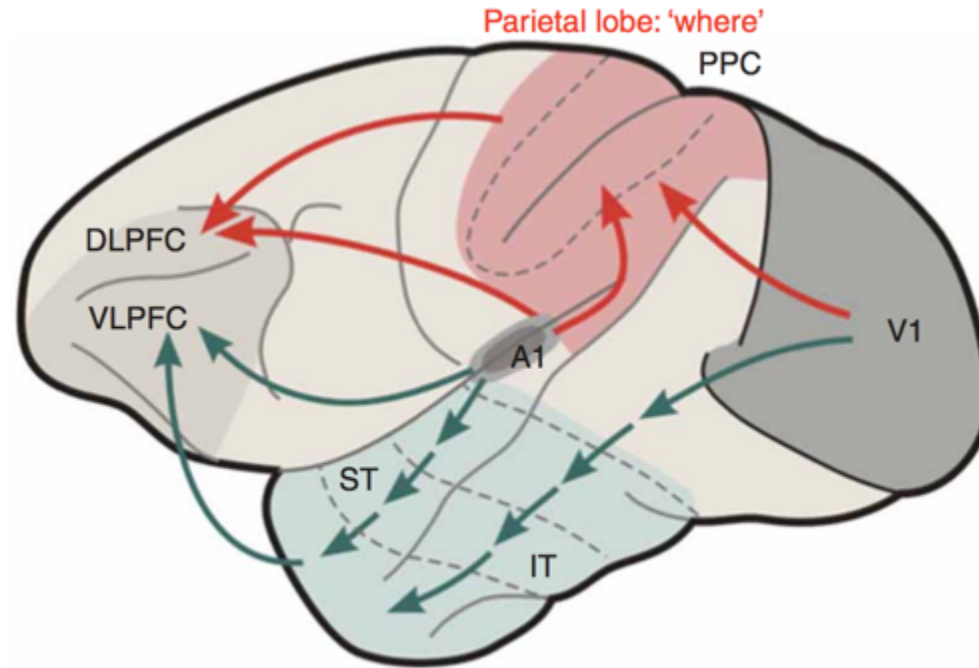


Overlap between BSL & English

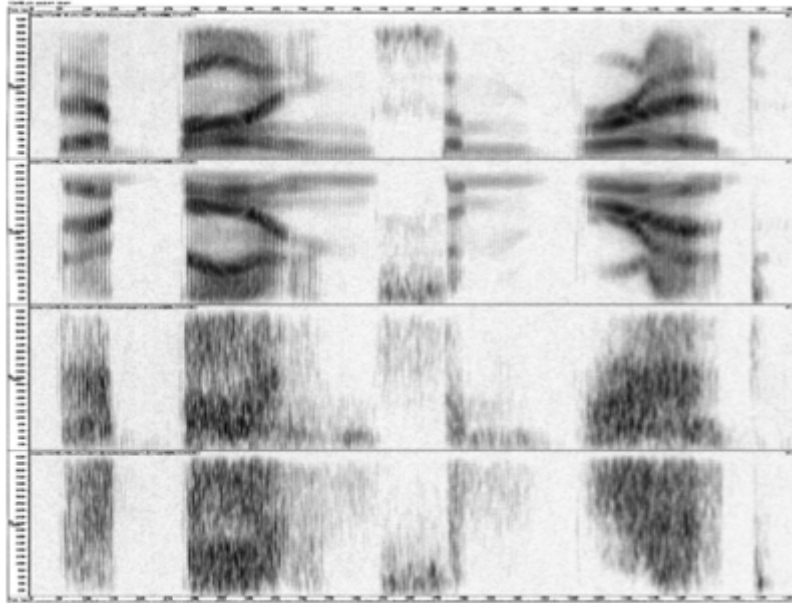


Dorsal & ventral streams: auditory & visual

- Monkey (macaque)



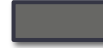
Complex “auditory objects”



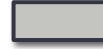
Normal speech



Spectrally rotated (not intelligible)



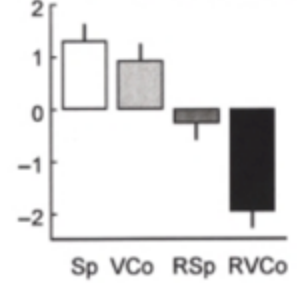
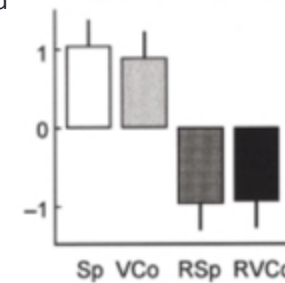
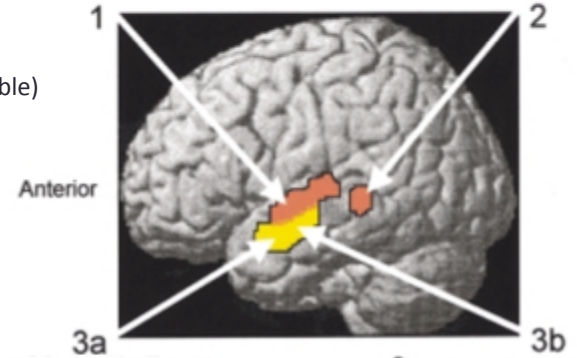
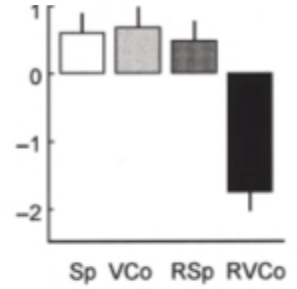
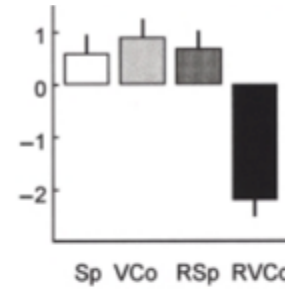
Noise vocoded (intelligible)



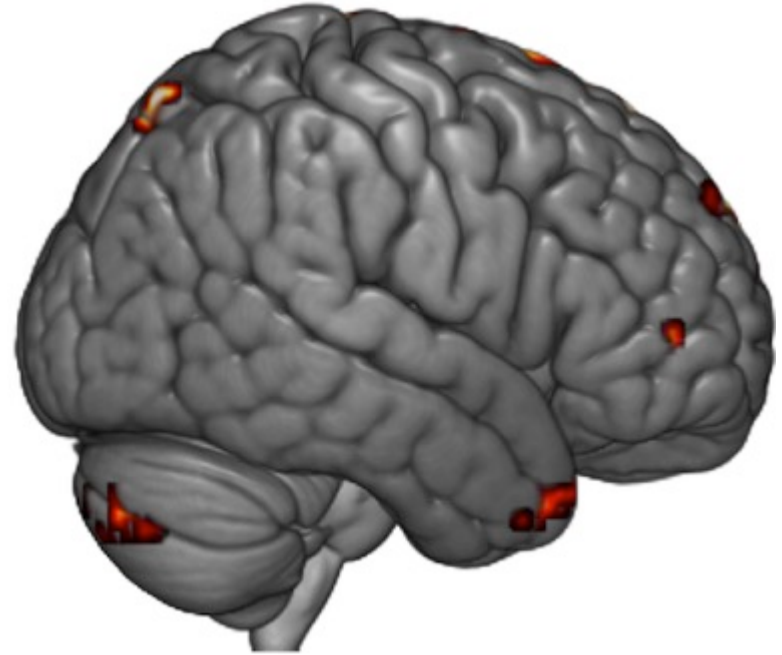
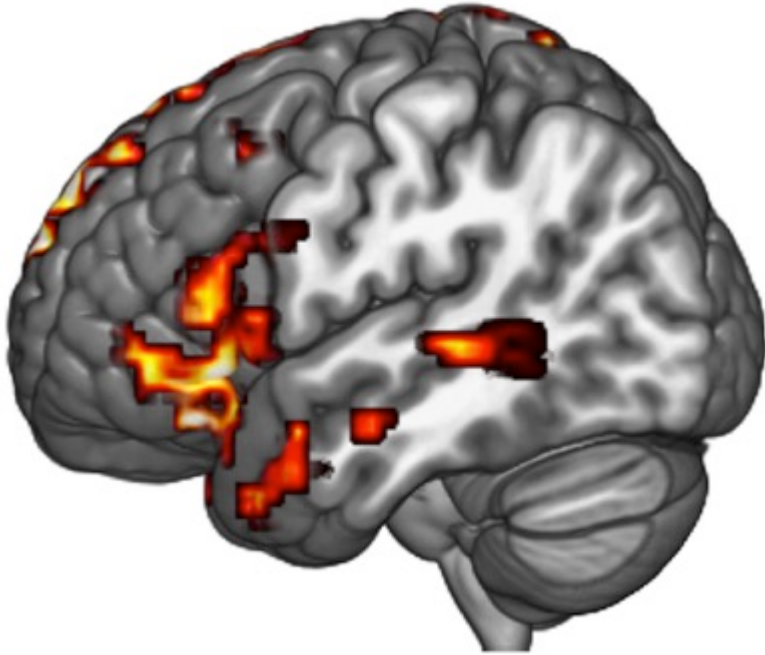
Rotated & noise vocoded (not intelligible)



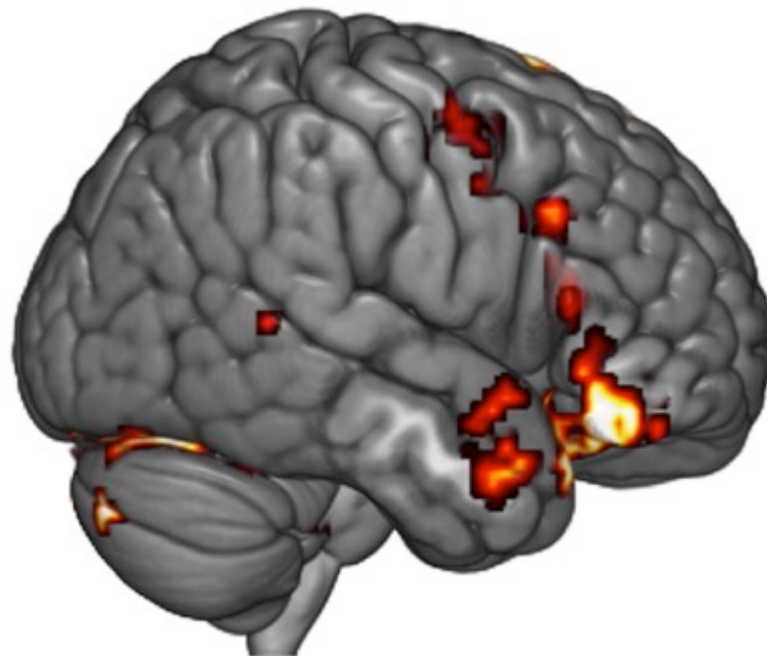
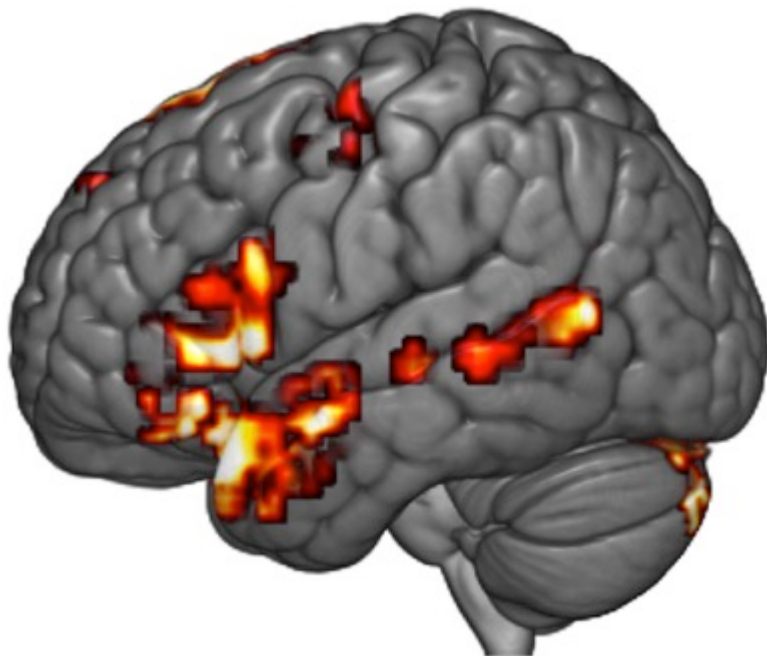
Scott et al., 2000 PET



4S > 4W: Deaf native

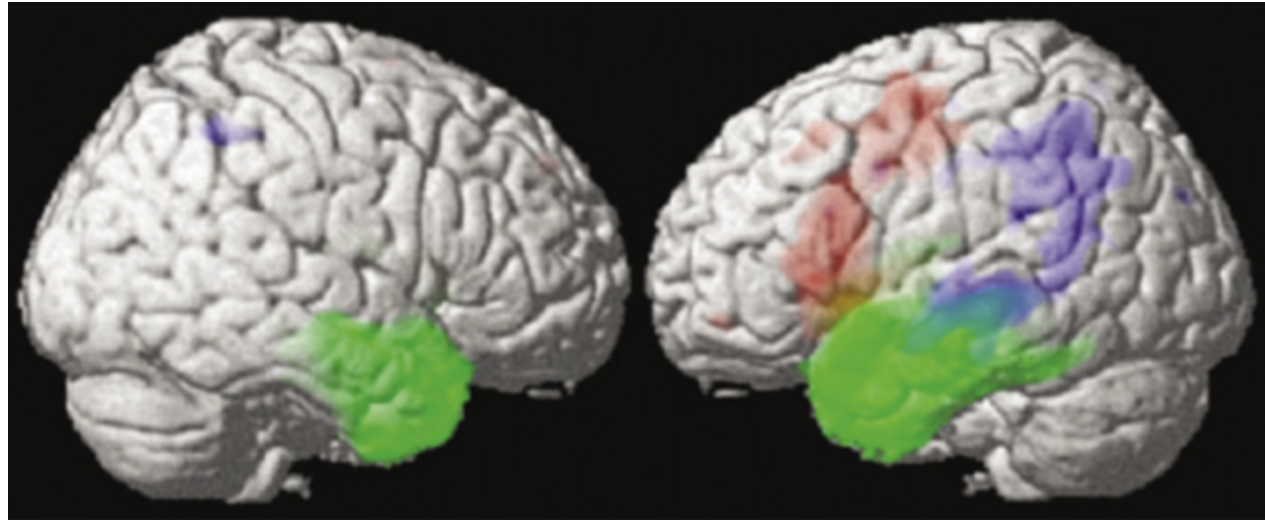


4S > 4W: L2

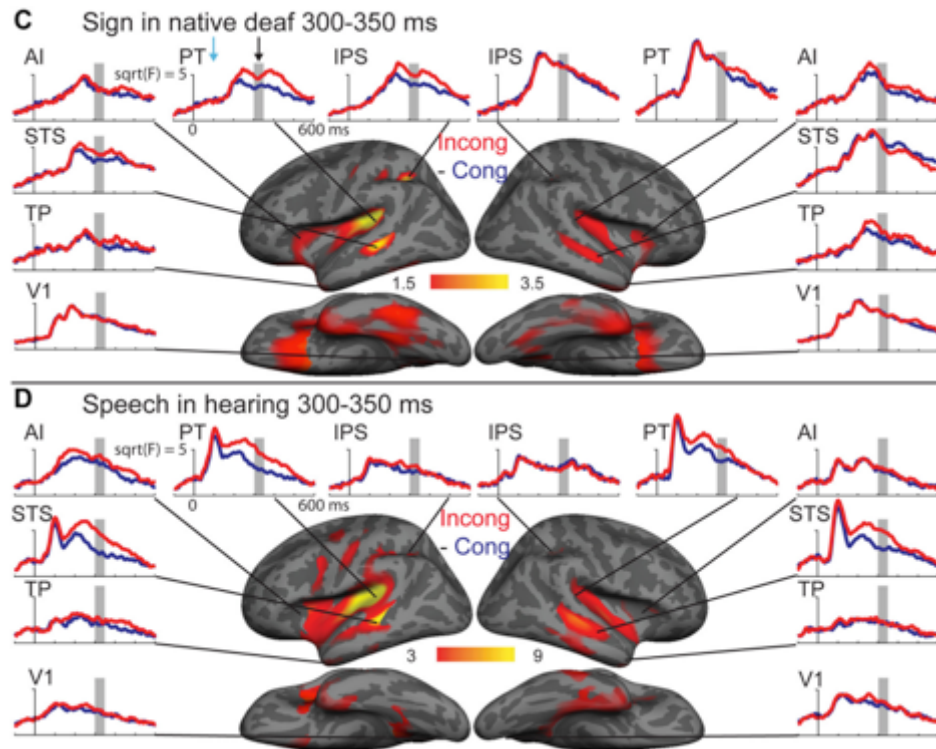
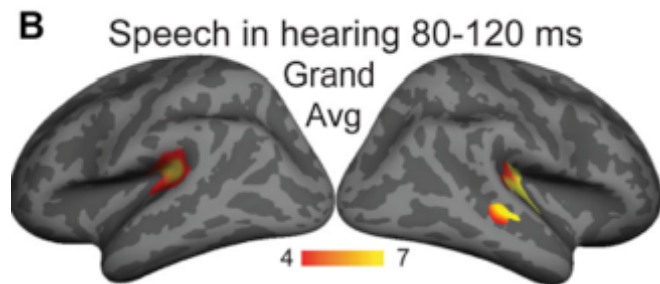
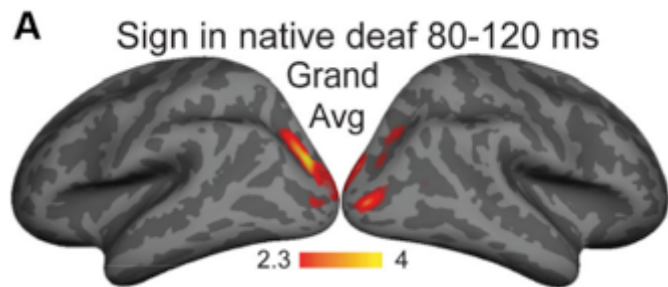


Aphasia & the language network

- Atrophy maps in three variants of primary progressive aphasia



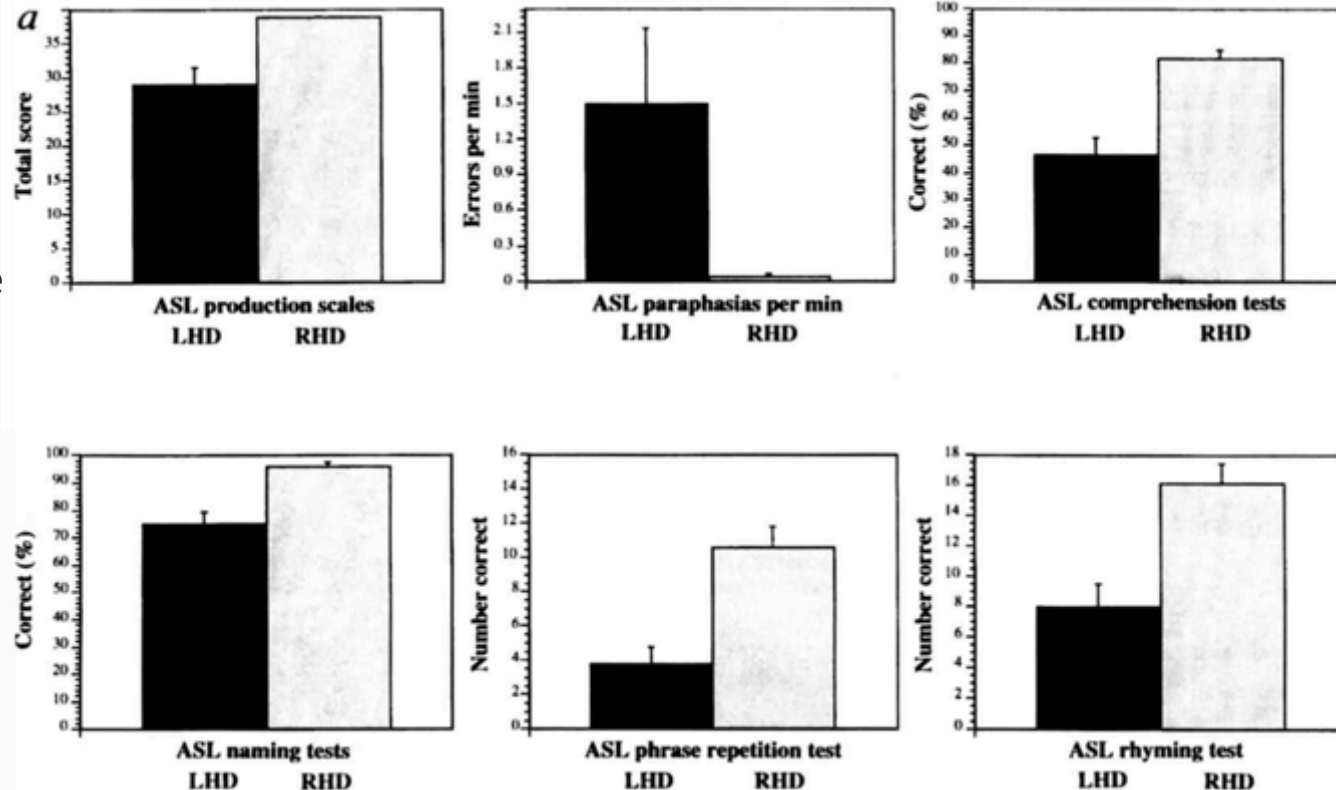
Lexical-semantic access: speech & sign



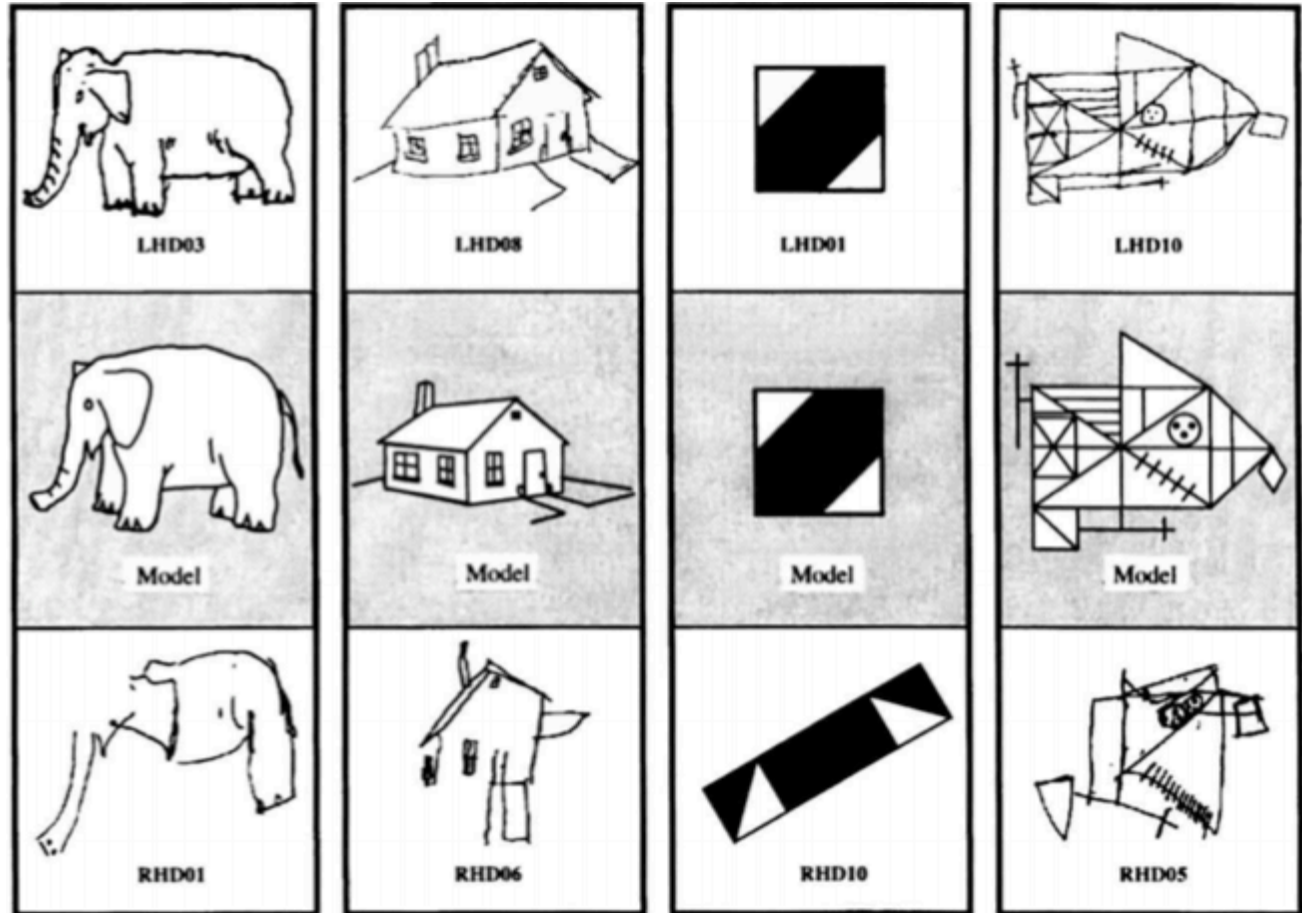
Aphasia in sign languages

Boston Diagnostic Aphasia Examination
(adapted for ASL)

- LHD: left hemisphere damage
- RHD: right hemisphere damage

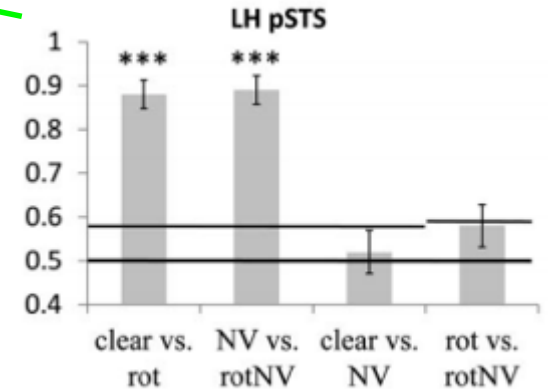
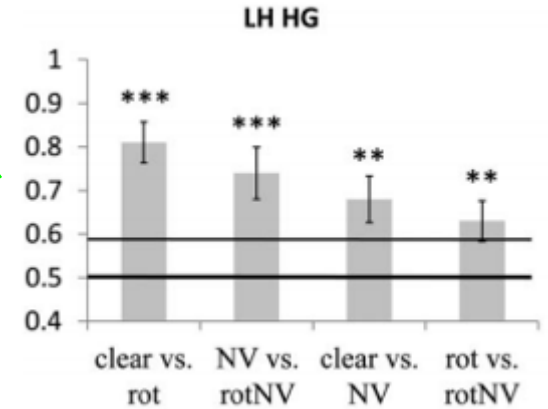
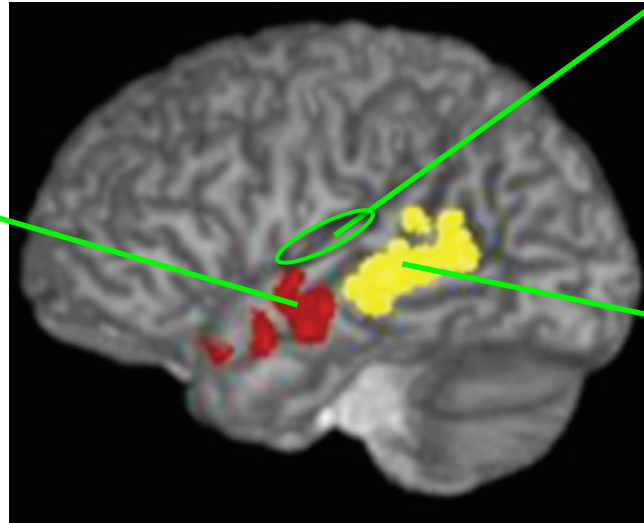
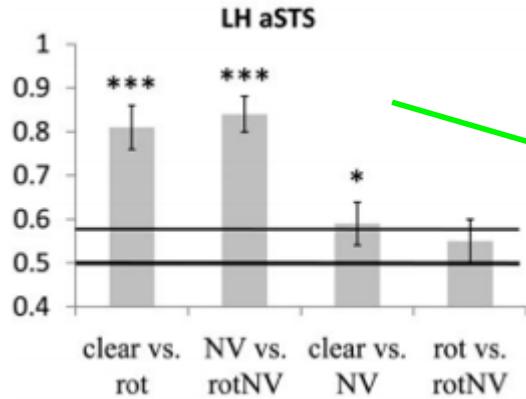


- **Left** hemisphere damage: Good spatial processing



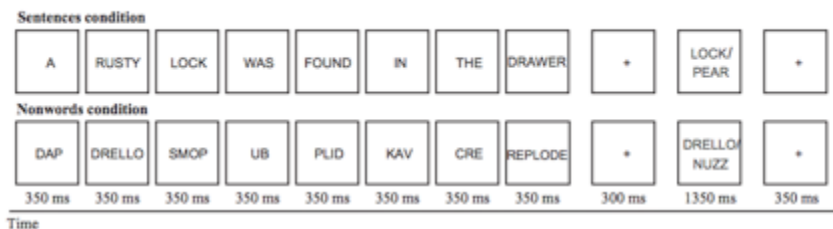
- **Right** hemisphere damage: Impaired spatial processing

Speech intelligibility

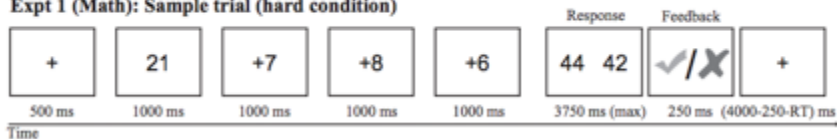


Fedorenko et al. (2011): tasks

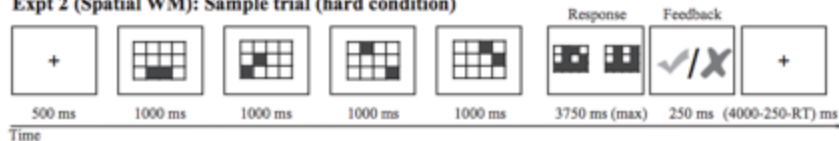
Language localizer: Sample trials



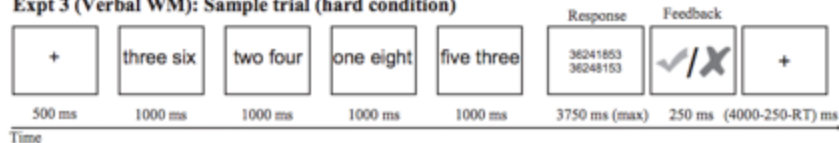
Expt 1 (Math): Sample trial (hard condition)



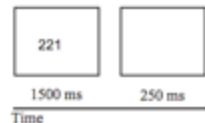
Expt 2 (Spatial WM): Sample trial (hard condition)



Expt 3 (Verbal WM): Sample trial (hard condition)



Expt 4 (MSIT): Sample trial (hard condition)



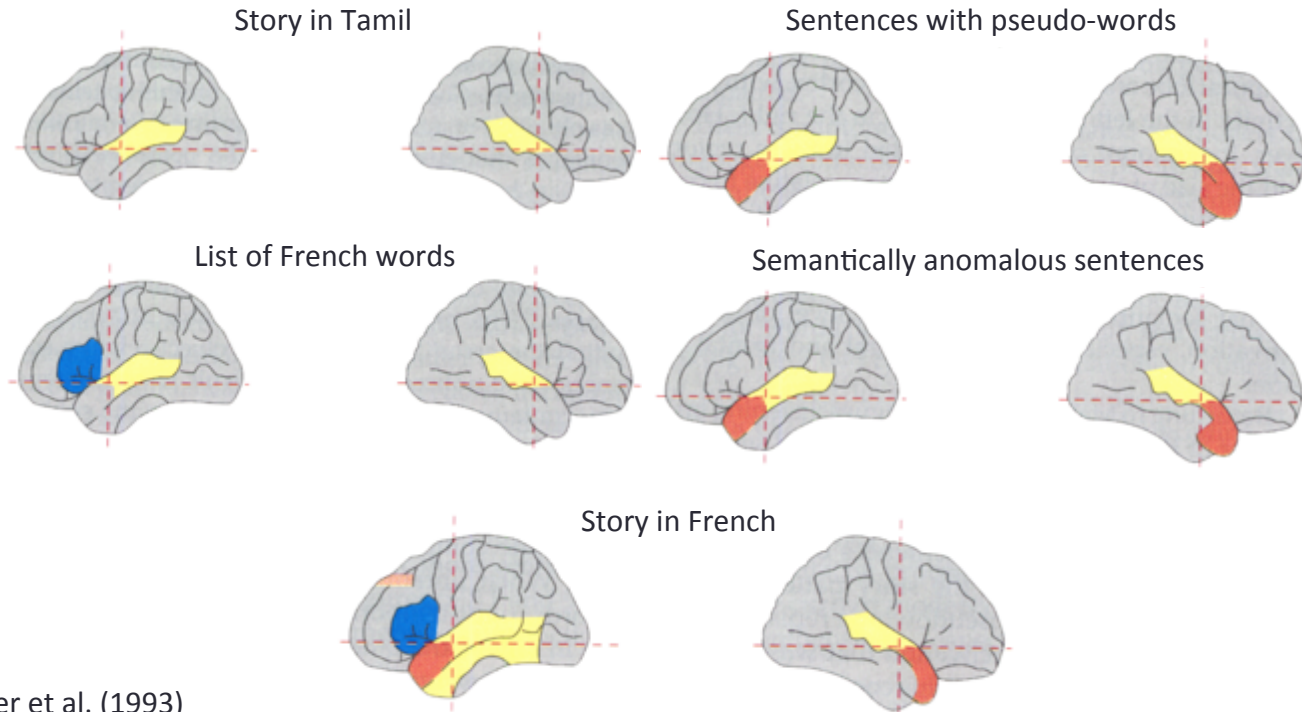
Expt 5 (vMSIT): Sample trial (hard condition)



Expt 6 (Stroop): Sample trial (hard condition)

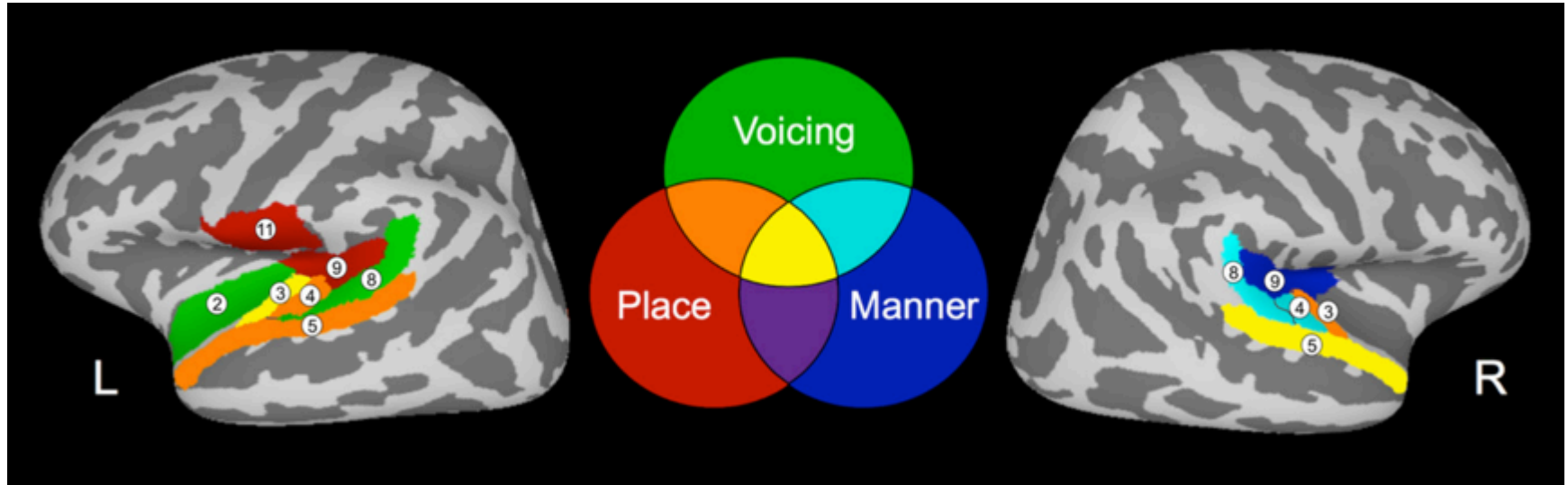


Inconsistent structural effects in IFG

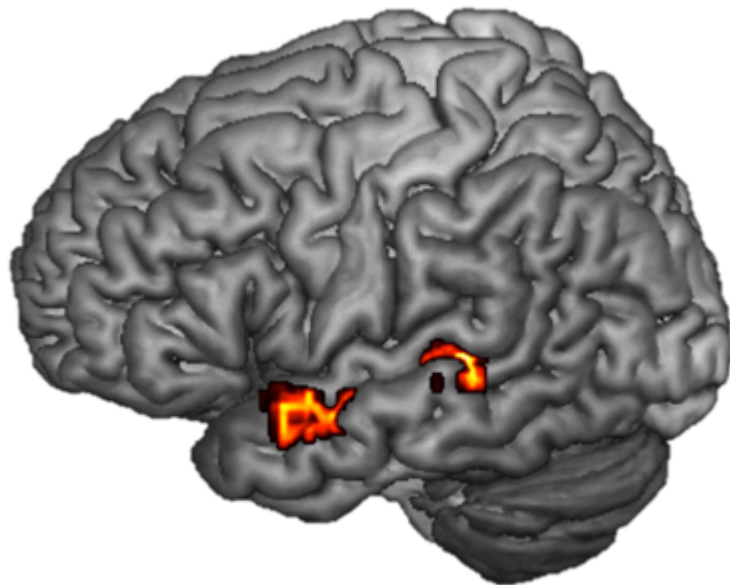


Mazoyer et al. (1993)

Phonological coding in superior temporal cortex



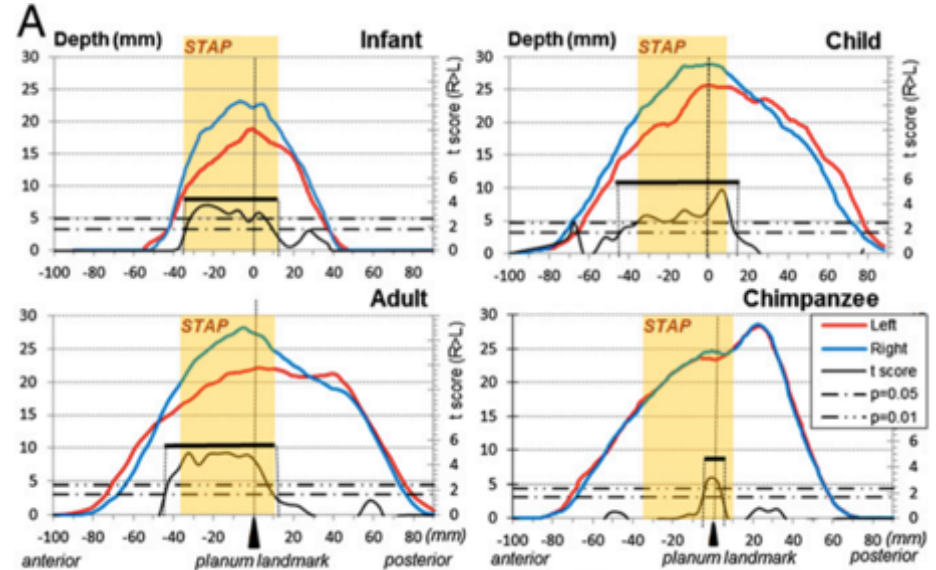
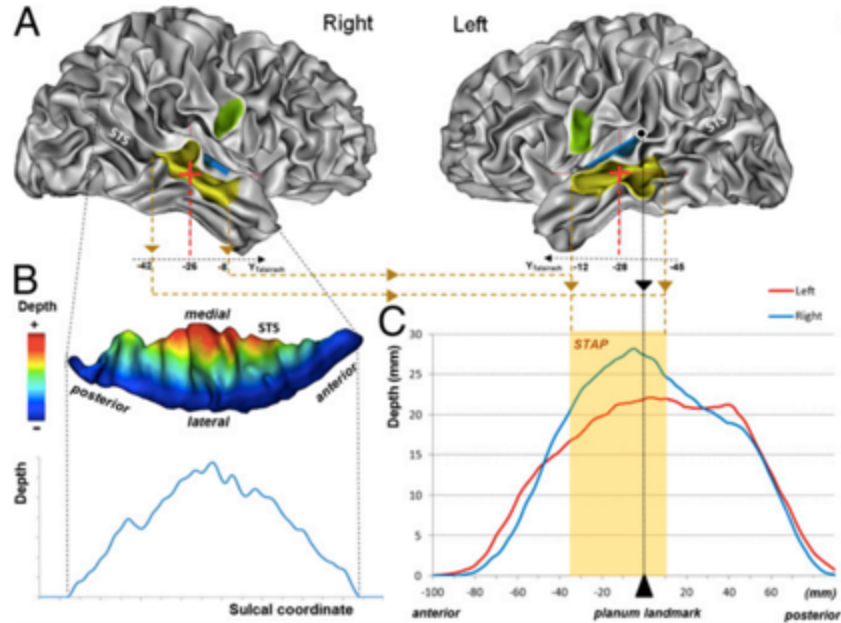
ASL syntax: 6S > 6W



% signal change



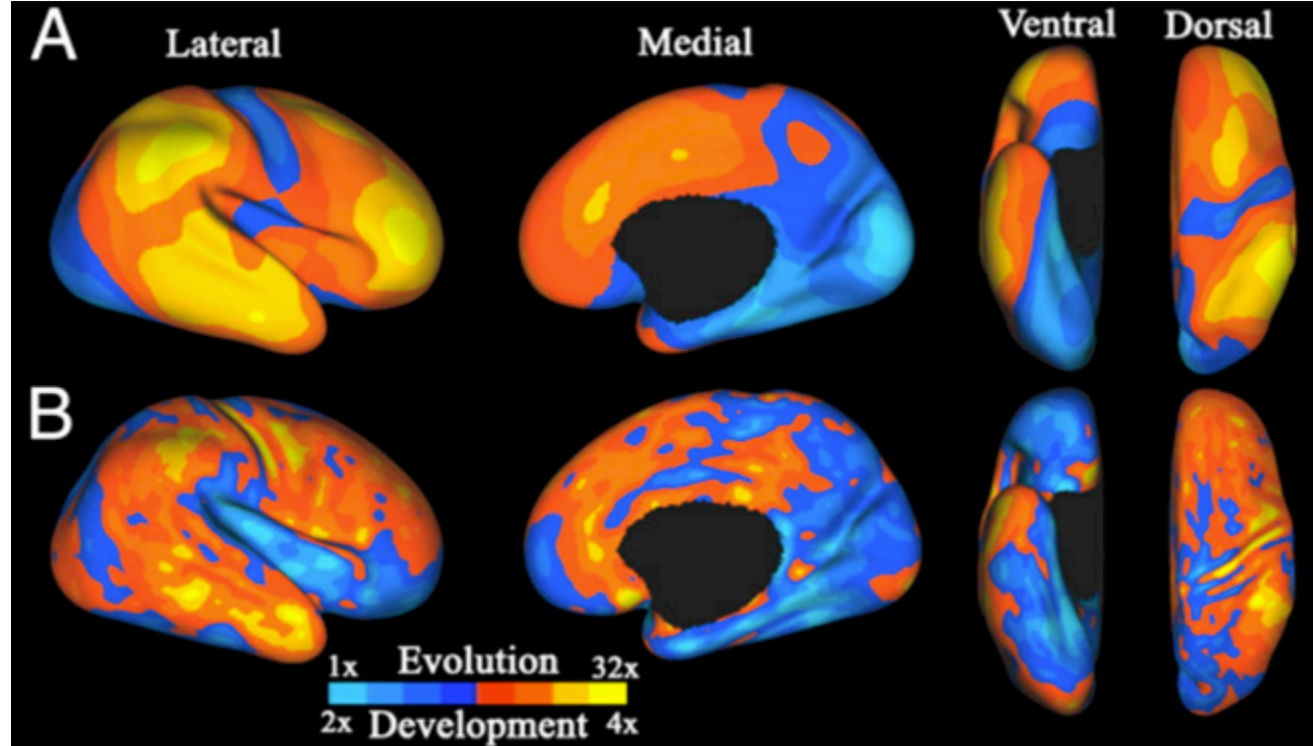
Uniquely human STS morphology



Leroy et al. (2015)

Cortical expansion: evolution & development

Human vs. macaque



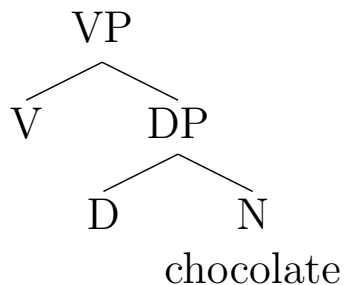
Adult vs. infant

Language and the brain

Conceptual combination (ATL)



Lexical-Syntactic objects (pSTS)

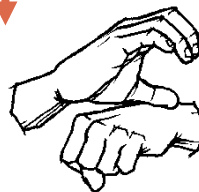


Event representation (AG)



Phonological systems

tʃakələt

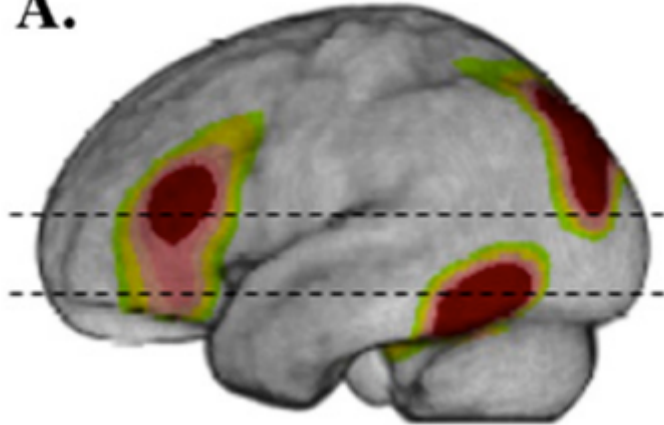


Matchin, *Faculty of Language*, 2016
Matchin & Hickok, *in preparation*

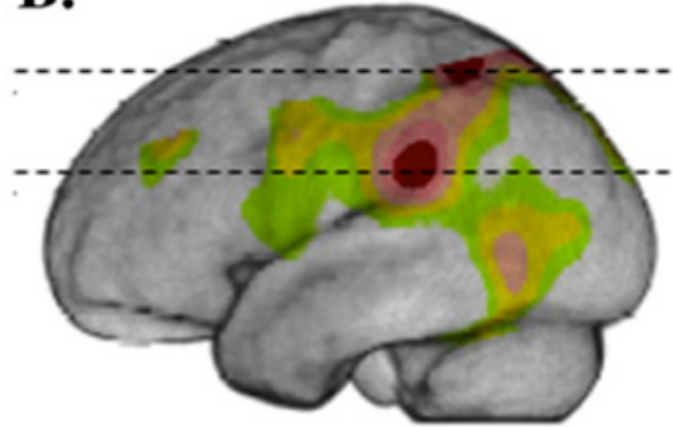
Broca's area & word production

- Overlap of word production in ASL & English
- ASL > English

A.



B.

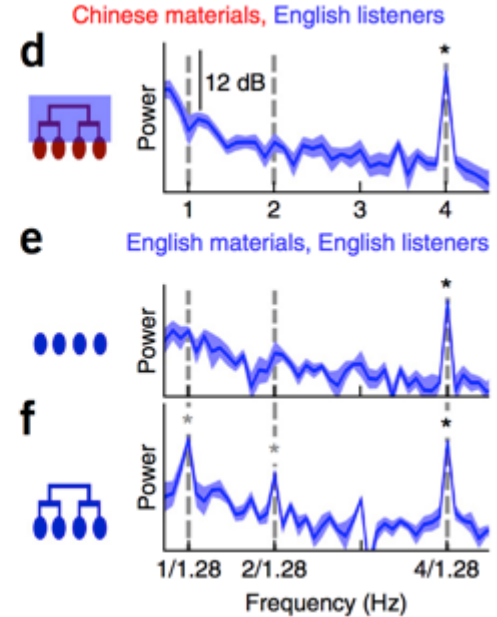
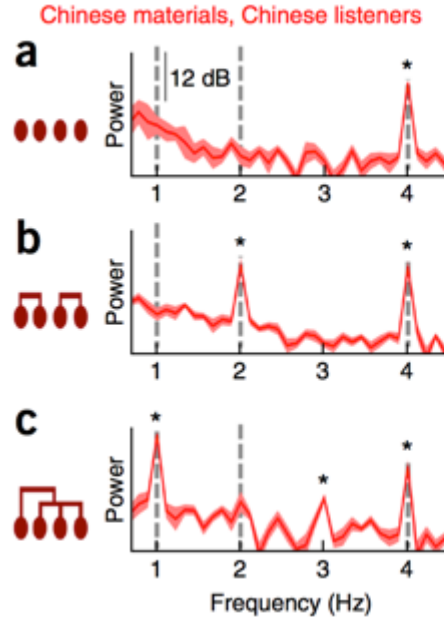
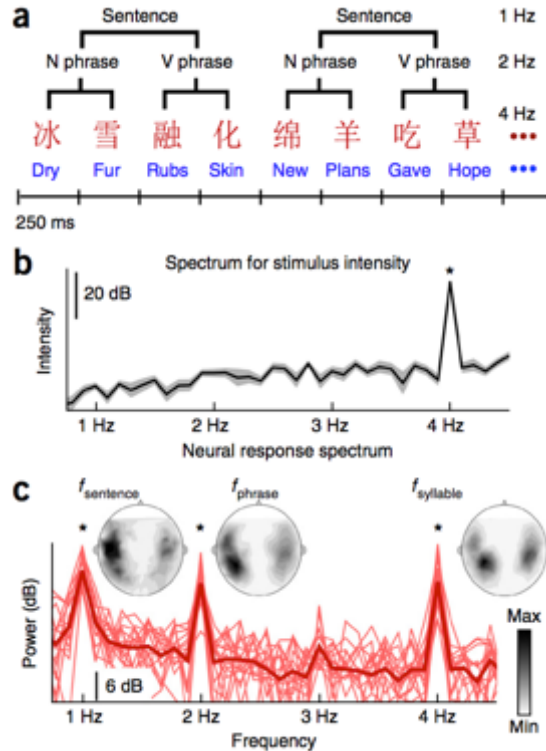


Emmorey et al. (2007)

PET

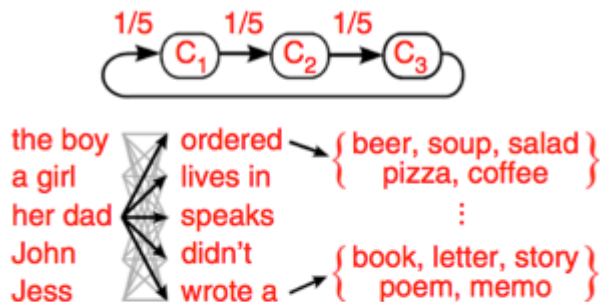


Syntactic entrainment



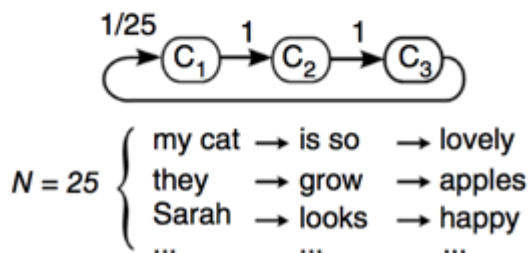
Transitional probability

a Constant transitional probability

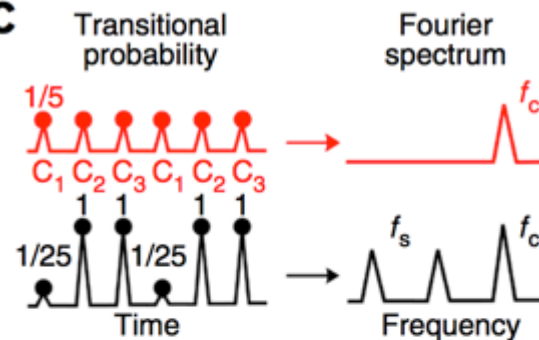


b

Varying transitional probability



c



d

