Differentiating Phrase Structure Parsing and Memory Retrieval in the Brain

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Introduction

Natural language comprehension relies on at least two cognitive processes:

- Retrieval of memorized elements
- Structural composition

Question

Where are these two language processing functions localized in the brain?

Retrieval is formalized here using "multiword expressions" or MWEs

Structure-building is formalized using a standard bottom-up parsing algorithm (see Hale, 2014)

Data Collection

Participants (n=51) were college-aged, right-handed, native English speakers.

Listened to a spoken recitation of *The Little Prince* for 1 hour and 38 minutes across nine separate sections.

Comprehension was confirmed through multiple-choice questions at the end of each section.

Analysis

Preprocessing was carried out with AFNI version 16 and ME-ICA v3.2 (Kundu et al., 2011).

MWE predictor and parser action count, convolved with HRF regressed, against observed BOLD signal during passive story listening.

GLM analysis includes four nuisance variables: word offset, frequency, pitch, intensity.

Predictors

The number of steps that a bottom-up phrase structure parsing algorithm would take at each word indexes structure-building effort, as shown in Fig. 2.

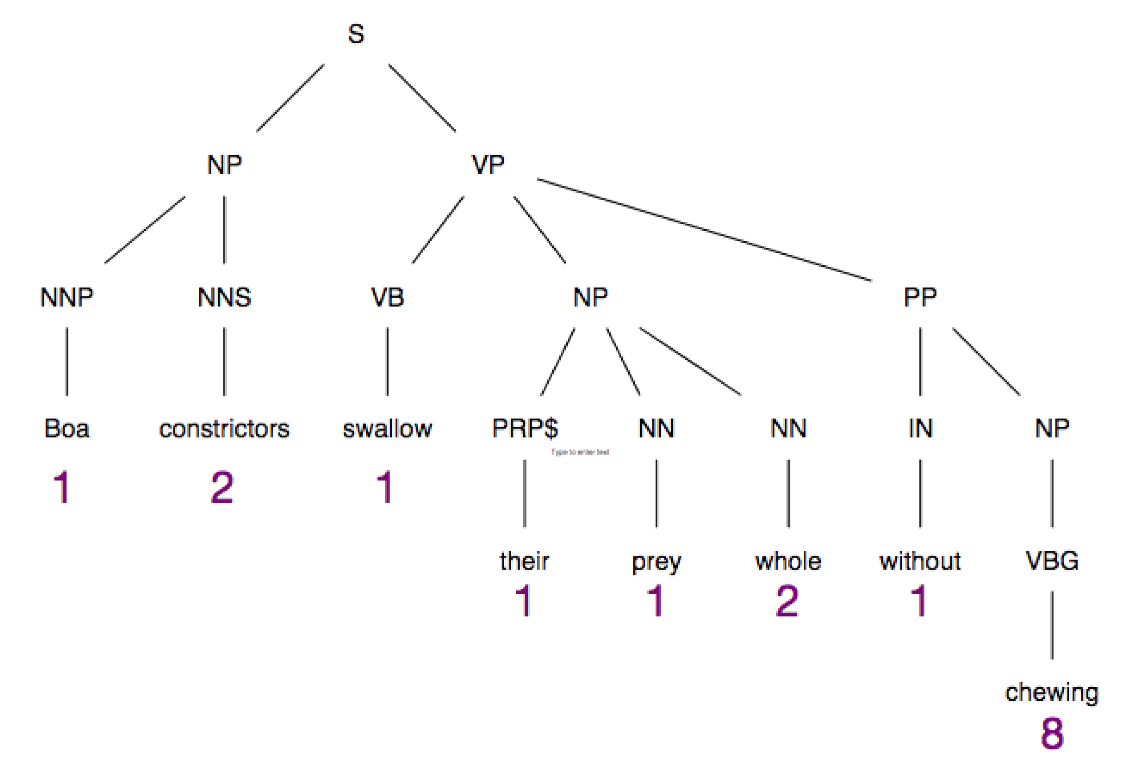

Figure 1: Illustrating bottom-up parser action count on a tree using the Stanford parse (Klein and Manning, 2003)

The Little Prince consists of 15,453 words.

1,274 MWE attestations were identified using a CRF tagger trained on English web treebank.

This was supplemented with 4 external lexicons: Cambridge International Dictionary of Idioms, Dictionary of American Idioms, Unitex lexicon, SAID corpus.

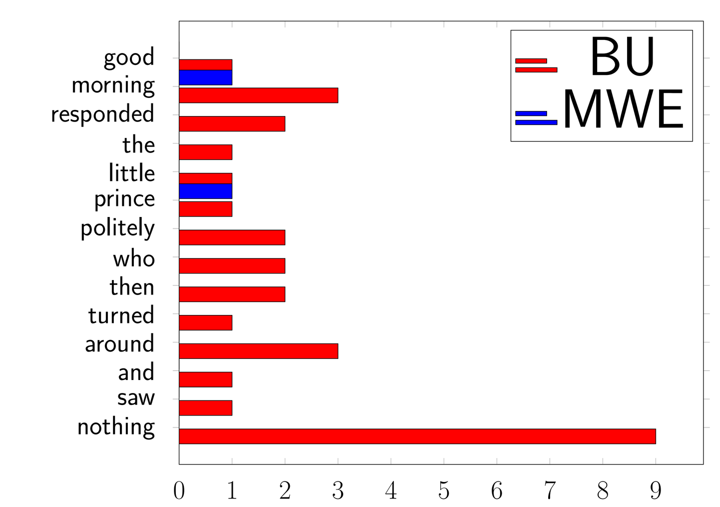

Figure 2: Example sentence: *"**Good morning**", responded the **little prince** politely, who then turned around and saw nothing.*

Conclusion

1. Memory retrieval for multi-word expressions evokes a pattern of activation that is spatially-distinct from the pattern evoked by compositional structure-building.
2. Phrase structure composition involves Anterior Temporal region which is consistent with earlier studies (Bemis and Pylkkänen, 2011; Dronkers et al., 2004; Ferstl et al., 2008).
3. While the Precuneus Cortex has not been traditionally viewed as part of the language network, it has been implicated in various memory tasks (Andreasen et al., 1995; Fletcher et al., 1995; Halsband et al., 2002; Mashal et al., 2014; Wallentin et al., 2008).

Future Work

- This work: categorical MWE predictor (0/1)
- Future work: gradient MWE predictors (PMI, Loglik, Dice,...)

Acknowledgements

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Selected References

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Kundu, P., Inati, S. J., Evans, J. W., Luh, W. M., & Bandettini, P. A. (2012). Differentiating BOLD and non-BOLD signals in fMRI time series using multi-echo EPI. *Neuroimage, 60*(3), 1759–1770.

Mashal, N., Vishne, T., & Laor, N. (2014). The role of the precuneus in metaphor comprehension: Evidence from an fMRI study in people with schizophrenia and healthy participants. *Frontiers in human neuroscience, 8.*

Result

The results most strongly implicate Anterior Temporal regions for structure-building and Precuneus Cortex for memory retrieval ($p < 0.05$ FWE), as seen in Fig. 3 and Fig. 4.

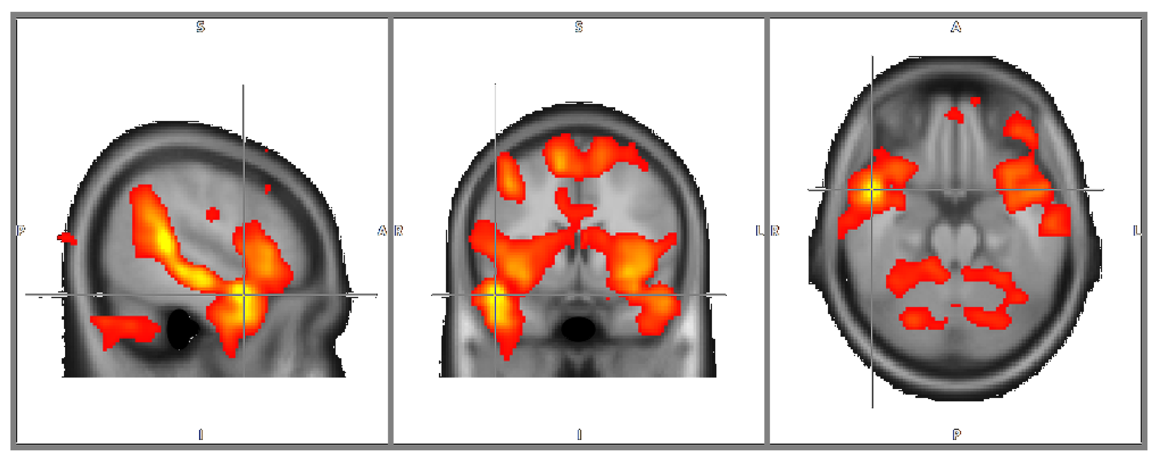

Figure 3: T-score map for the Bottom-up Parser Action count regressor

MNI Coordinates x	y	z	Region	p-value (corrected)	k-size (cluster)	T-score (peak-level)
52	8	-22	Temporal pole	0.000	2769	12.72
54	-40	12	Supramarginal Gyrus	0.000	2212	12.69
-34	18	-12	Frontal Orbital Cortex	0.000	2380	10.40
12	20	58	Superior Frontal Gyrus	0.000	7191	9.27
42	2	48	Middle Frontal Gyrus	0.000	286	9.19
-38	26	36	Middle Frontal Gyrus	0.000	382	8.47
-40	-78	6	Lateral Occipital Cortex	0.000	693	7.42
-52	-56	32	Angular Gyrus	0.000	802	7.12
28	-52	-8	Temporal Occipital Fusiform Cortex	0.001	83	6.74
-44	46	-12	Frontal Pole	0.000	176	6.28

Table 1: Significant clusters for bottom-up parser action count after FWE correction.

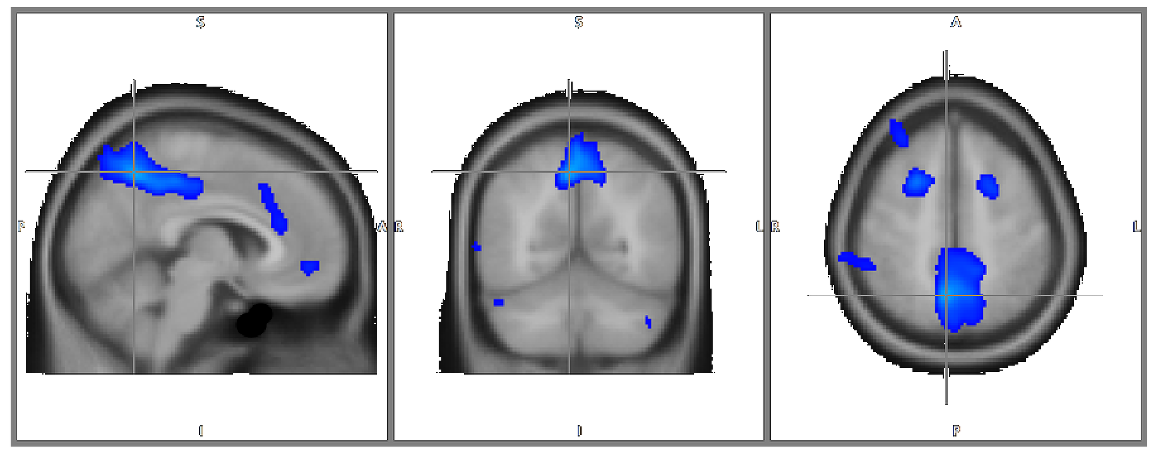

Figure 4: T-score map for the MWE status regressor

MNI Coordinates x	y	z	Region	p-value (corrected)	k-size (cluster)	T-score (peak-level)
6	-60	52	Precuneus Cortex	0.000	559	7.62
24	10	56	Superior Frontal Gyrus	0.000	182	7.23
-40	42	26	Frontal Pole	0.000	158	6.94
66	-38	34	Supramarginal Gyrus	0.000	103	6.77
34	38	36	Frontal Pole	0.001	58	5.83

Table 2: Significant clusters for MWEs after FWE correction