Break the ice vs. boa constrictors: Do they have different neural bases?

Shohini Bhattasali Murielle Fabre John Hale
Cornell University

10th Annual Meeting of the Society for the Neurobiology of Language, August 2018

Introduction

Natural language comprehension relies on at least two cognitive processes:

- Retrieval of memorized elements
- Structural composition

Frequent collocations like *break the ice*, *boa constrictor*, *safe and sound*, *see to it*, *in spite of* can help us address the neural bases of these processes. These collocations, often known as Multiword Expressions, form a heterogeneous family of word clusters.

Questions

1. Are the differences between the grammatical categories of MWEs observable at the cerebral level?
2. Does processing of verbal MWEs implicate separate brain areas from non-verbal MWEs?

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; 15,388 words in total.
Comprehension was confirmed through multiple-choice questions at the end of each section (90% accuracy, SD = 3.7%).

Multiword Expressions

742 MWEs were identified in the dataset through a transition-based MWE analyzer (Al Saied et al., 2017) trained on Children's Book Test dataset (Hill et al., 2015).
Stanford POS tagger & NLTK POS tagger were used to annotate the grammatical categories of MWEs' words (Bird and Loper, 2004; Manning et al., 2014).
Presence/absence of verbal expression yielded two categories of MWEs (i.e. 56% verbal vs. 44% non-verbal).

Group-level Results

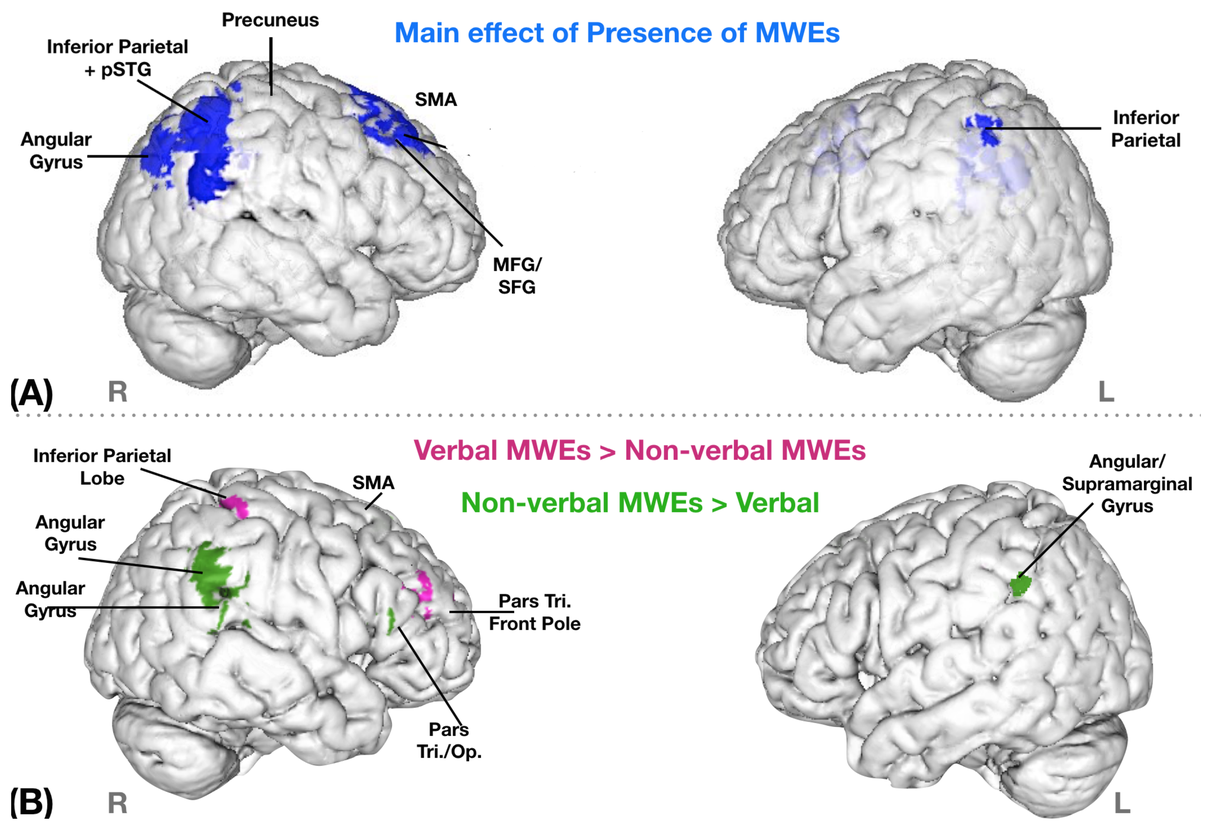

Figure 1: (A): Whole-brain effect for the presence of MWEs in blue. (B): Contrast images with significant clusters for [Verbal MWEs > Non-verbal MWEs] in pink and [Non-verbal MWEs > Verbal MWEs] in green. (FWE p < 0.05)

Main effect of MWEs

Regions for Multiword Expressions	Cluster size (in voxels)	MNI Coordinates x	y	z	p-value (corrected)	T-score (peak-level)
R Middle Frontal Gyrus	1308	28	22	46	0.000	8.36
R Superior Frontal Gyrus		24	18	58	0.000	8.36
R Inferior Parietal Lobule, Supramarginal Gyrus, Superior Temporal Gyrus	1652	52	-48	42	0.000	8.10
R Angular Gyrus		42	-66	32	0.000	8.10
R Inferior Parietal Lobule		40	-72	44	0.000	8.10
R Precuneus Cortex	98	4	-42	44	0.000	7.03
R Middle Frontal Gyrus (BA6)	105	10	30	46	0.000	6.93
L Inferior Parietal Lobule/Supramarginal Gyrus	141	-48	-46	48	0.001	6.81
R/L Precuneus Cortex	56	2	-62	54	0.002	6.49

Table 1: Significant clusters of increasing activation for multiword expressions after FWE voxel correction for multiple comparisons with p < 0.05 and cluster-extent threshold (k > 50) for display purposes. Peak activation is given in MNI Coordinates.

Verbal & Non-verbal MWEs

Regions	Cluster size (in voxels)	MNI Coordinates x	y	z	p-value (corrected)	T-score (peak level)
Verbal MWEs >Non-verbal MWEs						
R IFG Pars Triangularis	71	46	36	14	0.000	7.38
R Inferior Parietal Lobule	57	50	-40	52	0.002	6.38
Non-verbal MWEs >Verbal MWEs						
R Angular Gyrus	585	56	-42	14	0.000	9.43
R Supplementary Motor Area	235	12	20	60	0.000	8.91
L Cerebellum	58	-22	-72	-30	0.002	7.85
L Supramarginal Gyrus	32	-60	-50	34	0.001	6.50
R IFG Pars Triangularis/Opercularis	28	56	22	8	0.001	6.51

Table 2: Significant cluster for contrasts between verbal MWEs and non-verbal MWEs after FWE voxel correction for multiple comparisons with p < 0.05. Peak activation is given in MNI Coordinates.

fMRI Analysis

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

- ME-ICA denoises T2* signal using ICA into BOLD and noise components from physiology, motion, scanner artifacts.

MWE predictors convolved with SPM12's canonical HRF, regressed against observed BOLD signal during passive story listening.
To account for sentence-level compositional processes, a regressor formalizing syntactic structure building included (Hale, 2014).
GLM analysis includes four regressors of non-interest: word offset, frequency, pitch, intensity.

Conclusion

- Main effect of MWEs implicate areas associated with lexical semantic network (Binder et al., 2009), memory & naming tasks (Crosson, 2013; Halsband et al., 2002).
  - Also consistent with several neurobiological models of language processing (Friederici & Gierhan, 2013; Hagoort, 2016; Ulman, 2015).
- Verbal and non-verbal MWEs show spatially distinct patterns of activation:
  - Suggests that verb-argument selectional relations in verbal collocation involve right hemisphere activity in Broca's area and IPL.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1607441.

Selected References

Al Saied, H., Constant, M., & Candito, M. (2017). The ATILF-LLF system for PARSEME shared task: A transition-based verbal multiword expression tagger. In *Proceedings of the 13th Workshop on Multiword Expressions (MWE 2017)* (pp. 127–132).
Hale, J. T. (2014). *Automaton theories of human sentence comprehension.* CSLI Publications.
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.