Abstract Linguistic Structure Correlates with Anterior Temporal Activity during Naturalistic Comprehension

Jonathan Brennan¹, Edward P. Stabler², Sarah E. VanWagenen², Wen-Ming Luh³ & John T. Hale³

¹University of Michigan, ²University of California Los Angeles, ³Cornell University

jobrenn@umich.edu

Introduction

There is much debate over the level of syntactic detail used by the brain for sentence comprehension.

1. String-level word-to-word dependencies (Frank et al., 2015)?
2. “Good enough” hierarchical structures (Sanford & Sturt, 2002)?
3. Detailed grammars with abstractions like movement and empty categories from syntactic theory (Lewis & Phillips, 2015)?

Neurolinguistic studies implicate the left anterior temporal lobe in basic composition (Dronkers, 2004; Bemis & Pylkkänen, 2011). Posterior temporal and inferior frontal regions have also been linked with sentence comprehension, but studies often rely on single-sentence paradigms that only indirectly related to natural language use.

Using fMRI and a passive story-listening task, we test the level of syntactic detail used during sentence comprehension by:

- Quantifying the cognitive states that different theories imply and
- Correlating these estimates with fMRI-recorded brain activity.

Methods: fMRI

Participants & Stimuli

11 participants listened to 12 minutes of Alice in Wonderland and answered comprehension questions afterwards.

fMRI Pre-processing

BOLD signals from T2*‐weighted EPI sequences were (i) spatial realigned, (ii) co-registered with structural MP-RAGE images, (iii) smoothed with a 3mm gaussian filter and (iv) transformed in to MNI coordinates. The first 10 volumes were discarded.

Four Regions of Interest were localized per subject:

- Left anterior temporal lobe (LATL)
- Right anterior temporal lobe (RATL)
- Left inferior frontal gyrus (LIFG)
- Left posterior temporal lobe (LPTL).

Functional peaks within the 50% margin of each anatomical region (Harvard-Oxford Brain Atlas) were identified with a WordRate predictor that tracked with the amount of linguistic input per unit time. ROIs were 10mm spheres centered on maximum for this predictor.

Methods: Syntactic Modeling

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Results: Regression Weights and Model Comparison

Regression weights (±Std Err) for each syntactic predictor controlling for pre-lexical, lexical, and prosodic factors

Controlling for lexical and prosodic factors, surprisal from the string-level 2GRAM models predicts signal in all four ROIs (LATL, $\chi^2(1)=39.33$, p < .001; RATL, $\chi^2(1)=24.15$, p < .001; LIFG, $\chi^2(1)=16.09$, p < .001; LPTL, $\chi^2(1)=25.42$, p < .001).

CFG surprisal, which reflects hierarchy, improves model fits in LATL ($\chi^2(1)=25.29$, p < .001) and LPTL ($\chi^2(1)=25.74$, p < .001).

MG node counts from the most abstract grammar further improved model fits in LATL and RATL ($\chi^2(1)=6.68$, p < .05, $\chi^2(1)=6.42$, p < .05).

Conclusions

- Both string-level and hierarchical representations implicated in naturalistic comprehension
- Anterior temporal lobes involved in processing abstract syntactic structures

Statistical Analysis

Hierarchical models containing control predictors and estimates from each syntactic model were it against ROI timecourses. Model comparison tested target predictors with control for low-level and syntactic covariates.

ROI timecourse ~ WordRate + WordLength + WordFrequency + ProsodicBreaks (+2GRAM) (+3GRAM) (+CFG) (+MG)

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