Neural correlates of the effects of semantic coherence and derivational family entropy on processing of morphologically complex words

NEW YORK UNIVERSITY

***Joseph Fruchter*[1] & *Alec Marantz*[1,2]**

New York University, Departments of Psychology[1] & Linguistics[2]

Introduction

Time-course of Visual Word Recognition

1. Decomposition into mental representations of the visual forms of morphemes.
   Left Fusiform/Inferior Temporal, 100-200 ms (Solomyak & Marantz, 2010)
2. Lexical access for decomposed morphemes.
   Left Superior/Middle Temporal, 200-400 ms (Pylkkänen & Marantz, 2003)
3. Recombination of morphemes.
   Orbitofrontal, Left Superior/Middle Temporal, 300-500 ms (results of this study)

Lexical Access for a Stem

Investigated via the correlation of MEG data with derivational family entropy (Moscoso del Prado Martin, Kostic, & Baayen, 2004), a measure reflecting the distribution of lexical frequencies in the derivational family of the stem (e.g. the derivational family of *hunt* would include *hunt*, *hunter*, *hunting*, *huntress*, and *huntsman*).

Recombination of Stem and Affix

Investigated via the correlation of MEG data with surface frequency (whole-word frequency), as well as with a novel statistical measure of the semantic coherence (SC) of suffixed words, derived from the residuals of a regression model predicting surface frequency as a function of base frequency and biphone transition probability.

Examples: SC(*speakable*) = -1.38 (Low)
SC(*predictable*) = 1.12 (High)

Design

Stimuli

- 200 suffixed words (50 "-er", 50 "-ly", 50 "-ness", and 50 "-able").
- 200 non-words, matched for word endings and length.

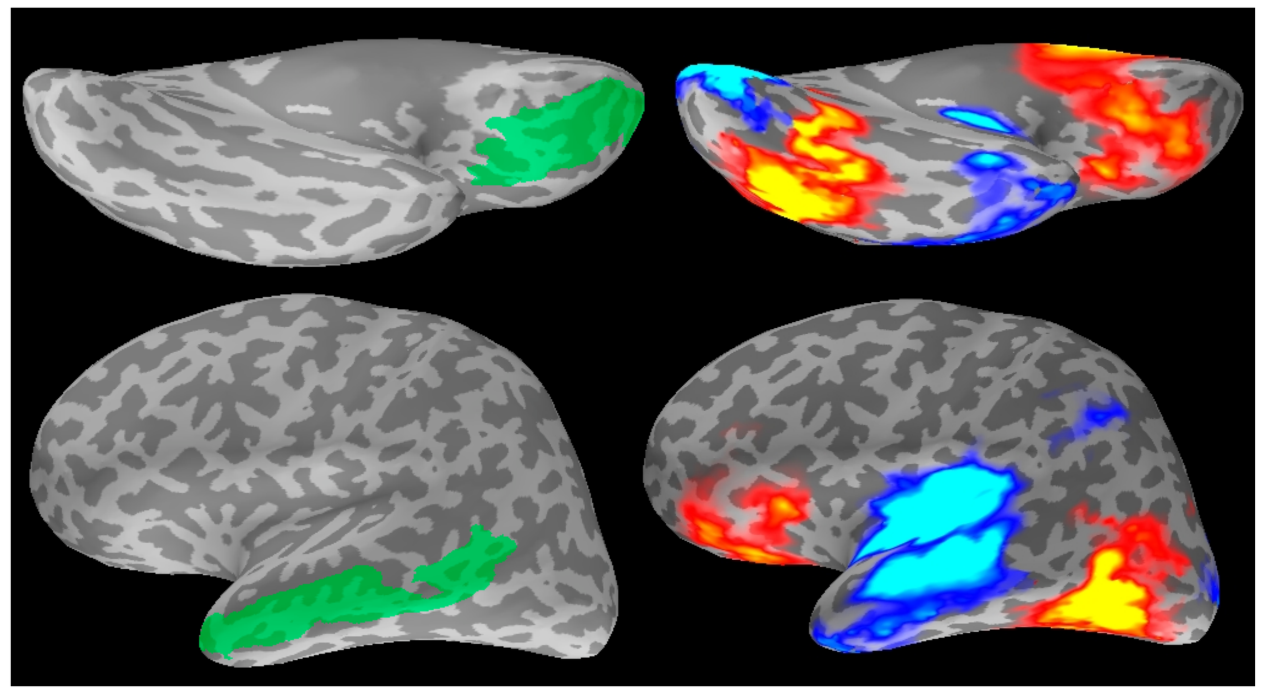
Stimulus Variables

Variable	Definition	Example
Surface Frequency (SF)	Frequency of whole word form	Frequency of *hunter*
Base Frequency (BF)	Frequency of base as a whole word	Frequency of *hunt*
Biphone Transition Probability (BTP)	Probability of the first 2 phonemes of the suffix given the preceding 2 phonemes	Given *'ər'*, probability of *'nt'*
Semantic Coherence (SC)	Residuals of regression model: $SF(X) = a + b_1*BF(X) + b_2*BTP(X) + e$	Semantic coherence of *'hunt'* and *'-er'*
Derivational Family Entropy (DFE)	Entropy of the frequencies of all words in the derivational family of the stem.	Entropy of the frequencies of: *hunt, hunter, hunting, huntress, huntsman*

Analysis

MEG Lexical Decision Experiment:
- Right-handed native English speakers (n=10) completed a visual lexical decision task (word vs. non-word) consisting of 400 trials.
- MEG data was acquired continuously during the task.
- Structural MRIs were analyzed via FreeSurfer.
- Cortically-constrained inverse solutions were computed via MNE.

Single-Trial Correlational Analysis:
- Anatomical regions of interest (ROIs) were selected from the automatic FreeSurfer parcellations of the cortex.
- Linear mixed effects models were employed millisecond-by-millisecond with the average activity within the ROI (for each trial) as the dependent variable, a stimulus variable as the fixed effect, and subject and item as random effects.



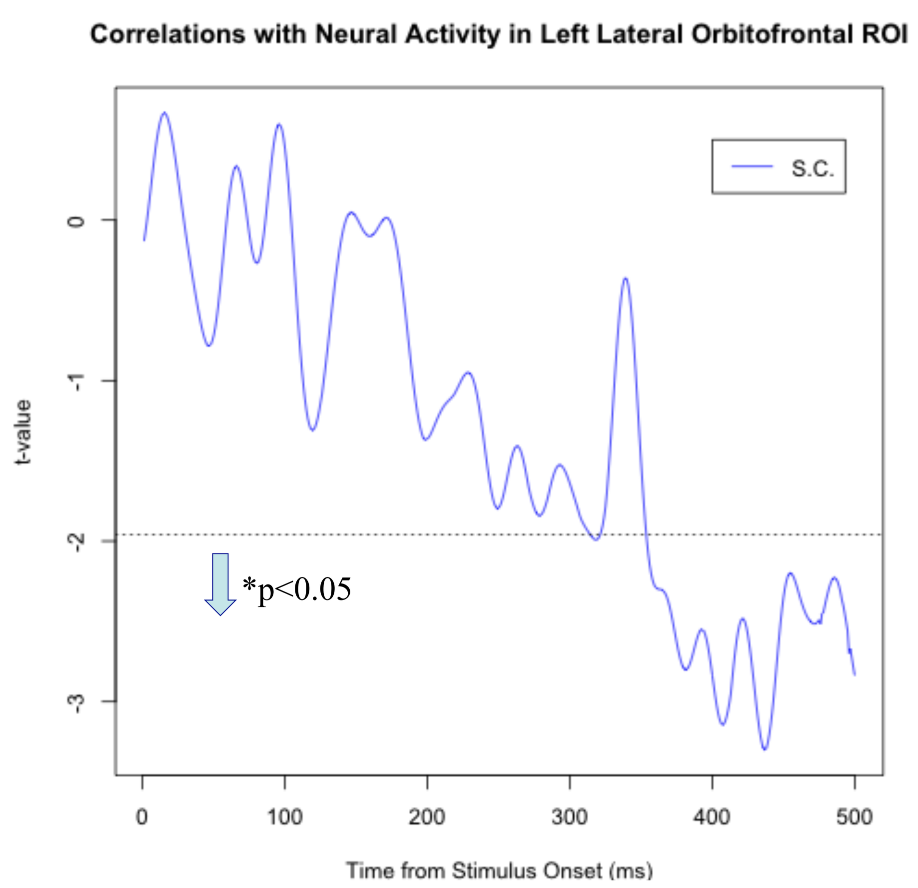
Left hemisphere of a representative subject's inflated cortical surface. The top row displays the lateral orbitofrontal ROI (highlighted in green), along with the average activity across all subjects and all trials at 380 ms post-stimulus onset, from a ventral view. The bottom row displays the middle temporal ROI (highlighted in green), along with the average activity across all subjects and all trials at 380 ms post-stimulus onset, from a lateral view. For the right column images, red indicates outgoing activity and blue indicates ingoing activity.

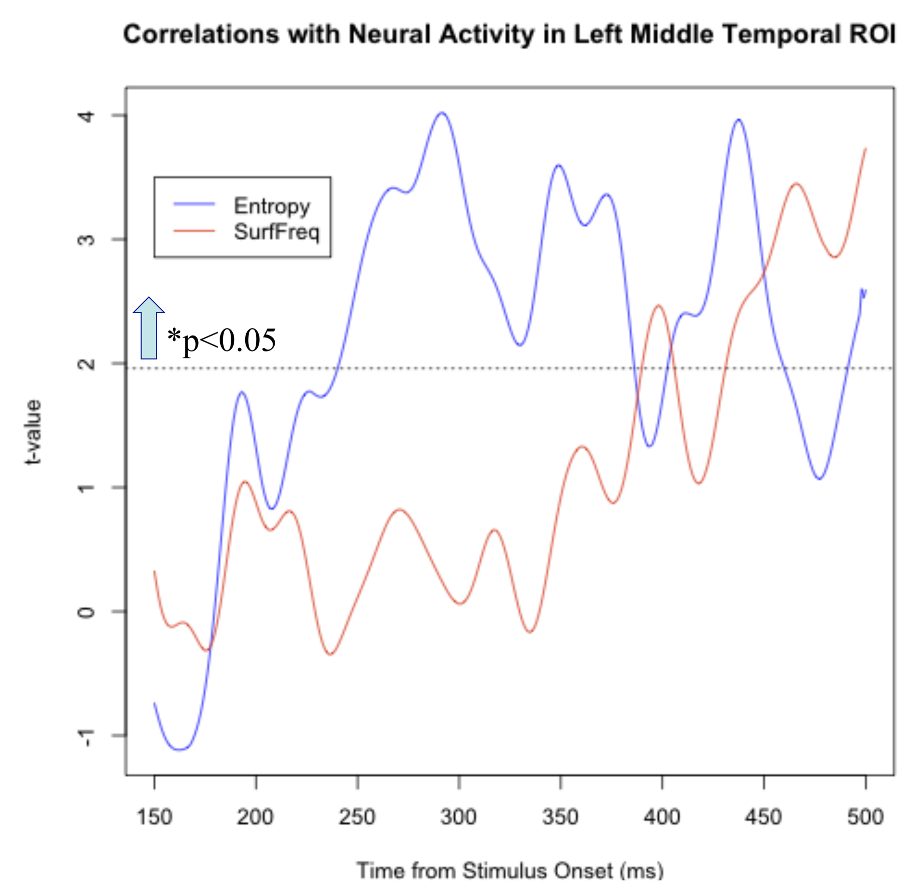
Anatomical ROIs in Left Hemisphere

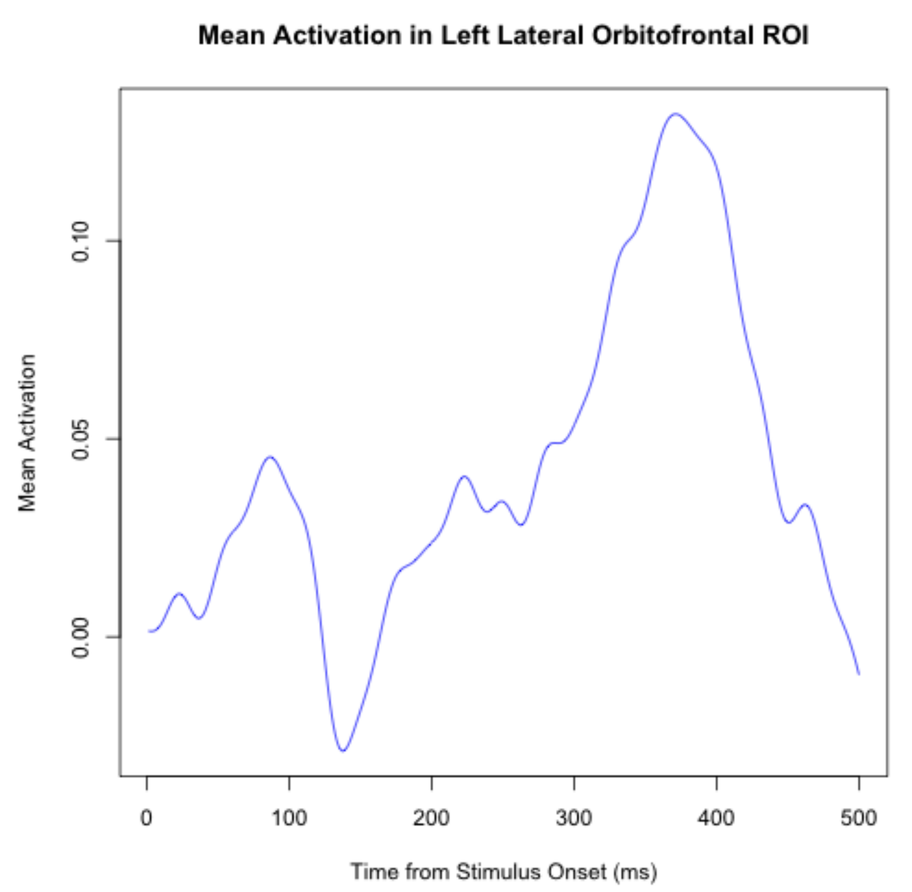
Orbitofrontal: Activity during the time window 300-500 ms was tested against SC, based on previous research demonstrating the sensitivity of this cortical region to semantic composition (Pylkkänen & McElree, 2007).

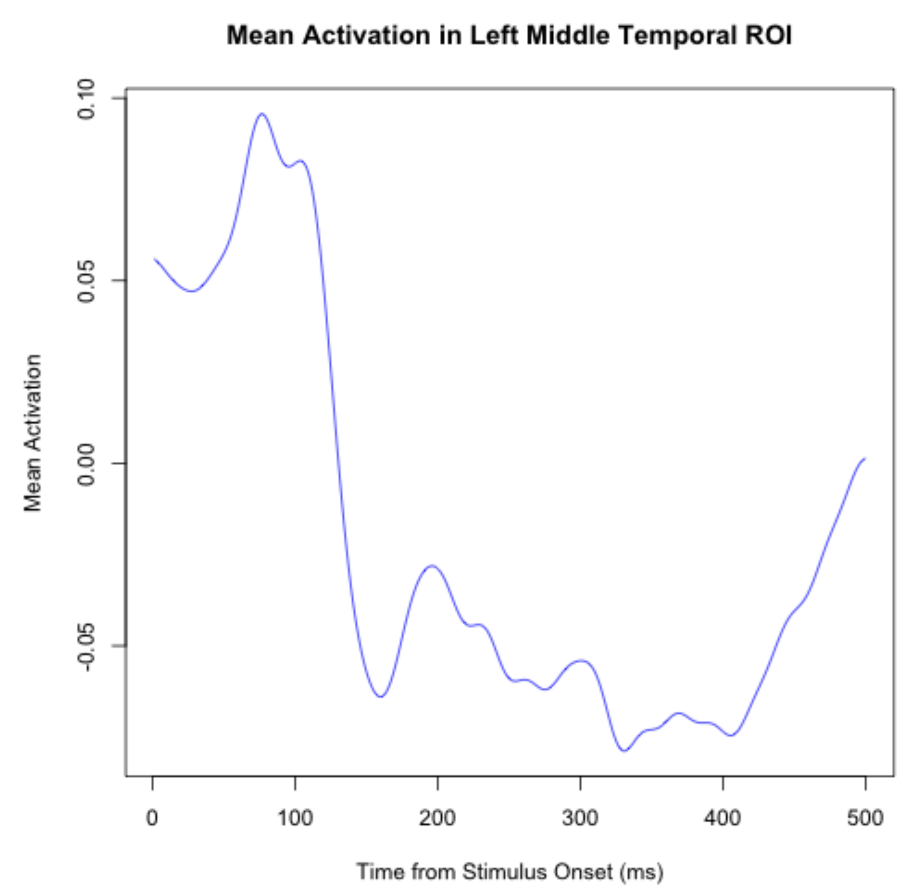
Superior and middle temporal: Activity during the time window 150-500 ms was tested against DFE and SF, based on previous research tying these regions to lexical access (Pylkkänen & Marantz, 2003).

Results









Variable	ROI / Hypothesized time window	Significance of effect*
Semantic Coherence	Left lateral orbitofrontal / 300 - 500 ms	$p = 0.0004$ for cluster at 354-500 ms
Derivational Family Entropy	Left middle temporal / 150 - 500 ms	$p < 0.0001$ for cluster at 241-387 ms
Surface Frequency	Left middle temporal / 150 - 500 ms	$p = 0.0034$ for cluster at 431-500 ms

*Significance calculated via 10,000 iterations of permutation tests, based on multiple comparisons correction algorithm in Maris & Oostenveld (2007), as adapted by Solomyak & Marantz (2010).

Conclusions

1. Derivational family effects on lexical access for a stem are observed relatively early, through the significance of derivational family entropy in modulating activity in the left middle temporal ROI (241-387 ms).
2. Effects of the recombination of stem and affix are observed relatively late, through the significance of surface frequency in modulating activity in the left middle temporal ROI (431-500 ms).
3. Recombination effects are also observed through the significance of the novel statistical measure of semantic coherence, which modulates activity in the left lateral orbitofrontal ROI (354-500 ms).
4. Statistical measures derived from lexical frequency allow us to investigate the various stages of complex word processing.

References

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