Tracking Lexical Ambiguity Resolution with Multi-Voxel Pattern Analysis

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Main Research Question

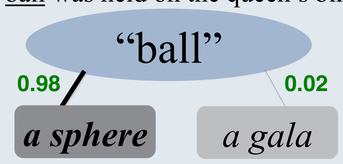
To successfully comprehend sentences that contain lexically ambiguous words, we must:

- *retrieve* the word's possible meanings from memory
- *select* contextually appropriate meanings over competing alternatives
- *reinterpret* the meaning, if the initial selection was incorrect

- Conceptual knowledge retrieval recruits several posterior brain regions, including left anterior temporal lobe (lATL) (e.g. Lambon Ralph et al., 2010; Binney et al, 2010)
- Comprehension of lexically ambiguous sentences recruits left ventrolateral prefrontal cortex (lVLPFC) (e.g. Rodd et al., 2005; 2012)

When selecting a contextually appropriate word meaning, how do conceptual memory systems and cognitive control mechanisms interact?

"The ball was held on the queen's birthday."



DOMINANT (DOM): Most frequently used meaning

SUBORDINATE (SUB): A less commonly used meaning

Predictions

1. Each homonym meaning will evoke a distinct multi-voxel pattern (MVP) of neural activity
2. When a SUB meaning must be activated, the DOM meaning will compete for selection.

Item-Level Index of Competition: DOM~SUB MVP similarity
Does the SUB pattern resemble the DOM pattern?

3. The stronger the DOM meaning, the greater the competition during selection of the SUB meaning
4. Left VLPFC response will bias selection toward the contextually appropriate SUB meaning, leading to decreased MVP similarity

Stimulus Words

30 polarized homonyms:

- Multiple meanings map onto a single word form
- One meaning dominates: the most frequently denoted referent

Meaning Dominance (M1): strength of a word's dominant meaning, measured from free association production norms (Twilley et al., 1994)

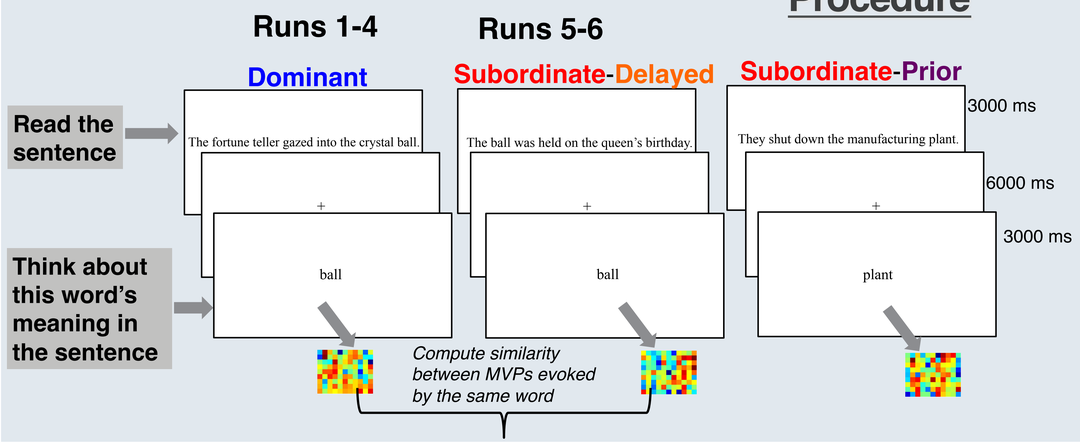
Sentence Conditions

Runs 1-4: sentences bias toward DOMINANT meanings

Runs 5-6: sentences bias toward SUBORDINATE meanings

Prior context: "The queen danced at her birthday ball."
OR
Delayed context: "The ball was held on the queen's birthday."

Procedure



Sentence Analysis

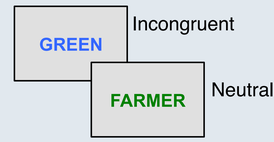
- Whole-brain GLM: contrast responses to sentence conditions

Item Analysis

- In lVLPFC ROI: mean BOLD response
- In roaming searchlight: MVP similarity analysis (cf. Kriegeskorte et al., 2008)

Run 7

Stroop-conflict task



lVLPFC Functional Localizer
(cf. Hindy et al., 2015)

- Subject-level Voxel Selection: top 100 *t*-statistics for (Incongruent vs. Neutral) in left VLPFC (BA 44 & 45)

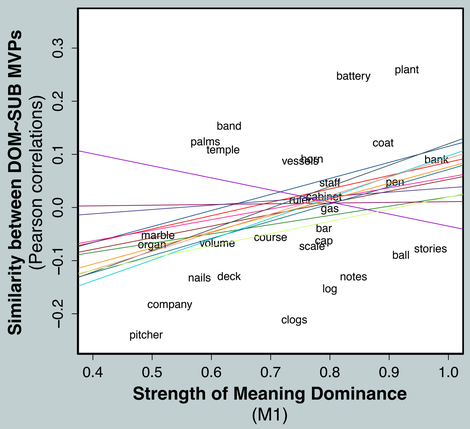
Item Analysis: Multi-Voxel Searchlight Results

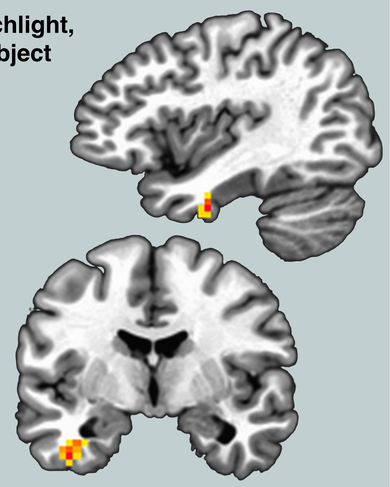
In each searchlight in a subject's native brain space:

- Compute similarity between each word's DOM & SUB MVP
- Across items, use meaning dominance (M1) to predict DOM~SUB similarity

Group-level searchlight results (collapsed across prior & delayed context):
In left anterior temporal lobe (lATL), **M1** predicts **DOM~SUB** MVP similarity, $t(13) = 5.45$, $p < .01$ (cluster corrected)

Subject correlations in peak lATL searchlight, with item values from an example subject





Follow-up analysis in peak lATL searchlight (within subjects):

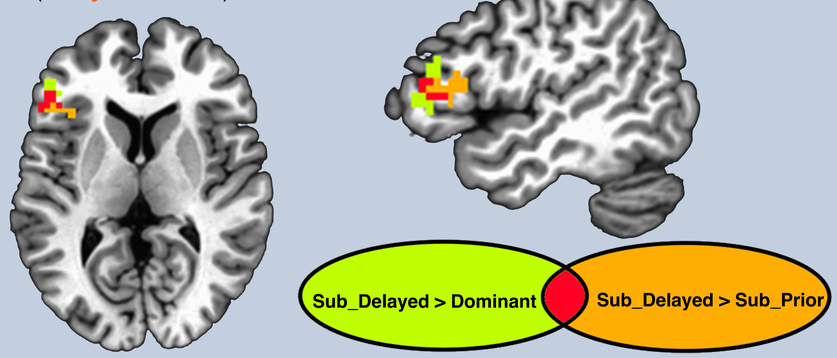
- Do changes in lVLPFC response track DOM~SUB MVP similarity?
- Mean response change in lVLPFC ROI:
  (**SUB** word presentation) – (**DOM** word presentation)
- Left VLPFC response negatively predicts DOM~SUB similarity in peak ATL searchlight, $t(13) = -3.50$, $p < .01$

Increases in lVLPFC activity predict decreases in DOM~SUB MVP similarity

Sentence Analysis: Univariate Results

In left ventrolateral prefrontal cortex (lVLPFC), responses increase when:

- A homonym is biased toward a **subordinate** meaning
- The disambiguating information appears AFTER the homonym (**delayed context**)



Whole-brain results (N= 14), cluster corrected $p < .05$

Discussion

- While reading sentences that bias interpretation toward a homonym's subordinate meaning, lVLPFC response increases, if the homonym appears BEFORE the disambiguating context.
  Without supporting context, the dominant meaning is initially selected, and lVLPFC is associated with sentence reinterpretation.
- In lATL, the similarity between MVPs evoked by distinct word meanings is predicted by two item-specific measures of competition:
  DOM~SUB *similarity (1)* ***increases*** *with* ***M1*** *strength and (2)* ***decreases*** *with lVLPFC response*
- These results suggest that lVLPFC biases selection toward a subordinate, context-appropriate meaning over a dominant, inappropriate meaning.

References

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