Semantic Variability Predicts Neural Variability of Object Concepts

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**Context-dependent Theory of Concept Representation**
- Meaning is generated by the dynamic interaction between a concept and the context in which it is accessed.
- Concepts are not represented as context-invariant, static entities retrieved in isolation.
- Neuroscientists often treat these representations as fixed.
  - Common practices to reduce “noise” in signal: averaging across stimulus presentations; limiting analyses to voxels with the most stable activation profiles.

**Objective**
- Compare neural patterns elicited by conceptual processing of the same stimulus item as it appears in different contexts.
- Relate within-item, cross-context neural variability to measures of semantic/contextual variability.

**Hypothesis**
- Corresponding neural variability: physical manifestation of concept-context coupling.
- Semantic features are neurally distributed & dynamically activated depending upon current task/context.
- Projected into high-dimensional semantic space: a concept’s meanings in its various uses.
- Traverse from one concept to another.
- Concept #2 has more diverse meanings than Concept #3.
- The 2 instantiations of Concept #2 are more variable than the 2 instantiations of Concept #3.

**Quantifying Semantic Variability**
- Concept: word appearances in large linguistic corpora.
- Context: paragraph of text in which the word appears.
- How many contexts does each concept appear in, and how similar are these contexts to one another?
  - SemVar: a composite score for each concept, computed using PCA on results from topic modeling, LSA, and context frequency counts.
  - A measure of diversity amongst a concept’s contexts.

**Creating Variable Contexts**
- 160 single-sense, concrete nouns:
  - 30 “target” & 130 “filler” words
  - 15 polysemous & homonymous words
  - Words assigned to 9 unique, randomly ordered lists, each with:
    - 10 targets
    - 15 fillers
    - 5 “poly/homs”
  - Each target & poly/hom word appears in 3 different lists.
  - Unique and unrepeated fillers added to lists, to increase list variability.

**Procedure**
- Subjects (n=19) completed 9 fMRI scans.
  - 1 scan per list, each 4 minutes long.
  - Sequential word presentations.
  - Task during scanning: memory encoding.
  - Task after each run: recognition memory tests.
    - Probes: 5 foils & 5 fillers.

**Whole-brain Voxel Selection**
- Gray matter voxels ranked by test statistic, those most responsive to both:
  - (1) words vs. fixation and (2) differences across word presentations.
  - Measured neural patterns in 12 voxel sets of varying sizes: top 25-10,000 voxels.
  - Contiguity constraint: each voxel must share a face with 1+ other included voxels.

**Measuring Neural Variability**
- Across spatially distributed voxels: measured average dissimilarity between neural patterns evoked by each concept in its three different contexts (1 - Pearson correlation coefficient).

**Results**
- Positive correlation between target words’ SemVar score and corresponding neural variability, t(18)=3.1, p=.006.
- Correlations significantly positive across subjects, when patterns measured in sets of 250-2000 voxels.

**Effects of Lexical-Semantic Ambiguity**
- Polysemous and homonymous words: 2+ different meanings or senses share the name same.
  - (e.g., chicken/meat & chicken/bird)
  - These words should exhibit especially variable patterns, since they denote multiple concrete meanings.
  - Polyhoms elicit less neural similarity than target words: t(19)=2.2, p=.04.
  - Robust at voxel set sizes: 25-750.

**Discussion**
- Neural activity varied across repeated stimulus presentations, and this variation was reliably predicted by measures of semantic variability.
- Supports a flexible, distributed theory of semantic memory organization, in which a concept’s meaning varies continuously as a function of its context.
- Within-stimulus “noise” can reflect context-modulated variation in a concept’s semantic representation.

**References**