Multi-Voxel Pattern Analysis of Noun and Verb Differences in Ventral Temporal Cortex

CENTER FOR COGNITIVE NEUROSCIENCE

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Introduction

Do predictions about upcoming lexical syntactic categories (e.g. nouns, verbs) generate form-based estimates in visual and/or ventral temporal cortex?

Previous Evidence:

- **Phonological form typicality**: probabilistic relationship exists between phonological/orthographic form of a word and its lexical-syntactic category (specifically in nouns vs. verbs in English) [1]
- Form typicality modulates early M100 visual response: at 100 ms post-word onset, form typicality of word predicts amplitude of MEG visual component [2]

Current Study:

- fMRI multi-voxel pattern analysis (MVPA) over left ventral temporal (VT) cortex (including "visual word form area", or VWFA) when subjects were **predicting, *but crucially not viewing***, nouns and verbs
  - This allowed us to investigate prediction effects in these ROIs without bottom-up orthographic input.
- Classified prediction of nouns vs. verbs in both sentence and non-sentence contexts

Materials and Design

Subjects: 20 (10 for Experiment 1, 10 for Experiment 2) undergraduates at the University of Pennsylvania, all right-handed native speakers of English.

Materials:

Experiment I: Sentences with low lexical cloze probability (mean cloze probability = 2.8%, range: 1.3%-29.3%) but high selectivity (100%) for either noun or verb completions (48 noun-type, 48 verb-type sentences). Sentence completions were normed over 75 subjects.

Noun1: (24 sentences)

Wh	V_{aux}	NP	PP_____?
Where	*was*	*the woman*	*for the* _____?

Noun2: (24)

Wh	V_{aux}	NP	VP_____?
When	*did*	*the janitor*	*mention the* _____?

Verb1: (24)

Wh	NP	V_{aux}	NP	VP_____?
Which	*budget*	*was*	*the mechanic*	*permitted to* _____?

Verb2 : (24)

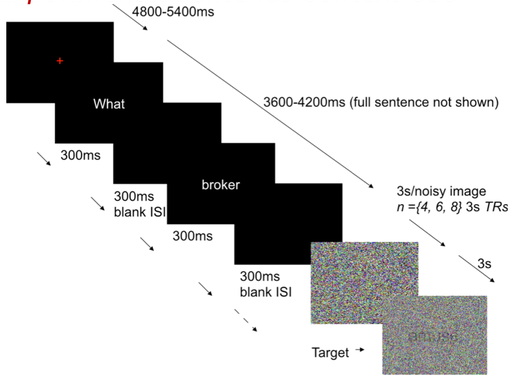
Wh	NP	V_{aux}	NP	VP_____?
What	*crib*	*did*	*the broker*	*plan to* _____?

Experiment II: Noun-typical noun tokens (*bible, movie*) and verb-typical verb tokens (*adopt, amuse)* [1,2]

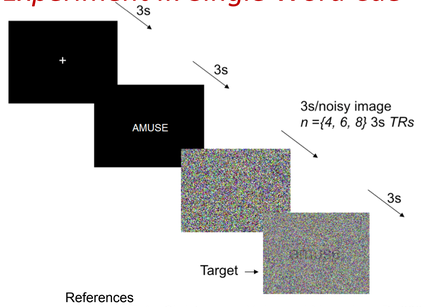
Task:

- Cue period (black screens) is either a sentence sans final word (Experiment 1) or a single word (Experiment 2).
- A series of noisy images is presented before "target" word appears. [3] "Target" word is presented at subject's visual threshold (assessed before scanning).
- At "target" word, subject indicates with button press whether the now-visible word sensibly completes the sentence (Experiment 1) or matches the cue word (Experiment 2).
- 17% catch trials (where target word is ill-formed completion or is a cue mismatch)

Experiment I: Sentence Context Cue



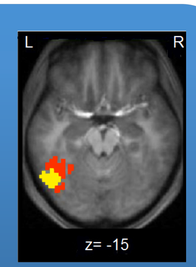
Experiment II: Single Word Cue



Methods

- Analyzed only those volumes when *subjects predicted a word but saw pure noise.*
- Implemented simple neural network with input layer of 20 best voxels; i.e. 20 voxels best accounting for variance between noun and verb trials (Experiment 1) or among 4 word tokens (Experiment 2) using best F scores from ANOVA [4].
- Trained NN on 3 out of 4 runs using conjugate gradient descent backpropagation algorithm [5]
- Tested model on 4th run in leave-one-out 4-fold cross-validation procedure
- Sought within-subject classifiers for sentence-context noun-vs.-verb prediction (Experiment 1) and individual form-typical word prediction (Experiment 2)

At left: across-subjects, across-folds map of voxel inputs to classifiers used in Experiment 1.
Voxels in VWFA shown in yellow, voxels in non-VWFA ventral temporal regions shown in red

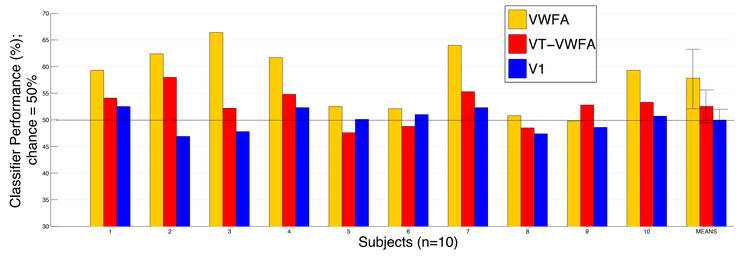


Results

Experiment I: Sentence Context Cue

Experiment I:

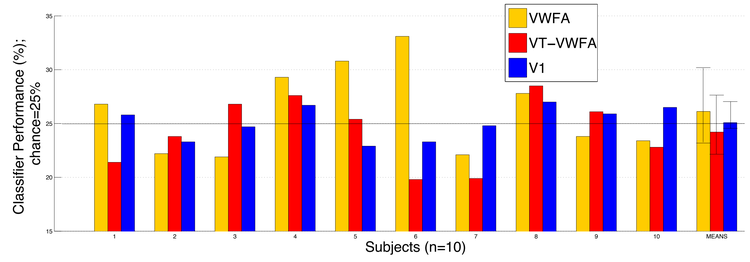
VWFA: significant classification across subjects (group mean: 58%, chance = 50%) and for 6/10 individual subjects
VT-VWFA: marginally significant classification across subjects (mean: 53%)
V1: not significant



Experiment II: Single Word Cue

Experiment II:

No significant classification at group level, though individual tokens *bible* and *amuse* show trending significance (cf. confusion matrix below)



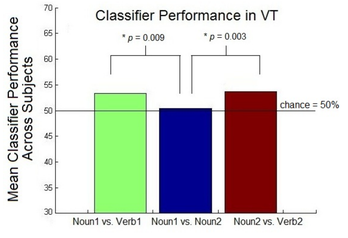
Does number of content words drive classification?

- Tested classification of Noun1- vs. Noun2-type sentences (1 vs. 2 content words). Classification not significantly above chance.

But is this just due to low power (24 sentences here vs. 48 above)?

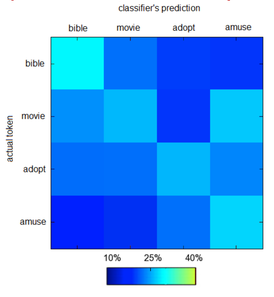
- Tested Noun1 vs. Verb1 (1 c.w. vs. 3 c.w.) and Noun2 vs. Verb2 (2 c.w. vs. 3 c.w.)

These cross-category classifications were reliably above chance despite decreased power.



Confusion Matrix across 4 tokens (2 nouns, 2 verbs)

- Given noun was more often confused with another noun than with a verb (chi-squared test, $p < 0.05$).
- Given verb was more confusable with another verb, but with only trending significance (chi-squared test, $p < 0.1$)



Conclusion

The sentence-context prediction results (Experiment I) suggest that syntactic cues are sufficient to drive top-down predictions of word form features in VT, particularly VWFA. The within-category confusability in VWFA of the individual word predictions (Experiment 2), for which lexical syntactic category was not necessary to predict the cued word form, suggests that retrieval of lexical category information may be automatic during word prediction.

References

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