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# BOLD Signal Correlations with Plausibility in Sentence Comprehension

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## INTRODUCTION

Sentence comprehension speed is affected by plausibility, with less plausible sentences comprehended more slowly (e.g., Rayner et al., 2004).

In fMRI, less plausible sentences yield greater BOLD signal than plausible sentences (e.g., Kuperberg et al., 2003; Ni et al., 2000).

But most neuroimaging studies of pragmatic or semantic meaning properties in sentence comprehension compare an entirely acceptable condition to a clearly anomalous condition using subtraction, with a comprehension task requiring an overt acceptability judgment.

To avoid some of the confounds in these designs, we compared a Yes/No comprehension question-answering task (Experiment 1) to an overt acceptability judgment task (Experiment 2), measuring BOLD signal change in event-related fMRI.

We also manipulated plausibility in 3 levels; regions sensitive to meaning computation should appear in contrasts among each of the levels.

Plausibility was independently verified with independent ratings.

We further examined effects of plausibility using correlation/regression techniques, allowing us to determine whether particular regions are differentially sensitive to meaning computation, and whether regions show sensitive to fine-grained variations as well as broader differences.

## METHOD

### Participants

16 Ss in each experiment (ages 18-30)

### Stimuli

240 sentence triples (always proper name + verb + 2-word direct object + 6-word completion)
Name+verb+direct object independently rated for plausibility (1-7, 7=most plausible)

| Condition | Example | Plausibility |
|---|---|---|
| Plausible | *Vanessa threw the javelin but did not win the competition.* | 6.4 |
| Implausible | *Vanessa threw the feather but did not win the competition.* | 3.9 |
| Anomalous | *Vanessa threw the situation but did not win the competition.* | 1.7 |

### Task

Word-by-word serial visual presentation (500ms/word), plus comprehension task:
Exp. 1: Yes/No Comprehension Question (*Was the throw good enough to win?*)
Exp. 2: 3-Alternative Plausibility Judgment (1=Plausible, 2=Implausible, 3=Anomalous)

### Data Acquisition

3T Allegra scanner at Massachusetts General Hospital

8 functional runs consisted of 30 slices along the AC-PC plane collected from an RF head coil (T = 2s, TE = 30 ms, in-plane resolution = 3.1 mm, slice thickness = 3 mm, FOV = 200 mm).

Data analysis was conducted in FSFast (Massachusetts General Hospital). SPMs were computed with a random effects model ($p$<.05). Clusters reported individually exceeded a cluster-threshhold of $p$ < .05 with a cluster-size of 300 mm$^2$.

### Correlational Analyses

Raw BOLD signal was extracted for each cluster (ROI), at 3 TRs reflecting activity at the critical word (8-14 s post-critical word onset). These 3 TRs were averaged separately for each trial.

Residual BOLD signal was computed by regressing out a pre-sentence baseline TR value, as well as critical word length and log frequency, trial-by-trial, separately for each subject.

Correlations were computed over items (collapsing over Ss), between mean item residual BOLD signal and rated plausibility.

## EXPERIMENT 1

**Goal: Isolate brain regions subserving computation of meaning during comprehension of simple sentences without an explicit judgment task.**

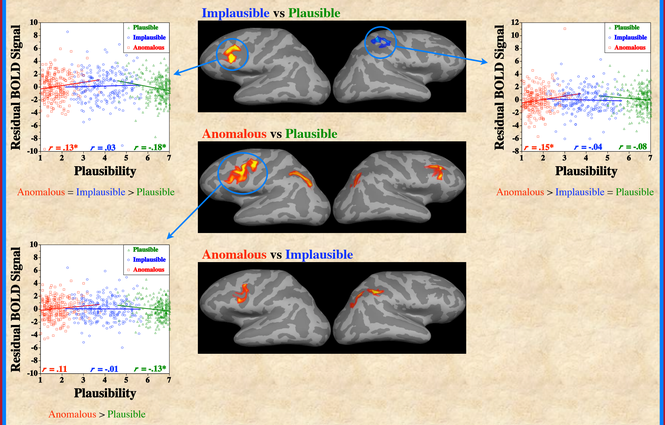
### Behavioral Results

Comprehension accuracy ≥ 90% in each condition; no effect of plausibility (questions did not ask about critical noun).
Question-answering RT: Anomalous > Implausible = Plausible.

### Neuroimaging Results

All trials included regardless of comprehension question response
All identified ROIs are shown for each contrast (warmer colors indicate positive contrasts).

Scatterplots for indicated ROIs show pattern of separate correlations within each condition and patterns of differences among *r*s.
Other ROIs showed similar correlation patterns but *r*s and differences among *r*s were not reliable.




BOLD signal was greatest for Anomalous cases in all ROIs, and BOLD signal generally increased as plausibility decreased across conditions.

The left frontal region is the only area sensitive to plausibility across all contrasts, and it shows the strongest pattern of intra-condition correlations with plausibility ratings.

Correlational analyses also showed that response to fine-grained plausibility variations within conditions is not identical to the inter-condition pattern:
In Plausible stimuli, BOLD signal response increased with decreasing plausibility, as in the overall pattern.
In Anomalous stimuli, BOLD signal response decreased with decreasing plausibility.
Implausible condition items showed no reliable intra-condition variation.

## EXPERIMENT 2

**Goal: Compare computation of meaning in Exp. 1 with an explicit judgment task (plausibility rating), using factorial and correlational methods.**

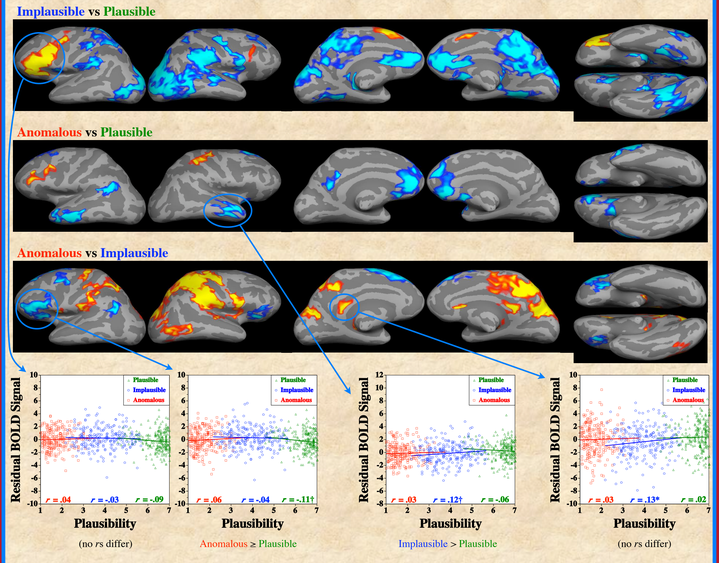
### Behavioral Results

Agreement between explicit judgment and pre-set plausibility level: Plausible - 90%, Implausible - 36%, Anomalous - 80%
Judgment RT: Implausible > Anomalous = Plausible.

### Neuroimaging Results

All trials were included regardless of rating response; all identified ROIs are shown for each contrast.

Scatterplots for left frontal regions are shown for comparison with Exp. 1.
Right two scatterplots show patterns for the only two ROIs with significant *r*s or differences among *r*s.




Much broader variety of locations involved in contrasts (vs Exp. 1), especially for contrasts involving Implausible cases.

In left frontal region identified in Exp. 1, BOLD signal was greatest for Implausible rather than for Anomalous cases.

Few reliable correlations within conditions or differences among correlation coefficients; the only reliable correlations were within the Implausible condition, with BOLD signal increasing with plausibility.

Correlation pattern was more variable than in Exp. 1; left frontal region showed similar but weaker pattern.

## SUMMARY

Comparing across three plausibility levels permitted isolation of a single left frontal cortical region sensitive to differences among all conditions.

This region showed sensitivity to plausibility in both experiments, but not identically:
During reading for comprehension, its response broadly increased with decreasing plausibility.
During plausibility judgment, its response was greatest to sentences intermediate in plausibility, which were hardest to judge (based on RT).

Correlational analyses within conditions showed that this region was most strongly linked to fine-grained variation in plausibility as well.

Correlational analyses also showed that sensitivity to fine-grained plausibility variation was stronger overall during reading for comprehension.

Additional correlational analyses revealed unexpected differential plausibility sensitivity of this region within different plausibility levels:
In Plausible sentences, BOLD signal decreased with increasing plausibility.
In Implausible sentences, BOLD signal was unrelated to plausibility.
In Anomalous sentences, BOLD signal increased with increasing plausibility.

## CONCLUSIONS

These findings reinforce earlier work showing substantial influences of task-specific parameters on fMRI result patterns (e.g., Caplan et al., 2006).

The specific interactions with task and the correlational analyses suggest:
In Exp. 1, Ss were comprehending the sentences and having more difficulty doing so as plausibility decreased. But below some minimum plausibility threshhold, readers stopped trying to construct an interpretation.
In Exp. 2, Ss were primarily concerned with classifying sentences, which was easy for Plausible and Anomalous cases but difficult for Implausible cases.

This raises concerns about the use of anomaly judgment tasks in understanding normal comprehension.

The broad result pattern and the correlational analyses suggest that the identified left frontal region is tightly connected to sentence comprehension, and that its activity increases as a comprehension task becomes more difficult.

The correlational analyses in particular suggest that in these experiments, difficulty in comprehending was specifically tied to computation of meaning.

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