# Individual Differences in Processing Anomalies of Form and Content

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## Introduction

A wide range of findings show that the sentence processing mechanism makes characteristically distinct responses to syntactic and pragmatic cues in the linguistic signal. Evidence supporting this supposition comes from diverse sources, including:

- ERP studies show distinct waveforms in response to syntactically and pragmatically anomalous sentences (Kutas & Hillyard, 1983; Neville, Nicol, Barss, Forster, & Garrett, 1991).
- fMRI and MEG studies show non-overlapping areas of brain activation in response to syntactically and pragmatically anomalous sentences (Helenius, Salmelin, Service, & Connolly, 1998; Ni et al., 2000).
- Distinct patterns of eye movements are engendered in reading sentences containing syntactic and pragmatic anomaly (Ni, Fodor, Crain, & Shankweiler, 1998; Braze, Ni, & Shankweiler, 2001; Braze, Shankweiler, Ni, & Palumbo, 2002)

Whether these distinct patterns emerge as a result of the operation of encapsulated processing sub-mechanisms is a debated matter. However, it seems clear that the contributions of different types of information to processing are reliably discernable. The present study explores individual variation in the sensitivity to these divergent informational cues.

Knowledge representation and retrieval capacities vary widely, of course. Yet, research in psycholinguistics has generally sampled from only a narrow portion of the population. Heretofore, college students have contributed nearly the entire database of the field.

Our intent was to sample broadly, assembling a more nearly representative group of people in their late teens and early twenties, a group which includes college students and graduates, but in addition others whose education ended or was interrupted during or after high school.

## Why Anomaly?

Anomaly can serve as a litmus test for specialized processes. Sentences can be made anomalous in specific ways that serve to challenge different aspects of comprehension. For example, a sentence might be (a) pragmatically odd or (b) grammatically defective.

(a) The cats won't usually bake (eat) the food.
(b) The cats won't usually eating (eat) the food.

Further, anomalies such as (a) and (b) can be localized to a single word within a sentence, allowing us to measure the response relative to that specific point. Given these characteristics, we can use anomalous test materials to disentangle the



processes that take place as sentence comprehension unfolds in time.

# Previous Work Using Eye-tracking

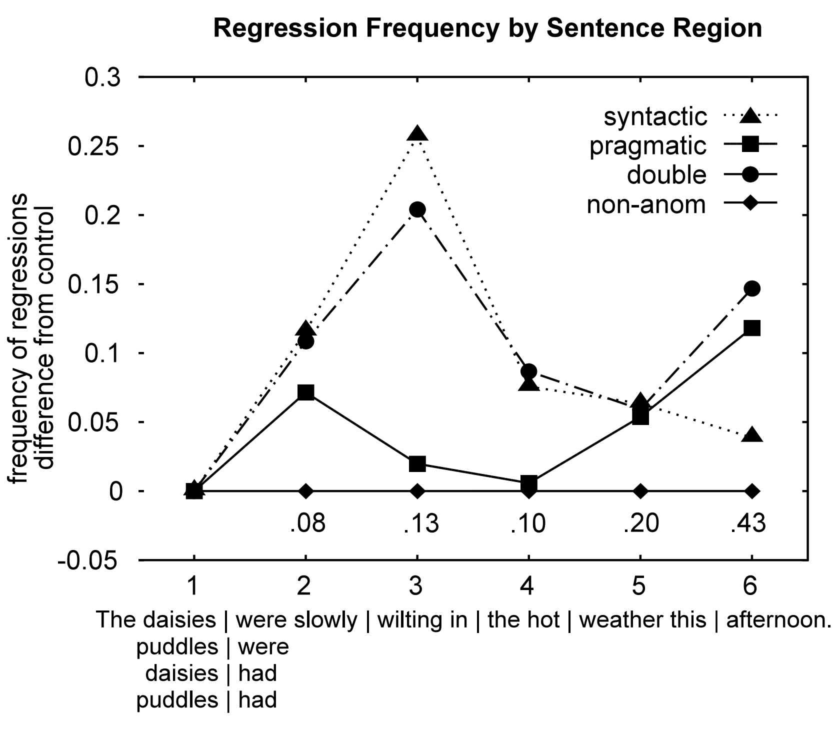
Recording eye-movements in reading affords highly sensitive indicators of cognitive load in sentence processing. Ni et al. (1998), Braze et al. (2001) and Braze et al. (2002) contrasted sentences containing flaws in morpho-syntax with other, grammatical sentences, depicting pragmatically odd subject-verb relationships to probe for specific cognitive processes associated with each type of informational cue (see examples below). A double anomaly condition was newly included in the Braze et al. (2001) study. Combining the two types of anomaly within a single condition allowed us to test whether effects due to each anomaly type remain distinguishable. In fact, that turned out to be true.

**Example Sentences**

- The shirt will surely wrinkle unless it is washed in warm water. Non-anomaly
- The shirt is surely wrinkle unless it is washed in warm water. Syntactic anom.
- The bus will surely wrinkle unless it is washed in warm water. Pragmatic anom
- The bus is surely wrinkle unless it is washed in warm water. Double anom.

Panel 5 shows a breakdown of regressive eye-movement frequencies by sentence region for each sentence type (Braze et al., 2001). Note the dissociation in peak regression frequencies for the two anomaly types. Syntactic anomalies trigger regressions in the region containing the verb, followed by a return to baseline. Pragmatic anomalies induce a spate of regressions at the ends of the sentences, but show no increase over controls at the region containing the verb. This pattern was reported earlier by Braze et al. (2002) and Ni et al. (1998), but of particular note is the pattern for the double anomaly, which shows a dual peak in backward eye-movements, an early peak at the verb and a later one at sentence end.





**Regression Landing Sites**

Regions targeted by regressions launched from the ends of sentences (region 6) were also tabulated. Distribution of regression targets for sentences containing pragmatic anomalies was found to differ from the distributions for sentences containing syntactic anomalies or non-anomalous controls. Distributions for non-anomalous and syntactically anomalous sentences did not differ from each other. The split between non-anomalous sentences and syntactic anomalies on the one hand, and pragmatic anomalies on the other, parallels the split seen in the overall frequency of regressive eye-movements from the sentence final region.

**Distribution of Regression Targets for Regressions from Region 6**
(frequency and column-wise percentages) (Braze et al., 2001)

| Target | Anomaly Condition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Region | non-anom. | | syntactic | | pragmatic | | double | |
| 1 | 8 | 14.3 | 10 | 17.0 | 23 | 32.9 | 8 | 12.7 |
| 2 | 12 | 21.4 | 18 | 30.5 | 13 | 18.6 | 26 | 41.3 |
| 3 | 5 | 8.9 | 3 | 5.1 | 10 | 14.3 | 8 | 12.7 |
| 4 | 12 | 21.4 | 12 | 20.3 | 8 | 11.4 | 7 | 11.1 |
| 5 | 19 | 33.9 | 16 | 27.1 | 16 | 22.9 | 14 | 22.2 |



These earlier studies show that eye-movement patterns associated with syntactic and pragmatic processing are dissociable, each displaying a distinct signature. These data are consistent with the hypothesis of separate processing mechanisms. However, questions can be raised about the generality of the results.

The present study is intended to address these questions:

- Are there individual differences in the ability to exploit syntactic and pragmatic informational cues in the linguistic signal?
- Do individual differences in working memory affect the processing of syntactic and pragmatic anomaly unequally?

# Individual Differences Experiment

## Method

**Subjects**
Thirty-four individuals were paid to participate. All were native speakers of English in the age range of 16 to 24 years who met a minimum standard for literacy as assessed by the Fast Reading subtest of the Stanford Diagnostic Battery. All participants reported their vision to be normal or corrected to normal. Participants had no knowledge of the purpose of the experiment and no prior exposure to the test materials.

Subjects were partitioned into high and low working memory groups based on a median split of scores on a test of verbal working memory (Daneman & Carpenter, 1980).

| Memory Group | |
|---|---|
| High | Low |
| 36.06 (2.36) | 26.56 (3.22) |
| (max possible score = 42) | |

**Apparatus**

Eye-movements were recorded with an Eyelink II eye-tracker manufactured by SR Research at a sample rate of 250hz. Sentences were presented in a monospace font on a computer monitor positioned 64 centimeters from the subjects' eyes. Font size was such that each character subtended about 17 minutes of visual arc.

**Materials and Design**

Materials were adapted from those used in Braze et al. (2001). Twenty-eight target sentences were blocked and counter-balanced such that subjects saw an equal number of each type. Target sentences were pseudo-randomly interspersed among ninety-six foils.



## Example Sentences

- The shirt will surely wrinkle unless it is washed in warm water. NA
- The shirt is surely wrinkle unless it is washed in warm water. SA
- The bus will surely wrinkle unless it is washed in warm water. PA
- The bus is surely wrinkle unless it is washed in warm water. DA

For the purpose of aggregating reading times and identifying regressive eye movements, each sentence was divided into regions of about 2 words each, as show:

- The shirt●will surely●wrinkle unless●it is●washed in●warm water.

Based on the outcome of earlier work, our analysis focuses on two sentence regions: the verb containing region (region 3) and the sentence final region (region 6). These are the sentence regions where eye-movement patterns have proved particularly responsive to the experimental manipulations. The modal response to syntactic anomaly showed up at the anomalous verb, while the modal response to pragmatic anomaly emerged much later, at sentence end.

## Predictions

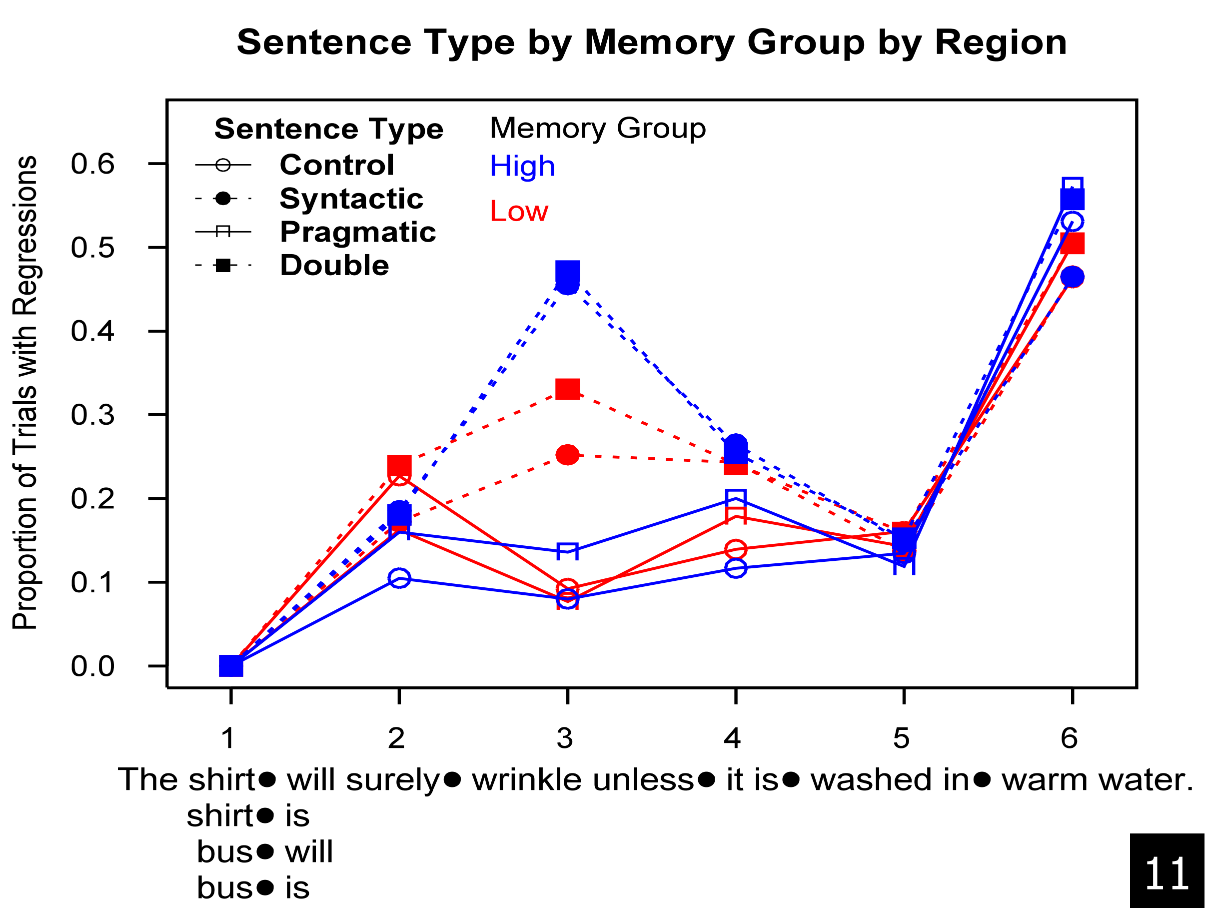
We predict that readers with low memory capacity will have more frequent and less well-targeted regressive eye-movements than high capacity readers, and that the difference will be accentuated in the case of pragmatically anomalous sentences.

## Results

- First-pass reading times show a significant or marginal main effect of Memory Group in every sentence region, but no other effect approaches significance in any sentence region.
- First-pass regressions:
  - At sentence region 3 (containing the verb) a three-way ANOVA was conducted (PragmaticAnomaly X SyntacticAnomaly X MemoryGroup). A reliable main effect of Syntactic Anomaly [$F1(1,33)=74.98$, $p<.0001$ ;$F2(1,27)=64.42$, $p<.0001$] and a marginal main effect of Memory Group [$F1(1,33)=3.84$, $p=.058$, ;$F2(1,27)=16.21$, $p<.001$] are qualified by the Syntactic Anomaly X Memory Group interaction [$F1(1,33)=4.62$, $p<.05$ ;$F2(1,27)=8.19$, $p<.01$]. No other effects approached significance. The interaction results from the fact that, in the presence of syntactic anomaly, low memory readers regress less often than high memory readers [$F1(1,33)$ ;$F2(1,27)$].
  - At sentence region 6 (sentence end), the same three way ANOVA failed to uncover any significant effects, contrary to the results from our earlier studies.

- Panel 11 shows the incidence of regressions from each region for each sentence type and Memory Group.





Distribution of Regression Targets for Regressions from Region 6 (frequency and column-wise percentages)

- **High Memory**

| Target | Anomaly Condition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Region | non-anom. | | syntactic | | pragmatic | | double | |
| 1 | 22 | 40.7 | 24 | 51.1 | 32 | 52.5 | 29 | 46.0 |
| 2 | 12 | 22.2 | 6 | 12.8 | 14 | 23.0 | 17 | 26.0 |
| 3 | 1 | 1.8 | 2 | 4.3 | 2 | 3.3 | 5 | 8.0 |
| 4 | 7 | 13.0 | 3 | 6.4 | 3 | 4.9 | 5 | 8.0 |
| 5 | 12 | 22.2 | 12 | 25.6 | 10 | 16.4 | 7 | 11.1 |
| sum | 54 | | 47 | | 61 | | 63 | |

- **Low Memory**

| Target | Anomaly Condition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Region | non-anom. | | syntactic | | pragmatic | | double | |
| 1 | 9 | 17.6 | 17 | 36.2 | 19 | 38.8 | 20 | 38.5 |
| 2 | 8 | 15.7 | 8 | 17.0 | 10 | 20.4 | 7 | 13.5 |
| 3 | 3 | 5.9 | 2 | 4.3 | 4 | 8.2 | 4 | 7.7 |
| 4 | 3 | 5.9 | 3 | 6.4 | 1 | 2.0 | 4 | 7.7 |
| 5 | 28 | 54.9 | 17 | 36.2 | 15 | 30.6 | 17 | 32.7 |
| sum | 51 | | 47 | | 49 | | 52 | |



- Panel 12 shows the distribution of target regions for regressions launched from sentence end (region 6).
  - As in our earlier study, distribution of regression targets for pragmatically anomalous sentences differs from that of sentences not containing a pragmatic anomaly [$X^2(4)=11.23$, $p< .05$]
  - Distribution of targets for Syntactically Anomalous sentences does not differ from that of regression targets for non-syntactically anomalous sentences. Nor is the interaction Syntactic Anomaly X Pragmatic Anomaly significant.
  - The effect of Pragmatic Anomaly on regression targets is, however, qualified by the interaction of Memory Group X Pragmatic Anomaly [$X^2(12)=36.58$, $p<0.001$] and also by the interaction of Memory Group X Syntactic Anomaly X Pragmatic Anomaly [$X^2(28)=50.06$, $p<.001$].

# Summary and Conclusion

- Working memory (measured by sentence span) was used as an indexing variable because, as is well known, language comprehension differences, and especially reading comprehension differences, are correlated with working memory span (Daneman & Carpenter, 1980).
  - Earlier results with college students indicated that eye-movement patterns in processing some sentences reflect working memory differences (Crain, Ni, Shankweiler, Conway, & Braze, 1996).

- Individual differences were observed in the rate of regression
  - Syntactic anomaly shows a pronounced influence on regression frequency at the verb, although significantly weaker for low memory than for high memory individuals.
  - Contrary to expectation, neither high span nor low span subjects showed the signature effect of pragmatic anomaly, increased frequency of regressions from sentence end.

- An effect of pragmatic anomaly was obtained on a different measure of eye regression behavior, however.
  - The effect appeared in the distribution of landing sites of regressions. As observed in earlier research, the presence of pragmatic anomaly often triggers long regressions from the end of the sentence to the earliest portion of the



sentence, whereas sentences without pragmatic anomaly do not generate this pattern of regression targets. In the present experiment, this effect is qualified by the interaction of Pragmatic Anomaly, Syntactic Anomaly, and Memory Group.

In sum, we found individual differences in eye-movement patterns associated with reading the anomaly materials, although the differences were not entirely those we had predicted. Our high span participants behaved much like the college students we studied previously with regard to syntactic anomaly. In contrast, low-span subjects showed reduced sensitivity to syntactic anomaly and possibly to pragmatic anomaly as well, taking account of regression landing sites. However, the reduced sensitivity of low span subjects to syntactic anomaly probably does not indicate that these rather egregious anomalies were undetected. There is no support in these data for the expectation, based on our conception of working memory, that pragmatic anomalies of these sorts pose greater costs to the processor than the syntactic anomalies we have studied (Crain et al., 1996).

Partly because of the puzzles they engender, these findings point up the need for further studies of sentence parsing to embrace a wider spectrum of individual differences than those afforded by a college student population.

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