Published in final edited form as:

J Psycholinguist Res. 2002 January ; 31(1): 25–44.

Readers' Eye Movements Distinguish Anomalies of Form and Content

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Abstract

Evidence is presented that eye-movement patterns during reading distinguish costs associated with the syntactic processing of sentences from costs associated with relating sentence meaning to real world probabilities. Participants (N=30) read matching sets of sentences that differed by a single word, making the sentence syntactically anomalous (but understandable), pragmatically anomalous, or non-anomalous. Syntactic and pragmatic anomaly each caused perturbations in eye-movements. Subsequent to the anomaly, the patterns diverged. Syntactic anomaly generated many regressions initially, with rapid return to baseline. Pragmatic anomaly resulted in lengthened reading times, followed by a gradual increase in regressions that reached a maximum at the end of the sentence. Evidence of rapid sensitivity to pragmatic information supports the use of timing data in resolving the debate over the autonomy of linguistic processing. The divergent patterns of eye-movements support indications from neuro-cognitive studies of a principled distinction between syntactic and pragmatic processing procedures within the language processing mechanism.

Virtually all models of comprehension and production of multi-word utterances acknowledge the application of constraints on how words can be structurally combined in parsing an utterance, or, alternatively, in production. Apprehension of syntactic structure is an integral part of language processing. In normal listening or reading, syntactic processing is intertwined with the derivation of meaning. It is possible, nonetheless, to show that these processes are dissociable. As Chomsky (1957) pointed out long ago, the possibility is revealed in the way people respond to various types of nonsense material. For example, "Jabberwocky" sentences, made up largely of non-words, can be parsed without understanding what the words mean. So, in Lewis Carroll's well-known poem, the word-like element "brillig" is treated as a noun and "gyre" and "gimble" are treated as verbs. Moreover, sentences that contain a *grammatical* violation may also yield evidence of dissociability of syntactic and semantic processing. For example, in the sentence "he *wear* socks under his sandals," we readily detect the anomaly, but the meaning is transparent.

The interplay of syntactic and semantic processes within the language processor has become a target of experimental investigation, both in psycholinguistic studies of the time course of

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on-line sentence processing and in neuro-linguistic studies of the effects of brain damage or of concomitant brain activity in non-impaired individuals. The introduction of anomaly into stimulus material offers a way to seek parallels between findings based on behavioral analysis and those directed at elucidating the neural underpinnings of language processing. In this connection, event-related brain potentials (ERPs) in response to linguistic stimuli yield phenomena that buttress the case for dissociability in processing structure and meaning. A well-established finding in the ERP literature is that the occurrence of a word that makes the meaning of a sentence anomalous gives rise to a distinct waveform in the centro-parietal region 350 to 500 ms after the onset of the anomalous word, the N400 (Kutas & Hillyard, 1980). Grammatical violations do not elicit the N400. However, ERP phenomena that register the occurrence of syntactic anomalies have been described in recent years. These include two negative-going waves. The earlier of these has a left-anterior distribution and peaks in the range of 130–180ms (Friederici, Pfeifer, & Hahne, 1993; Gunter, Stowe, & Mulder, 1997; Neville, Nicol, Barss, Forster, & Garrett, 1991). The second syntactic negativity has a left-temporal distribution and peaks at 300–500 ms (Friederici et al., 1993; Gunter et al., 1997; Neville et al., 1991). A later positive-going wave, the syntactic positive shift, or P600, may be associated with second-pass processing (Friederici, Steinhauer, & Frisch, 1999; Neville et al., 1991; Osterhout & Holcomb, 1992). In sum, these indicators distinguish between anomalies of meaning and syntactic form, although the issue of relative timing is not resolved.

Studies based on functional neuroimaging (Helenius, Salmelin, Service, & Connolly, 1998) yield findings that are largely in accord with the ERP findings. Thus, Helenius and her associates, using magneto-encephalography (MEG), detect a cortical response to a semantically anomalous word centered in the left temporal or neighboring parietal region. This activity is reminiscent of the familiar N400 phenomenon (of ERP) in that it occurs within the same time frame with latency of 300–500 ms. Further, our own research group, Ni et al. (2000), using event-related fMRI, studied effects of anomalies of structure and meaning on brain responses within the same group of listeners. The findings show evidence of dissociation within the perisylvian region: syntactic anomaly results in activity primarily in anterior regions of the left hemisphere, whereas semantic anomaly gives rise to a wider pattern of activity, distributed over both hemispheres, with a concentration in the posterior temporal region (consistent with Helenius et al.).

In view of these converging indications of syntactic dissociability, we decided to re-examine pertinent evidence from on-line behavioral studies, where the picture has been less clear. The record of eye-movements while a sentence is being read offers a time-tested vantage point from which to disentangle processes underlying comprehension. This is the approach we adopt in the present study. The sequential path and timing of successive eye fixations during reading is influenced by a variety of factors, including lexical, phrasal, and discourse properties of the text. Two measures obtained from the eye-movement record, regional reading times and frequency of leftward (regressive) eye-movements, yield information about processing difficulty that is not readily available to introspection. Elsewhere, we have speculated that first-pass reading time reflects the influence of information that is rapidly assimilated by the reader, whereas regressive eye-movements may reflect a processing barrier that cannot immediately be overcome (Crain, Ni, Shankweiler, Conway, & Braze, 1996; also see Ehrlich & Rayner, 1983; Frazier & Rayner, 1982; Kennedy, 1983). Brain activity and eye-movements are, of course, different kinds of phenomena. However, they are arguably similar in that each is sensitive to early, automatic processes in parsing (as distinguished from off-line tasks such as meta-linguistic judgments of grammaticality or meaning). If so, then sentence processing effects on which patterns of brain activity and eye-movement indicators coincide should be especially telling. We can anticipate that each aspect of the eye-movement record will yield clues about how a reader allocates cognitive resources while processing sentences that present challenges to the syntactic or meaning-related dimensions of language comprehension.

Pursuing this possibility, the present study compares the eye-movement patterns of subjects as they read (for meaning) sentences containing anomalies of verbal morpho-syntax, and anomalies that depend on the relationship between sentence meaning and real-world probabilities (we refer to these as pragmatic anomalies), and non-anomalous sentences. Each type is illustrated in Figure 1; sentence (1a) is rendered anomalous by introducing a syntactic violation while keeping the meaning transparent and plausible, while (1b) is made pragmatically anomalous by a word that makes the content odd or absurd without compromising grammatical correctness. One measure on which we might expect to find evidence supporting a distinction in the way the parser copes with syntactic and pragmatic anomaly is in the time the eyes linger in the region of the anomalous word. For example, if the parser's sensitivity to syntactic information is manifested earlier in time than its sensitivity to aspects of sentence meaning (e.g. Boland, 1997;McElree & Griffith, 1995), we might see longer eye fixations at a word that is syntactically unexpected than at a word that is pragmatically unexpected. But in a recent study of anomalous sentences conducted in our laboratory (Ni, Fodor, Crain, & Shankweiler, 1998), from which the sentences in Figure 1 are drawn, we found no evidence in the eye-movement record of a delay in initial sensitivity to pragmatic constraints (see also Murray & Rowan, 1998). Detection of the two kinds of anomaly was rapid and simultaneous. Thus there was no support for the prior availability of syntactic information within the parsing mechanism.

But the apparent simultaneous availability of the two types of constraint does not imply that the parser responds to syntactic and pragmatic anomaly in the same way. Even if detected simultaneously, each kind of information may be put to use at a different subsequent time by a different component of the sentence processing system. In fact, an examination of the pattern of eye-movement responses to anomalies of the two kinds showed that they were non-equivalent. Ni et al. (1998) found that, although both syntactic and pragmatic anomalies elicited simultaneous effects, each kind of anomaly played out subsequently in a distinctive way. This was true both of regional reading times and frequency of regressive eye-movements. For syntactic anomalies the incidence of regressions was immediately elevated at the point of anomaly and just beyond, thereafter returning to the baseline. In contrast, frequency of regressions for pragmatic anomalies increased progressively from the point of anomaly to the end of the sentence. Regional reading times for pragmatically anomalous sentences showed a similar monotonic increase; at no point did reading times for syntactically anomalous sentences rise above baseline. Thus, in keeping with the ERP and neuroimaging findings, a clear contrast between syntactic and pragmatic anomaly was in evidence.

The present study examined eye-movements during reading, with sentence materials similar to those of Ni et al. (1998). The goal was to look for additional manifestations of the parser's differential response to syntactic and pragmatic anomaly, including evidence of early sensitivity to pragmatic content together with evidence of a delay in interpretive commitment. Especially, we sought to determine how the pattern of regressive eye-movements is related to type of anomaly, both at the source, and subsequently, in later portions of the sentence. Therefore, we considered the incidence of regressive eye-movements, and, in addition, we compared the landing sites of regressions for each anomaly type. Does the pattern of regression landing sites fit the expectation that leftward saccades signal a break-down in the ongoing parsing routine, and reflect a need to re-read the sentence from a point prior to the anomaly? How does the pattern differ between syntactically and pragmatically triggered regressions? To examine how eye-movements play out in later portions of the test sentences, our materials incorporate sentence codas (post-anomaly portions) that are as long as feasible given the constraints of the eye-track technique. Finally, we sought to determine whether variation in processing load prior to the point of anomaly influences readers' responses to anomaly. Accordingly, we varied length and frequency of the subject noun preceding the anomalous verb. Imposing a decoding challenge prior to the anomaly might plausibly reduce a reader's capability to cope with the anomaly.

Method

Subjects

Thirty undergraduate students were paid to participate. All were native speakers of English with vision they reported to be normal or corrected to normal with soft contact lenses. Participants had no knowledge of the purpose of the experiment and had no prior exposure to the test materials.

Apparatus

Eye-movements were recorded with a Skalar 6500 eye-tracker. The system uses infra-red transducers positioned in front of the eye to detect eye-movements. The output is a continuously varying analog signal corresponding to gaze direction, which was digitized with a 1 ms sampling rate. A forehead rest and individually prepared bite bars were used to stabilize subjects' head positions in order to minimize noise in the signal due to head movements. Sentences were presented on a computer monitor positioned 64 centimeters from the subjects' eyes.

Materials and Design

Thirty-six sentence frames were devised to allow introduction of anomaly through manipulation of the main verb. Subject noun length was also varied within each frame. Three anomaly conditions were crossed with two noun length conditions to generate six versions of each sentence; see Figure 2.[1] The anomaly conditions, *syn*tactic anomaly, *prag*matic anomaly, and non-anomalous *con*trol, were fashioned by alternating the main verb within each sentence frame. In the syntactic anomaly condition the inflection of the verb conflicted with a preceding modal, but pragmatic congruity was preserved. In the pragmatic anomaly condition, the verb's pragmatic content was incongruous with the subject noun phrase, yet syntactic congruity was retained. Finally, in the control condition, both the verbal inflection and meaning were congruous with preceding material. Crucially, the syntactic anomaly introduces a violation of grammatical principles, while the pragmatic anomaly does not. Subject nouns are either *L*ong (mean length 9.94 letters, sd = 1.88) or *S*hort (mean length 5.39 letters; sd = 1.18).[2] Long and short nouns in each frame were selected to establish equivalent pragmatic expectations. Sentence frames contain 6–8 words after the anomaly (mean = 7.19, sd = .47). Other than the alternations of main verb and subject noun, the lexical content of each frame was held constant.

For both types of anomalous sentence the information leading to the incongruity resides in the relationship between the verb and some preceding word. All information relevant to the anomalies is available in the sentence at, or prior to, the verb. Verbs (stems) were frequency matched across anomaly conditions (Francis & Kucera, 1982). Roughly one-half (16) of the syntactically anomalous forms carry the progressive (*-ing*) affix while the rest carry the past-tense inflection. Each verb used in a syntactic anomaly (and control) in one frame was used in a pragmatic anomaly in another frame. Therefore, the verb sets are counterbalanced across items. The complete experimental materials are in appendix A.

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[1]We speculated that impaired readers might be especially sensitive to the greater processing load imposed by decoding long subject nouns, such that the difficulty engendered may persist to the point of anomaly and influence readers' capacity to cope with the anomaly itself. However, that surmise must await future affirmation. The present study, which includes only non-impaired readers, did not result in consistent effects of subject-noun length on eye-movement patterns associated with sentence anomaly.

[2]Length and frequency are correlated, of course; the set of long nouns is reliably lower in frequency that the set of short nouns (Francis & Kucera, 1982).

Each sentence within a frame appeared in one of six presentation lists. Each list contained six sentences in each of the six conditions, blocked to ensure that they were evenly distributed. The thirty-six target sentences in each list were interspersed quasi-randomly among 72 filler sentences. Of the fillers, 25 (35%) were anomalous so that anomalous target items were not conspicuous. Nine fillers preceded the first target sentence.

Procedure

After being briefed on the procedure, the subject was positioned in front of the eye-tracker, seated in a height-adjustable chair. A bite-bar was prepared and the forehead rest adjusted. The eye-movement sensor was then aligned before the right eye. The eye-tracker was calibrated using a series of five fixed targets distributed across the display. Sentences appeared on the monitor one at a time on a single line, with a maximum length of 76 characters. Each character subtended just over 12 minutes of visual arc. Viewing was binocular but eye-movements were recorded from the right eye only.

Before presentation of each sentence, a fixation target appeared at the screen position to be occupied by the sentence initial character. Subjects were instructed to focus on this point before clicking a computer mouse to display the sentence. This ensured that eye-movement records began uniformly with the initial word in each sentence. Subjects were asked to read each sentence for comprehension with normal speed. To ensure that subjects were not sacrificing understanding for speed, irregularly distributed comprehension questions followed 24 target trials and 12 filler trials. Subjects responded to the questions by clicking YES or NO with the mouse. Corrective feedback was given. Every trial was preceded by a brief calibration check. Adjustments were made as necessary.

Methods of Analysis

To examine the running record of eye-movements as a sentence unfolds, we initially divided each target sentence into six regions of approximately two words each, for the purpose of aggregating reading times and classifying leftward eye-movements, as shown in Figure 3. For each sentence frame, corresponding regions contain the same numbers of words in all six versions.

Region 1, the subject noun phrase, is 1 or 2 words long, Region 2 is a modal verb followed by an adverb. Region 3 is the main verb and the word following. Regions 4 and 5 also contain two words each. Region 6, the sentence final region, contains 1–3 words. In addition, we present the results of a second analysis that focuses on the portion of the sentence that initiates the anomaly, namely the verb, plus three immediately succeeding words. In this analysis, reading times and regressions are aggregated for each word individually.

The data were analyzed in terms of first-pass reading times and incidence of first-pass regressive eye-movements, tabulated separately for each sentence region. First-pass reading time is the summed fixation durations within a region, beginning with the first fixation inside the region and ending with, but not including, the first subsequent fixation outside the region. Reading times were statistically adjusted to compensate for inequalities in verb length across anomaly conditions. The correction was calculated separately for each subject, using a linear regression with region length (number of letters and spaces) as regressor and first-pass reading time as dependent variable. Deviations from predicted reading times were used as the length-corrected reading time measure in subsequent analyses (Trueswell, Tanenhaus, & Garnsey, 1994). As residual reading times obscure the actual time spent reading any particular region, uncorrected first-pass reading times are shown in Appendix B.

A region is counted as having a first-pass regression if its final first-pass fixation ends in a backward glance to an earlier part of the sentence. Within-region leftward eye-movements are not classified as first-pass regressions. The number of times each region is revisited was also tabulated. Since an initial regressive saccade is often followed by additional regressions resulting in a chain of backward eye-movements, or a regression path (Konieczny, Hemforth, & Scheepers, 1997), we count the regression target as the left-most sentence region visited during such a chain.[3] Both first-pass reading time and first-pass regression frequency are contingent upon there being at least one fixation of 50 ms or longer within the region (Carpenter & Just, 1983). Regions not meeting this criterion are excluded from the analyses.

Results

The focus of interest is on the effect of each anomaly condition on reading times and regressions at each sentence region. Table 1a shows mean residual reading times for syntactically and pragmatically anomalous sentences and non-anomalous control sentences for the 6 sentence regions indicated in Figure 3; Table 1b gives the same breakdown for regressions. Analyses of variance allowing generalization to subjects (F1) and items (F2) were conducted on residual reading times and on the frequencies of regressive eye-movements. We initially subjected the data to a three-way ANOVA: (3 anomaly conditions) × (6 sentence regions) × (2 subject noun lengths; See footnote 1). The interaction of interest was reliable both for reading times [$F1(10, 290) = 2.51$, $p < 0.01$; $F2(10, 350) = 3.14$, $p < 0.001$] and regressions [$F1(10, 290) = 14.54$, $p < 0.0001$; $F2(10, 350) = 12.72$, $p < 0.0001$]. Given this support for our expectation that eye-movements would play out differently for the different sentence types, we examined reading times and regressions in each sentence region from the point of anomaly forward.

Reading times show an immediate influence of anomaly at the region containing the verb, [$F1(2, 58) = 4.65$, $p < 0.05$; $F2(2, 70) = 5.34$, $p < 0.01$]. Sentences with pragmatic anomalies (*bite*) have longer reading times than non-anomalous sentences (*crack*) [$F1(1, 58)= 9.30$, $p < 0.01$; $F2(1,70) = 7.78$, $p < 0.01$], while those with syntactic anomalies (*cracking*) are marginally longer than controls [$F1(1, 58) = 4.61$, $p < 0.05$; $F2(1,70) = 2.91$, $p < 0.1$] (Figure 4a). However, syntactic anomalies generate dramatically more regressions from the verb region than non-anomalous sentences [$F1(1, 58) = 118.82$, $p < 0.0001$; $F2(1, 70) = 88.61$, $p < 0.0001$]. Pragmatic anomaly, on the other hand, gives rise to no more regressions from this region than the control sentences (Figure 4b). Comparing Figure 4a and 4b, we see that the parser's earliest sensitivity to syntactic anomaly is registered in a different component of the eye-movement record than is the response to pragmatic anomaly, but, so far as can be seen within the two-word regions shown in Figure 3, at essentially the same moment.

The influence of anomaly on reading time persists to region 4, the two-word region that follows the verb-containing region [$F1(2,58) = 4.65$, $p < 0.02$; $F2(2,70) = 5.06$, $p < 0.01$], largely due to a difference between the two anomalous sentence types [$F1(1,58) = 9.69$, $p < 0.01$; $F2(1,70) = 10.72$, $p < 0.01$], although pragmatic anomaly continues to induce reading times above the baseline [$F1(1,58) = 4.15$, $p < 0.05$; $F2(1,70) = 5.01$, $p < 0.05$]. In the same region, the incidence of regressions for pragmatic anomalies rises above baseline [$F1(1,58) = 7.40$, $p < 0.01$; $F2(1,70) = 6.61$, $p < 0.05$]. Regressions due to syntactic anomalies have begun to fall, but are also still above baseline [$F1(1,58) = 4.42$, $p < 0.05$; $F2(1,70) = 3.86$, $p = 0.05$]. By the penultimate region no significant differences are found in reading times or regressions. At sentence end, however, the effect of anomaly on regressions resurfaces [$F1(2,58) = 7.68$, $p < 0.005$; $F2(2,70) = 8.30$, $p < 0.001$]. This is due to a marked increase in regressions over baseline in the pragmatic case [$F1(1,58) = 12.05$, $p < 0.001$; $F2(1,70) = 15.55$, $p < 0.001$], as is apparent from Figure 5.[4]

[3]Results similar to those reported below are obtained when considering initial regression landing sites.

In order to examine the region containing the anomaly in greater detail, we divided the critical region 3 into its two component words -- the verb and the following word -- and computed residual reading times and regressions for each word individually (Table 2). Region 4 was treated similarly. This finer grained analysis, unlike the previous one, reveals a difference in the apparent onset of syntactic and pragmatic effects. For syntactic anomaly, increase in incidence of regressions over baseline is evident at the verb [$F1(1,58) = 52.09$, $p < 0.0001$; $F2(1,70) = 47.50$, $p < 0.0001$] as well as the word following the verb [$F1(1,58) = 21.72$, $p < 0.0001$; $F2(1,70) = 27.37$, $p < 0.0001$]. However, for the items containing a pragmatic anomaly, there is no increase in either reading time or incidence of regressions from the verb itself, relative to control sentences. At the word following the verb, pragmatic anomalies show elevated reading times [$F1(1,58) = 5.40$, $p < 0.05$; $F2(1,70) = 2.58$, $p < 0.15$] and incidence of regressions [$F1(1,58) = 8.31$, $p < 0.01$; $F2(1,70) = 12.21$, $p < 0.001$] as compared to control sentences. The influence on reading times carries over to the first word of region 4 as well [$F1(1,58) = 5.18$, $p < 0.05$; $F2(1,70) = 5.85$, $p < 0.05$].

The distribution of regression landing sites for regressions originating in the sentence final region is shown in Table 3.[5] There is a significant influence of anomaly type [$\chi^2 (8) = 37.68$, $p < 0.0001$]. Pairwise comparisons show that pragmatic anomalies result in a different distribution of landing sites than either controls [$\chi^2 (4) = 27.86$, $p < 0.001$] or syntactic anomalies [$\chi^2 (4) = 22.24$, $p < 0.001$], which do not differ from each-other. So, not only do pragmatic anomalies provoke more regressions from the sentence-final region, but those regressions land, on average, much closer to the beginning of the sentence than do regressions for either controls or syntactic anomalies. These differences in landing sites give additional evidence that the parser uses pragmatic and syntactic information differently to guide re-reading.

Discussion

In the present study we confronted the sentence processor with form-based and meaning-based anomalies. We show that the eye-movement indicators of syntactic and pragmatic processes each display a distinct signature, in keeping with expectations generated by the ERP and neuroimaging studies, and with the earlier eye-movement findings of Ni et al (1998). In the analysis based on 2-word regions (Table 1 and Figure 5), and also in the more detailed analysis of the critical region containing the anomaly (Table 2), we see confirmation that the sentence processor responds differently to each kind of anomaly. Syntactic anomalies trigger regressions in the region containing the verb, followed by a return to baseline. Pragmatic anomalies induce lengthened reading times, beginning at this region, and a spate of regressions at the ends of the sentences.

The finer-grained analysis, which takes the individual word as the unit and computes reading times and regressions separately for each of the four words in regions 3 and 4, does show an apparent difference in the timing of the earliest effect of the two types of anomaly on eye-movements. Syntactic anomalies manifest their effect at the verb itself, whereas for pragmatic anomaly the effect is not apparent until the word following the verb. The difference in timing of eye-movements suggests a slight precedence of syntax that is compatible with the findings of McElree and Griffith (1995), using other kinds of measures. The difference may be more apparent than real, however.

[4]Table 1b shows an increase in regressions in region 6 for all three anomaly conditions. We attribute this general rise to a “clause wrap-up effect” (Just & Carpenter, 1980). Of interest here is the fact that pragmatic anomaly triggers an increase in excess of this general effect.

[5]The distribution of regression landing sites for regressions originating in sentence regions 3–5 fail to distinguish the different anomaly conditions.

Analysis of the eye-movement record during sentence processing at the grain of the single word can be difficult to interpret for the following reasons. Processing of a particular word may begin during fixation of the preceding word, and, moreover, a word may be processed even though it does not receive a fixation, as is often the case with function words and other short words (Fisher & Shebilske, 1985). Conversely, processing initiated at a particular word is not always complete before the eye moves on. Effort spent incorporating one word into the analysis of a sentence may influence fixation time on the next word (Ehrlich & Rayner, 1983; Rayner & Duffy, 1986). For these reasons, the timing of eye-movement patterns on single words reflects the timing of text comprehension processes only imperfectly.[6] With the single-word analysis we run the risk of seeking greater precision than the technique is capable of providing. The upshot is that the issue of relative timing of the processor's response to anomalies of the two kinds is still an open question. We can be confident, however, that information regarding each type of anomaly is available to the processor within the time frame delineated by the two-word region containing the verb.

Examination of the eye-movement record beyond the point of anomaly yields additional information that is essential to a proper understanding of the differing effects of syntactic and pragmatic incongruities. The present study incorporates sentences with long post-anomaly codas, permitting an examination of the parser's response as reading continues beyond the anomalous region. The response to syntactic and pragmatic anomaly differs not only at the anomalous verb, but also in later portions of the sentence. The eye responds to syntactic anomalies immediately, but the departure is relatively brief. By the time the fourth word following the verb (region 5) is fixated, there is no detectable difference between syntactically anomalous sentences and controls. This is consistent with a model in which syntactic processes are rapid and mandatory. Pragmatically anomalous sentences incur more regressions than control sentences or syntactically anomalous sentences as reading continues beyond the point of anomaly, as we found both here and in Ni et al. (1998). Thus there is evidence of a delay in the integration of pragmatic information.

Evidence pointing to a separation in the availability and use of pragmatic information is pertinent to the issue of division of labor within the sentence processing system. As Fodor et al. (1996) observe, a dissociation in the availability and the use of extra-linguistic information during sentence comprehension is to be expected of a system that represents form separately from content. In the present study, slowed reading at the point of anomaly (region 3) in the pragmatic condition confirms that pragmatic information is rapidly available to the processing mechanism, as Ni et al. (1998) maintained. Yet, in each study, disruption of eye-movements due to pragmatic anomaly reaches its maximum in the sentence-final region. In the present study, this occurs after regressions and reading times have dropped to baseline in the penultimate region. Clearly, the integration of pragmatic information, accessible no later than the word following the anomalous verb, is deferred until sentence end. This contrasts sharply with the apparent immediate, but short-lived, impact of syntactic anomaly and supports other evidence of qualitative differences in structural and interpretive operations.

Regressive eye-movements have been interpreted as indicators of the processor's inability to incorporate material on-line (Crain et al., 1996). Analysis of regressions in the present study supports this hypothesis. Regression from the ends of sentences, in response to pragmatic incongruity at the verb, shows the persistence of the processing difficulty imposed by this type

[6]For mature readers, the average distance across which readers can effectively identify letters is about 8 character widths (Rayner, Well, Pollatsek, & Bertera, 1982), although reading-relevant information can be picked up from a somewhat wider region, up to about 15 characters (Rayner, 1986). Average saccade distance is about 8 characters, although there is considerable variability (Rayner & Pollatsek, 1989), indicating frequent overlap in sampling the stimulus array during successive fixations. The consequence of these considerations is that the window of input available to the processor at any given moment corresponds only imperfectly to the progress of eye-movements through the text.

of anomaly. Support for the hypothesis that regressions signal a breakdown in parsing comes from the fact that these regressions selectively redirect the gaze to the locus of the pragmatic mismatch. Seventy-three percent of regressions from the sentence final region of pragmatically anomalous items landed in the first three regions (Table 3). This is the informative portion of the sentence, where the mismatch occurs between the subject noun (*wall*) and the verb (*bite*). Analysis of regression targets in several studies has shown readers to be adept at consulting that portion of text where comprehension breaks down (Frazier & Rayner, 1982; Kennedy, 1983; Kennedy & Murray, 1987).

In summary, this study confirms that eye-movement measures are sensitive to constraints invoked by syntactic and pragmatic anomalies. Moreover, it confirms that the parser's immediate and subsequent responses to the two anomaly types are distinct. Although there was little difference in the timing of anomaly detection, syntactic anomalies perturbed the processor briefly whereas the effect of pragmatic anomaly was prolonged. These results are consistent with the hypothesis that there is a principled distinction between structural and interpretive processing procedures within the human language processing mechanism. In this respect they are in agreement with results of ERP and functional neuro-imaging studies.

Acknowledgments

The research reported here was supported by Program Project Grant HD-01994 to Haskins Laboratories from the National Institutes of Child and Human Development. We would like to thank David Swinney, Ted Gibson, and an anonymous reviewer for their helpful comments.

Appendix A

1. The ballerinas/dancers will smoothly glide/gliding/jam around the stage as the curtain falls.
2. The snapdragons/asters might even sprout/sprouted/whine early this year in the warm weather.
3. Kindergartners/Children will often cry/crying/rust the first time their parents leave them.
4. The chrysanthemums/roses will soon wilt/wilted/crack if left out of water for very long.
5. The kangaroos/rabbits can easily hop/hopping/wilt over the fence if they want to escape.
6. The helicopters/jets will gracefully soar/soaring/flood through the clear blue morning sky.
7. Alligators/Otters will sometimes swim/swam/ripen ten miles a day in search of food.
8. The margarine/butter will easily smear/smeared/cry over the freshly baked oat bran muffins.
9. The newspaper/paper will surely tear/tearing/prowl if wrapped too tightly around the parcel.
10. Butterflies/Bees will always fly/flying/burn to the brightest flowers in search of food.
11. Razorblades/Knives can easily cut/cutting/spread you if you handle them too carelessly.
12. The generator/engine will softly whine/whined/serve while it is running at low capacity.

13. Mosquitos/Flies will gently hum/hummed/close while hungrily looking for their next meal.
14. The compressor/pump will instantly jam/jamming/hop if the oil leaks from the reservoir.
15. The strawberries/pears will soon ripen/ripening/bind in the warm weather of early June.
16. The temperature/sun does not rise/rose/sing for very long during the arctic winter day.
17. The chimney/wall will surely crack/cracking/bite after a few years in this harsh climate.
18. The rhinoceros/bull might not charge/charged/sprout if we stand very still and pray.
19. Restaurants/Stores don't usually close/closing/swim quite so early this near the holidays.
20. Congressmen/Senators don't always serve/served/leap nearly as honestly as we would like.
21. The screwdrivers/pliers will probably rust/rusting/swerve if left out there in the rain.
22. Sunflowers/Daisies will generally grow/grew/fly quite large if they get enough water.
23. The lanterns/lamps will brightly glow/glowed/glide for the entire week of the festival.
24. The linoleum/tile will brightly shine/shone/hum if thoroughly cleaned with soap and water.
25. The sandcastles/mudpies will soon crumble/crumbled/charge in the unusually hot summer sun today.
26. The motorcycle/car can easily swerve/swerving/crumble around the barrier and evade the police.
27. The meatloaf/cake will probably burn/burned/roll if left in the oven for too long.
28. The spiders/ticks are likely to bite/biting/cut the puppy if they get a chance.
29. The coyotes/dogs can easily leap/leaping/drip over the garden gate if they wish.
30. The popsicles /water will likely drip/dripping/tear all over the brand new persian rug.
31. Nightingales/Finches will often sing/sang/glow their lovely songs the whole night through.
32. The basement/floor will likely flood/flooded/soar again during the heavy rains this spring.
33. Skateboarders/Skaters will often roll/rolling/grow down this hill too quickly to avoid.
34. The gossip/news will surely spread/spreading/shine through the whole office by lunch time.
35. Leopards/Lions will often prowl/prowled/rise all through the night in search of food.
36. Underwear/Socks will sometimes bind/binding/smear when worn for the very first time.

Appendix B

First-pass reading times per two-word region (Figure B-1), and per word in regions 3 and 4 (Figure B-2). Both regional and per-word reading times are contingent upon there being at least one fixation of 50 ms or greater duration on the region or word (Carpenter & Just, 1983).

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a. The cats won't usually eating the food we put on the porch.
b. The cats won't usually bake the food we put on the porch.
c. The cats won't usually eat the food we put on the porch.

Figure 1.

a.	The wall will surely crack after a few years in this harsh climate.	(S con)
b.	The wall will surely bite after a few years in this harsh climate.	(S prag)
c.	The wall will surely cracking after a few years in this harsh climate.	(S syn)
d.	The chimney will surely crack after a few years in this harsh climate.	(L con)
e.	The chimney will surely bite after a few years in this harsh climate.	(L prag)
f.	The chimney will surely cracking after a few years in this harsh climate.	(L syn)

Figure 2.

The wall | will surely | crack after | a few | years in | this harsh climate.

Figure 3.

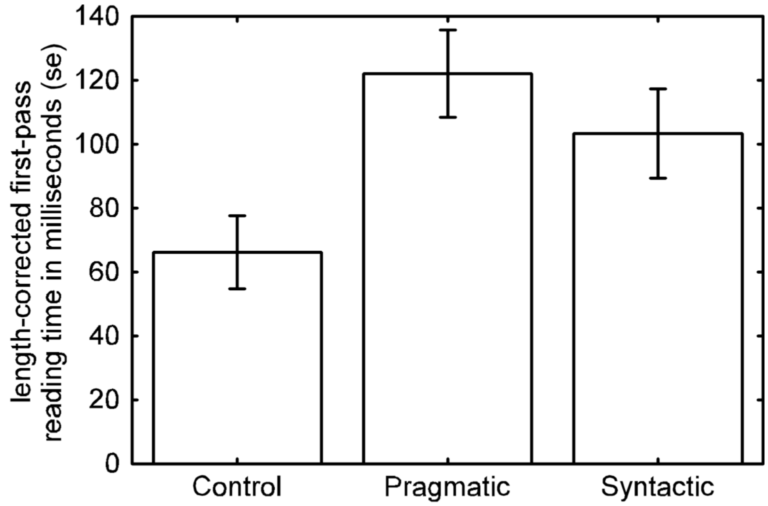

Figure 4a

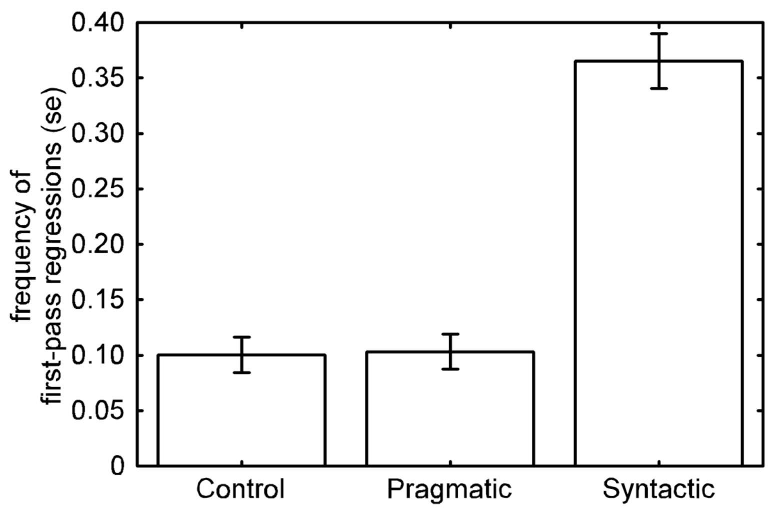

Figure 4b

Figure 4.
(a) Length-corrected first-pass reading times, and (b) frequency of regressive eye-movements for each anomaly condition, in the two-word region containing the verb (region 3). Error bars show standard errors.

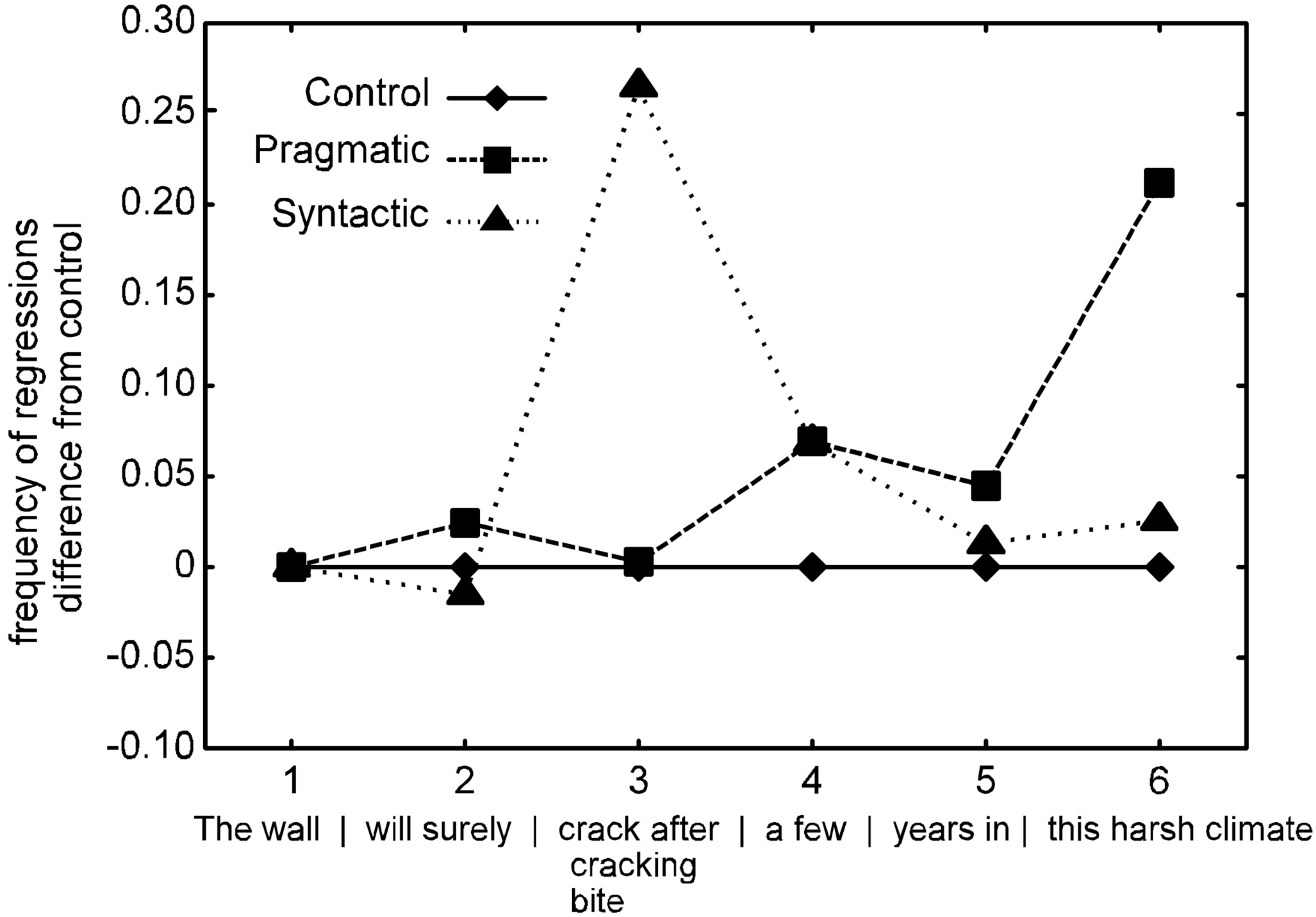

Figure 5.

Frequency of regressive eye-movements for each sentence region as a difference from the control condition.

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Table 1

(a) Mean length-corrected first-pass reading time in milliseconds, and (b) mean frequency of first-pass regressions, for each sentence region (SD).

Anomaly Condition	Sentence Region					
	1	2	3	4	5	6
control	−5	−5	66	−32	14	−124
	(204)	(239)	(218)	(201)	(241)	(241)
pragmatic	−15	11	122	−2	21	−154
	(197)	(229)	(265)	(221)	(220)	(194)
syntactic	−34	29	103	−54	−6	−135
	(196)	(247)	(275)	(179)	(201)	(241)

Table 1a

Anomaly Condition	Sentence Region					
	1	2	3	4	5	6
control	--	0.14	0.10	0.11	0.19	0.40
	--	(0.36)	(0.30)	(0.31)	(0.40)	(0.49)
pragmatic	--	0.17	0.10	0.18	0.24	0.61
	--	(0.38)	(0.30)	(0.39)	(0.43)	(0.49)
syntactic	--	0.13	0.37	0.18	0.21	0.42
	--	(0.34)	(0.48)	(0.39)	(0.41)	(0.50)

Table 1b

Table 2

(a) Mean length-corrected first-pass reading times in milliseconds, (b) mean frequency of first-pass regressions, per word in regions 3 and 4 (SD).

Anomaly Condition	Word Within Sentence Region			
	3a	3b	4a	4b
control	5	−5	−30	−46
	(127)	(130)	(115)	(102)
pragmatic	2	26	−3	−26
	(143)	(152)	(133)	(127)
syntactic	21	8	−25	−37
	(191)	(129)	(116)	(113)

Table 2a

Anomaly Condition	Word Within Sentence Region			
	3a	3b	4a	4b
control	0.08	0.10	0.12	0.12
	(0.27)	(0.30)	(0.33)	(0.32)
pragmatic	0.07	0.22	0.18	0.16
	(0.26)	(0.41)	(0.39)	(0.37)
syntactic	0.27	0.29	0.19	0.09
	(0.44)	(0.45)	(0.39)	(0.29)

Table 2b

Table 3

Distribution of regression landing sites for regressive eye-movements originating in sentence region 6, for each anomaly condition (%).

Sentence Region	Anomaly Condition		
	control	pragmatic	syntactic
1	9 (14.1)	30 (21.7)	8 (10.2)
2	11 (17.2)	41 (29.7)	20 (25.6)
3	3 (4.7)	30 (21.7)	6 (7.7)
4	13 (20.3)	14 (10.1)	13 (16.7)
5	28 (43.8)	23 (16.7)	31 (39.7)

Table B-1

Mean uncorrected first-pass reading time per region, in milliseconds (SD).

Anomaly Condition	Sentence Region					
	1	2	3	4	5	6
control	355	426	465	374	392	173
	(263)	(261)	(247)	(234)	(271)	(258)
pragmatic	324	450	528	397	406	200
	(261)	(248)	(283)	(249)	(247)	(215)
syntactic	321	463	541	341	367	167
	(252)	(268)	(297)	(208)	(234)	(241)

Table B-2

Mean uncorrected first-pass reading time per word for regions 3 and 4, in milliseconds (SD).

Anomaly Condition	Word Within Sentence Region			
	3a	**3b**	**4a**	**4b**
control	303	287	264	257
	(130)	(127)	(123)	(107)
pragmatic	298	314	289	279
	(147)	(154)	(139)	(134)
syntactic	359	294	269	268
	(201)	(132)	(112)	(114)