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**Eye Movements as a Measure of Syntactic and Semantic Incongruity  
in Unambiguous Sentences**

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## Abstract

In one normative and one eye tracking experiment, we investigated the relationship between eye movements and linguistic anomaly detection. We manipulated semantic congruency and two types of syntactic congruency in unambiguous sentences. The three types of manipulations produced different patterns of effects in the first pass measures in the anomalous region. Syntactic congruency affected first pass reading time when the manipulation involved a phrasal category error (substituting a noun phrase for a prepositional phrase), but not when it involved a morphological feature error (subject-verb agreement). Both types of syntactic congruency influenced the likelihood of a first pass regressive eye movement. Semantic congruency did not influence first pass reading time, but it did affect the regression path duration. These findings support a model of language comprehension that marks some distinctions among the construction of syntactic structure, morphological feature-checking, and semantic processing. Furthermore, our findings suggest that we may need to reassess some garden path effects in the literature.

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### **Eye Movements as a Measure of Linguistic Incongruity in Unambiguous Sentences**

Eye movement data from reading have been very influential for evaluating theories of human sentence processing. This is because the eye movement record provides an on-line measure of processing difficulty with high temporal resolution, without relying on any secondary task to produce the dependent measures. Furthermore, we know a lot about factors that influence the planning and execution of saccades, and the duration of fixations, because eye movements have been carefully studied for several decades within the domains of vision, motor control, and language processing (see Rayner, 1998, for a recent review). For example, during reading, factors such as a word's frequency, length, predictability, and ease of integration into the sentence influence how long it takes to access the lexical entry for that word and to incorporate the new lexical information into the structural and conceptual representations the reader is constructing for the sentence (e.g., Pollatsek & Rayner, 1990; Rayner et al., 1996). These same factors are also believed to influence whether the eyes fixate on a word and, if so, how long the fixation is maintained (Just & Carpenter, 1980; Rayner et al., 1998; Rayner et al., 1989; Reichle et al., 1998).

Nonetheless, there are many gaps in our understanding of eye movements and their relationship to cognitive processes. Our overall goal is to identify the relationship between eye movements and some of the cognitive processes that make up normal sentence comprehension, including garden path phenomena. It is well known that readers and listeners develop structural (syntactic) and interpretive (semantic) representations of sentences incrementally, as they read or hear each word. A garden path occurs when a temporarily ambiguous region of a sentence is misanalyzed. The initial analysis becomes anomalous when disambiguating words are encountered later in the sentence. Readers can often recover by restructuring the ambiguous portion. It is commonly assumed that detection of a syntactic, and perhaps semantic, anomaly will evoke longer first pass fixations, regressive eye movements, and re-reading (e.g., Altmann et al., 1992; Ferreira & Henderson, 1990). However, as we describe below, the evidence supporting this assumption is equivocal.

In the current paper, we focus on the eye movement pattern evoked by syntactic or semantic anomalies in syntactically unambiguous sentences. Our experiments were designed to determine which aspects of the eye movement record reflect detection of an anomaly, and to determine whether anomalies of different linguistic types differentially influence the dependent measures that are commonly used in sentence processing research (first pass fixations, percent regressions, etc.). We examined phrasal category violations, subject-verb agreement violations, and semantic violations—representing three aspects of linguistic processing that may be distinguished in models of language comprehension. In our experiments, we separated anomaly detection from the other facets of garden paths, such as ambiguity detection and resolution, by presenting the anomalies in unambiguous sentences. Thus, the anomalies of interest were not caused by misanalysis of an ambiguous region; rather, the sentences were globally anomalous.

We begin by reviewing theories about the structure of the language comprehension system. Next, we describe how garden paths are typically reflected in the eye movement record and the conclusions that have been drawn from such evidence. We then summarize previous eye movement studies that have examined anomaly effects in unambiguous sentences before presenting our experiments.

### **The structure of language comprehension**

Theories of language comprehension vary greatly in the number and type of subsystems proposed. Some accounts maintain that syntactic and semantic processing are essentially independent, creating distinct syntactic and semantic representations (e.g., Altmann & Steedman, 1988; Boland, 1997; Frazier & Clifton, 1996). Others maintain that syntactic and semantic processing are so completely intertwined that phrase-level and sentence-level representations integrate both syntactic and semantic features (e.g., Bates & MacWhinney, 1982; Elman, 1990; Langacker, 1987). Likewise, theories differ with respect to the components of syntactic processing. Some accounts have different processes underlying structure building and feature-based processes such as subject-verb agreement and anaphoric binding (e.g., Crocker, 1992;

Frazier & Clifton, 1996; Gibson, 1991). Other models use feature-based computation for both structure building and agreement/binding (e.g., Kay, 1985; Stevenson, 1994).

The proposal that syntactic and semantic processing and representations are distinct has received some support from traditional behavioral data (McElree & Griffith, 1995; Boland, 1991, 1997). However, most research on this proposal has used event-related potentials (ERP's). Semantic anomalies generally evoke an N400 whereas syntactic anomalies evoke a left anterior negativity (LAN) or a P600 (Ainsworth-Darnell et al., 1998; Friederici & Frisch, 2000; Gunter et al., 1997; Hagoort et al., 1993; Osterhout & Nicol, 1999; Rosler et al., 1993).<sup>1</sup> Thus, at least some aspects of syntactic and semantic processing seem to be distinct. ERP studies may also provide evidence for distinct components within syntactic analysis. Hahne and Jescheniak (2001) proposed that some aspects of structure building precede detailed syntactic analysis, in part because phrase structure rule violations evoke a LAN within 100 to 300 milliseconds (ms) post-stimulus (Friederici et al., 1993; Gunter et al., 1999; Neville et al., 1991). In contrast, morpho-syntactic violations of verb tense, pronoun case, and subject-verb agreement evoke a negativity in the range of 300 to 500 ms (Coulson et al., 1998; Friederici et al., 1993). A possible exception to this generalization is a study reported by Gunter et al. (1997), who found that morpho-syntactic violations in a sentence-final verb evoked a LAN around 150 ms.

The possible temporal distinction between phrase structure violations and morpho-syntactic violations is consistent with theories in which structure building precedes agreement/binding. However, there are at least two variants of this approach. In one, structure building is the process of linking together stored lexical structures, with the assistance of global syntactic rules (e.g., Gibson, 1991).<sup>2</sup> Under such an account, detailed lexical information such as

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<sup>1</sup> The N400/P600 nomenclature denotes the direction and latency of the named component. Thus, an N400 is a negative peak about 400 ms post stimulus and a P600 is a positive wave that arises about 600 ms post stimulus.

<sup>2</sup> Constraint-based lexicalist accounts (e.g., MacDonald et al., 1994; Trueswell et al., 1994) also maintain that detailed lexical information is used to build syntactic structure, but these accounts don't include a distinction between structure building and feature matching.

verb argument structure must be honored. The processing system could not, for example, construct a transitive structure using an intransitive verb (e.g., *The child sneezed the doctor.*) In the alternative approach, initial structure building occurs without regard to detailed lexical information (e.g., Frazier, 1978; Friederici, 1995). Under the first approach, argument structure violations are a type of phrasal construction error; under the second approach, argument structure features such as verb transitivity are checked after the phrase structure tree is initially assembled.

In the current paper, we investigate dissociations between (1) syntactic and semantic processing, and (2) levels of syntactic processing using an eye movement paradigm. In doing so, we follow a handful of similar studies. However, before discussing those experiments, we return to the garden path literature to outline the existing claims about eye movements and sentence comprehension processes.

### **Eye movements and garden path sentences**

Frazier and Rayner (1982) reported one of the first studies to examine eye movements in garden path sentences. Participants read sentences like those in (1), in which the structural position of *a mile* is temporarily ambiguous. It can either be the direct object of *jogs* as in (1a), or the subject of an embedded clause, as in (1b).<sup>3</sup>

- (1) a. *Since Jay always jogs a mile this seems like a short distance to him.*  
 b. *Since Jay always jogs a mile seems like a short distance to him.*

The experimenters expected readers to adopt the direct object structure and to experience processing difficulty in (1b) at the point of disambiguation, which is underlined. As predicted, *seems* was fixated longer and regressive eye movements occurred more frequently in (1b) than in (1a). The combination of long fixations and regressive eye movements at the point of disambiguation has become the hallmark of a garden path in eye movement studies of reading,

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<sup>3</sup> Some readers will be bothered by the absence of a comma in these sentences. However, similar garden path effects are found in other structures without “the comma problem.”

and such effects can be found even when the reader is unaware of any processing difficulty. Because garden paths are generally taken as evidence that the language processing system pursues only one analysis of the ambiguous material, the linking assumption is that the cognitive phenomena of anomaly detection and syntactic reanalysis are reflected in the eye movement data as longer first pass reading times and an increased probability of regressive eye movements.

As noted by Ni et al. (1998; see also Fodor & Inoue, 1994, 2000), anomaly detection plays a central role in the garden path experience. The anomaly at issue may be a breakdown in sentence structure, as in (1b), but sometimes it is a semantic violation, as in (2), from Rayner et al. (1983; see Ni et al., 1996, and Spivey-Knowlton & Sedivy, 1995, for more examples).

(2) *The spy saw the cop with a revolver, but the ....*

Logically, anomaly detection must precede reanalysis. Thus, under a serial analysis theory, anomaly detection must be linked to long initial fixations on the disambiguating material. Such an assumption was made explicit by Frazier and Rayner (1982, p. 193): “When the reader was garden-pathed, there was an awareness at some level on the first fixation in the disambiguating region that something was wrong, as evidenced by a longer fixation duration.” Because regressive eye movements often landed in the ambiguous region, Frazier and Rayner suggested that such regressions “indicate that subjects have detected an error in their initial analysis of the sentence and have identified the source of the error” (p. 203). These particular links between eye movements and the underlying cognitive behavior have been widely accepted over the past two decades. However, there have been some cautionary notes and some conflicting conclusions regarding the interpretation of eye movement data. For example, Rayner et al. (1989) noted that regressions “could reflect not only the existence of an erroneous initial analysis, but also the relative plausibility of competing analyses, the syntactic differences between the initial and the revised analyses, and so on” (p. 38). In fact, Spivey and Tanenhaus (1998) attributed increased reading times to competition between parallel structures--not to anomaly detection and reanalysis. Their constraint-based lexicalist account allows such an attribution because, in contrast to Frazier and Rayner, they assume that syntactic alternatives are postulated and

evaluated in parallel. In short, despite some commonly held assumptions, there are many open research questions concerning the relationships between the dependent measures in eye movement paradigms and the cognitive processes underlying sentence processing.

### **Eye Movements and Anomaly Detection in Globally Anomalous Sentences**

If noticing something anomalous is the initial component of processing difficulty in garden path sentences, then one would expect to see anomaly effects in the first pass fixations on the words that induce the anomaly, and similar anomaly effects should be found on the anomaly-inducing words in a globally anomalous sentence. However, a review of the small eye movement literature on unambiguous, globally anomalous sentences suggests that this is not always true.

Ni et al. (1998) investigated syntactic and semantic anomalies in unambiguous sentences like those in (3). The critical word is underlined, and ungrammatical sentences are starred. Both the syntactic and the semantic anomalies (illustrated in (3a) and (3b), respectively) led to more regressive eye movements compared to the control sentences (3c). The likelihood of an immediate regression, however, was higher for syntactic anomalies than for semantic anomalies. In contrast, only the semantic anomaly induced longer first pass fixations, and only after (rather than during) the anomalous region. Ni et al. interpreted these results to suggest qualitative differences in the cognitive response to the two types of anomalies—differences that are directly reflected in the eye movement patterns.

- (3) a. \**It seems that the cats won't usually eating the food . . .*  
b. \**It seems that the cats won't usually bake the food . . .*  
c. *It seems that the cats won't usually eat the food . . .*

More recently, Braze et al. (in press) focused on regressive eye movements in comparing morpho-syntactic and semantic anomalies. They found that syntactic anomalies elicited an immediate peak in the percentage of regressive eye movements, while semantic anomalies led to a gradual rise in regressions that peaked at the end of the sentence. Braze et al. also reported increased reading times just after the semantically anomalous word.

Pearlmutter et al. (1999, Experiment 2) examined subject-verb agreement errors in sentences like (4). As in Ni et al. (1998) and Braze et al. (in press), the eye movement pattern was dominated by regressions. However, Pearlmutter et al. did find longer first pass fixations for some conditions on a subset of trials. The effect was not localized to the anomalous word alone (*were*), but rather became apparent when fixations on the anomalous word and the following word were summed. Furthermore, the effect was only observed after excluding the trials on which there was a regression out of that region (about 14% of trials), and excluding eight participants who either always or never made regressions out of that region.

- (4) a. *The key to the cabinet was/\*were rusty...*  
b. *The key to the cabinets was/\*were rusty...*

Three important findings emerge from these experiments. First, Ni et al. (1998), Braze et al. (in press), and Pearlmutter et al. (1999) all found that morpho-syntactic anomalies in unambiguous sentences increased the probability of a regressive eye movement. Second, effects of morpho-syntactic anomalies on first pass fixation durations were either absent (Ni et al.), not significant (Braze et al.), or limited to a subset of the trials/participants (Pearlmutter et al.). Third, Ni et al. and Braze et al. found a difference between morpho-syntactic and semantic anomalies, motivating their hypothesis that the eye movement record captures cognitive differences in our response to semantic and syntactic anomalies. This conjecture is similar to claims in the ERP literature that different waveforms are evoked by syntactic and semantic anomalies (e.g., Ainsworth-Darnell et al., 1998; Gunter et al., 1997; Osterhout & Nicol, 1999).

The lack of strong evidence for first pass reading time effects in the syntactically anomalous regions of Ni et al. (1998), Braze et al. (in press), and Pearlmutter et al. (1999) is somewhat surprising. First pass reading time effects are virtually always found in garden path sentences, where they presumably reflect detection of a syntactic or semantic anomaly in the initial analysis. If detection of an anomaly does not typically evoke longer fixations—as the Ni et al. and Pearlmutter et al. data seem to indicate—then the fixation duration effects in garden path sentences require some other explanation. However, it is worth noting that Ni et al., Braze et al.,

and Pearlmuter et al. examined morpho-syntactic violations rather than phrase structure violations. As noted above, there is some evidence from the ERP literature that phrasal category violations are recognized more rapidly (e.g., Friederici et al., 1993). To our knowledge, there have been no previous attempts in the eye movement literature to distinguish between morpho-syntactic and phrasal category violations.

### Experiment 1

We first needed to determine the salience of our anomalies for our experimental participants, because the salience of an anomaly probably influences the strength of eye movement effects (Pearlmutter et al., 1999). Thus, this experiment collected normative data from the participant pool used in the eye tracking experiment.

We used two sets of critical stimuli, an “argument structure set” and an “agreement set.” The first set of stimuli contained verb argument structure violations on the indirect object. An example is given in (5). The anomalous indirect object was either of the wrong phrasal category—a noun phrase (NP) instead of a prepositional phrase (PP) as in (5b)—or had the wrong semantic properties (*signs*), or both. The anomalies in the agreement stimuli were either a syntactic subject-verb agreement violation as in (6b) or a semantic violation in which the sentential subject (*snake/s*) was not a suitable agent for the verb. Thus, in both stimulus sets, the semantically anomalous words were inconsistent with the thematic role that the verb assigned to one of its arguments. However, the syntactic violations were quite different between the argument structure stimuli and the agreement stimuli. The syntactic anomalies in the agreement stimuli were morpho-syntactic agreement violations similar to those used by Ni et al. (1998), Braze et al. (in press), and Pearlmuter et al. (1999). In the argument structure stimuli, the violations reflected a conflict between the verb’s argument structure and the phrasal category of the indirect object.

- (5) a. *Kim recommended Shakespeare to everyone/signs after she saw Hamlet.*  
 b. *Kim recommended Shakespeare everyone/signs after she saw Hamlet.*

- (6) a. *The canary/snake in the large cage sings beautifully.*  
b. *The canaries/snakes in the large cage sings beautifully.*

### Methods

**Participants.** Forty undergraduates from Rutgers University provided acceptability ratings. All were native English speakers.

**Materials and Procedure.** Examples of the critical stimuli are in (5) and (6). The stimuli are described in detail in the Methods section of Experiment 2. The items were randomly ordered and four stimulus lists were constructed by rotating the items across the four experimental conditions and balancing the number of items in each condition. Each list contained 15 congruent and 45 incongruent critical sentences. Thirty-eight congruent and eight incongruent filler sentences were added for a total of 106 sentences.

Ten participants rated each list. The stimuli were presented in paper packets. Each page consisted of a set of sentences, with a numerical scale for each sentence. The scale was from one (labeled “Very Natural”) to five (labeled “Completely Unacceptable”). The front cover of the packet contained instructions and examples of acceptable and unacceptable sentences. Participants were told to read each sentence and assign a rating by circling an integer. They were instructed to rate the sentences in the order presented, without going back to change any answers. Participants completed the task in less than 30 minutes.

### Results

For each item, we computed the mean rating. One item from the argument structure stimuli had to be omitted from the analysis because of an error in the packets. As shown in Table 1, both syntactic and semantic anomaly effects are apparent in the condition means, with better (lower) ratings for the congruent conditions compared to the anomaly conditions. The item means were first submitted to a 2(argument structure vs. agreement stimuli) by 2(syntactic congruency) by 2(semantic congruency) analysis of variance (ANOVA). There was no main effect of stimulus set, but stimulus set interacted with syntactic congruency [ $F(1,57) = 5.14, p <$

.05], semantic congruency [ $F(1,57) = 8.36, p < .01$ ], and the interaction between syntactic and semantic congruency [ $F(1,57) = 8.11, p < .01$ ]. Table 1 suggests that there was a larger effect of syntactic congruency in the argument structure stimuli and a larger semantic effect in the agreement stimuli. Therefore, separate ANOVA's were conducted for each stimulus set.

**Table 1. Mean Acceptability Ratings for Critical Stimuli (1 = most acceptable).**

	Argument Structure Stimuli	Agreement Stimuli
Congruent	1.60	1.80
Syntactic Anomaly	3.99	3.44
Semantic Anomaly	4.09	4.33
Double Anomaly	4.26	4.60

For both sets of stimuli, there were main effect of both syntactic congruency [argument structure:  $F(1,38) = 187.54, p < .01$ ; agreement:  $F(1,19) = 120.42, p < .01$ ] and semantic congruency [ $F(1,38) = 176.12, p < .01$ ;  $F(1,19) = 407.57, p < .01$ ], and an interaction between the two [ $F(1,38) = 121.38, p < .01$ ;  $F(1,19) = 99.72, p < .01$ ]. Paired *t*-tests on the argument structure items revealed that the congruent condition was rated better (lower) than each of the other conditions, while the syntactic and semantic anomaly conditions did not differ from each other ( $\alpha = .05$ ). In the agreement materials, each condition differed reliably from each of the other conditions.

## Experiment 2

We investigated the eye movements evoked by the semantic anomalies and the two types of syntactic anomalies normed in Experiment 1. We anticipated two possible patterns of results for the syntactic anomalies. If phrasal category and morpho-syntactic violations induce a similar cognitive response, both stimulus sets should produce syntactic anomaly effects like those found by Ni et al. (1998), Braze et al. (in press), and Pearlmuter et al. (1999): a higher probability of a first pass regression out of the anomalous region, but little or no effect on first pass fixation duration. However, such a finding would contradict one of the standard claims about garden path

effects in eye movement studies, namely, that longer first pass reading times reflect detection of an anomaly in the initial analysis. In contrast, the garden path literature suggests that phrasal category violations will induce longer first pass times, even if morphological violations do not. Thus, we might find longer first pass reading times for the syntactic anomalies in the argument structure stimuli, but not the agreement stimuli.

Except for Ni et al. (1998) and Braze et al. (in press), we know of no eye movement studies investigating semantic anomalies in unambiguous sentences. However, there have been garden path studies in which a semantic anomaly detected in the initial analysis was purported to induce longer first pass reading times and more regressions (e.g., Rayner et al., 1983). We had two primary goals with respect to the semantic anomalies. First, we wished to determine whether semantic anomalies evoke longer first pass reading times and regressive eye movements in the critical region, as suggested by Rayner et al. (1983). Second, we wished to determine whether or not the eye movement pattern evoked by semantic anomalies would be similar across the two experiments and distinct from the eye movement pattern evoked by syntactic anomalies. Recall that Ni et al. found longer first pass reading times and more regressive eye movements, but not until a few words after the semantically anomalous word.

The argument structure stimuli were taken from an event-related potential study, reported by Ainsworth-Darnell et al. (1998), in which distinct waveform patterns were evoked by syntactic anomalies, semantic anomalies, double anomalies, and well-formed sentences. Thus, we have some independent evidence that people notice these anomalies as they read, and that the syntactic, semantic, and double anomalies evoke cognitively different responses. Furthermore, the difference in response is unlikely to be due to a difference in the strength of the anomalies, because the syntactic and semantic anomalies were judged to be equally salient in the preliminary norms. The agreement stimuli were developed especially for this experiment.

## Methods

**Participants.** Twenty-four Rutgers undergraduates provided the eye movement data. All

participants were native English speakers and had either normal vision or vision corrected to normal with soft contact lenses.

**Materials.** The four conditions in the argument structure stimulus set were built around non-alternating dative verbs. Twenty verbs were each used twice to form forty sets of critical stimuli; the full set of critical stimuli is available in Ainsworth-Darnell et al. (1998). The vertical bars in (7) separate the sentences into four regions: Initial, (potential) Anomaly, Post-Anomaly, and Final. The anomalies were created by violations of the verb's syntactic and semantic constraints on its indirect object. This region consisted of a one-word NP, and also contained the preposition *to* in the syntactically congruent conditions. Non-alternating datives require the indirect object to be in a PP; thus, the congruent condition (7a) is perfectly acceptable, but (7b) is syntactically anomalous at *everyone*. In the semantically anomalous condition (7c), *signs* is syntactically acceptable, but does not meet the verb's semantic constraints. The doubly anomalous condition (7d) is both syntactically and semantically anomalous. We did not match the semantically congruent and incongruent nouns on frequency because we wanted to use the Ainsworth-Darnell et al. stimuli. The semantically congruent nouns were more frequent than the semantically incongruent nouns (126 words per million vs. 60; Francis & Kucera, 1982).

- (7) a. Kim recommended Shakespeare | to everyone | after she | saw Hamlet.  
 b. Kim recommended Shakespeare | everyone | after she | saw Hamlet.  
 c. Kim recommended Shakespeare | to signs | after she | saw Hamlet.  
 d. Kim recommended Shakespeare | signs | after she | saw Hamlet.

For the agreement stimuli, twenty sets of experimental items were constructed, with four versions of each item. The full set is in the Appendix. In half the items, the verb was singular and in half the items the verb was plural.<sup>4</sup> As shown in (8), the only difference across the four

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<sup>4</sup> It is often observed that number agreement has both a syntactic and semantic component. The semantic component is easily observed on the noun (*canaries* clearly means something different than *canary*), but less obvious on the verb (does *sings* mean something different than *sing*?). Because our anomaly becomes apparent at the verb, we consider the agreement error to be primarily syntactic in nature.

conditions was in the number and identity of the subject noun. It was either a good or a poor agent for the main verb. The sentence was divided into four regions: Subject, Modifier, (potential) Anomaly, and Post-Anomaly. Mean verb frequency in the Anomaly region was 80 (Francis & Kucera, 1982).

- (8) a. The canary | in the large cage | sings | beautifully.  
b. The canaries | in the large cage | sings | beautifully.  
c. The snake | in the large cage | sings | beautifully.  
d. The snakes | in the large cage | sings | beautifully.

The two sets of critical stimuli were interleaved into the same stimulus set. Together, they comprised 60 items, 45 of which contained an anomaly. An additional 68 sentences without anomalies and eight sentences that were grammatical, but implausible, were included as distracters. Thus there were 136 sentences in the stimulus list. Yes/no comprehension questions were presented after 54 of the sentences to insure that participants were reading carefully.

**Apparatus and Procedure.** A dental impression was made for each participant. This was attached to an adjustable “bite bar” in order to hold the participant’s head in a fixed position. A stationary forehead-rest and an adjustable chin-rest also helped secure the head in a comfortable fashion. The lights were dimmed in order to provide optimal viewing and measurement conditions. Eye-movements were measured using a Dr. Bouis monocular oculometer, monitoring the right eye. Viewing was binocular. The apparatus continuously output two voltages, corresponding to eye position along the X and Y axes. During the experiment, analog eye position was sampled every ms and converted to screen coordinates.

The sensor of the apparatus was first roughly aligned by mechanical means. It was then further adjusted to give zero-output voltages when the participant looked straight ahead, and balanced positive and negative voltages when the participant looked at equidistant points along the X and Y axes. During the calibration routine, the participant fixated nine points on the computer screen. The obtained voltages were fitted to a regression equation, to establish the relationship between X/Y voltages and screen position. If this could not be done with an error of

less than ten pixels in each dimension, the participant was excused and no data was collected. This criterion was used to check tracking accuracy throughout the experiment. Participants who were successfully calibrated completed ten practice trials and took a short break. Then the set-up was re-calibrated before beginning the experiment proper. All sentences fit onto a single line and were randomized for each participant. For each trial, the screen position and duration of each fixation were computed and stored.

## Results

We analyzed three first pass processing measures at the point of the potential anomaly: (length-corrected) reading times, probability of a regression, and regression path (or “go past”) duration. We do not report total reading times, because all the anomaly types evoked roughly equivalent effects in that dependent measure and because our focus here is on the initial detection of the anomaly. Thus, we also limit our discussion of the results to the Anomaly region, although we include the entire sentence in our figures to give the reader a more complete picture of the data. We preface the results with an analysis of the probability of fixation in the Anomaly region for the two sets of stimuli.

**Probability of Fixation.** The Anomaly region of the argument structure stimuli was the indirect object. It varied from two to fifteen characters and was fixated 90% of the time across conditions. The number of trials with first pass fixations in each participant-by-condition cell was submitted to a 4(list) by 2(syntactic congruency) by 2(semantic congruency) ANOVA. There were fewer trials with first pass fixations in the shorter, syntactically anomalous conditions [ $F(1,28) = 20.55, p < .01$ ]. The Anomaly region in the agreement stimuli was a verb that varied from three to eight letters and had a first pass fixation on 70% of the trials, overall. There was no effect of either syntactic or semantic congruency [ $F$ 's  $< 1.0$ ], and no interaction [ $F(1, 28) = 2.53, p > .10$ ]. For all regions and dependent measures, and both stimulus sets, we replaced the missing trials with the subject or item mean for that condition.

**First Pass Reading Times.** For each participant and each item, we computed the mean

duration of first pass fixations in each region by condition cell. When there were multiple first pass fixations in a region, the fixations were summed. First pass reading time is presumed to reflect the initial processing load, as word recognition and sentence comprehension processes commence. The raw reading times are summarized in Figure 1.

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Insert Figure 1 about here  
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This dependent measure was transformed to make a partial correction for differences in length between the agreement stimuli and the argument structure stimuli and within the argument structure stimuli. We used the linear regression technique that was introduced in Ferreira and Clifton (1986), and used by both Ni et al. (1998) and Pearlmutter et al. (1999). For each participant and across the entire stimulus set, we regressed reading time in a region against the number of characters in that region. We used this regression equation to predict reading time for the critical items, based on the number of characters in a region. The actual reading time was then transformed into a positive or negative deviation (in ms) from the predicted time. The transformed data are summarized in Figure 2.

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Insert Figure 2 about here  
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The effect of the data transformation can be seen by comparing Figures 1 and 2. For the agreement stimuli, there are no apparent effects in the Anomaly region, regardless of whether one examines the raw or transformed reading times (Figures 1b and 2b, respectively). However, the transformation makes a clear difference in the Anomaly region of the argument structure stimuli. Recall that the syntactically congruent conditions of the argument structure stimuli were always three characters longer than the syntactically incongruent conditions at the point of anomaly, and that first pass fixations were more likely in the longer syntactically congruent conditions. Not surprisingly, raw reading times appear slightly slower in the longer conditions (see Figure 1a). In contrast, after controlling for region length, reading times appear to be faster for the Anomaly region in the syntactically congruent conditions (see Figure 2a). We believe

that, all things considered, the transformed times are a more appropriate measure on which to examine anomaly effects.

Mean deviations were computed by participant and by item. The values in the Anomaly region were submitted to 4(list) by 2(stimulus set) by 2(syntactic congruency) by 2(semantic congruency) ANOVAs. There was a main effect of stimulus set, with faster reading times in the argument structure stimuli [ $F(1,28) = 86.32$ ;  $F(1,52) = 63.97$ ,  $p < .01$ ]. This effect is uninteresting, except to suggest that the critical nouns and PPs were initially read more quickly than the critical verbs. Syntactically congruent conditions were read faster than syntactically incongruent conditions overall [ $F(1,28) = 9.92$ ,  $F(1,52) = 14.68$ ,  $p < .01$ ]. However, syntactic congruency interacted with stimulus set [ $F(1,28) = 10.13$ ,  $F(1,52) = 17.59$ ,  $p < .01$ ], such that the syntactic congruency effect was reliable in the argument structure materials but not in the agreement materials [argument structure:  $F(1,28) = 32.01$ ,  $F(1,36) = 63.91$ ,  $p < .01$ ; agreement:  $F$ 's  $< 1.0$ ]. This pattern is consistent with the interaction between stimulus set and syntactic anomaly that we observed in our acceptability norms. Apparently, the syntactic anomaly was more salient in the argument structure materials. The lack of a syntactic agreement effect echoes the Ni et al. (1998) failure to find morpho-syntactic effects in the first pass reading times. There was no main effect of semantic congruency [ $F(1,28) = 1.17$ ,  $p > .10$ ;  $F(1,52) = 1.60$ ,  $p > .10$ ], nor an interaction with stimulus set [ $F$ 's  $< 1.0$ ].

We considered the possibility of parafoveal preview effects in the region prior to the anomaly, especially for the agreement stimuli because the Anomaly region was only fixated on 70% of the trials during the first pass. However, there were no reliable effects or interactions in the region prior to the anomaly.

**Probability of a first pass regression out of a region.** When a reader experiences difficulty on the first pass reading of a sentence, the difficulty can be reflected either in longer first pass reading times in the region or by regressive eye movements to earlier regions. The mean probability of a first pass regression out of a region was computed by participant and item for each condition. These data are summarized in Figure 3. In ANOVAs over the probabilities

for the Anomaly region, there was a main effect of syntactic congruency [ $F(1,28) = 6.87$ ,  $F(1,52) = 10.59$ ,  $p < .05$ ]. The only other effect to approach reliability was the main effect of stimulus set [ $F(1,28) = 3.94$ ,  $p < .10$ ;  $F(1,52) = 6.72$ ,  $p < .05$ ], with a tendency for more regressions in the agreement stimuli.

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Insert Figure 3 about here  
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**Regression Path Durations.** This measure includes all first pass fixations in a region, plus, if there was a first pass regression out of the region, all time spent in leftward regions before fixating on a region to the right. This dependent measure was not used by either Pearlmutter et al. (1999) or Ni et al. (1998). We included it because it provides a more complete measure than first pass reading times and because it is more local than total reading times. We did not regress this dependent measure against region length, because these reading times include time spent outside the region of interest. These results are summarized in Figure 4. Syntactic congruency was reliable by items and marginal by participants in the Anomaly region [ $F(1,28) = 3.96$ ,  $p < .10$ ;  $F(1,52) = 4.84$ ,  $p < .05$ ]. In addition, an interaction between syntactic congruency and stimulus set was found in the analysis by participants only [ $F(1,28) = 4.94$ ,  $p < .05$ ;  $F(1,52) = 2.21$ ,  $p > .10$ ]. In ANOVAs over each stimulus set, we found an effect of syntactic congruency for the agreement stimuli [ $F(1,28) = 7.62$ ,  $F(1,16) = 7.55$ ,  $p < .05$ ] but not the argument structure stimuli [ $F$ 's  $< 1.0$ ]. This is opposite the pattern observed in the first pass deviations and the acceptability ratings.

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Insert Figure 4 about here  
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In the ANOVAs on each stimulus set, there was also an effect of semantic congruency in the Anomaly region, but only for the argument structure stimuli [ $F(1,28) = 5.07$ ,  $F(1,36) = 4.12$ ,  $p < .05$ ; agreement:  $F$ 's  $< 1.0$ ]. This finding is difficult to interpret, because neither a main effect of semantic congruency nor an interaction with stimulus set was found in the overall ANOVA [main effect:  $F$ 's  $< 1.0$ ; interaction:  $F(1,28) = 3.88$ ,  $p < .10$ ;  $F(1,52) = 2.42$ ,  $p > .10$ ].

Furthermore, the acceptability ratings from Experiment 1 indicated that the semantic congruency manipulation was actually stronger in the agreement stimuli (where we see no semantic effect at the anomaly). Figure 4 suggests that semantic congruency had a greater impact in the region after the anomaly, as in previous studies. This was confirmed in an overall ANOVA at the Post-Anomaly region. Semantic congruency was reliable by participants and marginal by items [ $F(1,28) = 6.95, p < .05$ ;  $F(1,52) = 3.55, p < .10$ ]. The three-way interaction of stimulus set, syntactic congruency and semantic congruency was fully reliable [ $F(1,28) = 4.91, F(1,52) = 13.74, p < .05$ ].

### Discussion

As summarized in Table 2, first pass effects in the Anomaly region were found for all three types of anomalies, but with different patterns. Length-corrected first pass reading times were slower for phrasal category violations, but not for agreement violations. Both types of syntactic anomalies evoked regressive eye movements. The regression path durations yielded an anomaly effect for syntactic agreement violations, but not for phrasal category violations. In contrast, there was an anomaly effect for semantic violations in the argument structure stimuli, but not the agreement stimuli. This difference is surprising, given that both types of semantic anomalies violated the verb's thematic constraints on one of its arguments. However, in the Post-Anomaly region, a robust semantic anomaly effect was observed for both stimulus sets.

**Table 2. Summary of first pass effects at the anomaly by stimulus set and anomaly type**

First Pass Measure	Argument Structure Stimuli		Agreement Stimuli	
	Category	Semantic	Morpho-Syntactic	Semantic
Reading Times	√			
Probability of a Regression	√		√	
Regression Path Duration		√*	√	*

\* *There were robust effects in this measure in the Post-Anomaly region.*

Our findings are largely consistent with those of the previous relevant studies. The finding that regressions out of the anomalous region were more likely for syntactic anomalies than for semantic anomalies mirrors Ni et al.'s (1998) comparison of morpho-syntactic and semantic anomalies. Likewise, the lack of a morpho-syntactic anomaly effect in the first pass reading times of the agreement stimuli is consistent with earlier research by Ni et al. and Braze et al. (in press). Pearlmutter et al. (1999) did find morpho-syntactic effects in the first pass reading times, but only for a subset of their data, and only when including the word following the anomaly in their analysis.

The responses evoked by our phrasal category anomalies was different from the syntactic anomaly effects observed by Ni et al. (1998), Braze et al. (in press), and Pearlmutter et al. (1999), because we found robust effects of syntactic congruency in the first pass reading times on the anomalous material. The contrast between the syntactic effects in our argument structure stimuli and our agreement stimuli supports the hypothesis that different types of syntactic violations induce different eye movement patterns. While we cannot draw conclusions based on a null finding in a single experiment, it is significant that in four experiments from three different laboratories (Ni et al., Braze et al., Pearlmutter et al., and our Experiment 2), syntactic violations of verb morphology failed to induce longer first pass fixations across participants and trials, but did consistently lead to regressive eye movements. In contrast, our phrasal category violations induced both longer first pass reading times and increased regressions, as would be expected from the garden path literature.

Finally, the absence of semantic congruency effects in our first pass reading times and regressions is consistent with previous findings by Ni et al. (1998) and Braze et al. (in press). In fact, both studies reported reliable semantic congruency effects only after the anomalous region. Our study is the first to report semantic anomaly effects in unambiguous sentences, at the point of anomaly. However, we found such effects for only one of our two stimulus sets in the anomalous region, and only in our most global first pass measure, the regression path durations.

What can we conclude from our pattern of effects? If the three dependent measures in

Table 2 are assumed to reflect progressively later cognitive processes, one might conclude that constituent structure is constructed first, followed by morpho-syntactic feature checking, with semantic evaluation last. Alternatively, the processing system might identify violations of phrasal category, syntactic features, and semantics simultaneously. Such a view is consistent with our findings if the system has different strategies for coping with different violations. Note that the difference cannot be explained as a difference in the salience of the anomalies. Although our syntactic violations were rated more salient in the argument structure stimuli than in the agreement stimuli, our semantic violations were just as unacceptable as the worst syntactic violations. In short, we can conclude that there was a distinction between the processing of constituent structure, morpho-syntactic features, and semantics in this experiment, but we can't tell whether the distinction lies in the identification of the violations or in the strategies for coping with the violations once they have been detected. Nonetheless, the consistent absence of first pass reading time effects for semantic anomalies and morpho-syntactic anomalies may have direct implications for interpreting the garden path literature.

Before discussing the implications for garden path research, we must address several issues concerning the generality of our results. First, is it legitimate to generalize behavior on globally anomalous sentences to behavior on garden path sentences? In contrast to the anomalies used in the current studies, the apparent anomaly in garden path sentences can be resolved by adopting an alternative syntactic analysis. If, in fact, one assumes that syntactic (and perhaps semantic) alternatives are maintained in parallel, our results have little bearing upon garden path sentences. However, the predominant view is that difficult garden paths are themselves evidence for a serial parser that only pursues a single analysis. If a single structure is constructed and/or maintained throughout the ambiguous region in a garden path sentence, then the detection of the anomaly in the originally selected structure should be exactly the same cognitive phenomenon as the detection of an anomaly in an unambiguous structure. The only difference is the degree to which reanalysis and recovery are successful.

A second potential concern is the high proportion of anomalous sentences in Experiment

2: roughly half contained some kind of anomaly. Is this proportion sufficiently different from garden path experiments to prevent our results from generalizing to garden path studies? Gunter et al. (1997) and Hahne and Friederici (1999) both manipulated the proportion of anomalous sentences in ERP experiments and found that the early negatives (150-350 ms post-stimulus) elicited by a syntactic violation were equally pronounced whether there were 20%-25% anomalous sentences or 75%-80% anomalous sentences. In contrast, they found a P600 only when the proportion of anomalous sentences was low (but see Hagoort et al., 1993; Osterhout and Nicol, 1999; & Neville et al., 1991, for examples of P600s in studies in which 50% of the stimuli contained anomalies). The P600 has been linked to reanalysis and related processes in garden-path sentences (e.g., Gunter et al., 1997; Munte et al., 1997; Osterhout et al., 1994). By analogy, we would not be surprised if the later components of the eye movement record (e.g., total times, regression path durations) were affected by our relatively high proportion of anomalous sentences. But early measures, such as the first pass reading times, which reflect the first 400 ms or so of processing a word, are unlikely to be affected. That is one reason why we have focused on the earlier measures.

Because our findings are directly relevant to the interpretation of garden path effects under a serial view of parsing, we consider in turn garden paths that are disambiguated by a phrase of the wrong syntactic category, an agreement error, or a semantic anomaly. The bulk of garden path studies have used stimuli that are disambiguated by syntactic category information (e.g., Ferreira & Clifton, 1986; Frazier & Rayner, 1982; Garnsey et al., 1997; Trueswell et al., 1994). For these studies, there is no reason to doubt that long first pass fixations are caused by the detection of a syntactic anomaly in the initial analysis, because syntactic category violations led to immediate anomaly effects in both first pass reading time and regression measures.

On the other hand, first pass reading time effects for garden paths that are disambiguated by agreement information (e.g., Meng & Bader, 2000) are puzzling. Based upon our data, together with that from Ni et al. (1998) and Braze et al. (in press), it is unlikely that such first pass reading time effects reflect detection of an agreement violation. Likewise, one should be

suspicious of claims that semantic anomaly detection evokes longer first pass reading times on the anomalous material. For example, Ni et al. (1996) found long first pass reading times, but no increase in regressions, for *large cracks* compared to *new brushes* in sentences like *The man painted the doors with large cracks/new brushes....* They reasoned that readers initially attached *with the* to the VP and had to reattach the PP to the NP upon encountering the semantically anomalous *cracks*. Similar materials and logic are found in Rayner et al. (1983). While this is a possible interpretation of the data, anomaly detection is not the only cognitive phenomena that can lead to long first pass reading times. For example, if two structures are both highly activated, competition might lead to long reading times, as suggested by Spivey and Tanenhaus (1998).<sup>5</sup>

The difference between phrasal category errors and morpho-syntactic errors observed here, and bolstered by previous studies, provides some support for computational models and psycholinguistic theories that distinguish between construction of a phrase structure tree and feature-based processes such as agreement and binding (e.g., Crocker, 1992; Frazier, 1978; Frazier & Clifton, 1996; Gibson, 1991), as opposed to approaches that use feature-based computation for both attachment and binding/agreement (e.g., Kay, 1985; Stevenson, 1994).

Alternatively, we may be picking up distinctions in (attempted) error recovery processes. Fodor and Inoue (2000) suggested that number agreement violations are among the least helpful of errors in terms of guiding reanalysis and recovery. This is not true of all morpho-syntactic errors, however. For example, case mismatches in a richly case-marked language often provide clues about the new structure that must be built.

Ultimately, it may not be fruitful to divide syntactic phenomena into those concerning the configuration of the phrase structure tree versus those concerning the morphological features of the lexical items. In English, the data suggest that anomalies involving grammatical number

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<sup>5</sup>Competition accounts predict that the longer reading times (for ambiguous stimuli compared to unambiguous stimuli) should begin in the ambiguous region, where the two alternatives are most viable. Longer reading times would be found in the disambiguating region as well (where they are also predicted by a garden path account) if competition in the ambiguous region led to selection of the wrong structure.

(Pearlmutter et al., 1999) and verb tense (Ni et al., 1998) pattern similarly. However, a fundamental distinction between structural and morphological processing is unlikely to hold cross-linguistically. For example, in languages with flexible word order, like Japanese or even German, one cannot compute the structure of a sentence without considering the case features of the NPs (e.g., nominative, accusative), because case often disambiguates the sentence structure.

We expect that the important cross-linguistic generalization is a distinction between the information that guides structure building, which will differ from language to language, and the constraints on grammaticality that are not used to guide structure building. In the current experiments, both agreement and semantic congruency fell into the latter category. However, the information in both categories may include non-syntactic information. If semantic information is used to guide structure-building, we would predict that semantic violations would evoke long first-pass reading times, just as our phrasal category violations did. The sentences in (9), adopted from Boland (1997), illustrate how semantic properties can govern the structure of a sentence in English. A reading event can involve a reader, the thing being read, and a listener, which serve syntactically as subject, direct object, and indirect object, respectively. In (9) the semantic properties of the NP following the main verb determine whether that NP is the direct object or the indirect object, and the semantic properties of the *wh*-phrase render the sentence either felicitous or anomalous. Examples (9a) and (9d) are felicitous because the *wh*-phrase satisfies one set of semantic constraints and *Suzie/the newspaper* satisfies the other. In contrast, (9b) and (9c) both become anomalous at the underlined NP, because it satisfies the same set of constraints as the *wh*-phrase, thereby competing for the same syntactic position. (The syntactic position of the *wh*-phrase is represented by the blank line). In such a case, where semantics determines structure, we would expect long reading times for the underlined phrases in (9b) and (9c) compared to the same phrases in (9a) and (9d).

- (9) a. *Which poem did the babysitter read Suzie \_\_\_?*  
 b. \**Which child did the babysitter read Suzie \_\_\_?*  
 c. \**Which poem did the babysitter read \_\_\_ the newspaper?*

d. *Which child did the babysitter read \_\_ the newspaper?*

### Summary

We addressed two major questions about syntactic and semantic processing during sentence comprehension. First, do different types of syntactic anomalies yield similar patterns of eye movements? Second, do syntactic anomalies evoke different patterns of eye movements than semantic anomalies? We found that different types of syntactic anomalies clearly did lead to different patterns of eye movements. Phrasal category anomalies, but not morpho-syntactic anomalies, led to long first pass reading times. However, because syntactic anomalies as a broad linguistic class do not themselves give rise to a single, well-specified, and unique pattern of eye movements, it is probably not possible to distinguish between syntactic and semantic anomaly detection on the basis of eye movement data.

We chose to explore these particular questions because we hoped to better understand some of the cognitive processes that underlie garden path phenomena, and how these cognitive processes are reflected in the eye movement record. One critical question was whether long first pass fixations during a garden path indicate that the reader has detected an anomaly in the original analysis. This linking assumption has gone unchallenged in the literature, even as evidence emerged that syntactic anomalies did not necessarily yield longer first pass fixations (Ni et al., 1998; Pearlmutter et al., 1999). Our data reconcile much of the apparent contradiction, because we have demonstrated that phrasal category violations do yield long first pass fixations, even though morpho-syntactic violations do not. However, our failure to find first pass reading time effects in response to agreement violations and semantic anomalies suggests that some garden path studies do need to be re-evaluated, perhaps along the lines suggested by Spivey and Tanenhaus (1998; see also MacDonald et al., 1994). That is, increased first pass reading times might reflect increased competition between structural alternatives being considered in parallel. This alternative explanation of garden path effects should be considered especially in cases where the disambiguating material is semantic or morpho-syntactic, because we have independent evidence that such anomalies do not lead to increased first pass fixations.

Clearly, there is more work to be done before we really understand how the cognitive operations in sentence comprehension are reflected in the eye movement record. There is unlikely to be a one-to-one mapping. However, we have suggested a testable hypothesis to guide future research: Violations of all and only those constraints that affect structure building will evoke an immediate anomaly effect in the first pass reading times.

## References

- Ainsworth-Darnell, K., Shulman, H., & Boland, J. E. (1998). Dissociating brain responses to syntactic and semantic anomalies. *Journal of Memory and Language*, **38**, 112-130.
- Altmann, G. T. M., Garnham, A., & Dennis, Y. (1992). Avoiding the garden path: Eye movements in context. *Journal of Memory and Language*, **31**, 685-712.
- Altmann, G. & Steedman, M. (1988). Interaction with context during human sentence processing. *Cognition*, **30**, 191-238.
- Bates, E. & MacWhinney, B. (1982). Functionalist approaches to grammar. In E. Wanner & L. Gleitman (Eds.), *Language Acquisition: The State of the Art*. New York: Cambridge University Press.
- Bock, K. & Eberhard, K. M. (1993). Meaning, sound and syntax in English number agreement. *Language and Cognitive Processes*, **8**, 57-99.
- Bock, K. & Miller, C. A. (1991). Broken Agreement. *Cognitive Psychology*, **23**, 45-93.
- Boland, J. E. (1991). *The use of lexical knowledge in sentence processing*. Unpublished doctoral dissertation, University of Rochester.
- Boland, J.E. (1997). The relationship between syntactic and semantic processes in sentence comprehension. *Language and Cognitive Processes*, **12**, 423-484.
- Braze, D., Shankweiler, D., Ni, W., and Palumbo, L. C. (in press). Readers' eye movements distinguish anomalies of form and content. *Journal of Psycholinguistic Research*.
- Coulson, S., King, J. W., & Kutas, M. (1998). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and Cognitive Processes*, **13**, 21-58.
- Crocker, M. (1992). *A logical model of competence and performance in the human sentence processor*. Unpublished doctoral dissertation, University of Edinburgh.
- Eberhard, K. M. (1997). The marked effect of number on subject-verb agreement. *Journal of Memory and Language*, **36**, 147-164.
- Elman, J. (1990). Representation and structure in connectionist models. In G. T. M. Altmann (Ed.), *Cognitive Models of Speech Processing: Psycholinguistic and computational*

*perspectives*. Cambridge, MA: MIT Press.

Ferreira, F. & Clifton, C. (1986). The independence of syntactic processing. *Journal of Memory and Language*, **25**, 348-368.

Fodor, J. D. & Inoue, A. (1994). The diagnosis and cure of the garden path. *Journal of Psycholinguistic Research*, **23**, 407-434.

Fodor, J. D. & Inoue, A. (2000). Syntactic features in reanalysis: Positive and negative symptoms. *Journal of Psycholinguistic Research*, **29**, 25-36.

Francis, W. N. & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Houghton Mifflin Co., Boston.

Frazier, L. (1978). *On comprehending sentences: Syntactic parsing strategies*. Unpublished doctoral dissertation, University of Connecticut.

Frazier, L. & Clifton, C. (1996). *Construal*. Cambridge, MA: MIT Press.

Frazier, L. & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, **14**, 178-210.

Friederici, A. D. (1995). The time course of syntactic activation during language processing: A model based on neuropsychological and neurophysiological data. *Brain and Language*, **50**, 259-281.

Friederici, A. D. & Frisch, S. (2000). Verb argument structure processing: The role of verb-specific and argument-specific information. *Journal of Memory and Language*, **43**, 476-507.

Friederici, A. D., Pfeifer, E., & Hahne, A. (1993). Event-related brain potentials during natural speech processing: Effects of semantic, morphological and syntactic violations. *Cognitive Brain Research*, **1**, 183-192.

Garnsey, S. M., Pearlmutter, N. J., Myers, E., Lotocky, M. A. (1997). The contributions of verb bias and plausibility to the comprehension of temporarily ambiguous sentences. *Journal of Memory and Language*, **37**, 58-93.

Gibson, E. (1991). *A computational theory of human linguistic processing: Memory limitations and processing breakdown*. Unpublished doctoral dissertation, Carnegie-Mellon University.

Gunter, T. C., Friederici, A. D., & Hahne, A. (1999). Brain responses during sentence reading: Visual input affects central processes. *Neuroreport*, **10**, 3175-3178.

Gunter, T., Stowe, L. & Mulder, G. (1997). When syntax meets semantics. *Psychophysiology*, **34**, 660-676.

Hagoort, P., Brown, C., & Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language & Cognitive Processes*, **8** (4), 439-483.

Hahne, A. & Friederici, A. D. (1999). Electrophysiological evidence for two steps in syntactic analysis. Early automatic and late controlled processes. *Journal of Cognitive Neuroscience*, **11**, 194-205.

Hahne, A. & Jescheniak, J. D. (2001). What's left if the Jabberwock gets the semantics? An ERP investigation into semantic and syntactic processes during auditory sentence comprehension. *Cognitive Brain Research*, **11**, 199-212.

Just, M. A. & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, **87**, 329-354.

Kay, M. (1985). Parsing in function unification grammar. In D. R. Dowty, L. Karttunen, & A. M. Zwicky (Eds), *Natural Language Parsing*. Cambridge: Cambridge University Press.

Langacker, R. W. (1987). *Foundations of Cognitive Grammar: Theoretical Perspectives*. Stanford: Stanford University Press.

MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). The lexical nature of ambiguity resolution. *Psychological Review*, **101**, 676-703.

McElree, B. & Griffith, T. (1995) Syntactic and thematic processing in sentence comprehension: Evidence for a temporal dissociation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 134-157.

Munte, T. F., Matzke, M., & Johannes, S. (1997). Brain activity associated with syntactic incongruencies in words and pseudo-words. *Journal of Cognitive Neuroscience*, **9**, 318-329.

Ni, W., Crain, S. & Shankweiler, D. (1996). Sidestepping garden paths: Assessing the

contributions of syntax, semantics, and plausibility in resolving ambiguities. *Language and Cognitive Processes*, **11**, 217-336.

Ni, W., Fodor, J. D., Crain, S., & Shankweiler, D. (1998). Anomaly detection: Eye movement patterns. *Journal of Psycholinguistic Research*, **27**, 515-539.

Nicol, J. L., Forster, K. I., & Veres, C. (1997). Subject-verb agreement processes in comprehension. *Journal of Memory and Language*, **36**, 569-587.

Osterhout, L., Holcomb, P. J., & Swinney, D. A. (1994). Brain potentials elicited by garden-path sentences: Evidence of the application of verb information during parsing. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **28**, 786-803.

Osterhout, L. & Nicol, J. (1999). On the distinctiveness, independence, and time course of the brain responses to syntactic and semantic anomalies. *Language and Cognitive Processes*, **14**, 283-317.

Pearlmutter, N. J., Garnsey, S. M., and Bock, K. (1999). Agreement processes in sentence comprehension. *Journal of Memory and Language*, **41**, 427-456.

Pollatsek, A. & Rayner, K. (1990). Eye movements and lexical access in reading. In D. A. Balota, G. B. Flores d'Arcais, & K. Rayner (Eds.), *Comprehension Processes in Reading* (pp. 143-163). Hillsdale, NJ: Erlbaum.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, **124**, 372-422.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior*, **22**, 358-374.

Rayner, K., Reichle, E. D., & Pollatsek, A. (1998). Eye movement control in reading: An overview and model. In Underwood, G. (Ed.), *Eye Guidance in Reading and Scene Perception* (pp. 243-268). New York: Elsevier.

Rayner, K., Sereno, S. C., Morris, R. K., Schmauder, A. R., & Clifton, C. (1989). Eye movements and on-line language comprehension processes. *Language & Cognitive Processes*, **4**,

21-50.

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, **105**, 125-157.

Rosler, F., Putz, P., Friederici, A., & Hahne, A. (1993). Event-related brain potentials while encountering semantic and syntactic constraint violations. *Journal of Cognitive Neuroscience*, **5**, 345-362.

Spivey, M. J. & Tanenhaus, M. K. (1998). Syntactic ambiguity resolution in discourse: Modeling the effects of referential context and lexical frequency. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 1521-1543.

Spivey-Knowlton, M., & Sedivy, J. C. (1995). Resolving attachment ambiguities with multiple constraints. *Cognition*, **55**, 227-267.

Stevenson, S. (1994). Competition and recency in a hybrid network model of syntactic disambiguation. *Journal of Psycholinguistic Research*, **23**, 4, 295-322.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language*, **33**, 285-318.

Vigliocco, G., Butterworth, B., & Semenza, C. (1995). Constructing subject-verb agreement in speech: The role of semantic and morphological factors. *Journal of Memory and Language*, **34**, 186-215.

## Appendix

**Agreement Stimuli.** The four conditions are separated by slashes inside the brackets of each item. The first condition is syntactically and semantically consistent with the verb. The second condition is syntactically inconsistent because the grammatical number does not agree with the verb. The third condition agrees syntactically with the verb, but is inconsistent with the semantic/thematic constraints that the verb places on its agent (the sentential subject). The fourth condition is both syntactically and semantically anomalous.

We note that the Modifier region contains a singular noun phrase (NP) that is mismatched in number with the verb for the items that have a plural verb. In the literature on subject-verb agreement, an NP that intervenes between the subject and the verb is called a distracter noun. One possible concern is that the singular distracter noun may reduce the saliency of number disagreement when the verb is plural, or alternatively, cause the correctly agreeing sentences to be mistakenly perceived as disagreeing. The concern arises because a plural distracter noun increases the likelihood of an agreement error in sentences like *The key to the cabinets was/were....* However, it has been well established that agreement errors are not increased by the presence of a singular distracter noun (i.e., the unmarked form) in sentences like *The keys to the cabinet...* (Bock & Eberhard, 1993; Bock & Miller, 1991; Eberhard, 1997; Vigliocco et al., 1995). Likewise in comprehension, singular distracters do not induce the perception of an agreement violation the way plural distracters do (Nicol et al., 1997; Pearlmutter et al., 1999). Thus, the distracter nouns in our stimuli should not be problematic. Nonetheless, we divided the acceptability judgments from Experiment 1 into items with plural and singular verbs, to determine whether these two item groups were differentially affected by the agreement violation. Mean ratings for each item were submitted to a 2(plurality) by 2(agreement) by 2(semantic congruency) ANOVA. There was no main effect of plurality, nor did plurality interact with either agreement or semantic congruency [all  $F$ 's < 1.5]. Considering these offline judgments together with the previous work on agreement, we felt confident that agreement effects would be found uniformly across items with singular and plural verbs.

1. The { child/children/book/books } laying on the bed sleeps quietly.
2. The { frog/frogs/glove/gloves } sitting on the rock croaks loudly.
3. The { dog/dogs/tree/trees } that lives down there bites hard.
4. The { insect/insects/worm/worms } living in the garden flies around.
5. The { phone/phones/floor/floors } in the convention hall rings often.
6. The { parent/parents/pencil/pencils } of the musical genius brags frequently.
7. The { canary/canaries/snake/snakes } in the large cage sings beautifully.
8. The { truck/trucks/weed/weeds } out behind the barn runs well.
9. The { spouse/spouses/house/houses } of my best friend drinks heavily.
10. The { wind/winds/sign/signs } from the north side blows coldly.
11. The { kittens/kitten/jackets/jacket } with the black fur grow quickly.
12. The { clocks/clock/fruits/fruit } on the top shelf tick constantly.
13. The { hosts/host/containers/container } at the Tupperware party smile warmly.
14. The { assistants/assistant/menus/menu } at the new restaurant clean carefully.
15. The { firemen/fireman/procedures/procedure } on the morning shift cook occasionally.
16. The { pigs/pig/crops/crop } on Mr. Smith's farm dig everywhere.
17. The { models/model/dresses/dress } in the fashion magazine exercise vigorously.
18. The { weightlifters/weightlifter/photographs/photograph } in the national competition grunt deliberately.
19. The { neighbors/neighbor/guitars/guitar } of the rock star jog slowly.
20. { Some clerks/One clerk/Some apples/One apple } at the grocery store nap regularly.

**Figure Captions**

Figure 1. Raw first pass reading times for the argument structure stimuli (1a) and the agreement stimuli (1b).

Figure 2. Length-corrected first pass reading times for the argument structure stimuli (2a) and the agreement stimuli (2b).

Figure 3. The likelihood of a first pass regression out of each region of the argument structure stimuli (3a) and the agreement stimuli (3b).

Figure 4. The regression path durations for the argument structure stimuli (4a) and the agreement stimuli (4b).

Figure 1a

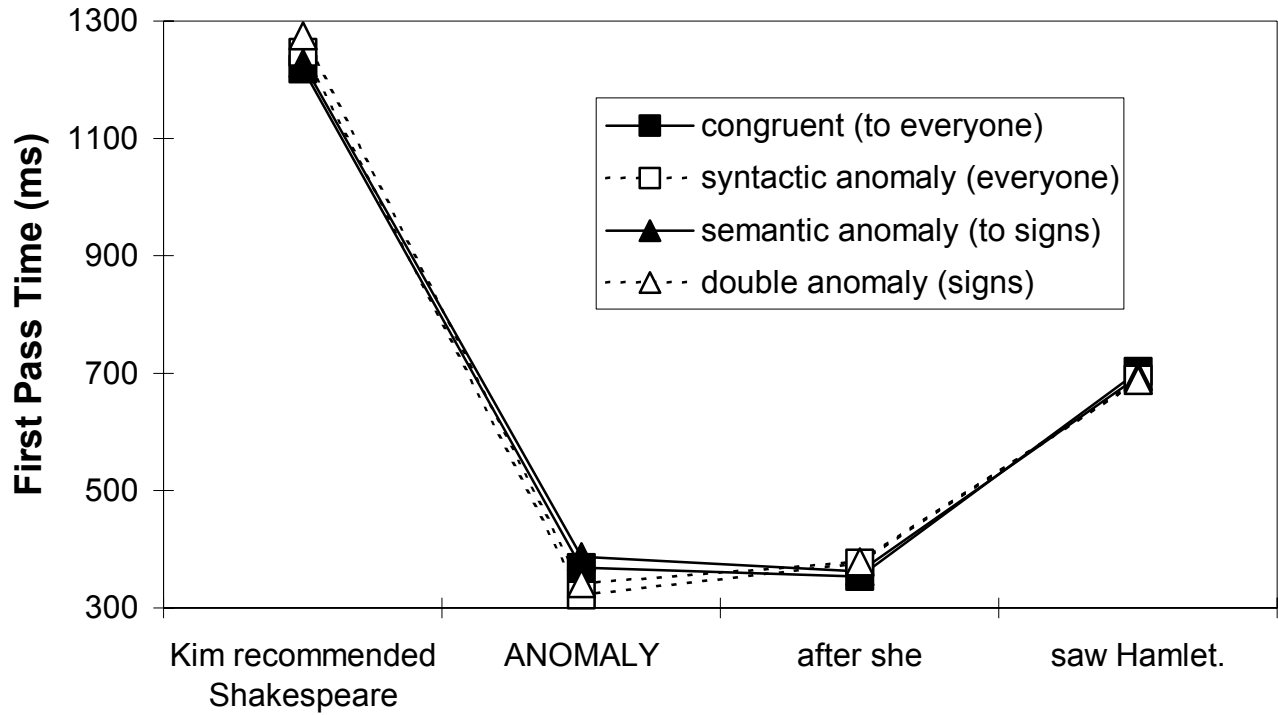


Figure 1b

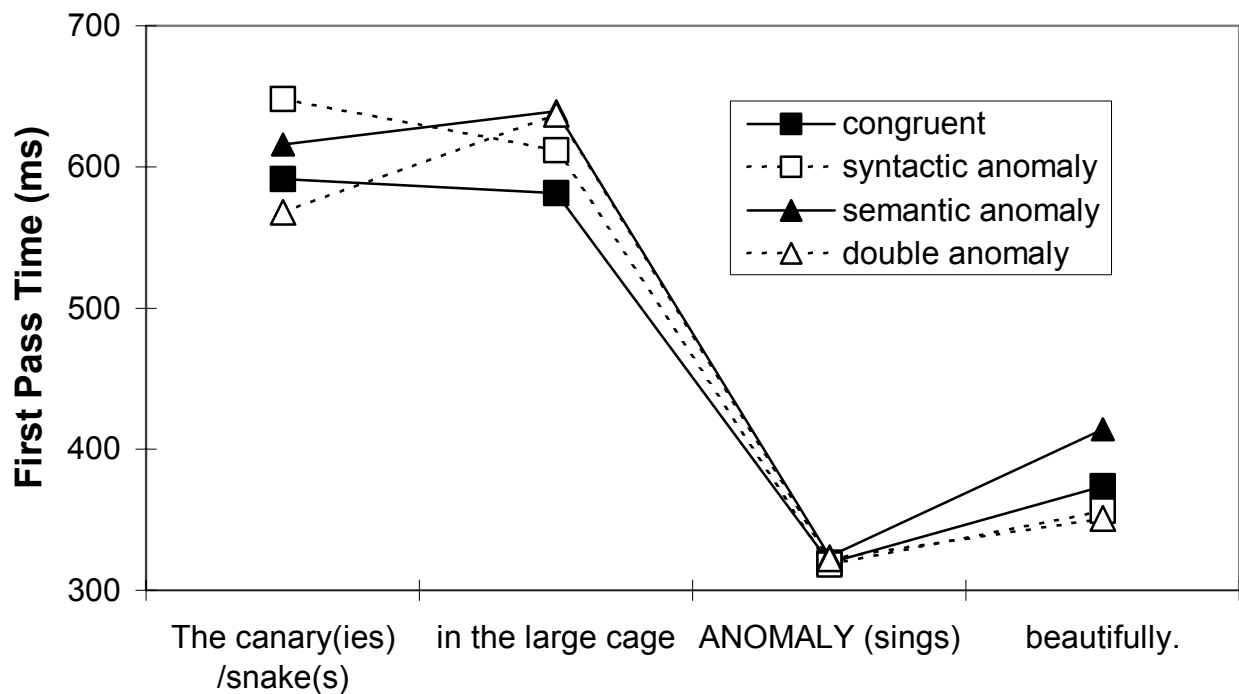


Figure 2a

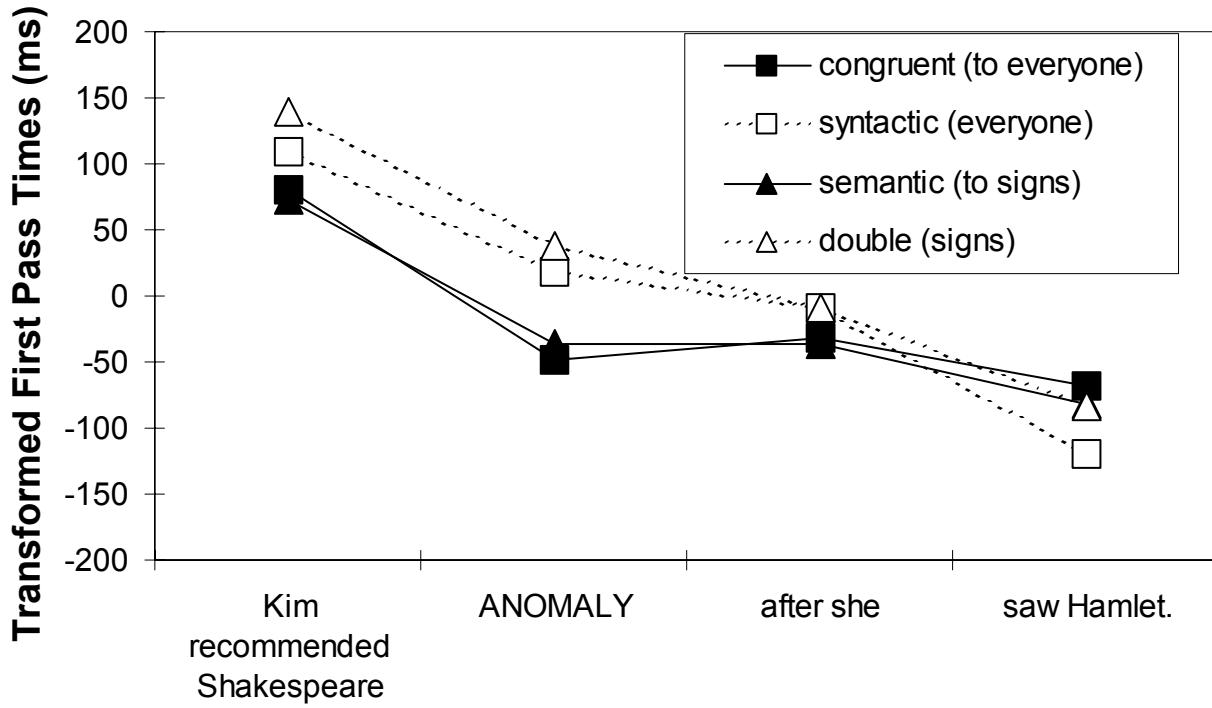


Figure 2b

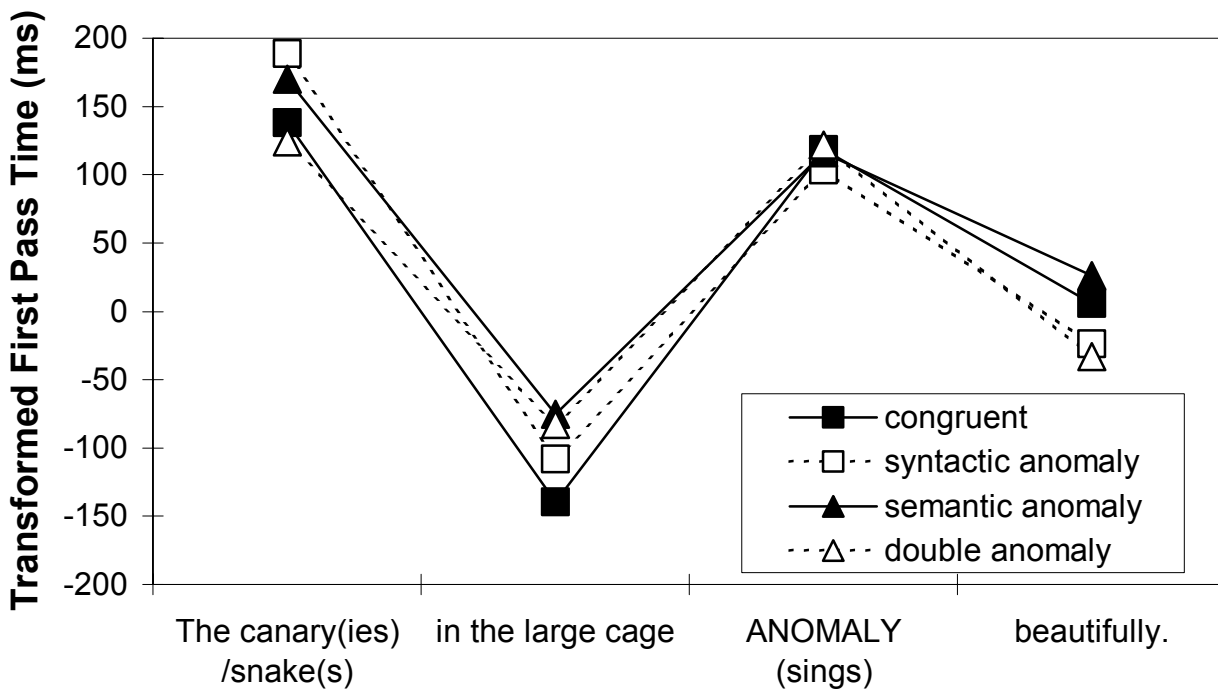


Figure 3a

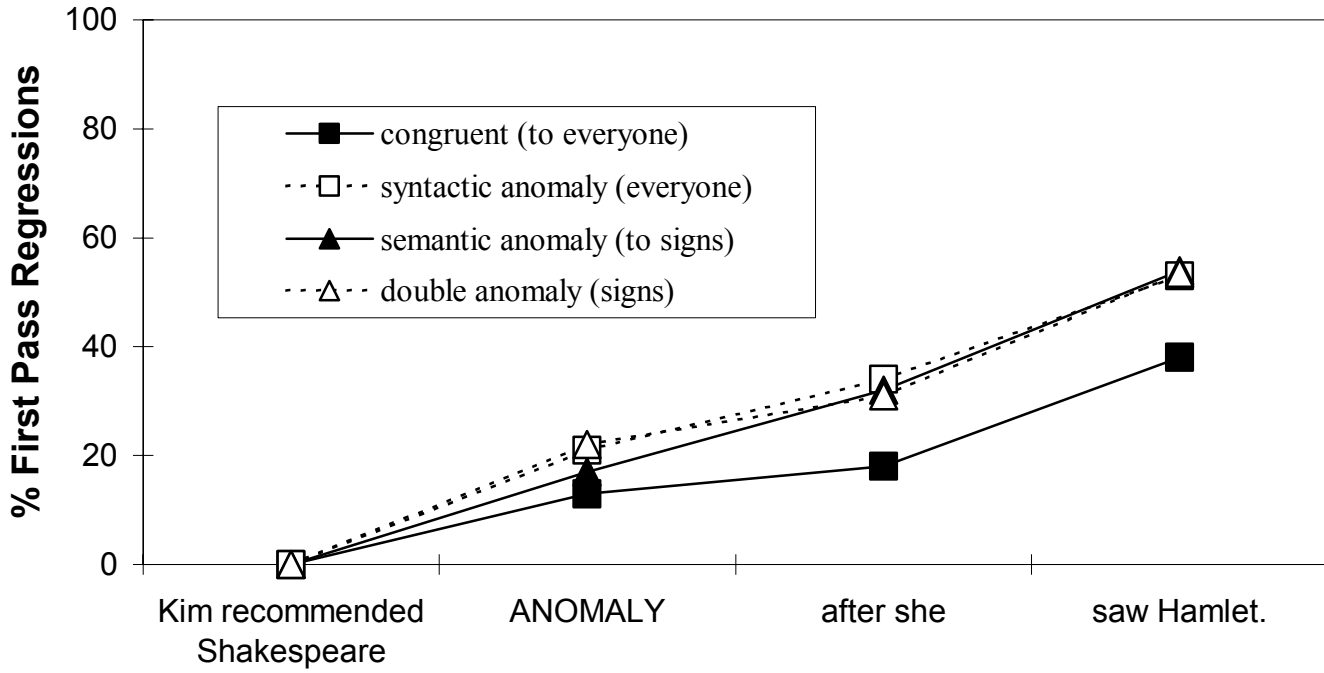


Figure 3b

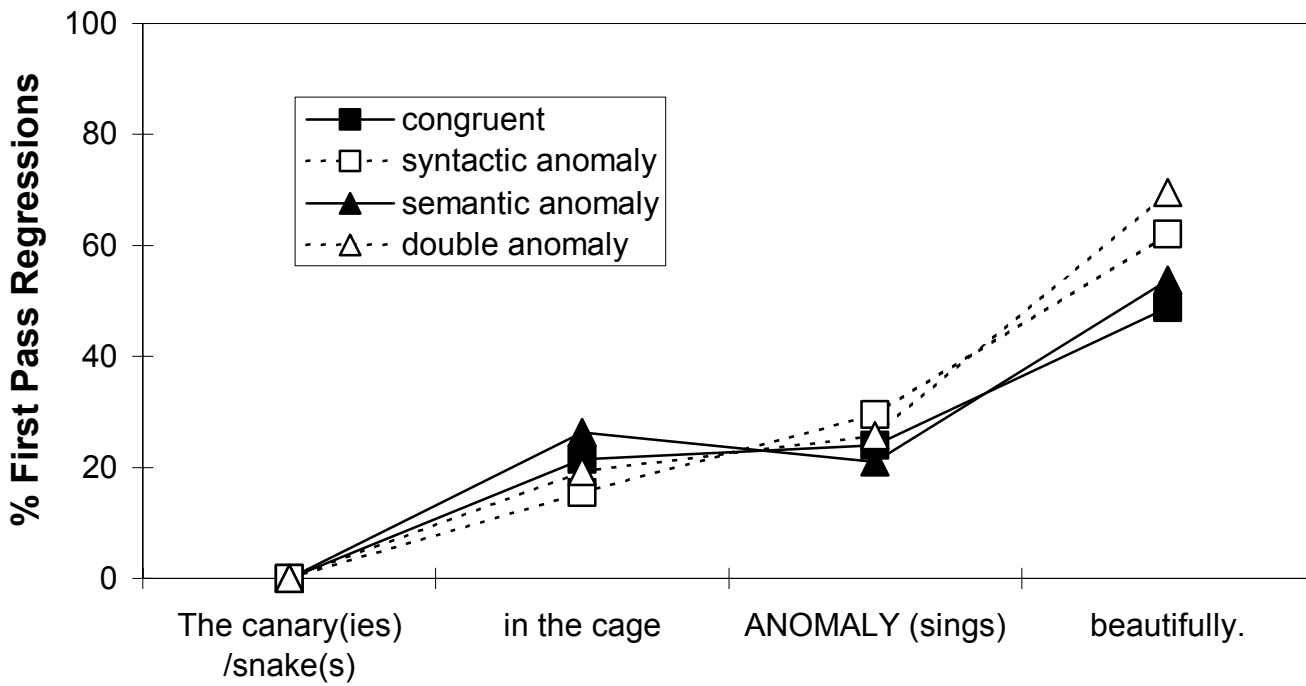


Figure 4a

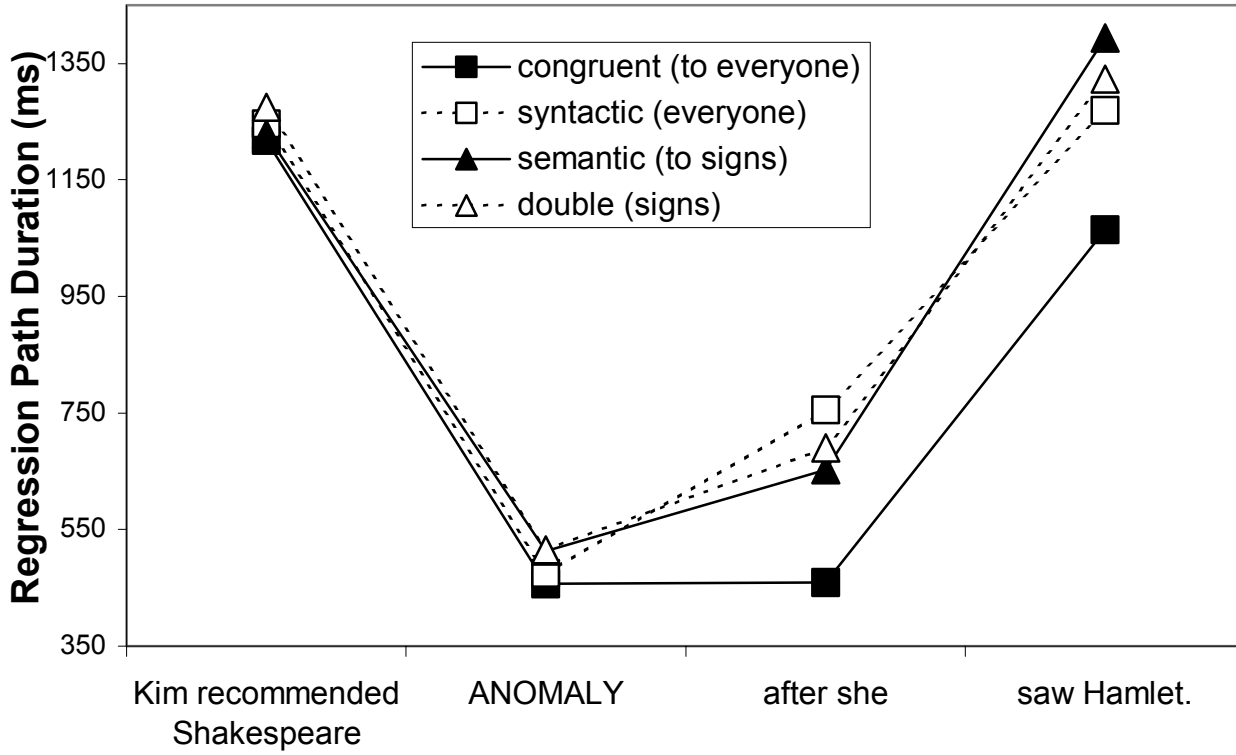


Figure 4b

