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Chapter 19

The Organization and Use of the Lexicon for Language Comprehension

John C. Trueswell

Our intuitions tell us that language comprehension is an incremental and integrative process. As we read or listen to a sentence, we have the strong sense that we are constantly updating our estimation of the intended meaning of the utterance, perhaps on a word-by-word basis. In addition, we make these rapid decisions by integrating a wide range of knowledge, including grammatical knowledge of the language, "referential" knowledge about what the expressions refer to in the world, and even pragmatic and semantic knowledge about what is plausible or likely given the situation.

One of the best illustrations of the incremental nature of language comprehension comes from the so-called garden-path effect, which can sometimes occur when a reader or listener is faced with a temporarily ambiguous phrase. For instance, temporary syntactic ambiguities can be found in the following sentence fragments, which are highlighted by examples of possible continuations.

- (1) Henry forgot Lila . . .
 - (a) . . . at her office. (direct object interpretation)
 - (b) . . . was almost always right. (sentence complement interpretation)

- (2) The man awarded the prize . . .
 - (a) . . . to his friend and colleague of many years. (main clause interpretation)
 - (b) . . . was deeply moved by the honor. (reduced relative clause interpretation)

In the first example, the noun phrase "Lila" could be the direct object of the verb, as in (1a), or the subject of an embedded sentence, as in (1b). In the second example, the entire fragment could make up a main clause, as in (2a), in which case the man is doing the awarding. Or, the phrase "awarded the prize" could be modifying "The man" as a reduced relative clause, in which case the man is being awarded (2b). When faced with syntactic ambiguities like these, readers and listeners show clear

signs of incremental interpretation in that they tend to pick a single interpretation at the point of ambiguity. Evidence for this comes from the fact that readers and listeners show systematic preferences, which need to be revised when incorrect (see, e.g., Bever 1970; Frazier and Fodor 1978). This revision (or garden-path) effect is revealed by increases in processing difficulty, such as long fixation times and regressive eye movements in reading (Frazier and Rayner 1982). For instance, readers prefer the direct object interpretation in examples like (1), resulting in difficulty with (1b). And, readers prefer the main clause interpretation in examples like (2), resulting in difficulty with (2b).

Although garden-path effects illustrate the incremental nature of interpretation, there has been considerable debate over whether readers' and listeners' initial decisions about ambiguous phrases are the result of integrative processes. For instance, one could argue that these decisions need to happen so quickly that only a subset of the most highly relevant information is initially consulted. Knowledge about the details of how particular words combine together (e.g., verb argument structure), as well as semantic and pragmatic knowledge, may either be too slow to access or too difficult to deal with during the rapid flow of incoming speech or text. Advocates of this approach have proposed that only basic syntactic knowledge (e.g., major category information and phrase structure rules) is used to structure the input, and that a decision metric of some type is used to select among ambiguous structures, for example, pick the simplest structure (see, e.g., Frazier 1989), or pick the most common structure (see, e.g., Mitchell, Cuetos, Corley, and Brysbaert 1995). Support for an encapsulated syntactic processor of this type has come from studies suggesting the existence of garden-path structures (e.g., a more complex or a less common syntactic alternative), which, when presented, always cause a garden path, regardless of the presence of biasing lexical or contextual information (see, e.g., Ferreira and Clifton 1986; Rayner, Carlson, and Frazier 1983). These studies have been appealing to those who support modular approaches to language and cognition, especially given the existence of neurological data indicating a dissociation between syntactic and semantic processing (see, e.g., Levy 1996; Schwartz, Marin, and Saffran 1979; Hodges, Patterson, and Tyler 1994; but cf. Bates, Harris, Marchman, Wulfeck, and Kritchovsky 1995).

Alternatives to Encapsulated Parsing

A number of recent experimental findings have, however, drawn into question the basic assumptions behind an encapsulated structural stage of processing (e.g., Juliano and Tanenhaus 1994; Pearlmuter and

MacDonald 1995; Taraban and McClelland 1988; Trueswell, Tanenhaus, and Garnsey 1994; Trueswell, Tanenhaus, and Kello 1993). Much of this work has focused on the use of lexical information, demonstrating that detailed syntactic and semantic information about individual words can have a rapid impact on parsing decisions. While space precludes a full description of these findings, it is important for this chapter to consider briefly two prior studies that I have conducted on this issue—one on lexically specific syntactic information, and the other on lexically specific semantic information. First, Trueswell, Tanenhaus and Kello (1993) looked at lexically specific syntactic constraints by examining how people dealt with the direct object / sentence complement ambiguity, as in example (1) above. We had people read ambiguous sentences that resolved toward the sentence complement alternative (e.g., "Henry forgot Lila was almost always right"). In this research, we compared two groups of verbs: DO-bias and SC-bias verbs, which differ in their tendency to be used with a direct object or sentence complement. DO-bias verbs permit a sentence complement, but have a strong tendency to be used with a direct object (e.g., "forgot"). SC-bias verbs tend to be used with a sentence complement and rarely use a direct object (e.g., "realized"). These tendencies were determined by syntactically analyzing how a separate group of participants used these verbs in a sentence production study. In the reading experiments, sentences with DO-bias verbs (e.g., "... forgot Lila was almost always right") showed the typical garden-path effect (i.e., long fixations and regressive eye movements in the "disambiguating" region, "was almost always . . ."), suggesting that readers had incorrectly taken the noun as the direct object and were revising their commitment. Sentences with SC-bias verbs (e.g., "... realized Lila was almost always right") showed no signs of difficulty in this region, suggesting that the noun was initially taken as the subject of a sentence complement. Thus specific syntactic knowledge about verbs was used quite rapidly to inform the decision about an ambiguous phrase.

Likewise, Trueswell, Tanenhaus, and Garnsey (1994) found rapid use of lexically specific semantic information. This research examined the reading of ambiguous reduced relative clauses, like the second example above. It was found that the usual garden path associated with reduced relative clauses (e.g., "The defendant examined by the lawyer was unreliable") could be eliminated when the initial noun was a poor subject and good object of the verb (e.g., "The evidence examined by the lawyer was unreliable"). What little difficulty that was observed with these items correlated with ratings of how plausible the noun was as the object (theme role) of the verb. Thus semantic information about what

makes a good subject or object of a verb can also be used to inform the early stages of syntactic ambiguity resolution.

These and other findings have helped to develop a "lexicalist" theory of sentence processing that emphasizes the integrative nature of interpretation (the constraint-based lexicalist theory; MacDonald, Pearlmuter, and Seidenberg 1994; Trueswell and Tanenhaus 1994). The framework assumes a constraint-based approach to ambiguity resolution (Marslen-Wilson and Tyler 1987; McClelland 1987), in which multiple sources of information can be used to converge on a single interpretation. The central claim of this approach is that word recognition includes the activation of rich lexical structures, including the parallel activation of lexically specific syntactic and semantic information (e.g., verb argument structure). Syntactic ambiguities hinge upon one or more of these lexical ambiguities, which define the initial set of possible interpretations. Frequency of usage determines the initial availability of information. Thus the grammatical information computed during word recognition determines the initial set of possible alternatives that contextual cues can support.

To make this more concrete, consider the account for the DO/S ambiguity. When readers or listeners encounter a verb like "forgot," the direct object (NP complement) and sentence complement structures would become active based on frequency. Just like an ambiguous word with multiple meanings can have dominant and subordinate senses, an ambiguous word can also have dominant and subordinate syntactic argument structures. If we estimate structural frequencies from the sentence production data of Trueswell et al. (1993), we can assume that the dominant structure for "forgot" is the NP complement, and the dominant structure for "realized" is the sentence complement. This asymmetry in availability of argument structure is the proposed source of the processing preferences observed in the reading study, in which readers prefer the DO interpretation for "forgot" and the SC interpretation for "realized."

The process of recognizing a verb also includes the activation of semantic information about the event denoted by the verb, including its thematic/conceptual roles. What is meant by this is that the semantic representation of an event includes knowledge about the possible participants of the event, as well as a mapping to the syntactic constituents of the verb (see, e.g., Carlson and Tanenhaus 1988). This type of structure permits an explanation of various semantic effects on parsing, like those found for the reduced relative clause ("The defendant/evidence examined . . ."). A verb like "examined" has two roles associated with it, the agent, who is doing the examining, and the theme, which is being examined. In active argument structures (like the main clause), the

agent maps onto the NP preceding the verb, and the theme maps onto the NP following the verb. In passive structures (like the relative clause) the opposite pattern holds. If this information is available when recognizing a verb, it could serve as a mechanism for explaining the initial preference for the reduced relative over the main clause when the first noun is a good theme and poor agent ("The evidence examined . . ."). Thus the thematic information of a verb can play a central role in integrating conceptual and syntactic constraints on interpretation.

Although the lexicalist theory is consistent with the findings described above, many of its central predictions have so far gone untested. For instance, there is little work that has demonstrated in a direct manner that the initial stages of recognizing a word include the activation of argument structure. Until quite recently, most studies examining the presence of verb argument structure during word recognition have relied upon secondary measures of processing load (e.g., Shapiro, Zurif, and Grimshaw 1987, 1989), and have found conflicting results (Schmauder 1991; Schmauder, Kennison, and Clifton 1991; Shapiro et al. 1987, 1989). In addition, these results have been inconclusive about whether the activation of argument structure, if it occurs during word recognition, is frequency based, showing signs of subordinate and dominant structures. Finally, others have suggested that rapid lexical effects on syntactic ambiguity, like those described above, may in fact be consistent with a structurally based system that permits extremely rapid revision of an initial, lexically blind stage of processing (Frazier 1995; Mitchell et al. 1995).

In the remainder of this chapter, I will present experimental evidence that addresses these issues. Two different groups of results will be presented, both of which explore the relationship between lexical and syntactic ambiguity. In the first section, I'll describe experiments that reveal how effects of lexically specific argument preferences proliferate in syntactic ambiguity resolution and interact with semantic constraints. In the second section, I will turn my attention to effects of word recognition on syntactic ambiguity resolution. I will present results that use a new lexical priming technique to examine whether the argument preferences of briefly displayed prime words (displayed for less than 40 msec) can have an impact on a reader's syntactic decisions about temporarily ambiguous sentences.

Lexical Frequency and Semantic Constraints

According to the lexicalist theory, the initial availability of a word's syntactic alternatives depends upon how often the reader or listener has encountered the word in each syntactic context. In addition, semantic/

contextual information can come into play quite rapidly to help resolve possible ambiguities. The theory also predicts that these two sets of constraints interact in particular ways. For instance, processing difficulty should arise when these constraints are in conflict, as when semantic information supports a subordinate (less common) structure. Such an effect has already been observed for words with multiple senses (the "subordinate bias" effect; Rayner and Frazier 1989; Rayner, Pacht, and Duffy 1994; Sereno, Pacht, and Rayner 1992). In these studies, the left context of an ambiguous word supported the intended meaning of the word (as determined by the upcoming right context). Local increases in reading time occurred only when the context supported a subordinate meaning of a word. No increases were found when the context supported the dominant meaning of a word, or when the context supported one meaning of a "balanced" word that has two equally frequent meanings (Rayner and Frazier 1989; Rayner et al. 1994; Sereno, Pacht, and Rayner 1992).

Similar effects of context interacting with lexical preference are expected for syntactic ambiguities. Consider again the semantic effects for the ambiguous reduced relative clause ("The defendant/evidence examined by the lawyer . . .," Trueswell et al. 1994), in which processing difficulty was eliminated when the noun was a poor agent ("evidence"). One might conclude from this finding alone that the presence of strongly biasing semantic information is sufficient for establishing an initial preference for the relative clause. However, the lexicalist account would expect that the effectiveness of a semantic constraint depends upon the availability of the appropriate structural alternative. It is well known that the reduced relative hinges upon an ambiguity involving the tense of the verb ("examined"). The "-ed" marker for most English verbs can indicate a past-tense verb in an active structure, such as the main clause, or a passive participle verb in a passive structure, such as the relative clause. (Compare with unambiguous verbs like "showed/shown.") Reading an ambiguous verb would provide partial activation for both the past-tense and participle forms of the verb. These alternatives would also activate corresponding argument structures (in this case, the main clause and relative clause) that are consistent with the syntactic context of a noun phrase followed by a verb. Thus there are two different types of frequency information predicted to play a role in this ambiguity. One is the overall frequency of the relative clause and main clause structures. This would result in an overwhelming preference for the main clause because a noun phrase followed by a verb+*"ed"* is almost always a main clause structure (Bever 1970 captured this in the NVN strategy). However, if structural information hinges upon the lexical properties of verbs, this overwhelming struc-

tural frequency asymmetry should be moderated for verbs with high participle frequency. As participle frequency increases, there is likely to be an increase in the availability of the otherwise subordinate relative clause alternative. For example, in Francis and Kucera (1982) frequency counts reveal that "searched" is hardly ever used in a participle form whereas "accused" is frequently used in a participle form. So one might expect to find that semantic support for the relative clause would be more effective at eliminating difficulty when the relative clause contains a verb like "accused" than when it contains a verb like "searched."

To test these predictions, I reexamined the reduced relative eyetracking data reported in Trueswell, Tanenhaus, and Garnsey (1994; see Trueswell 1996) for effects of participle frequency. Indeed, on average, verbs used in the study had relatively high participle frequencies, perhaps explaining why semantic support for the relative clause (e.g., "The evidence examined . . .") was in general so effective at eliminating processing difficulty (see also MacDonald et al. 1994). In addition, I found evidence that some of the variation in processing difficulty between items in this condition was predicted by variation in participle frequency. Regression analyses revealed that the initial processing difficulty for reduced relatives (as measured by first-pass reading times) negatively correlated with each verb's participle frequency ($r^2 = 0.41, p < 0.05$). In other words, contexts supporting the relative clause were much more effective at eliminating processing difficulty when the ambiguous verb was high in participle frequency. I have recently confirmed these findings in a series of reading studies that directly compared verbs with high and low participle frequency (Trueswell 1996). These studies held semantic support for the relative clause constant, while manipulating participle frequency. As expected, reduced relative clauses were more difficult to read when the verb was low in participle frequency than when the verb was high in participle frequency (a "subordinate bias" effect; see figure 19.1).

Although the relative clause data are consistent with the lexicalist predictions for ambiguity resolution, one could argue that the findings only provide indirect evidence in support of this view. Specifically, one would expect that the frequency of a verb's argument structures, not necessarily tense, determines the availability of syntactic forms. (Tense only indirectly estimates argument structure frequencies—see Trueswell 1996, for further discussion.) To address this issue, I examined how argument frequency affects the resolution of an ambiguity that does not depend upon tense (Trueswell, Kim, and Shapiro 1997). These experiments took advantage of Penn's syntactically analyzed corpora of English Text (the Penn Treebank, Marcus, Santorini, and Marcinkiewicz 1993) to estimate a verb's probability of appearing with particular

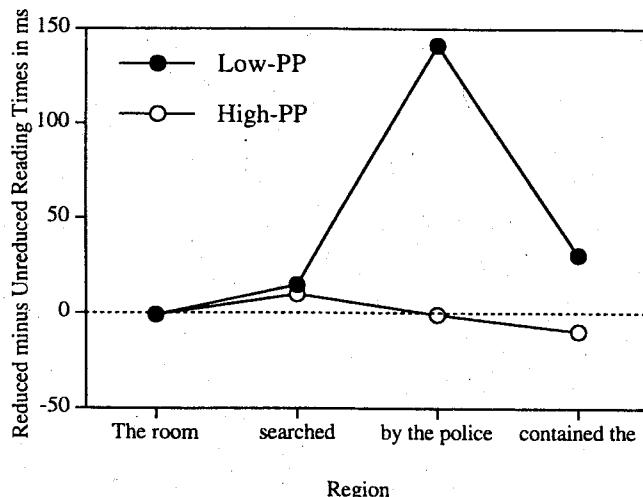


Figure 19.1.
Ambiguity effect for the reduced relative (Trueswell 1996; copyright by Academic Press).

arguments. These probabilities were then used to predict processing preferences in readers and listeners. The experiments examined a structural ambiguity that arises when an alternating dative verb is placed in a passive frame (e.g., "The woman was sent . . ."). The verb "sent" can allow a second noun-phrase argument, as in "The woman was sent some flowers," in which case the woman is the recipient of the event. "Sent" can also allow a prepositional argument, as in "The woman was sent to the bank," in which case the woman is the theme of the event. The ambiguity arises because "sent" is among a class of verbs called alternating datives, which have two competing syntactic structures for denoting the theme and recipient roles. The verbs can be used in the double object construction (as in the active sentence "Bill sent Susan the money," or the passive sentence "Susan was sent the money"), in which there are two noun phrases as syntactic arguments of the verb. The verbs can also be used in prepositional dative constructions (e.g., "Bill sent the money to Susan," "The money was sent to Susan").

Given this observation, one might expect that knowing how often "sent" takes a second noun-phrase argument or a prepositional argument could be very useful in determining the preferred interpretation of "The woman" when the verb is initially encountered in sentences like "The woman was sent . . .". In one experiment (Trueswell, Kim, and Shapiro 1997), a cross-modal integration technique was used to exam-

Table 19.1

Mean Naming Latency to Target Word in Milliseconds

| Context | Auditory Fragment | Type of Target | |
|-------------------|--------------------------------------|----------------|-----|
| | | THE | TO |
| Recipient-biasing | " <i>The boy was mailed . . .</i> " | 586 | 604 |
| Theme-biasing | " <i>The card was mailed . . .</i> " | 625 | 556 |

ine parsing commitments for the alternating dative. Participants heard auditory fragments that contained a noun that was a good recipient and poor theme ("The boy was mailed . . .") or a good theme and poor recipient ("The letter was mailed . . ."). Good recipients semantically support the double object construction, whereas good themes support the prepositional dative. Immediately after hearing the fragment, the participants were visually presented with the word "the" or "to" to name aloud. The target word "the" is highly consistent with the double object construction, whereas the word "to" is highly consistent with a prepositional phrase argument. Prior research using this technique has demonstrated that naming latencies are longer to target words that are ungrammatical, or grammatically unexpected, continuations of the context (Cowart 1987; Tyler and Marlsen-Wilson 1977; Trueswell et al. 1993; West and Stanovich 1986). Naming latencies (shown in table 19.1) were consistent with the rapid use of semantic information, mediated by the initial availability of the argument structures. A reliable interaction was found between type of thematic fit (recipient, theme) and type of target ("to," "the"). When the noun was a good recipient of the verb, a double object construction should be expected, and indeed, naming latencies in this condition were longer for "to" as compared to "the." When the noun is a good theme of the verb, a double object construction should not be expected, and naming latencies in this condition should be longer for "the" as compared with "to."

Crucially, we expected these effects to depend upon the frequency of the verb argument structures. Again, keeping track of how often a verb appears in the double object construction could be quite useful in determining the appropriate thematic assignment of the initial noun phrase. A corpus analysis was therefore conducted to determine the frequency with which each verb appeared in the double object construction. The analysis revealed that double object frequency is in fact relatively low for verbs used in this study. Indeed, as seen in table 19.1, semantic support for the recipient role (recipient-biasing nouns) is not completely effective at reversing preferences for "to" over "the." This is because the semantic constraint in this condition supports the subordinate syntactic

alternative (a subordinate bias effect). It was expected that the effectiveness of the semantic support for the double object (the recipient-biased context) would vary continuously across verbs, with the most effective items being associated with verbs that have relatively high double object frequency. This was confirmed in a regression analysis, which paired naming latencies in this condition with each verb's double object frequency. As expected, a reliable negative correlation was found between frequency and naming latencies ($r^2 = 0.22; p < 0.05$).

A second experiment (also in Trueswell, Kim, and Shapiro 1997) found that similar patterns hold for ambiguity resolution during reading. Eye movements were monitored as subjects read sentences like "The woman was mailed the letter . . .". The first noun was always a good recipient and poor theme. In this study, two classes of verbs were directly compared: verbs that are high in double object frequency and verbs that are low in double object frequency. As expected, processing difficulty was found immediately after encountering a verb with low double object frequency, despite the presence of semantic information in support of this alternative.

These results complement recent findings examining the comprehension of long-distance dependencies (e.g., "Which man/baseball did Bill toss . . ."), which find similar syntactic and semantic preference effects for alternating dative verbs (Boland 1997; Boland, Tanenhaus, Garnsey, and Carlson 1995). Taken together, the results suggest that both thematic and syntactic information associated with a verb is accessed and used quite rapidly during interpretation. Indeed, it seems likely that retrieval of this information during word recognition is needed to account for data indicating the early commitment to long-distance dependencies when the verb is first encountered (Boland et al. 1995; Boland 1997).

Thus it appears that for at least three ambiguities, the DO/S ambiguity, the relative clause ambiguity, and the alternating dative ambiguity, clear signs of verb argument preference emerge. The availability of the syntactic properties of lexical items predicts processing difficulty and the initial effectiveness of semantic constraints. As with other lexical ambiguities, semantic support for an alternative is less effective when this information supports a subordinate alternative.

Fast Lexical Priming of Argument Structure

This section turns to research that provides perhaps the most compelling evidence to date that word recognition itself includes the parallel activation of possible argument structures, and that it is this information that determines initial availability of syntactic alternatives during syntactic ambiguity resolution. These studies take advantage of

a new lexical priming technique, fast lexical priming, first introduced by Sereno, Rayner, and colleagues (Rayner et al. 1995; Sereno and Rayner 1992; Sereno 1995). The technique permits the examination of lexical priming during uninterrupted silent reading. In the eye-tracking version of this technique, fixation patterns are recorded as participants silently read text. When the eye lands on a critical target word, a prime word (of equal number of characters) appears in place of the target. The prime is displayed for a brief amount of time (the first 30–40 msec of the initial fixation), and is immediately replaced by the target word. This sequence appears as a "flicker" to the subject, with subjects rarely being able to identify a prime word. Analyses of fixation times have revealed reliable effects of the prime word's orthographic, phonological, and semantic properties (Rayner et al. 1995; Sereno and Rayner 1992; Sereno 1995). For instance, fixations on a target word are faster when the target is preceded by a semantically related prime, as compared to a semantically unrelated prime (Sereno 1995). Similar patterns have been observed for orthographically and phonologically related prime words (see, e.g., Rayner et al. 1995). Taken together, these data are highly consistent with theories of word recognition that allow for the parallel activation of the orthographic, phonological, and semantic information associated with a letter string.

A central prediction of lexicalist approaches to parsing is that word recognition also includes the parallel activation of rich grammatical information, in the form of possible syntactic complements for a word. If this is the case, the syntactic preferences associated with a briefly presented prime word ought to have a direct impact on a reader's parsing preferences of a syntactically ambiguous phrase. To test these predictions, we have examined fast lexical priming effects for the direct object complement / sentence complement (DO/SC) ambiguity, as illustrated in the following example (Trueswell and Kim 1998).

- (3) The man accepted (that) the fire could not be put out.
obtained (DO-prime)
realized (SC-prime)

Target sentences contained a main verb (e.g., "accepted") followed by a sentence complement. Unambiguous sentence complements always began with the optional complementizer "that." Ambiguous sentence complements did not contain the complementizer "that," making the noun phrase "the fire" a potential direct object of the verb. The main verb (e.g., "accepted") was always a verb that permits a sentence complement, but strongly prefers to appear with a direct object as its argument (i.e., DO-biased verbs, as confirmed by sentence production norms). The noun phrase (e.g., "the fire") was always a poor object of

the verb. Several reading studies (not involving fast-priming) have examined the reading of materials like these (e.g., Holmes, Stowe, and Cupples 1989; Garnsey, Pearlmuter, Myers, and Lotocky 1997; Trueswell et al. 1993). All of these studies have found large garden-path effects for DO-biased verbs when reading the ambiguous forms of these materials—consistent with the notion that readers initially pursued a direct object analysis of the noun phrase. For instance, Garnsey et al. (1997) found that when the optional complementizer “that” was absent, readers were surprised by the poor object “fire,” resulting in long reading times. Long reading times were also observed in the verb-phrase region (“could not be . . .”), suggesting that readers had difficulty retrieving the subordinate sentence complement argument structure.

In the present study, a self-paced reading version of fast-priming was used. Prior to reading each sentence, the participant saw groups of equal signs (“=”) covering each character in the sentence. Each press of a button uncovered a word and replaced the previous word with equal signs. When participants reached the target verb, a prime word was displayed in the verb position, for exactly three screen cycles (39 msec). The prime word was then replaced by the target word, which remained on the screen until the next button press. This event was typically perceived as a flicker on the screen, with participants rarely identifying the prime word.

Two different types of prime words were compared. DO-primes (e.g., “obtained”) were verbs that strongly prefer a direct object and do not permit a sentence complement. SC-primes were verbs that strongly prefer a sentence complement and rarely use a direct object. (Primes were matched for string length, overall frequency, and letter overlap with the target verb.) If the initial stages of word recognition include the activation of verb argument structures, one might expect that the subcategorization preferences of the “flicker” (the prime verb) would have a direct impact on the size of the garden path observed for these sentences. In particular, prime verbs that prefer direct objects (DO-primes) should induce a large garden-path effect, whereas prime verbs that prefer sentence complements (SC-primes) should reduce or eliminate the garden-path effect.

Data from twenty-eight subjects were collected, and the magnitude of the garden-path effect is shown in figure 19.2.² The differences between the ambiguous and unambiguous sentences are plotted, with positive numbers indicating increased reading times for ambiguous items. As can be seen in the figure, lexicalist parsing predictions were confirmed. The magnitude of the garden-path effect was much greater for DO-primes than SC-primes, resulting in a reliable interaction between ambiguity and prime type at the noun “fire,” and a marginal interaction at

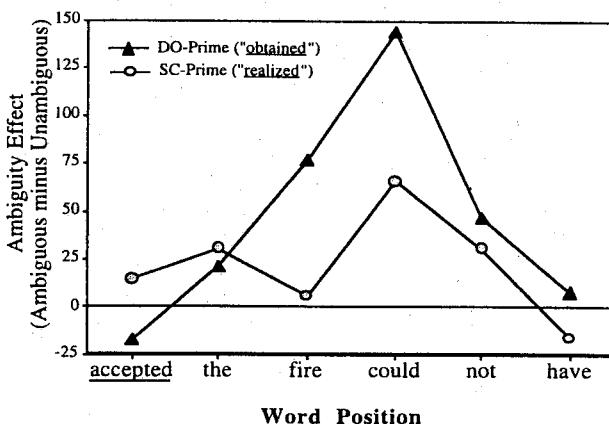


Figure 19.2.

Ambiguity effect for the sentence complement (Trueswell and Kim 1998; copyright by Academic Press).

the disambiguating verb "could." (Because differences are graphed, it is important to note that the effect of prime type is carried by ambiguous rather than unambiguous items, with a reliable effect of prime type occurring only for ambiguous items.)

Thus there were robust effects of lexical priming on syntactic ambiguity resolution. DO-primes showed much larger garden-path effects than SC-primes. What makes this finding even more striking is that the experiment is comparing reading times to perceptually identical sentences across conditions. The only difference is whether a DO-prime or SC-prime was flashed on the screen. Thus it is the subcategorization preferences of the "flicker" that are determining readers' parsing preferences.

To analyze in more detail the contribution of prime and target subcategorization preferences, corpus analyses were also conducted on all prime and target verbs, from the parsed text files of the Penn Treebank. We estimated the probability that each verb uses either a direct object, sentence complement, or some other argument structure. As can be seen in table 19.2, the probabilities confirm the various classifications of verbs. Space precludes a full discussion of the corpus data. However, note that evidence was found that the subcategorization preferences of both the prime and target verbs combined to predict the variation in garden-path effects between items. For instance, a simple averaging of a prime's DO probability and a target's DO probability reliably predicted garden-path effects at the disambiguating word "could," with garden-pathing being largest for targets and primes that more strongly prefer direct objects ($r=0.44$, $p<0.05$).

Table 19.2

Probability of the Direct Object (DO), Sentence Complement (S) Structures

| Type of Verb | DO-Comp | S-Comp | Other |
|------------------------|---------|--------|-------|
| DO-biased Target Verbs | 0.55 | 0.23 | 0.22 |
| SC-Prime | 0.12 | 0.41 | 0.47 |
| DO-Prime | 0.84 | 0.00 | 0.16 |

Finally, note that given this experimental design, we do not know if DO-primes increased the garden-path effect, or SC-primes decreased the garden-path effect, or whether both contributed to the pattern. A second self-paced study was completed to answer this question. The same design was used; however, nonword primes (random letter strings) were also included in the design. In addition, we doubled the number of experimental items. The overall pattern was replicated: DO-primes showed large garden-path effects, and SC-primes showed little or no garden-path effects. Critically, nonword primes showed garden-path effects that were in between these two classes of verbs, suggesting that DO-primes increased the garden-pathing and SC-primes decreased the garden-pathing.

Summary

A clear picture is emerging about the syntactic aspects of word recognition and their impact on incremental interpretation. The earliest stages of word recognition include the parallel activation of possible argument structures, and it is this information that determines initial availability of syntactic alternatives during ambiguity resolution. Perhaps more importantly, the data begin to explain how linguistic information is organized to provide rapid integration of different classes of information. Lexical information is arranged along partially independent stimulus dimensions (phonological, orthographic, semantic, and syntactic), which are relevant for the various ways that we use language. Each type of representation adheres to the same general processing principles, that is, information is made available in a probabilistic fashion and can be constrained by correlated information from other dimensions.

The rapid effects of semantic constraints on syntactic ambiguity resolution are consistent with interactive processing mechanisms. However, the results regarding the availability and priming of argument structure suggest partially independent representation of syntax and semantics. This theoretical description highlights a distinction between "modular representation" and "modular processing" (Garnham 1985;

Trueswell et al. 1994; Trueswell and Tanenhaus 1994). A modular encoding scheme can emerge when a system is faced with complex stimuli that contain partially independent regularities (i.e., information that can sometimes vary independently). For instance, the visual system has, to a first approximation, adopted this approach. Color and motion information can vary independently (red things can move up and down, for instance). It is therefore not surprising that this information is encoded along partially independent stimulus dimensions (color, motion, etc.). Within language comprehension, lexical items are also associated with distinct classes of information, which can vary independently and are only partially correlated. For instance, although it is clear that structures imply certain meanings, differences in meaning arise when these structures appear in particular contexts and with particular lexical items. It is therefore not surprising to find that the system has organized information along several dimensions. However, modular representation does not require modular processing. A system needs to develop consistent solutions across stimulus dimensions, and one efficient approach is to be highly sensitive to the correlations that exist and allow them to constrain ambiguous representations.

Finally, it is interesting that these findings, which emphasize a close relationship between the grammar and the lexicon, tie in nicely with recent developments in computational linguistics, and in particular work here at Penn. As is the case in psycholinguistics, computational linguistics has seen an increased interest in lexicalized syntactic accounts (e.g., Bresnan and Kaplan 1982; Joshi, Vijay-Shanker, and Weir 1991; Pollard and Sag 1994; Steedman 1996) and a reemergence of statistical approaches to parsing (see Church and Mercer 1993; Marcus 1995). Lexicalized grammar formalisms include combinatory categorial grammars (CCGs), head-driven phrase-structure grammars (HPSGs), and lexicalized tree-adjoining grammars (LTAGs). It will be important in the upcoming years to bridge the (relatively small) gap between these linguistic formalisms and the current psycholinguistic theories of sentence processing.

Closing Remarks

It is not surprising that this body of research has required the coordination of several different disciplines: psychology, linguistics, and maybe even a little bit of computer science. Interdisciplinary research has become the norm in the study of language—an everyday thing. Indeed, Lila and Henry Gleitman have been at the forefront of developing this interdisciplinary approach. But, over the last two decades, we have seen essentially all the subdisciplines of psychology move in this

direction. As Henry is fond of saying (quite dramatically of course), "These are changing times." Psychology is becoming more interdisciplinary, more "biological," more "computational." Many people are concerned about whether the broadening of psychology and the blurring of its boundaries will have a helpful or detrimental effect on the field. However, attending this tribute to both Henry and Lila, and listening to their students, has taught me a valuable lesson about this. We can worry a little bit less about these changes, if we know that there are people involved in this process who care deeply about their students, their colleagues, the exchange of a good idea, and the exchange of a good joke, for that matter—people who think and care. Henry and Lila have done the field a great service by promoting these ideals in their students. The changing field called psychology is in better hands because they have made a difference in so many lives. Henry once told me that he didn't feel that he had really earned his Ph.D. until a few years after he had received it. I know exactly what he means. I have had the opportunity of a lifetime by beginning my career at Penn. And, by watching Henry and Lila at work with their students, I have learned a great deal about what it means to be a teacher and a researcher. I thank them both for their hospitality, advice, and encouragement.

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Notes

1. Example sentences tend to use the name "John"—a practice that I have grown tired of. I have therefore developed a program that randomly selects from a list of two names, with the only constraint being that the names appear in alphabetical order in the sentence. Similarities to actual people and situations are purely accidental.
2. Four subjects were excluded from this analysis, because postexperiment interviews revealed that they could identify the majority of the prime words. Interestingly, these subjects show inhibitory effects of the prime's argument structure (see Trueswell and Kim 1998).

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