

The Role of Lexical Frequency in Syntactic Ambiguity Resolution

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The role of lexical frequency in syntactic ambiguity resolution was explored in two self-paced reading studies of ambiguous reduced relative clauses. Recent constraint-based models of syntactic ambiguity resolution have proposed that for a reduced relative clause (e.g., “The room searched by the police was . . .”), both the participle and past tense forms of the ambiguous verb (“searched”) are made available in parallel and that local syntactic and semantic information are used to resolve the ambiguity within a parallel constraint-satisfaction process (MacDonald, Pearlmutter, & Seidenberg, 1994a; Trueswell, Tanenhaus, & Garnsey, 1994). A crucial prediction of these models is that the frequency with which the verb is used as a participle form in the language should affect a reader’s ability to consider the relative clause alternative. This prediction was confirmed in two self-paced reading experiments that directly manipulated participle frequency while controlling for the degree of contextual constraint. Implications for constraint-based lexicalist accounts of sentence comprehension are discussed. © 1996 Academic Press, Inc.

Until recently, most researchers believed that how readers and listeners resolved an ambiguity between two possible meanings of a word was quite different from how they resolved an ambiguity between two possible interpretations of a phrase. This view has been challenged by constraint-based lexicalist models of sentence comprehension, which argue that **local syntactic ambiguity resolution is derived from lexical ambiguity resolution** (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994a; Trueswell, Tanenhaus, & Garnsey, 1994; Trueswell & Tanenhaus, 1994). This article presents critical experimental evidence in support of this view by showing that the resolution of a traditional

syntactic ambiguity, the reduced relative clause ambiguity, depends upon the availability of the competing lexical alternatives of a morphologically ambiguous word.

Even though serial and parallel models have been proposed for syntactic ambiguity resolution (e.g., Crain & Steedman, 1985; Frazier, 1987), most prior work has been guided by serial models that use a limited amount of structural information and decision principles to eliminate ambiguity (e.g., Frazier & Fodor, 1978; Frazier & Rayner, 1982; Frazier, 1987, 1989). In contrast, recent constraint-based lexicalist models have proposed that syntactic ambiguities are resolved in a way similar to lexical ambiguities. This framework takes an interactive or constraint-satisfaction approach to ambiguity resolution (Marslen-Wilson & Tyler, 1987; McClelland, 1987) and makes the general prediction that a variety of syntactically relevant sources of information can be used to converge on a single interpretation of an ambiguous phrase. It is further proposed that most, if not all, syntactic ambiguities hinge upon one or more lexical ambiguities present in a phrase or sentence (an observation first made by Ford, Bresnan, & Kaplan, 1982, but see also MacDonald et al., 1994a; Trues-

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well et al., 1994). The information computed when a word is recognized is used to define the set of syntactic and semantic possibilities as well as provide many of the constraints relevant for evaluating possible interpretations. Thus, the information computed during word recognition supplies the temporary parallelism needed to make available the alternatives over which constraints can apply.

This approach makes the prediction that many of the effects reported for lexical ambiguity resolution, in particular effects of context and lexical frequency, should also occur in syntactic ambiguity resolution. Most prior research on lexical ambiguity has tended to support a parallel access model of meaning resolution, in which multiple meanings of an ambiguous word are computed in parallel, with contextual information "selecting" an alternative (e.g., Swinney, 1979; Tanenhaus, Leiman, & Seidenberg, 1979). Subsequent research has revealed that the relative frequency of the alternative meanings is also important to the resolution process (e.g., Simpson & Burgess, 1985). These studies have found that the frequency of the different meanings of an ambiguous word affects the time course with which they become available for consideration, with dominant meanings being computed more rapidly. Moreover, it has been found that both context and frequency contribute to the resolution process (e.g., Duffy, Morris, & Rayner, 1988; Tabossi, Columbo, & Job, 1987; Tabossi & Zardon, 1993). The eye-movement research of Duffy, Rayner, and colleagues has found that when reading an ambiguous word with two equiprobable meanings, reading times are longer when the prior context is neutral or weakly biasing, compared to when the context strongly biases one meaning. In addition, when the context of an ambiguous word biases the subordinate (less frequent) meaning of the word, reading times are longer on and after the word, compared to sentences in which the context biases a word with two equiprobable meanings (see also Rayner, Pacht, & Duffy, 1994; Rayner & Frazier, 1989; Sereno, Pacht, & Rayner, 1992).

Taken together, these studies indicate that the time course with which context affects ambiguity resolution is in part determined by the initial availability of the alternative lexical forms.¹

The constraint-based lexicalist approach predicts similar effects for syntactic ambiguity resolution (see Burgess & Hollbach, 1988; MacDonald et al., 1994a; Trueswell et al., 1994). Within this framework, the recognition of a word in context also includes the computation of information concerning the type of argument structures within which the word can appear. If this representation is ambiguous, multiple forms may be computed in parallel. The availability of the alternative forms of a word should be determined in part by relative frequency, with more frequent alternatives being computed more rapidly. Crucially, this predicts that the effectiveness of a syntactically relevant contextual constraint should depend upon the frequency of the lexical form it biases.

Consider how these predictions apply to the relative clause/main clause ambiguity, which is the ambiguity used in the present experiments.

1. The thief searched. . . .

Fragments like Example 1 are ambiguous because the same morphological marker is used for the past tense and passive participle forms of most English verbs. A fragment beginning with a noun followed by a verb + "ed" is often ambiguous between the start of a main clause (e.g., "The thief searched the room") and the start of a relative clause (e.g., "The thief searched by the police was . . ."). Thus,

¹ The issue of selective access is not discussed here (see Simpson & Krueger, 1991, and Tabossi & Zardon, 1993, for recent reviews). Some of the more compelling evidence on this issue comes from studies showing that the consideration of multiple meanings is not exhaustive when context strongly biases the dominant meaning of an ambiguous word (Tabossi, 1988; Tabossi & Zardon, 1993). In general, these models of ambiguity resolution recognize that both context and meaning frequency play a role in the resolution process.

these verb forms have different information structures associated with them. For the past tense, the fragment is a main clause with the preceding noun phrase being the subject of the verb. The entity denoted by the noun phrase plays the role of Agent in the event denoted by the verb (i.e., the thief is doing the searching). For the passive participle, the verb is the start of a reduced relative clause and the noun phrase is the logical object of the verb. In this case, the entity denoted by the noun plays the role of Patient or Theme (i.e., the thief is being searched).

The processing of the ambiguous verb (e.g., “searched”) provides partial activation for both the past tense and participle forms of the verb. These alternatives will also activate corresponding argument structures consistent with the syntactic context (in this case the main clause and relative clause). The activation of this information should be determined by how often the system has computed this information. Thus, there are two different types of frequency information that are 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 bias for the main clause since a noun phrase followed by a verb + “ed” is almost always a main clause structure (Bever, 1970, captured this in the NVN strategy, but see also a corpus analysis in Tabossi, Spivey-Knowlton, McRae, & Tanenhaus, 1994). However, if structural information hinges upon the lexical properties of verbs, this overwhelming structural 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 relative clause alternative, such that verbs with high participle frequency should behave like balanced verbs equally supporting both the main clause and relative clause alternatives. For example, Francis and Kucera (1982) frequency counts reveal that “searched” is hardly ever used as a participle form, whereas “accused” is frequently used as a participle form. So, one

might expect to find earlier effects of context for verbs like “accused” than verbs like “searched” in the ambiguous environment of a reduced relative.²

Thus, the constraint-based lexicalist approach makes specific predictions for the resolution of the relative clause ambiguity. First, consistent with constraint-satisfaction systems in general, it is predicted that syntactically relevant contextual information will act as a rapid constraint on the resolution of the reduced relative. Second, the lexicalist approach predicts that this contextual information will be more effective for verbs with high participle frequency.

There are now several experiments demonstrating that syntactically relevant contextual information can have rapid effects on the resolution of the relative clause ambiguity (e.g., Burgess, 1991; MacDonald, 1994; Ni & Crain, 1990; Pearlmutter & MacDonald, 1992; Spivey-Knowlton, Trueswell, & Tanenhaus, 1993; Trueswell et al., 1994; Trueswell & Tanenhaus, 1991; Tabossi et al., 1994). In particular, consider the effects reported in Trueswell et al. (1994) which are directly relevant to the present research. **The results of two eye-tracking experiments demonstrated that local semantic constraints can have immediate effects on the processing of ambiguous reduced relative clauses.** Subjects read sentences containing a temporary ambiguity between the relative clause and main clause, as in Example 2.

2. a. The thief searched by the police was quite unpleasant.

² Two things should be noted here. First, past tense frequency should not have much of an effect on the resolution of the reduced relative clause. The NP + verb + “ed” syntactic context should keep this alternative partially active for all verbs. Second, it is not the case that structural and lexical frequencies must be encoded separately by the comprehension system. Several connectionist models of lexical processing have been found to capture lexically specific and more general (“rule-governed”) information in a single mechanism through what have been called lexical neighborhood effects (see Juliano & Tanenhaus, 1993; Plaut, McClelland, Seidenberg & Patterson, 1996; Seidenberg & McClelland, 1989).

b. The room searched by the police was quite unpleasant.

Reduced relative clauses were preceded either by a noun that was a good Agent of the verb (e.g., 2a) or by a noun that was a poor Agent of the verb (e.g., 2b). **Only reduced relatives preceded by good Agents showed clear signs of processing difficulty compared to unambiguous unreduced relative controls** (e.g., “The thief who was searched . . .”). In addition, subanalyses on the items from the poor Agent condition revealed that what little processing difficulty readers had with these items corresponded to the semantic fit of the individual noun/verb combinations — processing difficulty for these items partially correlated with ratings of how good the noun was as the Theme of the verb (e.g., how likely it is for a room to be searched).

There is, however, only suggestive evidence indicating that contextual effects like the ones described above depend upon the frequency of the participle form. In particular, MacDonald et al. (1994a) presented a meta-analysis of the results of several studies in the literature that had used relative clauses. Ambiguous verbs used in studies that found rapid effects of context had significantly higher participle frequency counts than ambiguous verbs used in studies that found delayed or no effects of contextual constraint. Although this meta-analysis is suggestive, it is not definitive, since the prior studies also varied greatly in the degree of contextual support for the relative clause. Indeed, **all of the studies that showed rapid effects of context have also been argued to have more strongly biasing contextual information.**

In addition, MacDonald et al. (1994b) presented a correlational analysis of the sentence completion results reported in Spivey-Knowlton et al. (1993). MacDonald et al. found that across different items in the Spivey-Knowlton et al. study, the participle frequency of a verb correlated positively with the probability that an ambiguous fragment (like “The thief searched . . .”) would be completed as a rela-

tive clause. The Spivey-Knowlton et al. data however came from a sentence completion task, which combines the tasks of comprehension and production. Thus, it is difficult to determine whether the frequency effects are due to sentence comprehension mechanisms or sentence production mechanisms.

Finally, I have recently found additional suggestive evidence for participle frequency effects in relative clauses. A set of regression analyses, described here, was conducted on the eye-tracking data reported in Trueswell et al. (1994). In the new analysis, first pass reading times for items from the poor Agent condition (e.g., Example 2b) were paired with each verb’s participle frequency, as it appears in the Francis and Kucera (1982) word frequency counts. If frequency matters, one would expect that semantic constraints would be more effective for verbs with high participle frequency. For each region, the reading times for the unreduced sentences were first entered into the regression to predict the reading times for the corresponding sentences with reduced relatives. Then, the log of the participle frequency was entered into the regression to determine the extent to which it accounted for the remaining variance. The pattern was similar for the two experiments. In Experiment 1, a nonsignificant negative correlation with participle frequency was found at the ambiguous verb ($R = -.47$, $F(1,13) = 3.67$, $p < .1$). In Experiment 2, a similar negative correlation was found at the by-phrase, e.g., “by the police” ($R = -.57$, $F(1,12) = 5.28$, $p < .05$). (One item was excluded from this analysis because the verb occurred only once in the corpus.) **A reliable negative correlation indicates that processing difficulty was less for items with higher participle frequency.** It is likely, however, that these relatively weak correlations underestimate effects of participle frequency, since the overall frequency of a verb was not taken into account. A verb that occurs more often in the language should, by chance alone, have a higher participle frequency count. In attempt to correct this, correlations were also conducted on normalized

participle frequencies, in which the log of the participle frequency was divided by the log of the verb's overall frequency. The correlations became stronger in Experiment 1 ($R = -.50$, $F(1,13) = 4.37$, $p < .05$) and in Experiment 2 ($R = -.64$, $F(1,12) = 8.15$, $p < .05$).

Thus, it appears that when an ambiguous verb has a relatively high participle frequency, semantic constraints act immediately, and processing difficulty is reduced. When an ambiguous verb has a relatively low participle frequency, semantic constraints are less effective, and processing difficulty is increased. Unfortunately, this interpretation suffers from a problem like the one described for the MacDonald et al. meta-analysis. In this analysis, the degree of semantic constraint across individual items was not controlled. Recall that Trueswell et al. (1994) found correlations between processing difficulty and the degree to which an individual item was a good Theme of the verb (as estimated in a separate rating study). Indeed, stepwise regressions that include both the degree of semantic fit and participle frequency were equivocal in their findings. Although the overall variance accounted for increases in the regressions, semantic fit and frequency could not simultaneously account for statistically significant independent portions of the variance.

In sum, **although there are strong theoretical reasons to expect lexical frequency effects in syntactic ambiguity resolution, there is currently only a small set of suggestive data in support of this view.** Moreover, these results either could not control for the degree of contextual support of the relative clause or involved a methodology that combines production and comprehension. The present paper describes results that **directly test the lexical predictions of the constraint-based approach to language comprehension.** In two different reading time experiments, the semantic constraints supporting the relative clause alternative were controlled as participle frequency was manipulated. The results confirm that syntactically relevant contextual constraints are

more effective when an ambiguous verb is high in participle frequency.

EXPERIMENT 1

This experiment used the **self-paced reading** paradigm to examine the effects of lexical frequency on syntactic ambiguity resolution. Subjects read syntactically ambiguous reduced relative clauses in which the semantic properties of the initial noun phrase strongly supported the relative clause alternative, as in the following example.

3. The room searched by the police contained the missing weapon.

Two different groups of ambiguous verbs were used to develop the stimuli. One group of verbs had relatively high participle frequency counts in the Francis and Kucera (1982) word frequency norms. These items were called High-PP items. Another group had relatively low participle frequency counts in the Francis and Kucera (1982) word frequency norms. These items were called Low-PP items.

If lexical frequency affects syntactic ambiguity resolution, the initial effectiveness of the contextual support for the relative clause should depend upon the participle frequency of the verb. Verbs with high participle frequency should behave like balanced verbs, making available both the main clause and relative clause alternatives. Thus, High-PP items should show immediate effects of the semantic constraint, resulting in little or no processing difficulty for the ambiguous reduced relative. Verbs with low participle frequency should behave like unbalanced verbs, with the relative clause being the subordinate alternative. Thus, Low-PP items should show delayed effects of the semantic constraint, resulting in increases in processing difficulty for the ambiguous reduced relative.

The presentation of the stimuli involved one word at a time self-paced reading, in which the ambiguous verb (e.g., "searched") was presented separately from the word "by" (see below for a full description). Single word self-paced reading was used because prior work

suggests that the simultaneous presentation of the verb and "by" may influence the availability of the relative clause alternative at the point of ambiguity (Burgess, 1991; Burgess, Tanenhaus, & Hoffman, 1994; Spivey-Knowlton et al., 1993). For example, in two self-paced reading experiments, Burgess et al. (1994) had subjects read sentences similar to those in Trueswell et al., 1994 (e.g., "The thief/room searched by the police was . . ."). In one experiment, the sentences were presented one word at a time. In the other, the same sentences were presented two-words at a time, with the verb and "by" presented together (e.g., "[The room] [searched by]"). Burgess found immediate effects of thematic fit, just like those reported in Trueswell et al. (1994), when the verb and the "by" were presented together, but not when they were presented separately. Single word self-paced reading showed processing difficulty for the relative clause regardless of whether the preceding noun was a good Agent or a poor Agent. It was argued that the presence of the "by" (either parafoveally in unrestricted reading or with a two-word window) provided probabilistic information supporting the relative clause structure. In fact, the only studies in the literature that have effectively eliminated processing difficulty with reduced relatives have been those that combined a strong contextual constraint with the parafoveal presence of the "by" (Burgess, 1991; Spivey-Knowlton et al., 1993; Trueswell et al., 1994). None of the studies showing delayed effects of context had consistent parafoveal support (i.e., Britt, Perfetti, Garrod, & Rayner, 1992; Ferreira & Clifton, 1986; Rayner, Carlson, & Frazier, 1983; Rayner, Garrod, & Perfetti, 1992).

While the Burgess et al. result implicates availability of the relative clause as contributing to the resolution process, it does not determine whether availability is structurally or lexically based. It is possible that structural frequency (the frequency of the relative clause structure) is the only information determining the availability of the

relative clause and that the presence of a "by" may simply provide additional support for this alternative, independent of any individual lexical preferences of the verb. Thus, when the "by" is present, contextual constraints supporting the relative clause can act immediately. The lexicalist framework requires that there be lexically varying effects on syntactic ambiguity resolution, which hinge on the verb in the relative clause. For these reasons, the present study manipulated participle frequency of the verb while excluding the parafoveal presence of the "by."

Method

Subjects

Fourteen subjects from the University of Pennsylvania participated in the experiment. Subjects received extra course credit or were paid for their participation. The experiment lasted for about 30 min. All subjects were native speakers of English.

Materials

Selection of verbs. Twenty verbs were selected for the experiment. All verbs were morphologically ambiguous between the passive participle and past tense. Each verb either had a relatively high frequency count for occurring in the participle form (High-PP verbs) or had a relatively low frequency count for occurring in the participle form (Low-PP verbs). Verbs were selected and categorized into these two groups by using the procedure described below.

Sixteen of the 20 verbs were selected from a set of ambiguous verbs that had been used in a semantic rating study conducted by McRae, MacDonald, Pearlmuter, Spivey-Knowlton, and Tanenhaus (see Tabossi et al., 1994). All verbs in the set had an overall frequency count of more than 20 (Francis & Kucera, 1982). Low frequency verbs were not used because they are likely to have unreliable participle frequency estimates. For each verb, its participle frequency count was compared to its over-

all frequency count (see Appendix 1 for the procedure). Eight verbs having a high ratio of participle frequency to overall frequency were selected as High-PP verbs, and eight verbs having a low ratio of participle frequency to overall frequency were selected as Low-PP verbs. Four additional verbs (two Low-PP and two High-PP) were added from the verbs used in Trueswell et al. (1994), each falling within the frequency ranges of these two groups. Thus, a total of 10 High-PP and 10 Low-PP verbs were used in the experiment.

Pairing of verbs with nouns. Each of the 20 verbs was paired with a noun that has semantic properties supporting a relative clause interpretation (i.e., a noun that is both a good Patient/Theme and a poor Agent of the verb). Animacy is often proposed as a semantic feature that may be relevant to the resolution of the relative clause ambiguity. For this reason, an equal number of animate nouns (three) was used in each verb group. All the nouns were selected based on the results of the semantic rating study mentioned above or a second identical study conducted by the author. Subjects rated the typicality of the Patient/Theme relation for verb–noun pairs, by answering a question like ‘‘On a scale from 1 to 7, how common is it for a room to be searched by someone? (1 = very uncommon, 7 = very common).’’ Subjects made similar ratings for the Agent relationship (‘‘How common is for a room to search someone or something?’’).

The average Agent and Patient/Theme typicality ratings for the verb groups (High-PP and Low-PP) and their standard deviations appear in Table 1. Nouns were selected so that the semantic constraints (as quantified by the ratings) did not differ significantly between the two groups. All nouns were poor Agents and good Patient/Themes. The ratio of participle frequency to overall frequency and standard deviations also appear in the table. Verb frequency information for each of the 20 verbs appears in Appendix 1. Overall, the two verb groups did not differ in their average overall frequency or past tense frequency, but did differ significantly in their participle frequency.

TABLE 1

MEAN TYPICALITY AND FREQUENCY MEASURES FOR LOW-PP AND HIGH-PP VERBS (STANDARD DEVIATION IN PARENTHESES)

Measure	Low-PP	High-PP
Agent Rating	1.5 (0.5)	1.7 (0.7)
Patient or Theme Rating	5.2 (1.4)	5.9 (0.7)
vbn/overall	0.11 (0.07)	0.47 (0.07)
log(vbn)/log(overall)	0.46 (0.12)	0.84 (0.04)

Note. Overall, overall verb frequency count; vbn, passive participle frequency count; log, logarithmic function; slash (/) denotes division.

Appendix 2 contains the typicality ratings for the noun–verb pairs.

Preliminary sentence completion study. A pencil-and-paper sentence completion study was initially conducted to determine whether a verb’s estimated participle frequency influences relative clause/main clause preferences in an ‘‘off-line’’ sentence generation task. Ten subjects participated in the study and did not participate in the subsequent reading-time study.

The 20 noun–verb pairs appeared in sentence fragments that were syntactically ambiguous between a relative clause and a main clause interpretation, as in the example.

4. The room searched —

Subjects were instructed that each fragment was to be completed grammatically with the first thing that came to mind. Subjects were not to skip fragments or go back and change their completions. The 20 target fragments were randomly embedded in a set of 60 distractor fragments of various constructions and lengths. To avoid unwanted subject bias or strategies, 10 of the distractor items contained inanimate nouns appearing in the subject position of a main clause fragment (e.g., ‘‘The toaster burned the —’’). Ten other distractor items contained the same syntactic category sequence as the targets (determiner–noun–ambiguous verb), except the noun–

verb pair biased a main clause (e.g., “The man liked —”).

Subjects always completed the target fragments as either a main clause or a relative clause, and the mean percentage of relative clause completions was computed. Fragments containing High-PP verbs were completed as relative clauses 71% of the time. Fragments containing Low-PP verbs were completed as relative clauses 44% of the time. Subject and item means were entered into two separate ANOVAs with Verb Type (High-PP, Low-PP) as a factor. The difference between the two Verb Types was significant ($F(1,9) = 16.36, p < .01$; $F(1,18) = 7.52, p < .05$). Thus, as expected, subjects generated significantly more relative clauses for ambiguous fragments containing a verb with a high participle frequency compared to ambiguous fragments containing a verb with a low participle frequency.

Target sentences and design. For each noun–verb pair, target sentences were generated, as in Example 5 below.

5. a. The room searched by the police contained the missing weapon.

b. The room that was searched by the police contained the missing weapon.

All target sentences contained a noun phrase (e.g., “The room”), a verb (“searched”), a “by”-phrase explicitly introducing an Agent (“by the police”), and a main clause verb phrase (“contained the . . .”). The self-paced reading experiment had two critical factors: Verb Type and Clause Type. Verb Type was a between-item factor indicating whether the ambiguous verb had a high or low participle frequency (High-PP or Low-PP). Clause Type was a within item factor indicating whether the sentence contained a reduced or unreduced relative clause (Reduced or Unreduced). The complete set of materials appears in Appendix 2.

Two presentation lists were constructed by randomly combining the 20 target sentences with 60 distractor sentences. Distractor sentences contained a variety of sentence types including main clauses with past tense verbs

(10 of these contained inanimate subjects). Within a presentation list, 10 target items were High-PP items and 10 target items were Low-PP items. For each of these verb types, 5 items were Reduced relatives and 5 were Unreduced. Reduced and Unreduced conditions were exchanged across the two lists to ensure a complete design in which no item was seen twice by the same subject. Target items were initially constructed and assigned to a condition such that average word length and average frequency of the head noun of the “by”-phrase (e.g., “police”) were approximately equal across conditions. Each test sentence was followed by at least two distractor sentences. Each subject was presented with 5 practice sentences and one of the two lists.

Procedure

The moving-window self-paced-reading technique was used (Just, Carpenter, & Woolley, 1982). At the beginning of each trial, the entire text was displayed on a computer screen, with each character (except spaces) covered by a single hyphen (-). The subject then pressed a key marked SCROLL to uncover and read the first word. With each press of the SCROLL key, the next word in the sentence was revealed and the previous word was replaced with hyphens again. This was repeated until the end of the sentence. Subjects pressed the SCROLL key with the index finger of their dominant hand. All sentences fit on one line of the monitor. Reaction times were collected for the reading of each word in each target sentence. After each sentence, a yes/no comprehension question was displayed on the screen and the subject responded by pressing a YES or NO key. Subjects were given feedback concerning whether their answer was correct. The subject was seated approximately 72 cm from the monitor (although this distance was not controlled), and the visual angle for each character was approximately 22 min arc.

The stimuli were presented using an IBM compatible personal computer equipped with a monochrome monitor and the Micro-Experimental Laboratory (MEL) software distrib-

TABLE 2

EXPERIMENT 1: MEAN READING TIMES IN MILLISECONDS FOR EACH WORD POSITION

Verb-type	Clause-type	Word position							
		The	room	searched	by	the	police	contained	the
Low-PP	Reduced	308	315	332	385	364	353	343	336
	Unreduced	303	321	317	327	307	328	315	334
	difference	+5	-6	+15	+58	+57	+25	+28	+2
High-PP	Reduced	288	312	366	350	307	340	331	335
	Unreduced	293	307	356	338	324	337	339	337
	difference	-5	+5	+10	+12	-17	+3	-8	-2

uted by Psychology Software Tools, Inc. The monitor was set to a text mode of 80 characters per line. The TEXT self-paced reading package of MEL was used. The original TEXT code for moving-window self-paced reading provides an accuracy of half the refresh rate of the monitor. Refresh rates are typically 1/60th of a second, resulting in approximately 8 ms of additional noise in response data. Before running this experiment however, the TEXT code was modified so that it provided 1-ms accuracy in recording responses to the visual stimuli.³

Results

All subjects scored better than 80% correct on the comprehension questions. Table 2 presents average self-paced reading times to the first eight word positions for each of the four conditions. Within each word position, reading times beyond 2.5 SD of the mean for each subject were adjusted to 2.5 SD, affecting less than 3% of the data. Reading times to "that was" were not included in the analysis.

Single word reading times were summed

³ It is relatively easy to provide 1-ms accuracy to visual displays by using MEL's WaitTop command. Please contact Psychology Software Tools directly for instructions on how to use this command (info@pstnet.com). The change to the code ensures that the response timer begins just before the computer is to redraw the computer screen with a new visual stimulus.

together to create four sentence regions: the initial noun phrase ("The room"), the verb ("searched"), the disambiguating by-phrase ("by the police"), and the first two words of the matrix verb ("contained the"). Figure 1 presents the reduction effects (reading times for the Reduced relatives minus reading times for the Unreduced relatives) for each sentence region. Positive numbers reflect increases in processing difficulty for the ambiguous Reduced relative. As can be seen in the figure, reduced relatives containing a verb with a high participle frequency (High-PP items) showed little or no processing difficulty in any region.

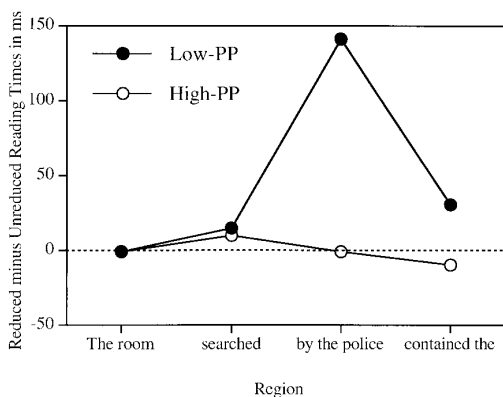


FIG. 1. Mean reduction effects in milliseconds (reading times for reduced relatives minus reading times for unreduced relatives) summed across words for each region (Experiment 1).

Reduced relatives containing a verb with a low participle frequency (Low-PP items) showed increases in difficulty in the disambiguating by-phrase region, despite the presence of semantic constraints that supported a relative clause interpretation.

For each sentence region, subject and item means were entered into separate analyses of variance (ANOVAs) having two factors: Verb Type (High-PP, Low-PP) and Clause Type (Reduced, Unreduced). All analyses of variance of reading time data in this paper are conducted on reading times adjusted for string length. Reading times for each subject were entered into a separate regression analysis with reading time as the dependent variable and string length as the independent variable (see Trueswell et al., 1994). Residual reading times were computed and used in the ANOVA. The results of these analyses are presented below. (Because string length was controlled in the experiment, the statistical patterns were similar between analyses of unadjusted and residual reading times.)

The initial NP ("The room"). No significant differences were found for this region.

The verb ("searched"). At the ambiguous verb, reading times to High-PP verbs were slightly longer than Low-PP verbs, resulting in an effect of Verb Type that was significant in the subject analysis but not the item analysis ($F(1,13) = 9.85, p < .05, F(1,18) = 2.49$).

The disambiguating by-phrase. At the by-phrase, an interaction occurred between Verb Type and Clause Type ($F(1,13) = 5.38, p < .05; F(1,18) = 4.77, p < .05$). Reading times to reduced relatives were on average 70 ms longer than unreduced relatives, resulting in a reliable effect of Clause Type ($F(1,13) = 9.70, p < .01; F(1,18) = 4.65, p < .05$). However, the effect of Clause Type was carried by the low participle frequency verbs (Low-PP items), which showed a reliable 141-ms difference between their Reduced and Unreduced conditions ($F(1,13) = 8.76, p < .05; F(1,9) = 5.40, p < .05$). In contrast, High-PP items showed no difference between Reduced and Unreduced relatives ($F_s < 1$).

The matrix verb phrase. No significant differences were found for this region.

Discussion

The experiment revealed that lexical frequency plays an important role in syntactic ambiguity resolution. When subjects read reduced relative clauses preceded by contextual information supporting this alternative, processing difficulty was eliminated for verbs with high participle frequency but not for verbs with low participle frequency. The low participle frequency items showed significant increases in reading time despite the presence of semantic constraints supporting the relative clause alternative.

The high participle frequency items showed no increases in reading time in any region of the reduced relative clause. This is the first time that processing difficulty has been eliminated for the relative clause without the word "by" being present parafoveally at the ambiguous verb. Previous studies that have manipulated the presence of the "by" indicate that the "by" increases the availability of the relative clause, allowing for immediate effects of context (Burgess et al., 1994; Spivey-Knowlton et al., 1993). The present experiment demonstrates that verb-specific lexical frequencies also increase the availability of the relative clause and do not require additional parafoveal support from the "by."

These conclusions depend upon the assumption that it is the semantic information of the initial noun that is helping eliminate processing difficulty. It is possible, for instance, that High-PP verbs on their own eliminate processing difficulty for reduced relatives, regardless of contextual constraints. This explanation does not require that semantic information play a role in initial processing. To confirm that this was not the case, a second experiment was conducted in which local semantic information supported the main clause alternative.

EXPERIMENT 2

A self-paced reading experiment was conducted using materials similar to those in Ex-

periment 1. The nouns of the target sentences were replaced with nouns that are good Agents, as in Example 6.

6. a. The thief searched by the police had the missing weapon.

b. The thief who was searched by the police had the missing weapon.

It was predicted that processing difficulty ought to occur for reduced relatives, regardless of verb frequency. For Low-PP items, the verb should initially make available only the main clause alternative. The semantic information should support this alternative, resulting in increased processing difficulty for the reduced relative. For High-PP items, the verb should initially make available both the relative clause and main clause alternatives. The semantic information should support the main clause, also resulting in processing difficulty. Despite the availability of the relative clause, contextual information will be supporting the equally available main clause alternative. It is likely, however, that overall processing difficulty for reduced relatives will be less for High-PP items, since the relative clause will at least be partially active during the resolution process.

If it is the case that High-PP verbs themselves eliminate processing difficulty for reduced relatives, we should instead see a pattern identical to the one found in the previous experiment. Low-PP items should show increases in reading time for reduced relative clauses compared to the unreduced relatives, but High-PP items should show no increases in processing difficulty for the reduced relatives compared to the unreduced relatives.

Method

Subjects

Eighteen students from the University of Pennsylvania participated in the experiment for extra course credit.

Materials

The materials and design were the same as those in Experiment 1, except that the nouns

were replaced with good Agents and the matrix verb phrase was changed for some items to make it continue sensibly with the new subject. An example item appears in Example 6 above, and Appendix 3 contains a list of the materials.

Preliminary sentence rating. The noun-verb pairs were used in separate Agent Typicality and Patient/Theme Typicality rating studies to determine the degree of thematic fit of each noun (see the materials section of Experiment 1 for a description of the rating procedure). In general, the nouns were rated as very good Agents and somewhat good Themes. The nouns for the High-PP verbs had a mean Agent rating of 5.8 and a mean Patient/Theme Rating of 3.9. The nouns for the Low-PP verbs had a mean Agent rating of 6.1 and a mean Patient/Theme Rating of 4.2. An analysis of variance on the Agent ratings revealed that the difference between High-PP and Low-PP items was not significant ($F(1,13) = 2.88$; $F(1,18) = 0.64$). The same analysis on the Patient/Theme ratings revealed that the difference between High-PP and Low-PP was significant in the subject analysis but not the item analysis ($F(1,13) = 7.59$; $p < .05$; $F(1,18) = 0.22$). The fact that the nouns for the Low-PP items may be somewhat better Patient/Themes than the nouns for the High-PP items does not confound the predictions of the study. Nouns that are better Patients/Themes should speed the recovery from difficulty for Low-PP items. The participle frequency differences make the opposite prediction: High-PP items should be the ones showing faster recovery from local increases in difficulty.

Procedure

The procedure was the same as that used in Experiment 1.

Results

All subjects scored better than 80% correct on the comprehension questions. Table 3 presents the average self-paced reading times to the first eight word positions for each of the four conditions. Within each word position,

TABLE 3

EXPERIMENT 2: MEAN READING TIMES IN MILLISECONDS FOR EACH WORD POSITION

Verb-type	Clause-type	Word position							
		The	thief	searched	by	the	police	had	the
Low-PP	Reduced	288	298	334	328	361	362	402	347
	Unreduced	293	296	330	340	306	320	317	332
	difference	-5	+2	+4	-12	+55	+42	+85	+15
High-PP	Reduced	297	290	339	327	316	339	352	344
	Unreduced	298	317	308	317	290	306	347	338
	difference	-1	-27	+31	+10	+26	+23	+5	+6

reading times beyond 2.5 SD of the mean for each subject were adjusted to 2.5 SD, affecting less than 3% of the data.

As in Experiment 1, single word reading times were summed together to create four sentence regions: the initial NP (“The thief”), the verb (“searched”), the disambiguating by-phrase (“by the police”), and the first two words of the matrix verb (“had the”). Figure 2 presents the reduction effects (reading times for the Reduced relatives minus reading times for the Unreduced relatives) for each sentence region. Again, positive numbers reflect increases in processing difficulty for the ambig-

uous Reduced relative. As can be seen in the figure, both High-PP and Low-PP items showed increases in processing difficulty in the disambiguating by-phrase region of the relative clause. In the next region, Low-PP items continued to show processing difficulty for reduced relatives compared to unreduced relatives, whereas High-PP items showed little or no processing difficulty.

For each sentence region, subject and item means were entered into separate ANOVAs having two factors: Verb Type (High-PP, Low-PP) and Clause Type (Reduced, Unreduced). The results of these analyses are presented below.

The initial NP (“The thief”). No significant differences were found for this region.

The verb (“searched”). No significant differences were found in this region.

The disambiguating by-phrase. Reading times to Reduced relatives were on average 76 ms longer than Unreduced relatives, resulting in a main effect of Clause Type ($F(1,17) = 8.31, p < .05; F(1,18) = 6.26, p < .05$). Clause Type did not interact with Verb Type (both $F_s < 1$). In addition, a small difference between High-PP and Low-PP items was significant in the subject analysis but not the item analysis ($F(1,17) = 5.74, p < .05, F(2 < 1)$).

The matrix verb phrase. At the verb phrase, an interaction occurred between Verb Type and Clause Type ($F(1,17) = 4.93, p < .05$;

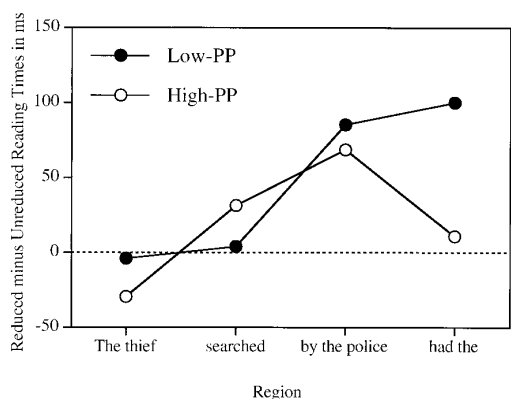


FIG. 2. Mean reduction effects in milliseconds (reading times for reduced relatives minus reading times for unreduced relatives) summed across words for each region (Experiment 2).

$F2(1,18) = 4.81, p < .05$). Reading times to reduced relatives were on average 54 ms longer than unreduced relatives, resulting in a main effect of Clause Type ($F1(1,17) = 7.99, p < .05; F2(1,18) = 7.41, p < .05$). However, the effect of Clause Type was carried by the low participle frequency verbs (Low-PP items), which showed a reliable 99-ms difference between their Reduced and Unreduced conditions ($F1(1,17) = 9.73, p < .01; F2(1,9) = 7.47, p < .05$). In contrast, High-PP items showed no difference between Reduced and Unreduced relatives. ($F_s < 1$).

Discussion

In this experiment, subjects read ambiguous reduced relative clauses in which the meaning of the initial noun supported the main clause alternative (i.e., it was a good Agent). As expected, reading times to reduced relatives increased for verbs with low and high participle frequencies. The fact that High-PP items showed increases in reading time indicates that the presence of a high participle frequency verb cannot on its own eliminate processing difficulty in a reduced relative clause.

In addition, the resolution of the ambiguity effect was reliably faster for High-PP items compared to Low-PP items. This suggests that the relative clause alternative was at least partially available for the High-PP items and that this information was used by the system to produce the correct interpretation. Thus, for High-PP items, both alternatives were available, but the contextual information supported the (incorrect) main clause alternative. Low-PP items showed even greater increases in processing difficulty because in addition to having contextual information supporting the incorrect alternative, the Low-PP verbs were unable to assist in initially computing the correct interpretation.

The distinction made here between different degrees of processing difficulty for Low-PP and High-PP items highlights an important methodological consideration about how to best interpret increases in reading times in sentence comprehension experiments. In most

prior work, longer reading times for a syntactically ambiguous phrase were taken as evidence for a syntactic reanalysis, or garden-path effect. Somewhat smaller increases in reading time were also interpreted as syntactic reanalyses and were sometimes called unconscious garden-paths. The experimental results presented here and the regression analyses described in the introduction suggest that processing difficulty for syntactic ambiguity lies on a continuum and cannot be entirely attributed to revision effects. This is further supported by recent studies that have used correlational analysis to relate degree of difficulty with continuous variables (see MacDonald, 1994; Tabossi et al., 1994; Trueswell, Tanenhaus & Kello, 1993). Thus, processing difficulty patterns may be best characterized as ambiguity effects within a parallel framework, just as they have been characterized for lexical ambiguities (e.g., Duffy et al., 1988). This approach allows one to make more fine-grained predictions concerning ambiguity resolution in language comprehension. Longer reading times for ambiguous phrases occur when there is strong conflict between the constraints supporting one alternative over another. It is likely that "true" reanalysis effects can occur for both syntactic and lexical ambiguities, but these effects depend upon the time course with which the system has received information supporting the correct interpretation. Strongly biasing information in support of an incorrect interpretation may cause the comprehension system to settle into the incorrect alternative relatively early. Receiving disambiguating information in this case may require the system to recover an inactive representation, resulting in even greater increases in reading times.

GENERAL DISCUSSION

The results confirmed that the participle frequency of an ambiguous verb plays an important role in resolving the reduced relative clause ambiguity. When semantic information supported the relative clause alternative (Experiment 1), contextual information acted immediately to eliminate difficulty for verbs with

high participle frequency but not for verbs with low participle frequency. When semantic information supported the main clause alternative (Experiment 2), local processing difficulty occurred for both verbs, but the resolution of the ambiguity effect was faster for verbs with high participle frequency.

The effects mirror those found for processing semantically ambiguous words in context. When the left context of a semantically ambiguous word supports the appropriate meaning (as determined by the upcoming right context), local increases in reading time occur when the context supports a subordinate meaning. No increases are found when the context supports one meaning of a word with two equally frequent meanings (Duffy et al., 1988; see also Sereno et al., 1992). This is similar to the pattern found in Experiment 1 of this article. When the left context supported the relative clause alternative, local increases in reading time occurred for verbs for which the relative clause was the subordinate alternative (Low-PP items) but not for verbs for which the relative clause and main clause were expected to be equally available (High-PP items). Experiment 2 found that when the left context supported the (eventually inappropriate) main clause alternative, processing difficulty occurred for both types of verbs, but was less severe for the High-PP verbs. Previous work on lexical ambiguity resolution has not examined this particular situation. A corresponding experiment would involve the reading of an ambiguous word in an environment in which the left context supports one meaning and the right context supports another meaning. The results from Experiment 2, however, are consistent with the notion that the reading of a balanced word makes available in parallel both alternative meanings.

Taken together, the results support the constraint-based lexicalist approach to sentence processing, which predicts that lexical and syntactic ambiguity resolution involve similar mechanisms. As outlined in the introduction, syntactic ambiguities emerge from the probabilistic properties of verbs in different syntac-

tic environments (see MacDonald et al., 1994a; Trueswell & Tanenhaus, 1994). Contextual information that supports a particular structure is expected to have immediate effects when lexical information also supports the alternative. For the relative clause/main clause ambiguity, it was predicted that a verb's participle frequency would be one source of lexical information that influences the availability of the otherwise subordinate relative clause alternative. The overwhelming structural frequency asymmetry in support of the main clause was expected to be moderated for verbs with high participle frequency, such that these verbs should behave like balanced verbs, equally supporting both alternatives. The results confirmed this prediction, since contextual information in support of the relative clause had rapid effects for only these verbs.

From the perspective outlined above, one would expect a similar pattern of contextual and lexical interactions to hold for a range of ambiguities, concerning those lexical dimensions relevant for resolving each particular ambiguity. An inspection of the recent literature confirms this (e.g., Boland, Tanenhaus, Garnsey & Carlson, 1995; Britt, 1994; Spivey-Knowlton & Sedivy, 1995). For instance, both Britt (1994) and Spivey-Knowlton and Sedivy (1995) found that the resolution of prepositional phrase attachment ambiguities (e.g., "Bill dropped/put the book on the civil war . . .") are influenced by both contextual constraints and verb argument preferences. Although Britt (1994) argues for the limited use of contextual information, both sets of results are consistent with an account in which contextual constraints interact with the availability of verb argument structures (see Spivey-Knowlton & Sedivy, 1995). Similarly, Boland et al. (1995) examined the effects of thematic fit on long-distance dependencies and found that thematic constraints are most effective when a verb makes available the relevant argument structure information.

The effects of argument structure information suggest that complex interactions may

arise from multiple lexical properties of verbs. One important consideration for the present research is the relationship between tense and argument structure. MacDonald (1994) has noted that transitivity preferences are also likely to play a role in resolving the relative clause ambiguity. A prepositional phrase that extends the relative clause ambiguity tends to be taken as evidence for the relative clause alternative when the verb is transitive-biased (e.g., "The cattle pushed into the pen were afraid . . .") but not when the verb is intransitive-biased (e.g., "The cattle moved into the pen were afraid . . ."), as evidenced by increased reading times at "were afraid" for the intransitive-biased items. This suggests that readers were sensitive to the fact that a prepositional phrase following a transitive-biased verb tends to be inconsistent with the main clause alternative.

Transitivity and participle frequency, however, are partially correlated in the language, such that intransitive-biased verbs have lower participle frequencies. This is because the intransitive use of a verb cannot occur in a passive form (e.g., "The man cheered"). Thus, it becomes difficult to distinguish contributions of participle frequency and transitivity to the resolution of the relative clause. It is possible to untangle the source of these effects, however. For instance, there is evidence that transitivity preferences played a smaller role in the results reported here. The sentence completion fragments used to prepare the materials for Experiment 1 did not contain prepositional phrases (e.g., "The room searched . . ."). Yet, High-PP items showed increased use of the relative clause compared to Low-PP items. Since no information was provided after the verb that could be consistent or inconsistent with the main clause transitive use of a verb, these results are likely to be due to participle frequency and not transitivity. In addition, the sentences from the reading studies contained "by"-phrases that explicitly introduced an Agent (e.g., "The room searched by the police was . . ."). Although "by"-phrases can sometimes be used after the active

form of some verbs, they never occurred for the main clause sentence completions of the verbs reported here. Thus, it is likely that this type of preposition supported the relative clause equally for both transitive- and intransitive-biased verbs in the reading experiments reported here. It should be possible to uncover the varying contributions of tense and argument structure by directly manipulating prepositional phrases from being highly consistent to highly inconsistent with the intransitive use of a particular verb. Indeed, MacDonald (1994) has found that different types of post-verbal modifiers have differing effects on the resolution process. The experiments, however, were not designed to examine the contribution of both participle frequency and transitivity.

Predictions concerning the use of multiple lexical constraints arising from the intersection of several lexical items can be derived from the constraint-based lexicalist approach. However, this raises two important issues that will need to be addressed in future research. First, computational models of on-line sentence processing will need to be implemented within a framework that takes advantage of the statistical properties of individual lexical items and their syntactic contexts. There are now a number of connectionist projects underway that use this approach (e.g., Juliano & Tabor, 1995; Pearlmutter, MacDonald, Daugherty, & Seidenberg, 1993). As has been suggested by these researchers, this work provides a better understanding of which aspects of the linguistic input are reliable enough to emerge as constraints for on-line sentence processing. Projects focusing on the learning of phonological and morphological information have yielded similar results and have helped reveal how lexically specific information may be encoded (e.g., Daugherty & Seidenberg, 1992; Plaut et al., 1996; Seidenberg & McClelland, 1989).

Similarly, it will be important to examine the role that nonsyntactic lexical information plays in the interpretation process. The focus so far has been on the syntactic properties of verbs and their arguments. This stems from a tradition in the sentence processing literature

to assume that a fully specified syntactic structure is an explicit subgoal of the interpretation process. Although syntactic information is undoubtedly an important aspect of the interpretation process, the incremental nature of interpretation makes it likely that a range of semantic properties and even discourse functions are associated with lexical items and are encoded in a probabilistic fashion. The relationship between lexically specific syntactic information and this nonsyntactic information is likely to alter how researchers conceive of both types

of representations. The correlation that exists between verb argument structure and the semantic similarity of verbs (e.g., Fisher, Gleitman & Gleitman, 1991) makes it likely that verb-specific semantic information will pertain to the results reported here. In addition, this aspect of the lexicalist approach will be relevant for understanding the processes underlying the rapid use of thematic information (e.g., Tabossi et al., 1994; Trueswell et al., 1994) and referential context (e.g., Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995).

APPENDIX 1: PROPERTIES OF VERBS

The following is a list of the verbs used in Experiment 1 and 2. The list is divided by verb type. The first 10 items are verbs with low participle preferences (Low-PP). The next 10 items are verbs with high participle preferences (High-PP). For each verb, the following information is provided: The overall frequency (base), the past tense frequency (vbd), the participle frequency (vbn), and two different normalized participle frequency measures (vbn/base and log(vbn)/log(base)).

Verb type	Verb	base	vbd	vbn	vbn/base	log (vbn)/log(base)
Low-PP	entertain	34	4	7	0.21	0.55
	help	352	40	26	0.07	0.56
	hunt	44	2	5	0.11	0.43
	lift	69	34	9	0.13	0.52
	love	145	45	11	0.08	0.48
	request	29	5	7	0.24	0.58
	scratch	22	4	3	0.14	0.36
	search	41	7	2	0.05	0.19
	want	631	204	21	0.03	0.47
	watch	209	68	13	0.06	0.48
High-PP	accept	193	28	67	0.35	0.80
	accuse	45	5	20	0.44	0.79
	adopt	71	11	33	0.46	0.82
	consider	317	31	120	0.38	0.83
	describe	200	28	92	0.46	0.85
	expect	335	30	153	0.46	0.87
	propose	110	19	63	0.57	0.88
	record	74	8	35	0.47	0.83
	release	39	7	19	0.49	0.80
	select	112	8	66	0.59	0.89

APPENDIX 2: TARGET SENTENCES
FROM EXPERIMENT 1

Each item is listed with the reduced and unreduced form (“that was”). The items are listed by verb-type. The first 10 relative clauses contain verbs with low preferences for being a participle (*Low-PP* verbs). The next 10 relative clauses contain verbs with high preferences for being a participle (*High-PP* verbs). Average Agent and Patient Typicality Ratings are provided in parentheses at the end of each sentence.

Low-PP Verbs

1. The audience (that was) entertained by the comedian left in high spirits. (1.7, 6.7)
2. The victim (that was) helped by the fireman was saved from serious injury. (1.9, 5.9)
3. The rabbit (that was) hunted by the wolves escaped into the bushes. (2.4, 6.7)
4. The bricks (that were) lifted by the crane were deposited on the roof. (1.3, 5.4)
5. The textbook (that was) loved by the students was informative and insightful. (1.0, 1.9)
6. The equipment (that was) requested by the hospital finally arrived yesterday. (1.1, 5.1)
7. The sofa (that was) scratched by the cat was badly damaged. (1.3, 4.8)
8. The room (that was) searched by the police contained the missing weapon. (1.1, 6.0)
9. The account (that was) wanted by the agency was worth a lot of money. (2.1, 4.6)
10. The building (that was) watched by the detective was in a bad part of town. (1.1, 4.9)

High-PP Verbs

11. The award (that was) accepted by the man was very impressive. (1.1, 6.6)
12. The suspect (that was) accused by the investigator had no real alibi. (3.3, 6.8)
13. The child (that was) adopted by the couple was happy to have a home. (1.7, 5.9)
14. The alternatives (that were) considered by the committee had some limitations. (1.3, 6.6)
15. The necklace (that was) described by the lady was quite beautiful. (1.2, 5.9)

16. The package (that was) expected by the doctor arrived much too late. (1.3, 5.5)
17. The solution (that was) proposed by the group works perfectly for the program. (1.5, 6.6)
18. The message (that was) recorded by the secretary could not be understood. (1.8, 5.6)
19. The hostage (that was) released by the terrorist had been unharmed. (1.8, 5.5)
20. The recipe (that was) selected by the judges did not deserve to win. (2.2, 4.4)

Note. The verb–noun pair “love-textbook” was accidentally included (it has a low patient typicality rating). Exclusion of this item from the item analysis of reading time data had no significant effect on the means or statistical pattern (the effect size for Low-PP items increased slightly).

APPENDIX 3: TARGET SENTENCES
FROM EXPERIMENT 2

Each item is listed with the reduced and unreduced form (“who was”). The items are listed by verb-type. The first 10 relative clauses contain verbs with low preferences for being a participle (*Low-PP* verbs). The next 10 relative clauses contain verbs with high preferences for being a participle (*High-PP* verbs). Average Agent and Patient Typicality Ratings are provided in parentheses at the end of each sentence.

Low-PP Verbs

1. The manager (who was) entertained by the comedian left in high spirits. (4.6, 3.7)
2. The man (who was) helped by the fireman was saved from serious injury. (6.4, 4.6)
3. The lion (that was) hunted by the wolves escaped into the bushes. (6.5, 3.9)
4. The workers (who were) lifted by the crane were deposited on the roof. (5.6, 2.2)
5. The teacher (who was) loved by the students was informative and insightful. (6.6, 4.9)
6. The specialist (who was) requested by the hospital finally arrived yesterday. (6.1, 5.1)
7. The woman (who was) scratched by the cat was seriously hurt. (5.6, 3.4)

8. The thief (who was) searched by the police had the missing weapon. (6.2, 5.7)
9. The client (who was) wanted by the agency was worth a lot of money. (6.9, 5.4)
10. The director (who was) watched by the detective was in a bad part of town. (6.8, 3.2)

High-PP Verbs

11. The friend (who was) accepted by the man was very impressed. (6.8, 6.4)
12. The witness (who was) accused by the investigator had no real alibi. (6.1, 3.9)
13. The person (who was) adopted by the couple was happy to have a home. (6.4, 3.0)
14. The secretary (who was) considered by the committee had some limitations. (5.9, 3.9)
15. The person (who was) described by the lady was quite beautiful. (6.7, 6.2)
16. The mailman (who was) expected by the doctor arrived much too late. (4.6, 5.5)
17. The speaker (who was) proposed by the group works perfectly for the program. (6.6, 2.9)
18. The man (who was) recorded by the secretary could not be understood. (6.1, 2.1)
19. The delegate (who was) released by the terrorist had been unharmed. (4.7, 2.5)
20. The gourmet (who was) selected by the judges did not deserve to win. (4.5, 2.8)

REFERENCES

- BEVER, T. G. (1970). The cognitive basis for linguistic structures. In J. R. Hayes (Ed.) *Cognition and the development of language*. New York: John Wiley and Sons.
- BOLAND, J. E., TANENHAUS, M. K., GARNSEY, S. M., & CARLSON, G. (1995). Verb argument structure in parsing and interpretation: Evidence from wh-questions. *Journal of Memory and Language*, **34**, 774–806.
- BRITT, M. A. (1994). The interaction of referential ambiguity and argument structure in the parsing of prepositional phrases. *Journal of Memory and Language*, **33**, 251–283.
- BRITT, M. A., PERFETTI, C. A., GARROD, S., & RAYNER, K. (1992). Parsing and discourse: Context effects and their limits. *Journal of Memory and Language*, **31**, 293–314.
- BURGESS, C. (1991). *Interaction of semantic, syntactic and visual factors in syntactic ambiguity resolution*. Ph.D. dissertation, Department of Psychology, University of Rochester, Rochester, NY.
- BURGESS, C., & HOLLBACH, S. C. (1988). A computational model of syntactic ambiguity as a lexical process. In *Proceedings of the 10th annual meeting of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- BURGESS, C., TANENHAUS, M., & HOFFMAN, M. (1994). Parafoveal and semantic effects on syntactic ambiguity resolution. In *Proceedings of the 16th annual meeting of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- CRAIN, S., & STEEDMAN, M. J. (1985). On not being led up the garden path: The use of context by the psychological parser. In D. Dowty, L. Karttunen, & A. Zwicky (Eds.), *Natural language parsing: Psychological, computational, and theoretical perspectives*. Cambridge, England: Cambridge University Press.
- DAUGHERTY, K., & SEIDENBERG, M. S. (1992). Rules or connections? The past tense revisited. In *Proceedings of the 14th annual meeting of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- DUFFY, S. A., MORRIS, R. K., & RAYNER, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory and Language*, **27**, 429–446.
- FERREIRA, F., & CLIFTON, C. (1986). The independence of syntactic processing. *Journal of Memory and Language*, **25**, 348–368.
- FISHER, C., GLEITMAN, H., & GLEITMAN, L. (1991). On the semantic content of subcategorization frames. *Cognition*, **23**, 331–392.
- FORD, M., BRESNAN, J., & KAPLAN, R. (1982). A competence based theory of syntactic closure. In J. Bresnan (Ed.), *The mental representation of grammatical relations*. Cambridge, MA: MIT Press.
- FRANCIS, W. N., & KUCERA, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Boston, MA: Houghton-Mifflin.
- FRAZIER, L. (1987). Sentence processing: A tutorial review. In M. Coltheart (Ed.), *Attention and performance XII*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- FRAZIER, L. (1989). Against lexical generation of syntax. In W. Marslen-Wilson (Ed.), *Lexical representation and process*. Cambridge, MA: MIT Press.
- FRAZIER, L., & FODOR, J. D. (1978). The sausage machine: A new two-stage parsing model. *Cognition*, **6**, 291–325.
- 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.
- JULIANO, C., & TABOR, W. (1995). *Frequency-contrast and grammatical representation: The case of frequency by regularity interactions*. Paper presented at the 8th Annual CUNY Conference on Human Sentence Processing. Tucson, AZ.

- JULIANO, C., & TANENHAUS, M. K. (1993). Contingent frequency effects in syntactic ambiguity resolution. In *Proceedings of the 15th annual conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- JUST, M. A., CARPENTER, P. A., & WOOLLEY, J. (1982). Paradigms and processes in reading comprehension. *Journal of Experimental Psychology, General*, **111**, 228–238.
- MACDONALD, M. C. (1994). Probabilistic constraints and syntactic ambiguity resolution. *Language and Cognitive Processes*, **9**, 157–201.
- MACDONALD, M. C., PEARLMUTTER, N. J., & SEIDENBERG, M. S. (1994a). The lexical nature of syntactic ambiguity resolution. *Psychological Review*, **101**, 676–703.
- MACDONALD, M. C., PEARLMUTTER, N. J., & SEIDENBERG, M. S. (1994b). Syntactic ambiguity resolution as lexical ambiguity resolution. In C. Clifton, L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- MARSLÉN-WILSON, W. D., & TYLER, L. K. (1987). Against modularity. In J. Garfield (Ed.), *Modularity in knowledge representations and natural language understanding*. Cambridge, MA: MIT Press.
- MCCLELLAND, J. L. (1987). The case for interactionism in language processing. In M. Coltheart (Ed.), *Attention and performance XII*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- NI, W., & CRAIN, S. (1990). How to resolve structural ambiguities. In *Proceedings of the 20th annual meeting of the North Eastern Linguistic Society*. Amherst, MA: Graduate Student Linguistics Association.
- PEARLMUTTER, N. J., & MACDONALD, M. C. (1992). *Garden-paths in "simple" sentences*. Paper presented at the Fifth Annual CUNY Conference on Human Sentence Processing. New York, NY.
- PEARLMUTTER, N. J., MACDONALD, M. C., & DAUGHERTY, K., SEIDENBERG, M. S. (1993). *Constraint satisfaction in main verb/reduced relative ambiguities*. Paper presented at the Sixth Annual CUNY Conference on Human Sentence Processing. Amherst, MA.
- PLAUT, D. C., MCCLELLAND, J. L., SEIDENBERG, M. S., & PATTERSON, K. E. (1996). Understanding Normal and Impaired Word Reading: Computational Principles of Quasi-Regular Domains. *Psychological Review*, **103**, 56–115.
- RAYNER, K., CARLSON, M., & FRAZIER, L. (1983). The interaction of syntax and semantics during sentence processing. *Journal of Verbal Learning and Verbal Behavior*, **22**, 358–374.
- RAYNER, K., & FRAZIER, L. (1989). Selectional mechanisms in reading lexically ambiguous words. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **5**, 779–790.
- RAYNER, K., GARROD, S., & PERFETTI, C. A. (1992). Dis-
- course influences during parsing are delayed. *Cognition*, **45**, 109–139.
- RAYNER, K., PACTH, J. M., & DUFFY, S. A. (1994). Effects of prior encounter and discourse bias on the processing of lexically ambiguous words: Evidence from eye fixations. *Journal of Memory and Language*, **33**, 527–544.
- SEIDENBERG, M. S., & MCCLELLAND, J. L. (1989). A distributed developmental model of word recognition and naming. *Psychological Review*, **96**, 523–568.
- SERENO, S. C., PACTH, J. M., & RAYNER, K. (1992). The effect of meaning frequency on processing lexically ambiguous words: Evidence from eye fixations. *Psychological Science*, **3**(5), 296–299.
- SIMPSON, G., & BURGESS, B. (1985). Activation and selection processes in the recognition of ambiguous words. *Journal of Experimental Psychology: Human Perception and Performance*, **11**, 28–39.
- SIMPSON, G. B., & KRUEGER, M. A. (1991). Selective access of homograph meanings in sentence context. *Journal of Memory and Language*, **30**, 627–643.
- SPIVEY-KNOWLTON, M. J., & SEDIVY, J. (1995). Resolving attachment ambiguities with multiple constraints. *Cognition*, **55**, 227–267.
- SPIVEY-KNOWLTON, M. J., TRUESWELL, J. C., & TANENHAUS, M. K. (1993). Context and syntactic ambiguity resolution. *Canadian Journal of Psychology*, **47**, 276–309.
- SWINNEY, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior*, **18**, 645–659.
- TABOSSI, P. (1988). Accessing lexical ambiguity in different types of sentential contexts. *Journal of Memory and Language*, **27**, 324–340.
- TABOSSI, P., COLOMBO, L., JOB, R. (1987). Accessing lexical ambiguity: Effects of context and dominance. *Psychological Research*, **49**(2–3), 161–167.
- TABOSSI, P., SPIVEY-KNOWLTON, M. J., MCRÆE, K., & TANENHAUS, M. K. (1994). Semantic effects on syntactic ambiguity resolution: Evidence for a constraint-based resolution process. In C. Umiltà & M. Moscovitch (Eds.) *Attention and performance XV*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- TABOSSI, P., & ZARDON, F. (1993). Processing ambiguous words in context. *Journal of Memory and Language*, **32**(3), 359–372.
- TANENHAUS, M. K., LEIMAN, J., & SEIDENBERG, M. S. (1979). Evidence for multiple stages in the processing of ambiguous words in syntactic contexts. *Journal of Verbal Learning and Verbal Behavior*, **18**, 427–440.
- TANENHAUS, M. K., SPIVEY-KNOWLTON, M. J., EBERHARD, K. M., & SEDIVY, J. C. (1995). Interpretation of visual and linguistic information in spoken language comprehension. *Science*, **268**, 1632–1634.
- TRUESWELL, J. C., & TANENHAUS, M. K. (1994). Toward

- a lexicalist framework for constraint-based syntactic ambiguity resolution. In C. Clifton, K. Rayner, & L. Frazier (Eds.), *Perspectives on sentence processing*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- TRUESWELL, J. C., & TANENHAUS, M. K. (1991). Tense, temporal context and syntactic ambiguity resolution. *Language and Cognitive Processes*, **6**, 303–338.
- 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.
- TRUESWELL, J. C., TANENHAUS, M. K., & KELLO, C. (1993). Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **19**(3), 528–553.

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