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Individual Differences in Syntactic Processing: The Role of Working Memory

JONATHAN KING AND MARCEL ADAM JUST

Carnegie Mellon University

The results of two experiments indicate that individual differences in syntactic processing are governed in part by the amount of working memory capacity available for language comprehension processes. Reading the verbs of an object relative sentence, such as *The reporter that the senator attacked admitted the error,* takes more time for readers with less working memory capacity for language, and their resulting comprehension is less accurate. Experiment 1 investigated the effects of a concurrent working memory load and found that with no load or a small memory load many Low Span readers comprehended object relative sentences very poorly although their reading times in the critical area of these sentences were greater than those of High Span subjects. Experiment 2 replicated the reading time effects of Experiment 1 for object relative sentences and showed that pragmatic information improved the comprehension of the lower capacity readers, although their use of this information was limited to the clause in which it was presented.

In this paper, we develop the hypothesis that individual differences in syntactic processing can be observed in normal readers, and that these differences are influenced by differences in working memory capacity for language. Although the processing of syntax has been an active topic of language research for several decades, only a few researchers have examined individual differences in the processing of syntactic information (e.g., Gleitman & Gleitman, 1970; Holmes, 1987). The present research investigates how syntactic processing and the resulting comprehension of sentences may be influenced by a reader's working memory capacity for language. Working memory capacity includes not only storage functions for intermediate or partial products, but a flexibly deployable pool of operational resources needed to perform the symbolic computations that generate those intermediate and partial products (Daneman & Carpenter, 1980). Individual differences in working memory capacity may be the result of differences in either the size of the pool, the efficiency of the processes that perform symbolic computations, or both.

There are several reasons for hypothesizing a relation between syntactic processing and working memory. Syntactic processing transforms a linear sequence of words into a nonlinear (hierarchical) syntactic structure, and this transformation requires the temporary storage of word representations during the left-to-right processing of a sentence. Moreover, linguistic parsing models have appealed to working memory storage limitations to account for the preferences among alternative interpretations in temporarily ambiguous sentences (e.g., Kimball, 1973; Frazier & Foder, 1978; Gibson, 1990). Limitations on the processing functions of working memory are similarly implicated in syntactic processing by evidence that certain syntactic gaps are difficult to find and process (e.g., MacDonald, 1989).

The classic example of a syntactic structure that makes large demands on working memory capacity is a center-embedded rel-

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ative clause, such as the one in sentence (1) below. It is also called an *object relative* for brevity, a name that reflects the role that the head noun plays as the object in the relative clause.

(1) *The reporter that the senator attacked admitted the error.*

Subjects who hear a sentence like (1) and then try to paraphrase it make errors in matching verbs with their agents approximately 15% of the time (Larkin & Burns, 1977). There are three kinds of demands such sentences make on working memory that combine to make them difficult to comprehend. First, the embedded clause in such sentences interrupts the main clause, drawing on the storage resources of working memory. The representation of the clause segment that precedes the interruption must either be retained in working memory during the processing of the embedded clause or be reactivated at the conclusion of the embedded clause (Miller & Chomsky, 1963; Wanner & Maratsos, 1978). Second, the assigning of the proper thematic roles to the two noun phrases imposes some difficulty. In particular, knowing whether the head of the relative clause is the agent or the patient of the relative clause verb causes comprehension of the relative clause to be less accurate than comprehension of the main clause in this kind of sentence (e.g., Holmes & O'Regan, 1981). Third, the assignment of two different roles to a single syntactic constituent also taxes working memory capacity. In the example above, *reporter* is the agent in one clause and the recipient of the action in the other. Associating a single concept with two different roles simultaneously seems to be a source of difficulty in language comprehension (Bever, 1970), and the switching of perspective in the construction of such a concept can also tax cognitive resources (MacWhinney & Pleh, 1988).

The difficulty of processing an object relative sentence contrasts with the relative case of processing a related construction, called a *subject relative*. In a subject relative sentence, like (2) below, the main clause is interrupted, but role assignments can be made one at a time, and the constituents have parallel roles in the two clauses.

(2) *The reporter that attacked the senator admitted the error.*

These subject relative sentences are both easier to comprehend and easier to process on-line than object relative sentences like (1) (Holmes & O'Regan, 1981). In the reading of the easier subject relative sentences like (2), the head of the relative clause needs to be maintained over only a short distance, since the agent role can be assigned to *the reporter* as soon as the verb *attacked* is processed; this leaves only a single role to assign when *the senator* is reached. This contrasts with the reading of an object relative sentence like (1), where the reader cannot assign a thematic role to either *the reporter* or *the senator* until the verb *attacked* is encountered. One would also expect a subject relative sentence like (2) to be easier, because the agent in the relative clause is also the agent in the main clause, and thus requires no assignment of conflicting roles to the actor and no perspective shift. Thus, the three aspects that make the processing of an object relative sentence demanding of working memory are all mitigated in a subject relative sentence. Our main hypothesis is that the difference between these two sentence types in their working memory requirements will interact with the differences in working memory capacity we can observe in a college level population.

The relation between working memory capacity and language processing has been addressed by the work of Daneman and Carpenter (1980, 1983) at the referential level of processing, but not at the syntactic level. Daneman and Carpenter have shown that differences in a measure of working memory capacity predict substantial differences in the ability to compute the referents of pronouns and the ability to integrate semantic information between and within sentences. The measure of working memory capacity developed by Daneman and Carpenter, called the Reading Span Test, determines the longest set of sentences (of approximately 15 words each) that subjects can orally read and from which they can then recall all the sentence-final words of the set. This task requires subjects to maintain the set of unrelated sentence-final words from preceding sentences while they process each successive sentence in the set. Performance on the Reading Span Test accounts for almost 35% of the variance on verbal SAT scores and 80% of the variance in performance on a task which measures the ability to associate pronouns with their antecedents over varying distances (Daneman & Carpenter, 1980; see also Turner & Engle, 1989). By contrast, simple word or digit span tests, which make little demand on any operational resources related to comprehension, typically are not substantially correlated with reading ability or other interesting language tasks (Perfetti & Lesgold, 1977). The advantage of the Reading Span measure over the simpler measures may derive from a similarity between the reading span task and more interesting linguistic tasks in their demands on the storage and processing functions of working memory. Our main hypotheses are that while all readers should have greater difficulty with object relative sentences than with subject relative sentences, it is the readers with less working memory capacity for language as assessed by the Reading Span test who should have the most difficulty.

The distribution of processing load during comprehension should be reflected in the word-by-word reading times for object relative and subject relative sentences like (1) and (2):

(1) *The reporter that the senator attacked admitted the error.*

(2) *The reporter that attacked the senator admitted the error.*

We assume that readers try to interpret each word as soon as they encounter it, in agreement with the Immediacy of Interpretation Hypothesis (Just & Carpenter, 1980, 1987). In the case of the object relative sentence such as (1), the increased processing demands first manifest themselves when the reader reaches the first verb (*attacked*). At that point, the head noun (*reporter*) must be assigned to the thematic role of patient and *senator* must be assigned to the thematic role of agent. Next, the reader encounters the verb (*admitted*) and must find an agent for this verb, but this agent is *not* the same as the agent of *attacked*. Thus the two adjacent verbs should be the locus of the extra processing load. This result was found by Ford (1983) with a continuous lexical decision task in which readers judged each successive word of a sentence to determine whether it was a real word or a nonword. Subjects took 25 ms longer to make a lexical decision on the verbs *attacked* and *admitted* in an object relative sentence like (1) than in a subject relative sentence like (2). Similar results were obtained by Holmes and O'Regan (1981) in a reading task which measured the duration of subjects' eye fixations using sentences in French, which has a similar subject/object relative clause distinction. Consequently, it is reasonable to expect that word-by-word reading times will be sensitive to syntactic processing load and to working memory capacity differences among individuals. It is also known that the process of role assignment in object relative sentences is difficult enough to cause a substantial number of comprehension errors, which suggests that comprehension scores could also be sensitive to working memory capacity differences.

The current studies also experimentally manipulated the subjects' effective working memory capacity by either imposing an extraneous memory load during the processing of the sentences (Experiment 1), or by supplying pragmatic information that would make it easier to comprehend object relative sentences (Experiment 2). In previous studies that used a memory load manipulation, Baddeley (1986) examined sentence comprehension that was concurrent with retaining a string of digits or articulating nonsense syllables. The concurrent storage task imposes an additional load which consumes some of the resources of working memory; consequently, it is expected to degrade some facet of performance in a demanding comprehension task. By contrast, when additional pragmatic information is supplied, comprehension performance should improve, because the pragmatic information could obviate some of the syntactic processing usually required by object relative sentences.

EXPERIMENT 1

This experiment investigated how differences in the working memory capacity of readers affected the processing of syntactic structure. The experimental task itself varied two factors: the syntactic structure of the sentences read and whether or not a memory load was carried in working memory concurrently while reading. The third and central factor studied was the working memory capacity of the subjects, which was assessed by the Reading Span task. The structure of the reading task was similar to that of the Reading Span task described in the introduction. Subjects read sets of one, two, or three sentences and were asked to recall the sentence final words at the end of the set. The syntactic factor was manipulated by varying the structure of the final, target sentence. Half of these targets included subject relative clauses, while the other half contained more difficult object relative clauses. The external memory load factor was manipulated by varying the number of sentences preceding the target. In addition, subjects were required to respond to a true–false probe item testing their comprehension of the final target sentence in the set. This design allowed us to measure the proportion of sentence-final words recalled, the proportion of comprehension probes answered correctly, and the reading times on each word of the target sentence. While recall of sentence-final words will primarily be a reliability check on our use of the Reading Span Test, sentence comprehension accuracy and reading time results will be crucial to our hypothesis. This is particularly true for one- and two-sentence trials, which should be within the capacity limitations of all subjects.

Our hypothesis is that when the combination of storage and processing requirements of a comprehension task exceeds working memory capacity, performance on one or more aspects of the task will deteriorate. Thus, when comparing performance between groups of subjects differing in working memory capacity for language, we would expect the lower capacity subjects to show lower comprehension accuracy for syntactically more complex object relative sentences and increased reading times at the sentence locations in object relative sentences where substantial syntactic computations must be performed. This pattern of results can be expected from the increased processing demands of the object relative sentences compared to subject relative sentences, as described above. The effect of a working memory load should depend on the working memory capacity of the subjects themselves. The performance of high capacity subjects maintaining a working memory load should more closely resemble the performance of low capacity subjects without any load. Similarly, the performance of low capacity subjects maintaining a working memory load should become worse up until the point when their capacity is entirely exhausted, at which point patterns of performance may cease to be easily interpretable.

Method

Materials. Each target sentence occurred as the final sentence of a set of either 1, 2, or 3 sentences. In a set with one sentence, the subject read only the target sentence; then he or she recalled the last word of the sentence and then answered a question about the sentence. In a set of two sentences, there was one sentence prior to the target sentence. The subject read each of the two sentences, recalled the two sentence-final words, and then answered a question about the target sentence. Three sentence trials were the same, except that all three sentence-final words were recalled. For convenience, we will refer to these conditions as sets of 1, 2, or 3 words. However, it is important to remember that when the subject was reading the target sentence, she or he was retaining only 0, 1, or 2 words, respectively, from the preceding sentences. Thus, the number of words retained *during the reading* of the critical sentence was one less than the number of sentences in the set.

There were 60 trials in the experiment, evenly divided among sets consisting of 1, 2, or 3 sentences. There were 36 experimental sets and 24 filler sets. Half of the experimental sets contained an object relative sentence as the last sentence in the trial, while the other half contained a subject relative sentence as the last sentence. The experimental and filler trials were presented in a different random order for each subject. All target sentences were constructed so that the relative clauses were completely reversible and both the correct and reversed versions were equally plausible and appropriate in the context of the sentence. All the sentences were between 12 and 17 words in length. An example of an object relative sentence is:

The reporter that the senator attacked admitted the error publicly after the hearing.

Its subject relative counterpart would be:

The reporter that attacked the senator admitted the error publicly after the hearing.

Eighteen familiar transitive verbs that take animate subjects and objects were each used twice (with different grammatical subjects and objects) in the embedded clauses of the target sentences. Each of the sentences ended with an extra prepositional or adverbial phrase that followed the direct object of the main verb. This was done so that the reading time on the direct object was not contaminated by any effect due to encountering the end of the sentence, where subjects sometimes pause briefly (Just & Carpenter, 1980). The filler sentences that preceded the last sentence in either the experimental or filler sets were sentences that had previously been found to be fairly easy to process, as measured by per-character reading times. The final sentence of each filler set was chosen from another set of sentences which had previously been found to be rather difficult, in order to reduce the likelihood of subjects noticing the object relative sentences as being more difficult than the filler trials. An example of this type of sentence is:

To equivocate on issues that are maladaptive for mankind is a futile objective.

The comprehension test probe for a target sentence was constructed by combining one of the two verbs in the sentence with two of the three nouns. All pragmatically possible orders were used in equal numbers to defeat guessing strategies. Possible comprehension probes for the object relative sentence (1) would include any of the following sentences:

(1) *The reporter that the senator attacked admitted the error . . .*
The reporter attacked the senator. (False)
The senator attacked the reporter. (True)
The reporter admitted the error. (True)
The senator admitted the error. (False)

The same four statements served as the comprehension test items for the subject relative sentence, except that the two statements probing the relative clause would have opposite truth values. The number of true and false comprehension test items was balanced across clause type and memory load. To better assess the comprehension of the embedded clauses of object relative sentences, which have proved to be more difficult to answer in previous research, these were interrogated twice as often as the main clauses; to compensate for this frequency bias, the main clauses of subject relatives were interrogated twice as often as the embedded clauses. (All comprehension analyses below are therefore based on weighted means to correct for the unequal frequencies of main clause and relative clause probes in the two syntactic conditions.)

Procedure. Each set of sentences was presented word-by-word, using a subject-paced moving window paradigm on an IBM-PC/XT (Just, Carpenter, & Woolley, 1982). The procedure is schematically illustrated in Fig. 1. When subjects clicked the handheld microswitch to advance the display to the next word in a sentence, the letters of that word would replace the dashes, and the letters of the previous word would revert to dashes. Each sentence in a set began on a new line, and the final word of each sentence was padded out to a length of 10 characters using underscores, so that the number of dashes in the display would not be a clue to the actual length of the sentence-final word. The critical sentence was followed by an instruction to recall the sentence-final words of the 1, 2, or 3 sentences in the set. Subjects were allowed to recall these words in any order, provided that the sentence-final word of the last sentence not be recalled first, unless there had been only one sentence in the set. After recalling all the sentence-final words that they could, subjects advanced the display to a true/false comprehension probe, which always interrogated the last sentence of the set. Subjects were told to favor accuracy over speed in their responses to the probe. After the probe was answered, the next set started.

Reading Span Test. This test was administered last, and only to those subjects whose reading spans had not been previously measured in other unrelated experiments. Subjects read sets of sentences aloud, one sentence at a time, and then recalled each of the sentence-final words from that set. Subjects were given sets of an increasing number of sentences until they failed to recall all final words for every group of a given set size. Reading span was

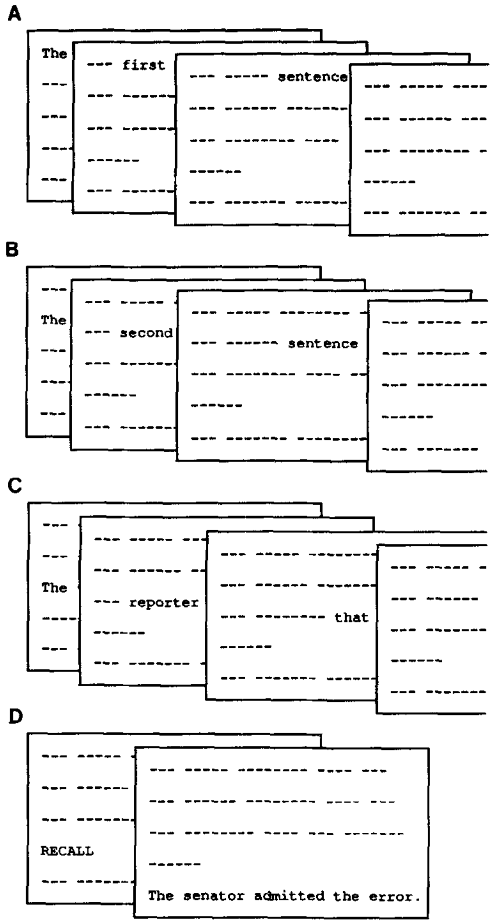

FIG. 1. A diagram showing the course of a three-sentence trial in Experiment 1: (A and B) The subject reads the first two sentences one word at a time and encodes the two sentence-final words. (C) The subject reads the experimental sentence one word at a time and then advances the display one more time to the recall prompt (D), where he recalls as many of the sentence final words as possible. After recall is complete the subject pushes a button to expose the comprehension probe, and answers "True" or "False" by pressing the appropriate button on the response box.

defined as the size of the largest set for which the subject had perfect recall for final words in three of five sets of that size. If a subject showed perfect recall in two of five groups of a given size, then half credit for that size was given. For example, a subject who recalled final words correctly in all 2-sentence groups, in four of the 3-sentence groups, and only two of the 4-sentence sets received a span score of 3.5. The test sentences in each group were 13 to 16 words long and were unrelated to each other. (See Daneman & Carpenter, 1980, 1983, for a further description of the Reading Span Test.)

All subjects were classified according to their performance as having either being *High* Span, *Medium* Span, or *Low* Span. High Span subjects were those whose reading spans were 4.0 or higher, while Low Span subjects were those whose reading spans were 2.5 or lower. All subjects whose reading spans were either 3.0 or 3.5 were classified as Medium Span subjects. Given that the aim of this work was to seek out differences between readers with large and small working memory capacities, only the data from High and Low Span subjects bear directly on the hypotheses we present, and only these data are analyzed below. In this and several other studies undertaken by our research group, the performance of Medium span subjects has been generally intermediate between that of Low and High Span subjects.

Subjects. A total of 46 Carnegie Mellon students participated in the experiment either to fulfill a course requirement or to receive a \$5.00 payment. The data from one subject, whose word-by-word reading times were almost all greater than 2 s, and the data from two other subjects, whose misunderstanding of the comprehension task led them to respond "true" to every probe in the experiment, were discarded. The data considered below come from 24 High Span subjects and 22 Low Span subjects.

Data analysis. In each of the experimental conditions, the mean reading time per word was calculated for four areas, as indicated by the square brackets:

The [reporter that the senator]
1

[attacked] [admitted] [the error] . . . .
2 3 4

The four areas will be referred to below as the *initial area,* the *relative clause ending,* the *main verb,* and the *final* areas, respectively. The time on the first word of each sentence (the determiner *The*) and on the sentence final phrase was not analyzed because these data were not crucial to any hypothesis. For the object relative sentences, the two areas of primary interest were the relative clause ending and main verb areas, which correspond to the locations of the two verbs (*attacked* and *admitted*); these are expected to be the loci of difficulty when compared to the initial and final areas. The corresponding segmentation of the subject relatives was identical, except that the relative clause ending area falls on the object, rather than on the verb, of the embedded relative clause.

The [reporter that attacked the]
1

[senator] [admitted] [the error] . . . .
2 3 4

For the reading time analysis, all observations that exceeded 1800 ms were trimmed to that value (less than 4% of the times collected). The reading time results reported below and following Experiment 2 include those trials in which the comprehension question interrogating the target sentence was answered incorrectly; however, the results are not substantially changed when such trials are excluded.

Results and Discussion

Recall Accuracy

As expected, recall accuracy of sentence-final words in the experimental task was similar to that in the task that measures span. Recall was worse for Low Span subjects (79%) than for High Span subjects (90%). These results provide a simple reliability check. Moreover, recall was worse for large memory loads (68%) than for small memory loads (100% recall for one-word sets). Also, because both Low and High Span subjects could perfectly recall one-word sets, whereas Low Span readers were much worse than High Span readers at recalling three-word sets, there was a significant interaction of Memory Load and Span. An analysis of variance found all these effects to be quite reliable (with all $p < .001$).

As predicted, the recall of the largest working memory loads was affected by the syntactic complexity of the final, target sentence. The recall rate on three sentence trials was 7% lower if the final sentence was an object rather than a subject relative. This interaction of sentence type and load was significant, with $F(2,88) = 4.86$, $p < .01$. Similar results have been demonstrated using different paradigms, (e.g., Foss & Cairns, 1970; Wanner & Maratsos, 1977) but not to our knowledge in an uninterrupted reading task. This finding suggests that object and subject relative sentences differ in the demands they make on working memory, leaving differential amounts of residual capacity to retain a memory load.

Comprehension Accuracy

High Span readers were hypothesized to have sufficient computational resources to comprehend both object and subject relative sentences at an equally high rate without a memory load, whereas Low Span subjects should be less accurate in their comprehension of the more difficult object relatives, but not necessarily less accurate than High Span subjects on the easier subject relatives. Figure 2 shows the comprehension data for both sentence types with the level of working memory load increasing from left to right in each panel. The data for one-sentence trials show both a main effect of working memory capacity and an interaction between working memory capacity and sentence type. Without any memory load, High Span subjects have a better overall comprehension rate than do Low Span subjects, ($F(1,44) = 10.34$, $p < .01$), but this is particularly true for object relative sentences, where the comprehension difference between High and Low

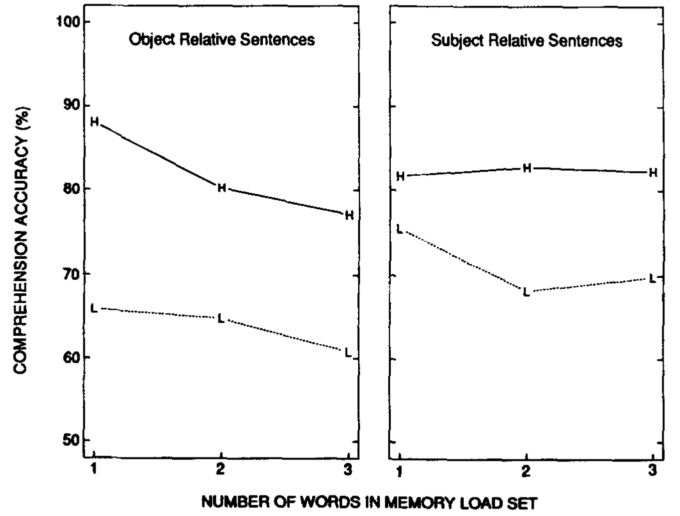

FIG. 2. Mean percentage of comprehension items answered correctly as a function of the number of sentence-final words preceding the tested sentence. The parameter on the curve, "H" or "L," indicates whether comprehension was given by High or Low Span subjects, respectively.

Span readers is 22%, compared to a much smaller 6% difference on subject relative sentences. This predicted interaction between working memory capacity and sentence type was reliable for one-sentence trials ($F(1,44) = 6.50, p < .02$).

Figure 2 shows that the comprehension rate for Low Span subjects on object relative sentences even without a memory load is so low that there is very little room for their performance to deteriorate under a memory load. Indeed, further inspection of the data indicated that 11 of the 22 Low Span subjects had overall comprehension rates that fell within a 95% confidence interval of chance, while only 2 of the 24 High Span subjects did so. If we label those subjects whose overall comprehension was above chance the *comprehending* subjects and those whose overall comprehension was at or near chance the *noncomprehending* subjects, an interesting interaction becomes evident. With no memory load, noncomprehending Low Span subjects gave correct responses to object relative sentences only 51% of the time, while comprehending Low Span subjects averaged 81% correct on these trials. This contrasts with the much smaller difference on computationally easier subject relatives, where the noncomprehending subjects responded correctly over 70% of the time while comprehending subjects responded correctly approximately 80% of the time. Thus, the comprehension of the noncomprehending Low Span subjects was not just globally less accurate, but, as one would expect from our theory, it was particularly poor on the more computationally demanding object relative sentences. The reading time data will provide further evidence that noncomprehending and comprehending Low Span subjects differ primarily in their processing of object relative sentences.

Overall, as Fig. 2 indicates, High Span subjects show better comprehension than Low Span subjects ($F(1,44) = 17.77, p < .001$). The effect of sentence type was marginally reliable ($F(1,44) = 3.31, p < .08$). Responses to relative clause probes were less accurate than responses to main clause probes ($F(1,44) = 6.75, p < .02$). The effect of working memory load was in general accord with the pattern predicted, although the highly variable performance of Low Span subjects noted above prevented the interaction of working memory capacity and other factors from being reliable. High Span subjects show a 10% decline in their comprehension of object relative sentences as the load increases from zero to two words, but no decline in their comprehension of subject relative sentences. Low span subjects, who as a group show near chance-level performance on object relatives with no memory load, show no decline in their comprehension of object relative sentences as the memory load increases, but do show a decline in their comprehension of the easier subject relative sentences as their processing capacity is increasingly consumed by the demands of storing the memory load.

Reading Times

The reading times of all comprehending subjects (as defined above) are shown in Fig. 3. (The performance of the noncomprehending subjects is reported below.) These reading times provide striking support for the hypothesis that differences in working memory capacity affect the on-line processing of syntactic information. In general, the difficulty of processing the critical area was magnified by syntactic complexity, and the amount of magnification was dependent on working memory capacity. The reading time results focus on the one-sentence and two-sentence sets, because it was only in these cases that the comprehension and recall performance were good enough to indicate that subjects understood the sentences and maintained the extraneous memory load. Reading times for the three-sentence sets, while similar in general appearance to the data presented here, were somewhat faster, particularly for low span subjects. Subject reports indicated

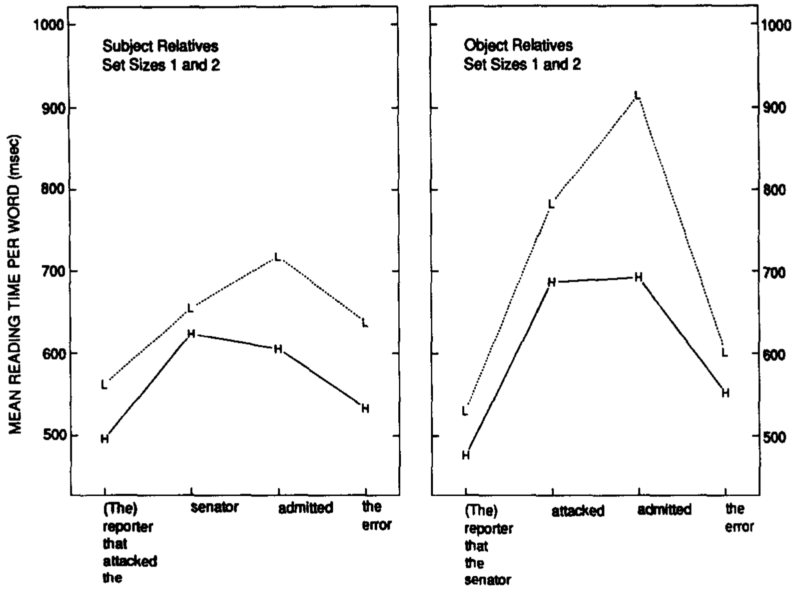

FIG. 3. Mean reading time per word for successive areas of the sentence. (The reading times for parenthesized words are not included in the plotted points.) "H" and "L" are used to plot reading times for High and Low Span subjects, respectively. The left panel shows reading times for subject relatives, and the right panel shows the reading times for object relatives; these reading times are combined from the no working memory load and one-word working memory load conditions.

that the faster reading times in the three-sentence sets was part of an unsuccessful strategy to rush through the sentence in order to recall sooner the memory load materials, so it is difficult to interpret these times, which are given in the Appendix. To examine the reading time results, an ANOVA contrasted the two set size conditions, the two syntactic constructions, and various words (areas) in the sentences as within-subjects factors, and the span group as a between-subjects factor.

The left panel of Fig. 3 depicts the reading times for subject-relative sentences. There is approximately a 60-ms difference in the reading times of High and Low Span subjects, and both groups of subjects show a similar selective increase in reading time at the relative clause-ending sector (*senator* or *attacked*) and at the main verb (*admitted*). The contrast between the left panel and the right panel, which depicts reading times for the harder object-relative sentences, reveals the substantial effect of syntactic complexity. Although the reading times increase in the computationally demanding areas for both sentence types, the increase is much larger (by about 150 ms) for the object relatives in the right panel. Specifically, the reading time on the clause-ending word is reliably longer in object-relative sentences than in subject relative sentences, $F(1,32) = 10.78$, $p < .01$. Similarly, the reading time is reliably longer on the second word in the difficult region, the main clause verb, in the case of object relatives, $F(1,32) = 23.99$, $p < .001$. While High Span subjects spend significantly less time reading the main clause verb of both sentence types ($F(1,32) = 4.99$, $p < .05$), the much sharper divergence of the curves for High and Low Span subjects in the right panel of Fig. 3 suggests the predicted interaction between reading span and sentence type, which is indeed reliable ($F(1,32) = 4.26$, $p < .05$). Although the High Span subjects read more quickly in all four sectors of the object relative sentences, their reading time advantage over the comprehending Low Span subjects is, as predicted, larger in the critical areas and smaller where less processing is required; only in the main verb sector of the object relative sentences is there a significant difference in reading times between High and Low Span readers. Low Span subjects are also the only group that shows any evidence of an effect of memory load on their reading times. As predicted, their reading times are slower on both subject and object relative sentences under a one-word load, but the approximately 100 ms difference did not reach significance due to the small number of comprehending Low Span subjects.

The reading times of the 11 Low Span subjects who comprehended at above-chance levels provide evidence that the effects of syntactic structure do interact with working memory capacity where the processing difficulty is greatest, but this group of subjects represents only half of the Low Span subjects tested in this experiment. Do the non-comprehending Low Span subjects show some sensible pattern of reading times? Because these subjects show little evidence of having comprehended the more difficult object relative sentences, it is possible they simply did not spend the time or resources necessary to construct the correct parse. Thus their reading times should be similar to those of the comprehending Low Spans *except* that they would be spending significantly less time at the critical area of object relative sentences. Figure 4 shows that this is exactly what is happening. While reading times for both comprehending and noncomprehending Low Span subjects were similar outside the critical area of the two sentence types, they were very different for the main verb. Here, the Low Span comprehenders took reliably longer than the noncomprehenders, $F(1,20) = 6.63$, $p < .02$, and there was an interaction between this factor and sentence type, $F(1,20) = 4.20$, $p = .05$. This pattern of reading times suggests that the Low Span

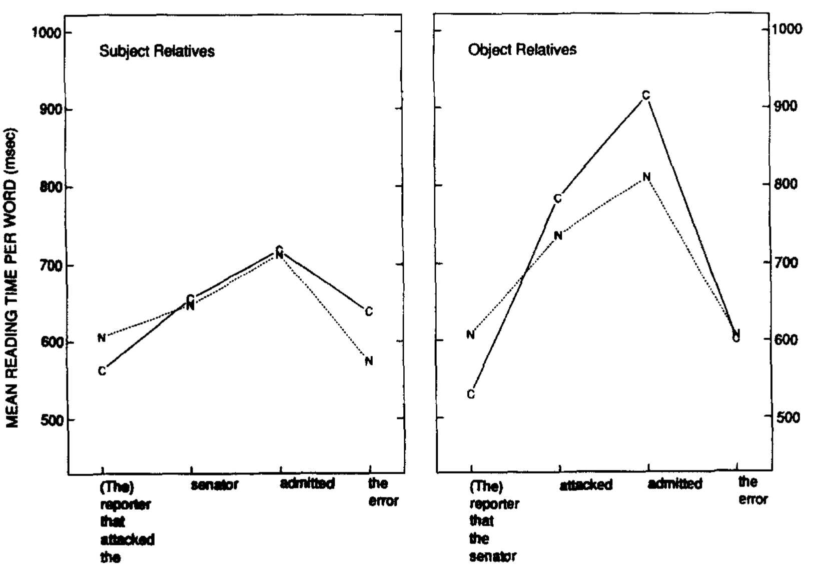

FIG. 4. Mean reading time per word for successive areas of the sentence for Low Span readers only. "C" and "N" are used to plot reading times for Low Span subjects who comprehended at above chance and for those who did not comprehend at above chance, respectively. Reading times for subject relatives are on the left, and reading times for object relatives are on the right. As in Fig. 3, these reading times are combined from the no working memory load and one-word working memory load conditions.

noncomprehenders did not spend the time necessary to associate actors with their appropriate thematic roles, particularly in objective relative sentences where such assignments were most demanding.

These reading time results when combined with the comprehension results discussed above provide converging sources of evidence for the hypothesis that individual differences in working memory capacity can be an important factor in syntactic processing. On the less computationally demanding subject relative sentences with no memory load, Low Span readers performed much like High Span subjects both in their comprehension and in their on-line reading times. On the more computationally demanding object relatives, however, Low Span subjects were much poorer in their comprehension, and even those Low Spans who showed adequate comprehension spent much longer reading on-line in the critical sector of these sentences than did High Span subjects. Furthermore, those Low Span subjects who showed some evidence of having comprehended object relative sentences spent more time in the critical area of the sentence than those who showed little evidence of having comprehended object relative sentences. The primary effect of a small memory load was to reduce the comprehension of High Span subjects on more difficult object relative sentences; this effect did not occur for Low Span subjects apparently because their comprehension of object relatives was nearly at chance in the first place.

The poor performance of many Low Span subjects on object relative sentences in this experiment suggests that they were not processing some critical syntactic cues effectively, apparently because they lacked the working memory capacity to do so. Fortunately for these subjects, pragmatically unbiased and contextually isolated object relative sentences, such as the critical sentences in Experiment 1, are rather rare in normal reading material. It seems possible that Low Span readers may make greater use of other kinds of information in their processing of complex syntactic structures to compensate for their lack of capacity. Experiment 2 was designed to replicate the basic findings of Experiment 1 and investigate how these Low Span subjects might differ from High Span subjects in their use of pragmatic information.

Experiment 2

One surprising result of Experiment 1 was the very low level of comprehension that Low Span subjects showed for the object relative target sentences. One half of all Low Span subjects comprehended these sentences at chance level. These readers may normally rely on extra-syntactic information in order to build correct representations, and their efforts may fail in the absence of such information. A Low Span reader could make use of the pragmatic associations between each of the nouns and the verb in order to help decide which of two possible nouns is the subject and agent of the relative clause. For example, if the two possible agents of the verb *rescued* were *the fireman* and *the robber,* the pragmatic association between *rescued* and *fireman* might lead a Low Span subject to represent *fireman* as the agent of *rescued.* Although this kind of pragmatic information is potentially misleading, it could be an attractive option for Low Span subjects, whose lack of extra processing and storage resources limit their use of other syntactic cues. Because pragmatic associations between nouns and verbs are independent of syntactic relationships, their use requires only the retrieval of familiar stored information rather than computationally expensive syntactic processing. Further, the pragmatic bias of a verb towards one of two possible agents occurs at precisely the point where the information would be useful, and thus does not tax the storage functions of working memory. Indeed, an early experiment by Stolz (1967) demonstrates that people can use pragmatic cues to decode doubly embedded object relative clauses whose syntactic structure they may not be able to evaluate. Experiment 2 investigates how pragmatic information affects the processing of object relative sentences by readers who differ in working memory capacity.

The target sentences of Experiment 2 were all object relative sentences containing verbs that either did or did not provide strong pragmatic cues as to which of the two potential actors in the sentence was the agent of the given verb. There were four different biasing conditions: *both* verbs were pragmatically biased, only the *relative* clause verb was biased, only the *main* clause verb was biased, or *neither* verb was biased, as shown in the examples below:

The robber that the fireman *rescued stole* the jewelry. (both)
The robber that the fireman *rescued* watched the program. (relative)
The robber that the fireman detested *stole* the jewelry. (main)
The robber that the fireman detested watched the program. (neither)

The last sentence type, with no pragmatic cues associated with either verb, resembles the type of sentences used in Experiment 1.

If Low Span readers make substantial use of pragmatic information to construct referential representations, then these pragmatic cues should at least partially relieve them of the need to process syntactic cues based on nonlocal information such as word order, which they were poor at using in Experiment 1. Thus, if both the main clause and the relative clause verb are pragmatically biased towards their agents, Low Span readers should perform comparably to readers who have a greater working memory capacity. As the amount of pragmatic information decreases, the comprehension performance of the Low Span subjects should diverge from that of the other subjects. Indeed, overall performance in the condition where neither verb is biased should resemble that observed under no memory load in Experiment 1.

Working memory capacity should determine not only how much a subject will rely on pragmatic information to comprehend object relative sentences, but also at which point in processing this information will be most beneficial. Low span subjects, who are able to retain less information in working memory while reading, should benefit most when pragmatic information is provided at the point in processing where it is needed. By contrast, pragmatic information which occurs after the point where it is needed should be more difficult for Low span readers to use effectively. Specifically, pragmatic information provided in the main clause verb phrase, which occurs after the end of the relative clause, might be of no help to Low Span readers in comprehending the relative clause. Readers with higher working memory capacities, whose capacity for syntactic processing makes them less dependent on pragmatic information, should comprehend the relative clause similarly regardless of whether pragmatic information was provided during the processing of that clause. In general, the differences between High and Low Span subjects should be much smaller when the main clause is queried than when the relative clause is queried, primarily because the main clause is easier to process, and all the pragmatic information available will occur before or at the point in the sentence where it is most needed.

In contrast to its large effect on comprehension, the immediate effects of pragmatic information on syntactic processing measured with on-line techniques have proven difficult to find in the past (e.g., Clifton & Ferreira, 1987). Given that our materials are manipulating a pragmatic variable that is only heuristic in value and does not directly affect syntactic well-formedness, it is likely that considerable syntactic processing will occur before this information affects processing. This does not mean that the pragmatic cueing is unimportant, (it may be quite important for Low Span subjects) but that it may not have as large an effect on reading times as does working memory capacity. Indeed, without any advance context, this pragmatic information may not become available rapidly enough to guide a reader's initial parsing efforts, so that the factors of working memory and pragmatic bias may not interact in the reading time data.

Method

Materials. The 32 experimental sentences each contained an object relative clause, with eight sentences in each of the four conditions: sentences either had pragmatic cues for *both* verbs, the *relative* clause verb, the *main* clause verb, or *neither* verb. All of the experimental sentences were 13–15 words in length, with the last four to six words of the sentence simply supplying a prepositional or adverbial phrase modifier. An example target sentence from the both condition would be *The robber that the fireman rescued stole the jewelry from the heavy steel safe.*

There were equal numbers of probes testing comprehension of the relative and main clauses of the experimental sentences, and equal numbers of "True" and "False" items were used in each condition. The probe items in this experiment were constructed in the same way as the probes in Experiment 1. Sixty-eight other sentences of similar length (but not containing object relative clauses) were used as fillers. Comprehension items for fillers often tested for information that was not explicitly given in order to discourage subjects from adopting artificial reading strategies.

Procedure. The 100 sentences were presented word-by-word on the screen of an IBM-PC/XT, using the moving window program described in Experiment 1. Otherwise, the procedure was simpler because memory load effects were not being assessed. The initial display for each trial consisted of three lines of dashes (where letters would appear) and blanks; the first two lines contained the sentence (the break being located in the sentence-final phrase) while the third line contained the comprehension probe. There were five practice trials followed by the 32 experimental and 68 filler sentences presented in a different random sequence for each subject.

Subjects. The subjects were 48 students of Carnegie Mellon or the University of Pittsburgh who were native monolingual speakers of English and served either for course credit or a $5.00 payment. The data for one additional subject, whose mean word-by-word reading times were twice that of the other subjects, were discarded without further analysis. All subjects whose reading span scores were not previously known were given the Reading Span Test before they did the primary experimental task. Subjects were classified as being High or Low Span as in Experiment 1 and the results reported below derive from 24 High Span and 24 Low Span subjects.

Data analysis. As in Experiment 1, all reading times that exceeded 1800 ms (less than 2% of the total) were trimmed to that value. For each of the experimental trials, the mean reading time per word was calculated for each of the same four areas of the object relative clause as in Experiment 1:

The [*robber that the fireman*] [*rescued*]
1 2

[*stole*] [*the jewelry*] *from the heavy*
3 4

steel safe.

Results and Discussion

Comprehension Accuracy

As the amount of pragmatic information decreases, readers have to rely more on the strictly syntactic cues present, and comprehension accuracy should decrease. Figure 5 shows that comprehension for all subjects was inferior following sentences in which neither verb was pragmatically biased. Overall comprehension accuracy for trials with both verbs biased was 90% and was almost as high when either the main or relative clause verbs were biased (88% and

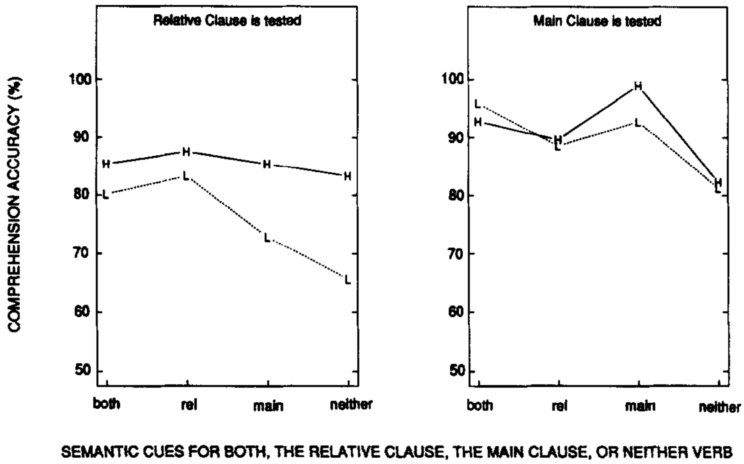

FIG. 5. Mean percentage of comprehension items answered correctly as a function the pragmatic bias, which fell on both verbs (B), the relative clause verb (R), the main clause verb (M), or neither verb (N). On the left, comprehension is plotted for trials where the relative clause verb was queried, and on the right for trials where the main clause verb was queried. The parameter on the curve, "H" or "L," indicates whether comprehension is being plotted for High or Low span subjects, respectively.

87%, respectively). When neither verb was pragmatically biased, however, comprehension accuracy dropped to 78%. This pattern of performance led to a significant effect of pragmatic bias overall, with $F(3,138) = 8.90$ ($p < .001$).

Comprehension of the main and relative clauses differed reliably. When the information being tested was from the main clause, subjects responded accurately over 90% of the time, but when the information was from the relative clause, subjects were correct only 80% of the time, $F(1,46) = 26.03$ ($p < .001$). This latter result corresponds well with the 85% accuracy rate found in a sentence paraphrase task, which requires that both clauses be paraphrased (Larkin & Burns, 1977). As predicted, comprehension performance was poorest (74%) on trials that queried the relative clause when neither verb was pragmatically biased. This compares with an average comprehension rate of 82% in the three other biasing conditions. In the case of main clause comprehension, the difference between the neither verb biased condition (82%) and the other three biased verb conditions (93%) was even larger. High span subjects were not affected by the presence or absence of pragmatic information when the relative clause was tested, although their comprehension accuracy was lower overall when the relative clause was tested. This uneven contribution of verb bias information led to a significant two-way interaction of pragmatic information condition and the clause probed ($F(3,138) = 2.94$, $p < .05$).

Differences in working memory capacity had a large effect on the comprehension responses to more difficult relative clause probes, but not on responses to easier main clause probes. Thus, as Fig. 5 shows, High Span readers showed better comprehension than Low Span readers primarily when the relative clause is probed, and the interaction of working memory capacity and the clause probed is reliable ($F(1,46) = 5.04$, $p < .05$). This result contrasts with the smaller overall comprehension advantage of High Span readers, which is not quite reliable ($F(1,46) = 3.42$, $p < .08$). Figure 5 also indicates that pragmatic bias is quite helpful to Low Span subjects in their comprehension of relative clauses, but not at all helpful to High Span subjects. This pattern contrasts with the comprehension data for the main clause probes, where both High and Low Span readers react similarly to pragmatic information. Because the difference in the helpfulness of pragmatic bias to High and Low Span groups is only apparent for relative clause probes, the overall interaction between working memory and pragmatic bias is unreliable ($F(3,138) = 1.84$, $p > .1$). None of the other interactions in this analysis approach reliability.

Experiment 2, therefore, has enabled us to further restrict the locus of the comprehension difficulty experienced by Low Span subjects. They have difficulty comprehending the information in the relative clause, particularly if no pragmatic information is available. High Span subjects comprehend well if either or both verbs provide pragmatic information. Even when there is no pragmatic information, they still perform better than Low Span subjects when answering questions about the content of the relative clause, but no better when answering questions about the content of the main clauses. This pattern of results suggest High Span subjects can use pragmatic information in their construction of either the clause where the information is provided or the clause where it is absent, whereas Low Span subjects can only use pragmatic information locally. To sum up, the comprehension results provide strong evidence that working memory capacity plays an important role in the use of pragmatic information in comprehending difficult syntactic structures.

Reading Times

The results of Experiment 1 indicated that the difficulty in processing object relative sentences was restricted to the critical area of the relative clause and main clause verb, and that Low Span subjects had relatively more difficulty in the critical area than High Span subjects. Figure 6 shows that the reading times for each group collapsed over the four biasing conditions. High Span subjects processed the verb of the main clause 116 ms faster than Low Span subjects at the verb of the main clause. An ANOVA indicates that the only significant difference between High and Low Span subjects occurs at the verb of the main clause, where $F(1,46) = 4.68, p < .05$. While differences in working memory capacity had large and reliable effects on reading times, differences in pragmatic biasing had only weak effects on reading times. In particular, if both verbs or the relative clause verb were pragmatically biased, readers spent an average of 597 ms on the main clause verb, while if only the main clause verb or neither verb was pragmatically biased, readers spent an average of 624 ms, an effect of only marginal reliability ($F(1,46) = 2.93$, $.05 < p < .10$). There was no evidence of any interaction between working memory capacity and pragmatic bias in the reading time data; indeed, the pragmatic bias effect on main verb reading times was virtually identical for both High and Low Span readers.

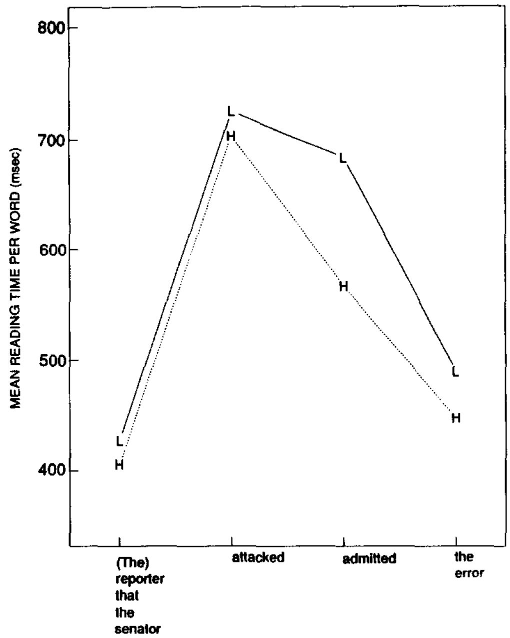

FIG. 6. Mean reading time per word for successive areas of the sentence, comprehending subjects only. (As in Fig. 3, parenthesized words are not included in the plotted points.) As before, "H" and "L" are used to plot reading times for High and Low span subjects, respectively.

In summary, the reading time results replicate the basic effect of Experiment 1, which is that Low Span readers spend reliably more time processing syntactically difficult sentences at the point where the processing is most difficult, but still comprehend more poorly than those subjects who have greater working memory capacity, particularly when the relative clause is queried and when there is no pragmatic information available.

General Discussion

This research shows that individual differences in effective working memory capacity can cause systematic differences in the processing of complex syntactic structures. In both experiments, low capacity readers showed poorer comprehension despite spending more time processing the critical portions of object relative sentences. In addition, the results of Experiment 1 showed that high capacity readers showed reduced comprehension of object relative sentences when an increased working memory load reduced the resources available for comprehension. Experiment 2 showed that an increase in the availability of pragmatic information helped all readers, but particularly Low Span readers, in their comprehension of object relative sentences. In this discussion, we will describe how individual accounts that emphasize storage, role assignment, and perspective maintenance could partially explain these results and how aspects of these accounts have been combined in a larger computational model (Just & Carpenter, 1991).

Storage. The classical explanation for the observed difficulty in parsing object relative constructions primarily rests on the difficulty of maintaining a representation of the head noun in working memory while processing the interrupting clause (e.g., Miller & Chomsky, 1963). Indeed, the difficulty of a double center embedding (*The reporter that the senator that the schoolboy . . .*), would seem to arise from this double interruption. A strict storage account, however, seems less compelling if there is only a single simple noun phrase to be maintained while parsing the inner clause, although Wanner and Maratsos (1978) have found measurable loading effects. Storage-based accounts usually assume that the length of the interruption is important in order to explain why subject relative sentences (which have a short interruption) are easier to process than object relative sentences (which have a longer interruption). Yet other interrupting structures, such as a relatively long appositive phrase in the middle of a sentence like this one, do not seem nearly as difficult to process and comprehend. Similarly, an increase in the interruption length might explain the increase in reading time at and following the relative clause verb as a difficulty in reactivating the memory trace of the head noun, but in fact the accessibility of the first actor in a sentence is actually quite high, even when that actor is not the agent of the action depicted and accessibility is tested near the end of a sentence (Gernsbacher, Hargreaves, & Beeman, 1989). It is unlikely, however, that this representation is kept active without some pressure on working memory, as the model presented below will indicate.

Role assignment. Models of syntactic processing that emphasize the assignment of syntactic and thematic roles of constituents naturally localize these operations to just the places where elevated reading times are observed—at the relative clause and main clause verbs. Indeed, a strictly syntactic account together with an assumption about processing difficulty can explain many of our results. As explained in the introduction, extra computational resources must be used to determine that the gap in the relative clause has been found, and then to make multiple role assignments in case of the object relative clause and a single role assignment in the case of the subject relative clause. The role assignment account correctly predicts that readers who have fewer computational resources available would have more difficulty at this stage, and the model presented below includes a similar mechanism. Pragmatic information, if available, can be used to help assign roles to the actors represented by noun phrases at some point in the process. Reading time results from Experiment 2 suggest that relatively high-level pragmatic biasing does not have an early effect on thematic processing, but it does have an eventual effect; pragmatic information weaker than animacy constraints are probably not used on-line, but can help lessen the comprehension gap between high and low capacity readers.

Although the role assignment account makes accurate predictions about some of the data, there are two problems with this account, considered alone. The first problem is that it is unclear why the assignments made in the object relative clause should be particularly difficult per se. In English, an embedded clause of the form NP1-(that)-NP2-V *always* has the directly preverbal noun phrase (NP2) as its syntactic subject and the other noun phrase (NP1) as its object; there is never any ambiguity. Indeed, adult speakers of English are very consistent in their use of word order information, which is both highly predictive and highly available even when it conflicts with cues like animacy or verb agreement (MacWhinney, Bates, & Kliegl, 1984). Further, if the clause is active and the verb is strictly transitive (as in the present experiments), then the thematic roles of agent and patient directly map onto the syntactic subject and object, respectively. Despite these facts, however, making these assignments in object relative sentences took a substantial amount of time in the current experiments and led to a large number of regressive eye movements in the study done by Holmes and O'Regan (1979).

A more important difficulty with this account of our data is that it does not directly explain why reading times should also be elevated on the main clause verb of the object relative sentence compared to subject relative sentences, since there is only one role assignment to make in both cases. Similarly, it is unclear why differences in reading times explained by working memory capacity should appear here, where processing should be relatively easier than at the relative clause verb. One explanation is that readers may "miss" the gap in the relative clause and realize their mistake only when reading the following main clause verb, but then it would be difficult to see why reading times are *also* elevated at the relative clause verb, unless the extra time was being used to find the gap and begin making role assignments to the unattached noun phrases. Thus a complete computational model will have to include other processes in addition to simple role assignment.

Resolving conflicts in thematic assignment and perspective maintenance. It has been long assumed that it is difficult to make two different and conflicting thematic assignments to a single noun phrase/actor (Bever, 1970, provides one early account). This hypothesis accounts for the relative difficulty of object relative sentences, in which the agent of the main clause is the patient of the relative clause, when compared to subject relative sentences, in which the agent of the main clause is also the agent of the relative clause. The principle of perspective maintenance gives a slightly different (and more general) explanation for this difficulty in the main clause of object relative sentences. This principle suggests that the difficulty in parsing certain relative clause constructions arises from the need to switch perspective from one actor to another in the construction of the referential representation for a sentence (MacWhinney & Pleh, 1988). In a subject relative sentence, the first actor is the subject (and often the agent) of both clauses, and a reader can build a consistent referential representation of the sentence by simply adding new facts to what is already known about that actor. In an object relative clause, however, the actor described in the initial noun phrase is *not* the subject or agent of the relative clause, and since readers tend to follow the point of view of the agent as a sentence progresses, a reader would begin building a referential representation centered on the second actor. But when the main verb is reached, the reader must shift perspective back to the first actor. Attentional shifts draw resources away from other processes, degrading their performance; this is particularly a problem for Low Span readers, who have fewer resources to spare. The principle of thematic conflict and the principle of perspective maintenance both reflect the importance of higher level processing to a sentence processing model that can include an account of individual differences.

A capacity constrained model of parsing. The three accounts discussed above are actually not mutually exclusive, but can be integrated into a single capacity constrained parsing model that implicitly includes aspects of each of them (Just & Carpenter, 1991). The new model is a modified, capacity constrained version of the READER simulation model (Thibadeau, Just, & Carpenter, 1982; Just & Thibadeau, 1984) called Capacity Constrained READER (CC READER for short). CC READER, like READER before it, is based on a production system model that performs computations by matching production rules to the contents of a working memory and performing the action(s) of each matching production to alter the contents of working memory. An unconventional aspect of this production system model is that it allows all of its productions whose conditions are satisfied on a given cycle to fire in parallel, with each production accomplishing its function by incrementing or decrementing the activation levels of various elements in working memory. Individual productions change the activation level of a given working memory element by computing a weighted function of the activation levels of the working memory elements matched by the production. Most productions do not do their full work in a single cycle, but reiteratively increment the activation levels of their target working memory elements over several cycles until some specified threshold value is reached. These unconventional features make the processing of both READER and CC READER closely resemble the processing of connectionist networks.

The greatest difference between CC READER and older versions of the READER model is that CC READER directly imposes constraints on processing by limiting the total amount of activation available on each cycle. When the limit on a given cycle would be exceeded, the actual activation that each production propagates is scaled back in proportion to the amount requested. As one would expect, this limitation on activation applies primarily when there are either a large number of partial products that must be maintained in working memory or when many different productions are firing at the same time. (In this system, both storage and active processing are the result of production firings.) CC READER can model individual differences in working memory capacity either by varying the total amount of activation available, or by varying the efficiency with which particular productions can activate their target working memory elements, or both. In practice, the first of these is generally used and is discussed below.

When parsing sentences with relative clauses, CC READER reflects the partial truth of both storage-based and role assignment-based models. Maintaining the head of an object relative clause in working memory is a source of difficulty for CC READER because the representation of the head of the object relative receives less maintenance support from other items in working memory until it is well integrated into higher level structures. Similarly, it is more difficult to perform simultaneous multiple role assignments because the productions that perform the assignments end up competing against each other for activation. And it is more difficult to assign a second, conflicting thematic role to the head of the object relative clause because the two different thematic structures also end up competing for maintenance activation. CC READER solves this last difficulty while it is still processing the main verb of an object relative sentence by gradually building a more complex thematic representation that adequately supports both role assignments. This more complex structure is in some ways equivalent to the consolidation of discourse perspective predicted by the perspective maintenance model, although the referential level of CC READER is still quite limited.

CC READER also successfully models individual differences between High and Low Span readers in their processing of object relative sentences. If the activation capacity limit is set high enough, the model will always make the correct thematic role assignments within a reasonable number of cycles, but if the activation capacity limit is lowered, the model begins to take substantially longer and can even make errors. Just and Carpenter (1991) include more information on the qualitative fit of the CC READER model not only to the data from this study, but also from other studies investigating the role of working memory capacity in language comprehensions.

Although this research has focused on higher level processes, individual differences are certainly not confined to this level of processing, and the CC READER model is in principle extendable to other levels of processing. For example, one could postulate in the model that word-encoding and lexical access processes are indirectly responsible for the comprehension differences observed in our experiments and see if the modified CC READER provided a better or worse fit of the data. The speed of lexical access has a small but reliable correlation with measures of reading proficiency (Hunt, Lunneborg, & Lewis, 1975; Jackson & McClelland, 1979), which suggests that some Low Span readers could have less efficient lexical access productions that either draw away resources from other levels of processing or provide data that arrives too late to be fully integrated into higher levels of processing. Indeed, there are slight differences in the way the lexical access processes of High and Low Span readers respond to a working memory load (Carpenter & Just, 1989), although higher level differences are more pronounced.

The differences between High and Low Span readers in their comprehension of object relative clauses imply that the supply and efficient use of cognitive resources may differ from person to person. The diversity and sometimes great specificity of acquired language processing deficits also supports this hypothesis, and some recent theories of cognitive functioning before and after brain damage make explicit mention of the allocation and use of cognitive resources (Shallice, 1988). It is possible that such differences in resource use could produce substantial variation in "normal" people as well. Individual differences in syntactic processing exist, just as individual differences in mechanical reasoning or writing ability exist, because complex cognitive phenomena arise from the interaction of many different processes and subprocesses, each of which makes demands on limited cognitive resources.

APPENDIX 1

Mean Reading Times for Two-Word Load Trials in Experiment 1 (Standard Errors in Parentheses)

Area	Group: High span	Low span
Subject relative sentences		
Initial	529 (27)	574 (29)
Rel. clause	619 (53)	713 (55)
Main clause	631 (45)	809 (75)
Final	530 (28)	641 (34)
Object relative sentences		
Initial	502 (26)	581 (33)
Rel. clause	665 (60)	758 (70)
Main cause	708 (47)	767 (39)
Final	588 (32)	676 (59)

Appendix 2: Materials Used in Experiment 2

Both Verb Phrases Biased

The banker that the teacher instructed approved the loan after asking a few questions.

The lawyer that the doctor examined drafted the contract before leaving the office.

The salesman that the accountant audited sold the merchandise at a rather large discount.

The waiter that the comedian amused opened the wine carefully to avoid spilling any.

The detective that the barber shaved investigated the accident at the suburban shopping center.

The judge that the reporter interviewed dismissed the charge at the end of the hearing.

The robber that the fireman rescued stole the jewelry from the heavy steel safe.

The governor that the broker advised signed the legislation just before the end of the year.

Relative Clause Verb Phrase Biased

The comedian that the banker funded answered the telephone after the third ring.

The accountant that the lawyer sued read the newspaper on the train to New York.

The doctor that the salesman assisted watched the movie later with several friends.

The teacher that the waiter served clipped the coupons out of the newspaper.

The broker that the detective questioned drove the sportscar through the tiny village.

The fireman that the judge sentenced dominated the conversation in the bar that evening.

The reporter that the robber mugged cooked the pork chops in a large metal frying pan.

The barber that the governor endorsed climbed the mountain on the following weekend.

Main Clause Verb Phrase Biased

The broker that the banker admired purchased the stock in the new hi-tech company.

The fireman that the lawyer insulted extinguished the blaze in the old abandoned house.

The reporter that the salesman ignored wrote the editorial about the increase in fraud.

The barber that the waiter disliked sharpened the razor with a fine oiled stone.

The comedian that the detective despised delivered the punchline at the crowded night club.

The accountant that the judge liked balanced the books only with great difficulty.

The doctor that the robber phoned prescribed the medication despite the risks.

The teacher that the governor praised graded the essay in the large busy office.

Neither Verb Phrase Biased

The banker that the barber praised climbed the mountain just outside of town.

The lawyer that the reporter phoned cooked the pork chops in their own juices.

The salesman that the fireman liked dominated the conversation about the pennant race.

The waiter that the broker despised drove the sportscar home from work that evening.

The detective that the teacher disliked clipped the coupons out with the dull scissors.

The judge that the doctor ignored watched the movie about Colombian drug dealers.

The robber that the accountant insulted read the newspaper article about the fire.

The governor that the comedian admired answered the telephone in the fancy restaurant.

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