Research Article

MEMORY-LOAD INTERFERENCE IN SYNTACTIC PROCESSING

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Abstract—*Participants remembered a short set of words while reading syntactically complex sentences (object-extracted clefts) and syntactically simpler sentences (subject-extracted clefts) in a memory-load study. The study also manipulated whether the words in the set and the words in the sentence were of matched or unmatched types (common nouns vs. proper names). Performance in sentence comprehension was worse for complex sentences than for simpler sentences, and this effect was greater when the type of words in the memory load matched the type of words in the sentence. These results indicate that syntactic processing is not modular, instead suggesting that it relies on working memory resources that are used for other nonsyntactic processes. Further, the results indicate that similarity-based interference is an important constraint on information processing that can be overcome to some degree during language comprehension by using the coherence of language to construct integrated representations of meaning.*

Although there is general agreement that working memory plays a fundamental role in sentence comprehension, there is considerable disagreement over what working memory is and what role it plays. Consideration of the topic in contemporary psycholinguistics began with the observation by Miller and Chomsky (1963) that doubly center-embedded sentences (e.g., *The squirrel the dog the cat saw chased climbed the tree*), though grammatically acceptable at a theoretical level, are nearly impossible to understand. The problem in understanding such a sentence appears to arise from holding its parts in memory while trying to integrate them. Research on working memory and sentence processing has focused on complex sentences of a variety of sorts, particularly on certain syntactic relatives of doubly-embedded sentences. This article addresses two questions that have emerged from this research: (a) What is the nature of the capacity limits on the working memory resources used for language comprehension? (b) Is syntactic processing modular, or does it draw on the same memory resources used by more general cognitive processes? Answers to both of these questions have value beyond the study of language. The nature of capacity limits is fundamental to the understanding of attention, relating to such diverse issues as cognitive aging, attention-deficit disorders, and multitask performance (e.g., driving while talking on the phone). The question of modularity is central in many domains of cognitive processing (e.g., visual perception) where the degree of specialization of processes is thought to provide important information about how cognitive abilities evolved and are organized in the brain (Fodor, 1983). Because language is an essential and possibly unique ability of human beings, it is a central domain in which to address issues of capacity limits and modularity.

CAPACITY

The idea of limited resources or capacity has been a recurring theme in discussions of human information processing (Cowan, 1988; Miller, 1956). Although few researchers have completely rejected the notion (cf. Hirst, Spelke, Reaves, Caharack, & Neisser, 1980), its usefulness has been criticized because of its conceptual looseness. Navon (1984) cleverly characterized resources as having the theoretical power of the proverbial soup stone, something that in reality adds nothing to attempts at explanation. Despite that criticism, capacity remains prominent in many explanatory recipes, and it is worthwhile to examine how it interacts with other ingredients in current theories of how people understand complex sentences.

Just and Carpenter's (1992) capacity-constrained theory of comprehension asserts that activation is the fuel that both supports representations in working memory and performs the computational operations necessary to understand language, thus leading to trade-offs between processing and storage (Daneman & Carpenter, 1980; King & Just, 1991). Gibson's (1998) locality model asserts that the processing load in sentence comprehension increases as the distance, in terms of number of intervening discourse units, increases between to-be-integrated linguistic constituents. Lewis (1996) presented a model in which the architecture for parsing has a sharply limited capacity of being able to represent no more than two (or maybe three) sentence constituents under the same syntactic relation. It can be seen from these three models that a main ingredient of capacity models of language comprehension is the number of items (defined in various ways) that must be stored as language is being understood. As additional ingredients, the different theories include activation that is interchangeable between processing and storage (Just & Carpenter, 1992) and a processing architecture with a memory specifically for syntactic relations (Lewis, 1996).

These recipes notably lack the ingredient of interference as it has been typically conceived of in memory research (Crowder, 1976). Something of an exception to this characterization is the work of Lewis (1996), who referred to his model as involving "similarity-based interference." However, in his model, interference is the product of having a short-term memory system that can represent only two (or three) pieces of the same type of information. With respect to complex sentences, syntactic dependencies constitute the relevant type of information. The system fails abruptly when the capacity of the syntactic memory is exceeded. More standard psychological approaches have viewed memory interference as emerging in a process in which retrieval cues are matched against representations of targets in memory. The facility with which the target is retrieved is an increasing function of the cue-to-target strength for the to-be-retrieved trace and a decreasing function of the sum of the cue-to-trace strengths for all other traces stored in memory (e.g., Gillund & Shiffrin, 1984; Hintzman, 1986). When a distractor item is similar to the target, there is an increase in cue-to-trace strength for the distractor, which interferes with retrieval of the target.

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We have recently reported a study providing evidence that memory interference of this sort plays a role in the processing of complex syntactic relations (Gordon, Hendrick, & Johnson, 2001). This study used cleft sentences to examine the well-known difference in comprehension difficulty between sentences in which the noun phrase (NP) modified by a subordinate clause is extracted from subject position (as in 1) as compared with object position (as in 2).

1. It was the barber/John that saw the lawyer/Bill in the parking lot.
2. It was the barber/John that the lawyer/Bill saw in the parking lot.

The results showed the usual *object-subject difference*: Object extractions led to higher error rates in comprehension and longer reading times than did subject extractions. In addition, the study provided two important findings. First, performance was worse when the two critical NPs were matched in type (two descriptions, e.g., "barber" and "lawyer," or two names, e.g., "John" and "Bill") than when they were unmatched (a name and a description). Second, the object-subject difference was greater with matched NPs than with unmatched NPs. The object-subject difference in processing complexity can be explained by the idea that the object constructions impose greater memory demands than do the subject constructions. For the object constructions, representations for both of the critical NPs must be maintained and accessed before either NP is integrated with the verb of the modifying clause. In contrast, for the subject constructions, the modified NP can be integrated with the verb of the modifying clause before the second NP is encountered.

SPECIALIZATION IN WORKING MEMORY

The idea of specialization in working memory is clearly established in Baddeley's (1986) model, in which working memory has three parts: a central executive and two slave systems (a phonological loop and a visuo-spatial sketchpad). Some theorists who are interested in sentence processing and memory, notably Just and Carpenter (1992), have focused on the central executive as the component of working memory most relevant to language comprehension. As the central executive covers not just language but general cognitive processing, regarding the central executive as the home of critical aspects of language processing is inconsistent with the modular view that language is supported by specialized mechanisms (Fodor, 1983). Other researchers interested in sentence processing have been agnostic as to how their proposed processing mechanisms map onto possible specializations of working memory (Gibson, 1998, p. 15). The view that language processing makes use of specialized memory resources was championed in a recent, comprehensive review by Caplan and Waters (1999). They argued that the working memory resources used for sentence processing are separate from those used for consciously controlled processes, such as remembering a list of words, and cited evidence from neurological patients, individual differences in the normal range, language comprehension in elderly adults, and the comprehension of language while simultaneously maintaining a memory load. They concluded that processing syntactically complex sentences involves memory from a "separate sentence interpretation resource" (p. 79). This conclusion puts them at odds with the view advanced by Just and Carpenter (1992; Just, Carpenter, & Keller, 1996; Waters & Caplan, 1996), but it is supported by Lewis (1999) as consistent with his view that memory for syntactic relations is independent of the memory used for lists of words.

In the current experiment, we used a memory-load task to determine whether memory interference affects language processing and whether the same memory resources support both processing complex syntax and remembering a list of words. In a memory-load task, participants must remember a set of items while simultaneously engaged in a language-processing task; the straightforward rationale is that the external memory load will compete with the language comprehension task for shared working memory resources, thereby providing a tool for manipulating the amount of working memory available for language processing and seeing whether this differentially affects the understanding of language with different kinds of complexity (Baddeley, 1986; Wanner & Maratsos, 1978). We departed from the past practice of manipulating the number of items in the memory load (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Morris, Craik, & Gick, 1990) and instead manipulated the similarity between items in the memory load and critical words in the sentence being understood. The memory load in our experiment was a list of either three names or three role descriptions. The subsequent sentence was either a subject-extracted or an object-extracted cleft sentence in which both of the critical NPs were either names or descriptions. The potential for memory interference was manipulated by having the load words and critical NPs be either matched (both names or both descriptions) or unmatched.

According to the hypothesis that general memory interference is a critical ingredient in language processing, a match between the load and the NPs in the sentence should impair sentence comprehension, and further, this effect should be greater for the more difficult object-extracted clefts than for the less difficult subject-extracted clefts. Current models that conceptualize capacity in sentence processing in terms of number of items to be remembered combined with processing activation (Just & Carpenter, 1992) or syntactic distance (Gibson, 1998) would have to be modified to accommodate such an effect. A model, like that of Lewis (1996), in which interference is a by-product of exceeding the capacity for representing syntactic dependencies would predict that a match between load and sentence NPs would have no effect because the words in the memory load do not involve syntactic relations.

According to the hypothesis that working memory involves a separate sentence-interpretation resource (Caplan & Waters, 1999), a match between the load and the NPs in the sentence should not interact with the syntactic complexity of the sentence. Caplan and Waters made an important distinction between the syntactic complexity of a sentence and its propositional content. Pairs of sentences such as object-extracted versus subject-extracted clefts differ in syntactic complexity but do not differ in number of propositions. Other pairs of sentences (e.g., *The boy hugged the girl and the baby* and *The boy hugged the girl and kissed the baby*) can be similar but differ in the number of propositions that they contain (one vs. two in this example). Caplan and Waters reviewed studies showing that the negative effect of an external memory load on sentence comprehension increases with the number of propositions in the sentence; they argued that this is because the increased number of propositions in a sentence increases the memory requirements for postinterpretive storage, and that it is only at this postinterpretive level that the external-memory-load and language-comprehension tasks interact. Caplan and Waters further argued that no experiment that has controlled the number of propositions has demonstrated an interaction between external memory load and syntactic complexity, unless the memory-load task interrupted the language-comprehension task. This failure to find such an interaction

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Table 1. *Sample experimental item*

Condition	Memory-load set	Cleft sentence
Matched		
Name load, subject cleft	Joel—Greg—Andy	It was Tony that liked Joey before the argument began.
Name load, object cleft	Joel—Greg—Andy	It was Tony that Joey liked before the argument began.
Description load, subject cleft	poet—cartoonist—voter	It was the dancer that liked the fireman before the argument began.
Description load, object cleft	poet—cartoonist—voter	It was the dancer that the fireman liked before the argument began.
Unmatched		
Name load, subject cleft	Joel—Greg—Andy	It was the dancer that liked the fireman before the argument began.
Name load, object cleft	Joel—Greg—Andy	It was the dancer that the fireman liked before the argument began.
Description load, subject cleft	poet—cartoonist—voter	It was Tony that liked Joey before the argument began.
Description load, object cleft	poet—cartoonist—voter	It was Tony that Joey liked before the argument began.

Note. The true/false comprehension statement for this experimental item was "The fireman liked the dancer" or "Joey liked Tony."

has occurred despite very powerful and focused experimental designs; it supports Caplan and Waters's contention that processing syntactically complex sentences involves a language-specific resource that is independent of the general memory resource that maintains the external memory load.

METHOD

Participants

Fifty-six students at the University of North Carolina at Chapel Hill served as participants in the experiment. They were native English speakers and received either course credit or $10 for their participation.

Stimulus Materials

The experimental sentences consisted of 48 clefts, half drawn from Appendix 2 of Gordon et al. (2001) and half created for this experiment. Each item appeared in eight conditions (see Table 1) created by crossing the type of cleft (subject-extracted or object-extracted), the type of words in the memory load (descriptions or names), and the match between the words in the memory load and the type of NPs in the sentence (matched or unmatched). Both critical NPs in a sentence were either familiar definite descriptions referring to human roles (e.g., the banker, the dancer) or familiar proper names. Sentences were constructed so that there was no inherent semantic relation between the actions depicted by the verbs and the roles depicted by the descriptions. An equal number of typically male and female names were used, and the two names in a sentence carried the same gender. The memory-load sets consisted of three words that either matched or did not match the type of NPs in the sentence (see Table 1). Thus, the memory-load items were either all descriptions or all proper names. The same constraints that applied to the descriptions and names in the sentences applied to the memory-load items. For each sentence, we created a true/false comprehension statement that tested understanding of the syntactic-semantic relations between the two NPs and the verb. Half of the statements were true and half were false. In addition to the experimental items, 64 fillers were created.

Design and Procedure

Eight counterbalanced lists were created such that each experimental item appeared in only one condition in a list, and across lists every item occurred in all conditions. The items were grouped into an initial warm-up block of 16 filler items followed by three experimental blocks each containing 16 experimental items and 16 filler items. Every block contained equal numbers of experimental items in the eight conditions. The items within a block were presented in a different random order for each participant.

The sequence of events in a trial is shown in Figure 1. Participants were presented first with a memory-load set; the words were in all capital letters, centered on a computer monitor. The participants were instructed to read the three items aloud twice and to remember them. Following this, they read a single sentence presented one word at a time in the center of the screen using self-paced reading time methodology. They were instructed to read the sentence at a natural pace, not to hurry but not to linger longer than necessary before pressing the space bar to see the next word. Immediately after they read the last word of the stimulus sentence, a true/false comprehension statement was presented, and the participants responded by pressing the "/" key for "true" and the "z" key for "false." After the comprehension statement, the participants were prompted to recall the three memory-load words aloud.

RESULTS

Comprehension

Because research using load tasks has frequently used comprehension as the primary measure of load effects (Baddeley, 1986; Caplan & Waters, 1999), we first present the comprehension results. Figure 2 shows the mean error rates on comprehension questions for subject and object clefts in the matched and unmatched conditions. Error rates were significantly higher for object clefts than for subject clefts, $F_1(1, 55) = 37.06$, $MSE = 2,901$, $p < .001$, and $F_2(1, 47) = 73.47$, $MSE = 1,463$, $p < .001$. Further, error rates were significantly higher in the matched condition than in the unmatched condition, $F_1(1, 55) = 12.72$, $MSE = 1,273$, $p = .001$, and $F_2(1, 47) = 13.31$, $MSE = 1,218$, $p = .001$. Critically, the object-subject difference was larger in the
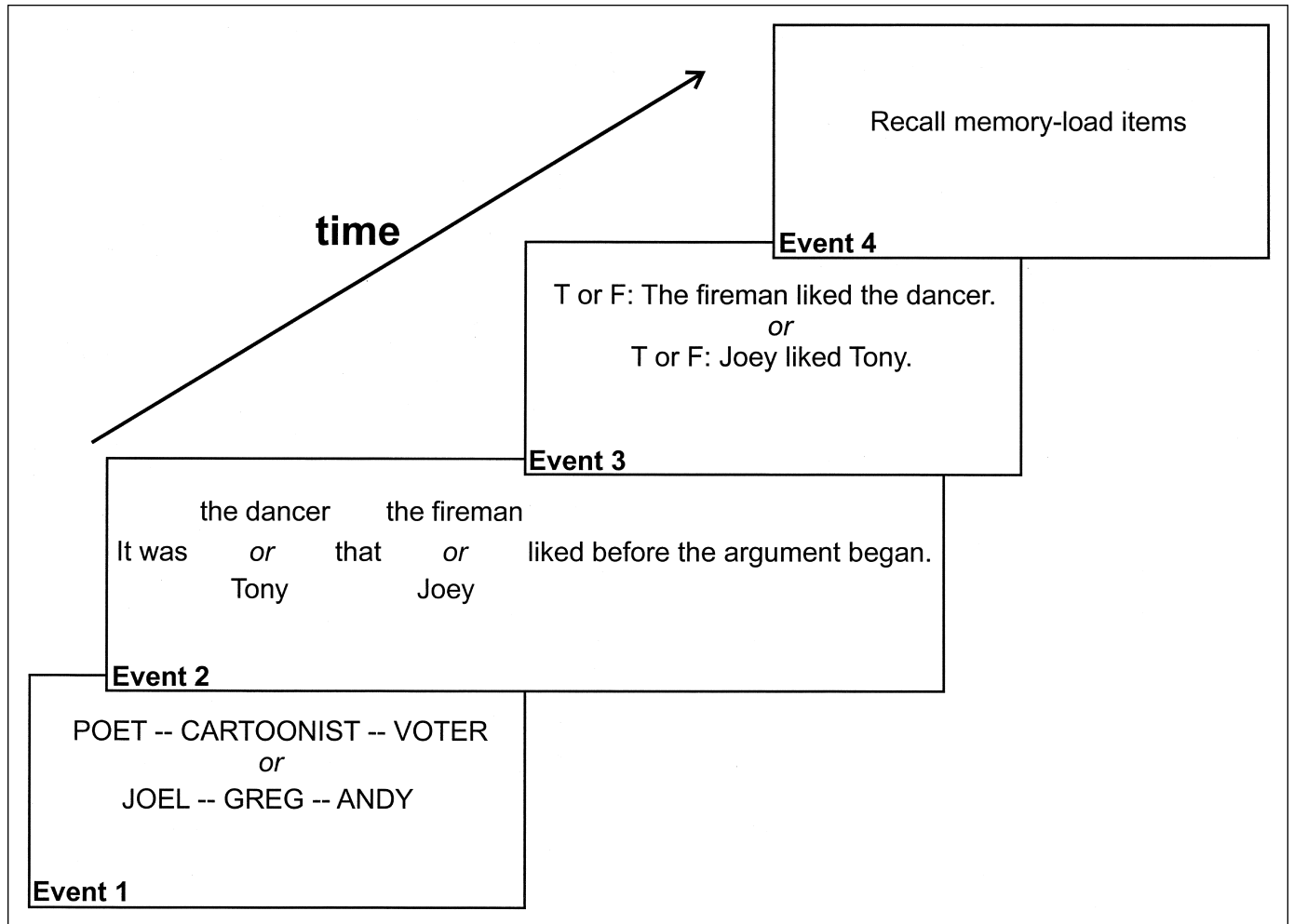
Fig. 1. Schematic illustration of the sequence of events on a trial. Participants read the memory-load items aloud twice (Event 1), read the sentence one word at a time at their own pace (Event 2), responded to a true/false comprehension statement (Event 3), and finally recalled the memory-load items (Event 4).

matched condition than in the unmatched condition, $F_1(1, 55) = 8.67$, $MSE = 988.10$, $p = .005$, and $F_2(1, 47) = 9.75$, $MSE = 878.85$, $p = .003$.[1] Both the main effect of match and the interaction of match and cleft type indicate that interference from an external memory load disrupts sentence processing. This shows that memory interference, based on the similarity of words, should be considered as an important component of models of sentence processing and that the memory used for the processing of complex syntactic relations shares resources with the memory used for keeping track of a list of words.

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1. There was also a larger effect of cleft type for names than descriptions, $F_1(1, 55) = 9.11$, $MSE = 864$, $p < .005$, and $F_2(1, 47) = 6.47$, $MSE = 1,217$, $p < .05$, suggesting that similarity may be higher among a set of names than among a set of role descriptions. In addition, there was a significant three-way interaction due to the effect of match on the object-subject difference being larger for the names than for the descriptions, $F_1(1, 55) = 5.43$, $MSE = 1,096$, $p < .05$, and $F_2(1, 47) = 6.19$, $MSE = 962$, $p < .05$. This interaction is difficult to interpret because it lacks balanced materials.

Reading Time

Figure 3 shows the mean reading times per word in three regions of the cleft sentences. Region 1 included the first clause of the sentence and the relative pronoun (i.e., "It was NP that . . .") and thus was constant across cleft types. The only significant effect for this region was a match effect: Reading times were longer when the memory-load items were of the same type as NPs in the sentence, $F_1(1, 55) = 4.98$, $MSE = 23,818$, $p < .05$, and $F_2(1, 47) = 4.11$, $MSE = 28,852$, $p < .05$. Region 2 is the critical region for the cleft manipulation. It contained the same words for the two cleft types but for subject-extracted clefts the words were in the order verb-NP whereas for object-extracted clefts the order was NP-verb. As expected, reading times were significantly longer in this region for object clefts than for subject clefts, $F_1(1, 55) = 20.49$, $MSE = 66,996$, $p < .001$, and $F_2(1, 47) = 22.56$, $MSE = 60,858$, $p < .001$.[2] In addition,

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2. As with the comprehension data, the object-subject difference was larger for names than for descriptions, $F_1(1, 55) = 11.10$, $MSE = 53,584$, $p < .01$, and $F_2(1, 47) = 4.87$, $MSE = 122,156$, $p < .05$.
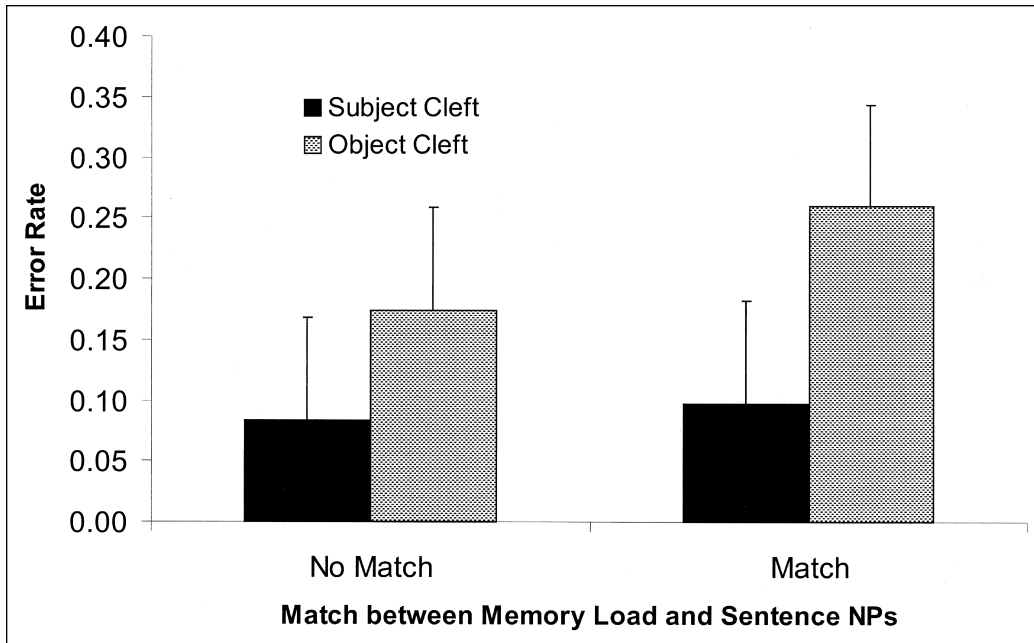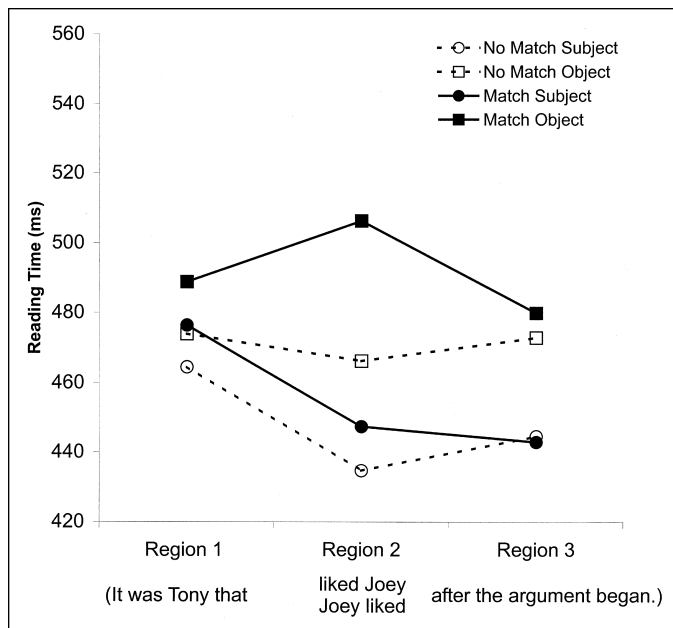
Fig. 2. Mean error rates (with 95% confidence intervals) on true/false statements for subject-extracted and object-extracted clefts with noun phrases (NPs) that matched and did not match the memory-load sets.

reading times for this region were significantly longer in the matched condition than in the unmatched condition, $F_1(1, 55) = 12.35$, $MSE = 37,847$, $p = .001$, and $F_2(1, 47) = 6.74$, $MSE = 69,342$, $p < .05$. More-

over, the effect of cleft type was somewhat larger in the matched condition than in the unmatched condition, although this effect did not reach significance, $F_1(1, 55) = 2.37$, $MSE = 52,999$, $p = .13$, and $F_2(1, 47) = 1.74$, $MSE = 71,965$, $p = .19$. Region 3 included the remainder of the sentence and was the same across all conditions. The object-subject difference persisted into this region, with longer reading times observed for object clefts than for subject clefts, $F_1(1, 55) = 18.99$, $MSE = 37,564$, $p < .001$, and $F_2(1, 47) = 31.40$, $MSE = 22,720$, $p < .001$.

The reading time data show that syntactic complexity and match between memory load and sentential NPs had on-line effects on language comprehension that parallel those seen in the comprehension scores. The interaction between complexity and load match was in the same direction as that observed for comprehension accuracy, though it was short of statistical significance. Thus, the reading time data bolster the comprehension data to some degree and provide no suggestion of a trade-off between comprehension accuracy and speed of reading.

Recall

Recall was higher for names (94.9%) than for descriptions (89.8%), though this effect was not significant in an analysis of covariance that controlled for the greater length in syllables of the descriptions than the names, $F(1, 54) = 0.71$, $MSE = 452$, $p = .40$. The breakdown of recall by experimental conditions was as follows: matched load, subject cleft—92.5%; matched load, object cleft—90.8%; unmatched load, subject cleft—93.8%; and unmatched load, object cleft—92.4%. Recall was higher following subject clefts than following object clefts, $F_1(1, 55) = 5.25$, $MSE = 283$, $p < .05$, and $F_2(1, 47) = 3.50$, $MSE = 424$, $p = .07$, consistent with the idea that object clefts impose higher memory demands than subject clefts. Recall was marginally higher in the unmatched condition than the matched condition, $F_1(1, 55) = 2.86$, $MSE = 485$, $p < .1$, and $F_2(1, 47) = 4.44$, $MSE = 313$,

Fig. 3. Mean reading time per word by region broken down by cleft type (subject extracted vs. object extracted) and relation between memory-load and sentential noun phrases (matched vs. unmatched). The sample sentence shows the alignment of reading times with regions of the sentence (see the text for complete definitions of the regions).

$p < .05$, consistent with idea that similar materials in the memory load and sentence impaired memory. The interaction between load and match was not significant.

In summary, analysis of the recall data for the load items shows that syntactic complexity and match both affected recall in the expected direction, but that the effects were small and only marginally significant. There was no indication in the data of trade-offs between the sentence-comprehension and recall tasks such that better performance in the recall task might offer an explanation of poorer performance in the sentence-comprehension task.

DISCUSSION

The overall results of the experiment show two effects of particular interest: (a) that a match between the type of words in a memory load and the type of NPs in a complex sentence impairs sentence comprehension and (b) that the extent of this impairment is greater for sentences that are more complex syntactically. These results have clear implications about the extent to which syntactic processing is supported by memory resources that are modular and specific to language, and also for understanding the nature of capacity limits in language comprehension.

With respect to specialization of working memory in language processing, the results are inconsistent with the view advanced by Caplan and Waters (1999), and partially echoed by Lewis (1999), that there is a separate sentence-interpretation resource used for syntactic processing. Comprehension accuracy in the current study showed a significant interaction between cleft type and match between load words and NPs in the sentence. This occurred even though the two types of cleft sentences contained the same words and the same number of propositions. Thus, the observed interaction supports the view that processing the syntactic structure of the sentences and maintaining the load items drew on the same memory resources. We would argue that previous studies failed to uncover such an interaction (Caplan & Waters, 1999) because researchers have focused on number of items as the crucial characteristic of the memory load rather than on the representational characteristics of the memory load and of the language that is being understood.

With respect to capacity limits, the results show that memory interference can play a large role in sentence comprehension. Current memory models (e.g., Hintzman, 1986) can be applied to the results in the following way. Memory traces are formed both from the words in the memory load and from the words in the sentence, with those traces consisting of the words integrated together with contextual information specifying their source (i.e., the memory set or a specific position in the sentence). Understanding a cleft sentence requires that a word trace from a specific sentential position be retrieved during processing. The similarity of available memory traces will be greater when load words and nouns in the sentence are of matched rather than unmatched type, and this similarity will interfere with accurate and efficient retrieval because as the similarity of irrelevant and relevant traces increases, so does the cue-to-trace strength for retrieving irrelevant traces.

In our view, memory interference and the special nature of working memory for language comprehension are closely tied together. Ericsson and Kintsch (1995) have argued that the ability of working memory to support skilled performance does not stem from the efficiency that it derives from representing only a small number of items, but rather from how its high degree of organization supports efficient retrieval of the appropriate information. We would argue more specifically that the special characteristic of language comprehension that supports efficient retrieval of linguistic information from memory is the ability to quickly generate very fine-grained representations of utterances that are richly differentiated and highly organized. This ability greatly reduces the degree of memory interference that arises during sentence comprehension compared with simply trying to remember a list of unrelated words, and provides the basis for the generally high level of memory performance observed with linguistically coherent material, a high level of performance that can, however, be strained by certain types of syntactic complexity.

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