

## Memory Interference During Language Processing

Peter C. Gordon, Randall Hendrick, and Marcus Johnson  
University of North Carolina at Chapel Hill

The authors studied the operation of working memory in language comprehension by examining the reading of complex sentences. Reading time and comprehension accuracy in self-paced reading by college students were studied as a function of type of embedded clause (object-extracted vs. subject-extracted) and the types of noun phrases (NPs) in the stimulus sentences, including relative clauses and clefts. The poorer language comprehension performance typically observed for object-extracted compared with subject-extracted forms was found to depend strongly on the mixture of types of NPs (descriptions, indexical pronouns, and names) in a sentence. Having two NPs of the same type led to a larger performance difference than having two NPs of a different type. The findings support a conception of working memory in which similarity-based interference plays an important role in sentence complexity effects.

Figuring out how the noun phrases (NPs) and verb phrases (VPs) in a sentence go together is essential to understanding what a sentence means. The syntactic organization of a language offers a basic road map for integrating these NPs into a semantically interpreted mental representation (Steedman, 1996), but even when this map is completely explicit, achieving the integration can be difficult for complex sentences. This is especially apparent when a sentence contains multiple NPs and VPs. The difficulties involved in understanding complex sentences provide an opportunity to gain an understanding of the mental processes underlying language comprehension.

Sentences with restrictive relative clauses (RCs) are a type of complex structure that has proven very useful for studying language processing. This is particularly so for subject-extracted and object-extracted RCs, as illustrated below.

- (1) *The cook that helped the plumber quit work after a month.*
- (2) *The cook that the plumber helped quit work after a month.*

A restrictive RC is a clause attached to a description that purports to distinguish the unique entity (or class of entities) to which reference is being made. In a *subject-extracted* RC, like Example 1, the modified description (i.e., *cook*) is understood to function as the unexpressed logical subject of the verb of the embedded clause (i.e., *helped*). In an *object-extracted* RC, like Example 2, the modified description is understood to function as the unexpressed logical object of the verb of the embedded clause. Object-extracted

RCs are generally harder to understand than subject-extracted RCs, even though the two constructions can have exactly the same words, only in a different order. This *object-subject difference* in processing complexity has been demonstrated in many different ways: reading time (King & Just, 1991), probe tasks (Wanner & Maratsos, 1978), accuracy by children in enacting the meaning of sentences (MacWhinney, 1982), comprehension by aphasic patients (Caramazza & Zurif, 1976), and measures of brain activity (Just, Carpenter, Keller, Eddy, & Thiborn, 1996; Caplan, Alpert, & Waters, 1998).

Many explanations have been offered for the processing of RCs and for related complexity effects; excellent reviews can be found in MacWhinney and Pleh (1988) and in Gibson (1998). Two broad classes of explanation are most relevant to the specific English constructions that this article examines. The first class is what MacWhinney and Pleh (1988) call "role-determinant" explanations, which account for the object-subject difference by the fact that in a subject-extracted RC the first NP is the subject of both the matrix and the embedded clause, whereas in an object-extracted RC the first NP is the subject of the matrix clause but the object of the embedded clause. Maintaining consistent roles is thought to confer a processing advantage over changing roles. Prominent examples of role-determinant explanations are the double function hypothesis (Bever, 1970), the parallel function hypothesis (Sheldon, 1974), and the perspective maintenance hypothesis (MacWhinney, 1977). The second class of explanation relates to increases in memory load for the object-extracted as compared with the subject-extracted RCs. In one way or another, these general memory-load accounts explain the object-subject difference in that semantically unintegrated sentence fragments must be kept in memory longer for the object-extracted than for the subject-extracted RCs. Prominent examples of general memory-load accounts include those of Ford (1983), MacWhinney (1987), and Wanner and Maratsos (1978).

The phenomenon addressed in the current study arose from consideration of double-center embedded sentences, such as Example 3, which contain two object-extracted RCs. Bever (1974) noted that his intuition was that such sentences, which are usually

---

Peter C. Gordon and Marcus Johnson, Department of Psychology, University of North Carolina at Chapel Hill; Randall Hendrick, Department of Linguistics, University of North Carolina at Chapel Hill.

The research reported here was supported by National Science Foundation Grant SBR-9807028. We thank Aaron Kaplan, Jennifer Poorbaugh, and Emily Roach for help in conducting the research and Bill Levine for comments on an earlier version of this article.

Correspondence concerning this article should be addressed to Peter C. Gordon, Department of Psychology, CB #3270, Davie Hall, University of North Carolina, Chapel Hill, North Carolina 27599-3270. Electronic mail may be sent to [pcg@email.unc.edu](mailto:pcg@email.unc.edu).

nearly impossible to understand (Miller & Chomsky, 1963), appear to become much more intelligible when they have a mixture of different types of NPs, as in Example 4.

(3) *The reporter the politician the commentator met trusts said the president won't resign.*

(4) *The reporter everyone I met trusts said the president won't resign.*

Bever (1974) conjectured that when the NPs are "of a different surface lexical type," then a basic rule for assigning NPs and verbs to semantic relations is differentiated into different rules (pp. 188-189). According to Bever (1974), this differentiation into different rules reduces processing complexity associated with the double-function interpretations of object-extracted RCs.

Gibson and colleagues (Gibson, 1998; Gibson & Warren, 1998) argued that Bever's (1974) characterization is empirically incorrect. They (Gibson & Warren, 1998) conducted a complexity rating study in which they varied the type of the centermost NP (description, short name, referential pronoun, or indexical pronoun) in double-center embedded sentences. They found that complexity was reduced by having an indexical pronoun (e.g., *you* or *I*) in the centermost position but that the other types of NPs had no effect; this suggests that Bever's (1974) characterization that NPs with a different surface lexical type reduced complexity was too general. Gibson and Warren's (1998) finding that complexity was only reduced for indexical pronouns is the primary evidence indicating the type of memory representation that imposes a cost in Gibson's (1998) model of how complex sentences are processed. According to Gibson and Warren's locality model, the processing load of integrating components of a sentence increases with the distance between those components, with distance being a function of the number of intervening discourse referents (see the definition of "linguistic integration cost," Gibson, 1998, pp. 12-13).<sup>1</sup> The claim that discourse referents are the determinant of distance is critically dependent on evidence that indexical pronouns have unique effects on sentence processing. It is based on the idea that indexical pronouns refer to entities that are implicitly present in the discourse environment and therefore do not impose a memory cost for representing a discourse referent or create memory-based distance when present between components of a sentence to be integrated. Thus, the contrast between the effects on sentence complexity of indexical pronouns and other types of NPs is central to how Gibson's locality model characterizes distance between components of a sentence and how it relates sentence processing to discourse processing.

In this article, we use the performance measures of reading time and comprehension accuracy to explore how different syntactic and semantic classes of words influence the comprehension of complex sentences. By examining the comprehension of subject-extracted and object-extracted constructions, we provide a detailed evaluation of the relative merit of contrasting empirical claims made by Bever (1974) and Gibson (1998; Gibson & Warren, 1998). More generally, examining such constructions provides evidence about the processing and representation in memory of syntactic and semantic information over the course of language comprehension. That evidence supports a model of working memory that is susceptible to similarity-based interference that can contribute to the difficulty of understanding complex sentences.

## Experiment 1

The goal of Experiment 1 was to establish that the methods and materials used in the subsequent experiments produce the expected difference in processing difficulty for subject- and object-extracted RCs. The method for the experiments was generally similar to that used by King and Just (1991) in a series of experiments that looked at the comprehension of sentences with RCs. The method involved self-paced reading of single sentences presented one word at a time, although our version of the task involved presentation of single words at the center of the screen whereas King and Just (1991) used a moving-window technique. After each sentence was read, a comprehension question was presented. Answering the question accurately required understanding of the RC or the main clause.

## Method

**Participants.** Forty-four students at the University of North Carolina at Chapel Hill served as participants in the experiment. They were native English speakers and received course credit in Introductory Psychology for their participation.

**Stimulus materials.** Stimuli for the experimental trials consisted of 24 sentences, each with a RC that modified the subject NP of the main clause. They are shown in Appendix A. Eight of the sentences were taken with minor modifications from Appendix 2 of King and Just (1991); an additional 16 sentences were created for the experiment. The two NPs in each sentence, which were arguments of the verbs in the main and embedded clauses, were always definite descriptions relating to human roles (e.g., *doctor*, *lawyer*, *barber*). The experimental sentences were constructed so that there was no inherent semantic relation between the descriptions and the actions described by the verbs (e.g., there is no necessary semantic relation between *barber* and *admired*). A set of 44 filler sentences was created. The fillers were ideationally complex with a variety of syntactic structures, but they did not include restrictive RCs.

**Design and procedure.** The sentences were grouped into an initial warm-up block of 14 filler sentences followed by three experimental blocks that contained eight experimental sentences and 10 filler sentences. Every block contained equal numbers of experimental sentences with the two types of RCs, subject- and object-extracted. Each participant was shown an experimental sentence with only one type of RC; across participants, every sentence occurred with both types of RCs. The sentences within a block were presented in a different random order for each participant.

On each trial, participants 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. After reading the sentence, a true-false comprehension question was presented that tested knowledge of the preceding sen-

<sup>1</sup> Further, Gibson (1998, p. 12) says "Although processing all words probably causes some integration cost increment, it is hypothesized here that substantial integration cost increments are caused by processing words indicating new discourse structure (Kamp, 1981; Heim, 1982), particularly new discourse referents." Gibson (1998, pp. 4 & 13) mentions three other factors that might contribute to integration cost: semantic similarity, the complexity of the integration, and interference, as discussed by Lewis (1996). However, the only factor incorporated in Gibson's (1998) formal model of integration cost is the effect of new discourse structure and referents, presumably because they are hypothesized to have the most substantial effect.

tence. Half of the comprehension questions were true and half were false. For the experimental sentences, correct answers required understanding of the syntactic-semantic relations between the two NPs and the matrix verb or the verb in the embedded clause. One third of the questions involved the matrix verb and two thirds involved the verb in the embedded clause. For example, possible comprehension questions for Example 1 would be:

*The cook quit work after a month.* TRUE or FALSE  
*The cook helped the plumber.* TRUE or FALSE

The first example question above tests knowledge of the matrix verb, whereas the second tests knowledge of the embedded verb. The correct answer for both of the example questions is *true*. Versions where the correct answer was *false* were created by switching the NPs in the statements.

**Results and Discussion**

Figure 1 shows the mean reading times for sentences with subject-extracted and object-extracted RCs. In analyzing similar data, King and Just (1991) showed that the presence of an RC caused a general elevation in reading time at two critical words. For subject-extracted RCs, the first critical word is the head of the second NP (the logical object of the RC). For object-extracted RCs, the first critical word is the verb of the embedded clause. For both subject-extracted and object-extracted RCs, the second critical word is the verb of the main clause. Inspection of our data shows the same general pattern. Further, King and Just (1991) showed that these two critical words constitute the principal locus of the difference in ease of processing between object-extracted and subject-extracted RCs. Accordingly, our initial analysis of the

effect of RC type consisted of analyses of variance, by participants ( $F_1$ ) and items ( $F_2$ ), on the mean reading times for the two critical words in the RC.

Reading times for the first critical word were significantly longer in object-extracted RCs than in subject-extracted RCs,  $F_1(1, 43) = 20.96$ ,  $MSE = 83.754$ ,  $p < .001$ ;  $F_2(1, 23) = 57.99$ ,  $MSE = 16.511$ ,  $p < .001$ . It should be noted that this comparison involves two different words, a verb in the object-extracted RC and a noun in the subject-extracted RC, which raises the possibility that the observed difference was due to a main effect of word class rather than to an effect of syntactic structure. This possibility can be evaluated because the object- and subject-extracted RCs have exactly the same words, only in a different order. Accordingly, an additional comparison was made on the reading times for a region that included the words after the relative pronoun (*that*) and before the verb of the matrix clause (e.g., *climbed*). For an object-extracted RC, this region consists of an NP followed by a verb (e.g., *the barber praised*). For the paired subject-extracted RC, this region consists of the same NP and verb in the opposite order (e.g., *praised the barber*). Reading times in this first critical region were higher for object-extracted RCs than for subject-extracted RCs,  $F_1(1, 43) = 12.01$ ,  $MSE = 12,040$ ,  $p < .0025$ ;  $F_2(1, 23) = 18.86$ ,  $MSE = 4,181$ ,  $p < .001$ . This difference cannot be due to a main effect of word class because the two regions contain exactly the same words, only in a different order.

Reading times for the second critical word (i.e., the matrix verb) were also significantly longer in object-extracted RCs than in subject-extracted RCs,  $F_1(1, 43) = 10.43$ ,  $MSE = 88,933$ ,  $p < .0025$ ;  $F_2(1, 23) = 18.38$ ,  $MSE = 27,525$ ,  $p < .001$ . Unlike the

F1

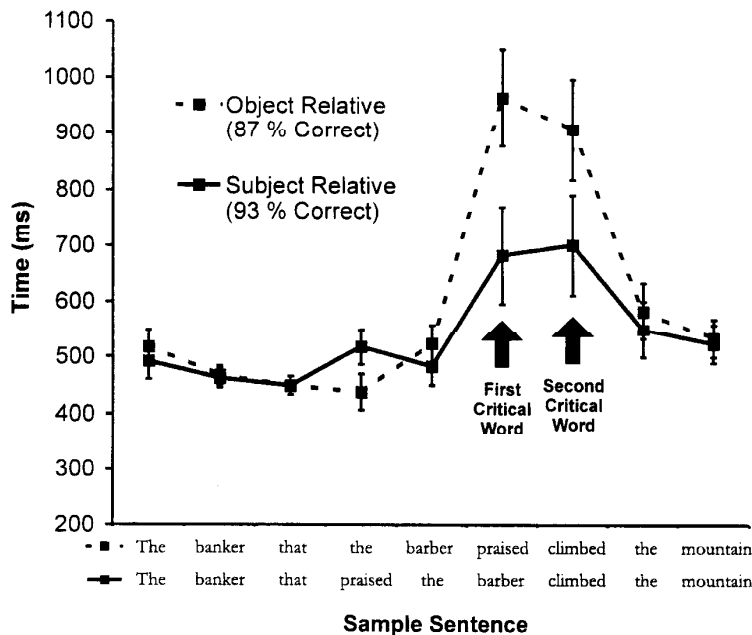


Figure 1. Results of Experiment 1. The mean reading time by word (with 95% confidence intervals) is shown for sentences with subject-extracted and object-extracted relative clauses. The sample sentences show the alignment of reading times with words in the sentence.

comparison at the first critical word, this comparison involves exactly the same word in both kinds of RCs. Further, higher accuracy was observed for comprehension questions about the subject-extracted RCs (93%) than for the object-extracted RCs (87%),  $F_1(1, 43) = 10.04$ ,  $MSE = 66.123$ ,  $p < .005$ ;  $F_2(1, 23) = 5.23$ ,  $MSE = 69.151$ ,  $p < .05$ .

The results of the experiment show a very robust difference in the ease of understanding object-extracted and subject-extracted RCs. Longer reading times were observed for the object-extracted RCs than for the subject-extracted RCs. In addition, accuracy in answering the comprehension questions was lower for the object-extracted RCs than for the subject-extracted RCs. Both the reading time and accuracy results indicate that object-extracted RCs are more difficult to understand than subject-extracted RCs.

## Experiment 2

The goal of Experiment 2 was to determine if the difference in difficulty in processing object- and subject-extracted RCs is affected by having an indexical pronoun (*you*) as the second NP in the sentence. Sample stimuli for the experiment are shown in Example 5

- (5) *The barber that the lawyer/you admired climbed the mountain.*  
*The barber that admired the lawyer/you climbed the mountain.*

Gibson's (1998) locality model predicts that having an indexical pronoun as the second NP should reduce the difference in processing difficulty between the object- and subject-extracted RCs. According to the model, the difficulty in sentence processing increases as the distance between to-be-integrated syntactic structures increases. As noted earlier, the primary determinant of distance is the number of new discourse referents that intervene between the structures to be integrated. A description (e.g., *the lawyer*) requires that a discourse referent be represented and remembered. In contrast, according to Gibson, an indexical pronoun (such as *you*) imposes no such cost, because it refers to an entity that is implicitly available in any discourse situation, and therefore it need not be remembered. The analysis presented by Bever (1974) also leads to the prediction that the pronoun should reduce the object-subject difference because it can plausibly be regarded as a different type of NP from the description that begins the sentence.

Other explanations of the object-subject difference predict no effect from the presence of an indexical pronoun. Role-determinant models (such as perspective maintenance, MacWhinney, 1977; and parallel function, Sheldon, 1974) attribute the object-subject difference to the fact that the initial NP maintains its subject role throughout the subject-extracted RC but switches from subject to object and back to subject in the object-extracted RC; this switching occurs regardless of whether a pronoun is involved. Simple memory models (such as the stacked NP model) do not indicate that memory loads vary with the syntactic or semantic class of the unintegrated NP stored in memory, again indicating that the presence of a pronoun should not influence the sentence complexity effect. Accordingly, in Experiment 2 we tested the sufficiency of these previous explanations of the object-subject difference.

## Method

*Participants.* Forty-eight students from the same population as in Experiment 1 participated in the study.

*Stimuli, design, and procedure.* The stimuli were the same as in Experiment 1 (see Appendix A) except that the experimental sentences were presented in the four conditions defined by the combination of type of RC (subject-extracted vs. object-extracted) and type of second NP (description vs. the pronoun *you*). Once again, assignment of individual sentences to experimental conditions was counterbalanced across participants. All other aspects of the design and procedure were the same as in Experiment 1.

## Results and Discussion

Figure 2 shows the mean reading times for the different conditions of the experiment. Analyses were performed on the same regions as in Experiment 1. For the first critical word, reading times were longer for object-extracted RCs than for subject-extracted RCs,  $F_1(1, 47) = 6.22$ ,  $MSE = 49,533$ ,  $p < .025$ ;  $F_2(1, 23) = 4.68$ ,  $MSE = 32,902$ ,  $p < .05$ . Reading times were also longer in the description condition than in the pronoun condition,  $F_1(1, 47) = 10.63$ ,  $MSE = 128,702$ ,  $p < .0025$ ;  $F_2(1, 23) = 19.04$ ,  $MSE = 35,922$ ,  $p < .001$ . Further, the effect of type of RC was greater in the description condition than in the pronoun condition, an interaction that was significant,  $F_1(1, 47) = 6.28$ ,  $MSE = 50,919$ ,  $p < .025$ ;  $F_2(1, 23) = 5.55$ ,  $MSE = 28,836$ ,  $p < .05$ . As in Experiment 1, consideration of a broader region provides an important control for the possible inherent differences in the reading times for the first critical word (which could either be a verb, a common noun, or a pronoun). Therefore, an additional set of analyses was conducted on the mean reading times per word for a region that included the words after the relative pronoun (*that*) and before the verb of the matrix (main) clause. For the first critical region there was no main effect of type of RC,  $F_1(1, 47) < 1$ ,  $MSE = 6,395$ ,  $p = .38$ ;  $F_2(1, 23) < 1$ ,  $MSE = 13,494$ ,  $p = .09$ . Reading times were significantly longer in the description condition than in the pronoun condition,  $F_1(1, 47) = 8.50$ ,  $MSE = 17,018$ ,  $p < .01$ ;  $F_2(1, 23) = 8.88$ ,  $MSE = 8,145$ ,  $p < .01$ . It should be noted that possible inherent differences between the pronouns and descriptions cannot be ruled out in the analysis of this region. Of critical importance, a significant interaction was observed for the region where the effect of type of RC was greater in the description condition than in the pronoun condition,  $F_1(1, 47) = 8.24$ ,  $MSE = 12,833$ ,  $p < .01$ ;  $F_2(1, 23) = 9.25$ ,  $MSE = 5,721$ ,  $p < .01$ . The interpretation of this interaction for the first critical region is not complicated by possible inherent differences in the words because the pronoun and description conditions contribute equally to the object-extracted and subject-extracted RCs.

For the second critical word, the only significant effect was that the pronoun condition was read more quickly than the description condition,  $F_1(1, 47) = 27.38$ ,  $MSE = 75,739$ ,  $p < .001$ ;  $F_2(1, 23) = 40.75$ ,  $MSE = 25,448$ ,  $p < .001$ . Because the second critical word is identical in all conditions, this difference is not due to inherent differences in the word itself. It is possible that the difference is due to some spillover effect where reading the relatively brief and frequent pronoun leads to faster reading of the subsequent second critical word. If such spillover is the cause of the difference, then it would have to be a very powerful effect

INTERFERENCE DURING COMPREHENSION

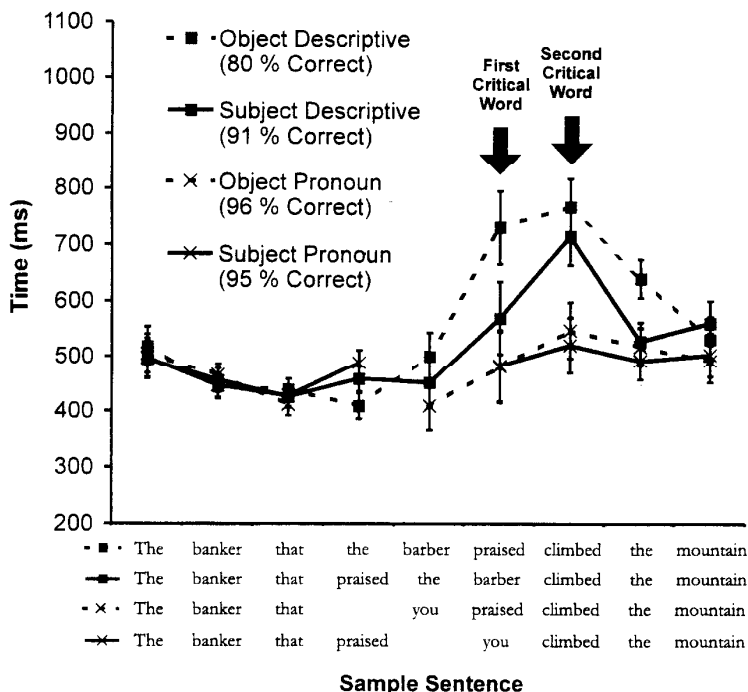


Figure 2. Results of Experiment 2. The mean reading time by word (with 95% confidence intervals) is shown for sentences with subject-extracted and object-extracted relative clauses with descriptions and with pronouns. The sample sentences show the alignment of reading times with words in the sentence.

because it occurs to an equal degree when the pronoun is the immediately preceding word (in a subject-extracted RC) and when it occurs two words previously (in an object-extracted RC). It seems more plausible to us, that rather than simply being easy to recognize, the pronoun in some way contributes to making the sentence simpler, leading to the shorter reading times for the second critical word. However, this point is not critical to the main arguments being made in this article. The absence of a main effect of clause type for the second critical word is surprising, given previous results, though the difference is in the expected direction for the description condition. The main effect of clause type does appear solidly for the first critical word, the region analysis, and for the accuracy results to be discussed below. The overall pattern shows very clearly that for the description condition, comprehension of object-extracted RCs was more difficult than comprehension of subject-extracted RCs.

The effect of the experimental conditions on accuracy in answering the comprehension question (Figure 1) was similar to that observed for the reading time of the first critical word. Accuracy was higher for subject-extracted RCs than for object-extracted RCs,  $F_1(1, 47) = 13.64$ ,  $MSE = 101.920$ ,  $p < .0025$ ;  $F_2(1, 23) = 5.79$ ,  $MSE = 119.987$ ,  $p < .05$ . Accuracy was also higher in the pronoun condition than in the description condition,  $F_1(1, 47) = 19.72$ ,  $MSE = 238.346$ ,  $p < .001$ ;  $F_2(1, 23) = 30.05$ ,  $MSE = 78.219$ ,  $p < .001$ . Finally, the effect of type of RC was greater in the description condition than in the pronoun condition, an interaction that was significant,  $F_1(1, 47) = 15.17$ ,  $MSE = 103.890$ ,  $p < .001$ ;  $F_2(1, 23) = 12.79$ ,  $MSE = 61.613$ ,  $p < .0025$ .

A set of contrasts on the three measures (reading time for the two critical words and comprehension accuracy) was conducted in order to specifically address whether an object-subject difference was observed for sentences containing a pronoun as the second NP. When examining only the pronoun condition, there was no effect of object versus subject for the first critical word,  $t_1(47) = 0.03$ ,  $p > .25$ ;  $t_2(23) = 0.03$ ,  $p > .25$ , for the second critical word,  $t_1(47) = 0.76$ ,  $p > .20$ ;  $t_2(23) = 0.82$ ,  $p > .25$ , or for comprehension accuracy,  $t_1(47) = 0.17$ ,  $p > .25$ ;  $t_2(23) = 0.03$ ,  $p > .25$ .

These results demonstrate that having an indexical pronoun as the second NP in a restrictive RC reduces (or even eliminates) the object-subject difference in ease of processing. Two of the three relevant measures (reading time of the first critical word and comprehension accuracy) showed significant interactions between type of NP and the type of RC. None of the three relevant measures showed an effect of type of RC when the pronoun condition was examined alone. This pattern of results is consistent with predictions generated from both the Bever (1974) and Gibson (1998) accounts of how types of NPs influence the processing of complex sentences. These results are not expected under the role-determinant and general-memory explanations of the object-subject difference in the difficulty of understanding RCs.

Experiment 3

In Experiment 3, we examined the comprehension of RC sentences that have proper names as the second NP, as illustrated in

Example 6, because the Gibson (1998) and Bever (1974) models make different predictions about how names should affect the object-subject difference in processing load.

- (6) *The barber that the lawyer/Joel admired climbed the mountain.*  
*The barber that admired the lawyer/Joel climbed the mountain.*

According to Gibson, a name differs critically from an indexical pronoun because its referent is not implicit in the discourse situation. Hence, comprehension of a name should introduce a discourse referent to a discourse just as a definite description does. When that discourse referent intervenes between components of a sentence that need to be integrated (as it would in the object-extracted RC), then it should increase processing load. Therefore, the model predicts that the name should have no effect on the object-subject difference. In contrast, Bever's (1974) analysis (though it does not explicitly discuss names) suggests that simply having NPs of a different surface lexical type can reduce the difficulty of processing a complex sentence, therefore predicting that having a name as the second NP should reduce the object-subject difference in processing difficulty for RC sentences. Role-determinant models and general-memory models would agree with Gibson's model and would predict that names should not reduce the object-subject difference.

**Method**

*Participants.* Forty-eight students from the same population as in Experiments 1 and 2 participated in the study.

*Stimuli, design, and procedure.* The stimuli were the same as in Experiment 2, except that a proper name was substituted for the pronoun *you* in the proper name condition (see Appendix A). A different proper name was used in each sentence. All proper names were familiar and were three letters in length so that they matched the length of the pronouns used in Experiment 2; an equal number of stereotypically male and female names were used. All other aspects of the design and procedure were the same as in Experiment 2.

**Results and Discussion**

Figure 3 shows the mean reading times for the different conditions of the experiment. Analyses were performed on the same regions as in Experiment 2. For the first critical word, reading times were longer for object-extracted RCs than for subject-extracted RCs,  $F_1(1, 47) = 8.01, MSE = 100,465, p < .01; F_2(1, 23) = 8.90, MSE = 45,184, p < .01$ . Reading times were also longer in the description condition than in the name condition,  $F_1(1, 47) = 6.04, MSE = 79,858, p < .025; F_2(1, 23) = 10.03, MSE = 24,039, p < .005$ . Further, the effect of type of RC was greater in the description condition than in the name condition, an interaction that was significant,  $F_1(1, 47) = 5.52, MSE = 98,750, p < .025; F_2(1, 23) = 8.65, MSE = 31,481, p < .01$ . When the analysis was expanded, as in the previous experiments, to include the region preceding the critical word, neither of the main effects were significant and the interaction between them fell short of significance,  $F_1(1, 47) = 2.31, MSE = 16,098, p < .15; F_2(1, 23) = 3.16, MSE = 5,866, p < .10$ . Though not significant, this

F3

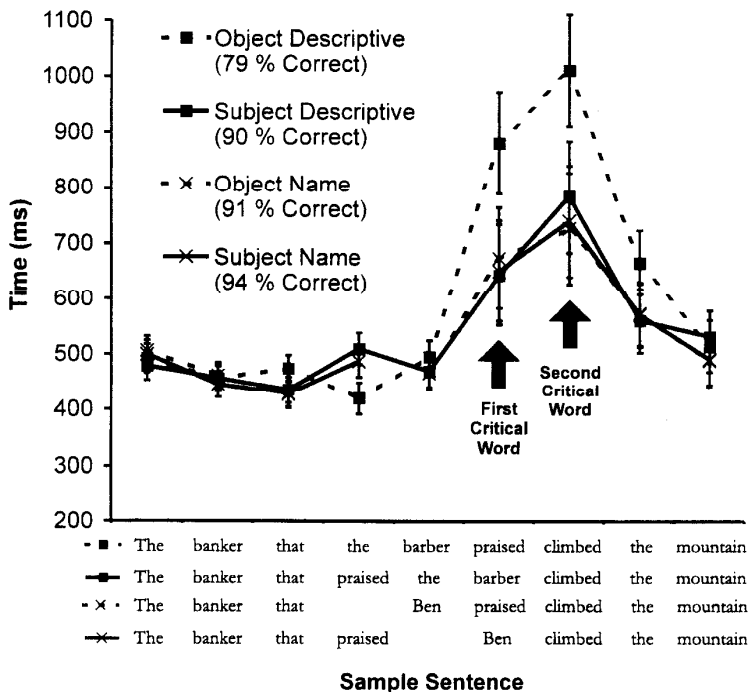


Figure 3. Results of Experiment 3. The mean reading time by word (with 95% confidence intervals) is shown for sentences with subject-extracted and object-extracted relative clauses with descriptions and with proper names. The sample sentences show the alignment of reading times with words in the sentence.

interaction was in the same direction as for the critical word. For the description condition, the average reading time per word for object-extracted RCs was 599 ms as compared with 542 ms for subject-extracted RCs. For the name condition, the average reading time per word for object-extracted RCs was 570 ms as compared with 569 ms for subject-extracted RCs.<sup>2</sup>

For the second critical word, the main effect of type of RC fell short of significance,  $F_1(1, 47) = 3.89$ ,  $MSE = 139,514$ ,  $p < .10$ ;  $F_2(1, 23) = 2.98$ ,  $MSE = 90,975$ ,  $p < .10$ . Reading times were longer in the description condition than in the name condition,  $F_1(1,47) = 14.67$ ,  $MSE = 87,628$ ,  $p < .001$ ;  $F_2(1, 23) = 8.84$ ,  $MSE = 72,752$ ,  $p < .01$ . Of critical importance, the effect of type of RC was greater in the description condition than in the name condition, a difference that was significant,  $F_1(1, 47) = 5.72$ ,  $MSE = 118,809$ ,  $p < .025$ ;  $F_2(1, 23) = 7.02$ ,  $MSE = 48,422$ ,  $p < .025$ . The pattern of effects on the second critical word cannot be due to differences in the inherent characteristics of that word across conditions because it is the same word in all conditions. The possibility that critical aspects of this pattern are due to spillover effects of the difficulty of recognizing different preceding words seems remote. For object-extracted RCs, the second critical word (*climbed* in Figure 3) was read more slowly in the description condition than in the name condition,  $t_1(47) = 4.02$ ,  $p < .001$ ;  $t_2(23) = 4.45$ ,  $p < .001$ , even though the preceding word was identical (*praised* in Figure 3). The word that occurred two words earlier was different, being a name in one condition and a common noun in the other condition. However, there was no significant difference in the reading times for those words themselves. The average reading time was 466 ms for the names and 496 ms for the common nouns, a difference that is not significant;  $t_1(47) = 1.41$ ,  $p > .2$ ;  $t_2(23) = 1.32$ ,  $p > .2$ . Substantial differences in the ease of recognizing names and common nouns would be more likely to be observed on the reading times of those words themselves than in a spillover effect two words later. The pattern of reading times that was observed on the second critical word is most plausibly explained in terms of how different words affect the process of understanding the sentences, not in terms of how different words are recognized.

The effect of the experimental conditions on accuracy in answering the comprehension question (Figure 3) was similar to that observed for the reading time of the first critical word. Accuracy was higher for subject-extracted RCs than for object-extracted RCs,  $F_1(1, 47) = 17.00$ ,  $MSE = 157.327$ ,  $p < .001$ ;  $F_2(1, 23) = 13.63$ ,  $MSE = 98.097$ ,  $p < .0025$ . Accuracy was also higher in the name condition than in the description condition,  $F_1(1, 47) = 18.56$ ,  $MSE = 157.820$ ,  $p < .001$ ;  $F_2(1, 23) = 22.40$ ,  $MSE = 65.387$ ,  $p < .001$ . Finally, the effect of type of RC was greater in the description condition than in the name condition, an interaction that was significant,  $F_1(1, 47) = 4.89$ ,  $MSE = 156.589$ ,  $p < .05$ ;  $F_2(1, 23) = 5.23$ ,  $MSE = 73.187$ ,  $p < .05$ .

A set of contrasts on the three measures (reading time for the two critical words and comprehension accuracy) was conducted in order to specifically address if an object-subject difference was observed for sentences containing a name as the second NP. When examining only the name condition, there was no effect of object versus subject for the first critical word,  $t_1(47) = 0.36$ ,  $p > .25$ ;  $t_2(23) = 0.45$ ,  $p > .25$ , for the second critical word,  $t_1(47) = 0.18$ ,  $p > .25$ ;  $t_2(23) = 0.20$ ,  $p > .25$ , or for comprehension accuracy,  $t_1(47) = 1.36$ ,  $p > .10$ ;  $t_2(23) = 1.41$ ,  $p > .10$ .

These results demonstrate that a name, like an indexical pronoun, reduces (or even eliminates) the object-subject difference in ease of comprehension. Two of the three relevant measures (reading time of the second critical word and comprehension accuracy) showed highly significant interactions between type of NP and the type of RC. The third measure (reading time of the first critical word) showed a strong trend toward the same interaction. None of the three relevant measures showed an effect of type of RC when the name condition was examined alone. This pattern of results is consistent with the prediction generated from Bever's (1974) analysis but not with the prediction generated from Gibson's (1998) model. Further, as with Experiment 2, the results are not expected by role-determinant and general-memory accounts of the object-subject difference.

A comparison of the results of Experiments 2 and 3 shows one interesting difference between the indexical pronouns and the proper names. The critical words in the pronoun condition of Experiment 2 were read quite rapidly (508 ms) as compared with the critical words in the name condition of Experiment 3 (698 ms), suggesting that the names do impose a greater processing load than the pronouns. However, the names still cause a substantial reduction in the object-subject difference, suggesting that the reduction of that difference by the indexical pronouns was not simply due to their being relatively easy to process.

#### Experiment 4

The results of Experiment 3 are consistent with Bever's (1974) analysis. They conflict with the predictions of Gibson's (1998) model, and the results of both Experiments 2 and 3 would not be expected under most traditional role-determinant or general-memory explanations of the object-subject difference. We see two basic explanations that could account for the pattern of results.

The first explanation relates the magnitude of the object-subject difference to the similarity, and hence the confusability, of the two NPs that participate in the RC. When the two NPs are both drawn from the same class (e.g., descriptions in our studies), then their memory representations will be quite similar, at least until they are "integrated" semantically with the verb. This similarity could cause interference in retrieving information associated with the two representations. In particular, the order of the two NPs must be correctly remembered up to the point of semantic integration, a task that is more difficult when the items (NPs) to be remembered are similar. The integration of the NPs in the object-extracted RCs occurs later than in the subject-extracted RCs, which is why the

<sup>2</sup> An alternative control for the first critical word involves examining the reading times for those same words when they occur earlier in the sentences. There are no significant differences in the reading times between those words in their earlier positions in the sentences. This contrasts with the very strong differences between those same words when they appear in the first critical word position where the difficulty of processing the embedded clause is starting to appear. If that reading-time difference were due to inherent differences in the ease of recognizing the words, then that same pattern should be observed at the earlier point in the sentence. The fact that the interaction of NP type and RC type falls short of significance for the critical first region most likely reflects a loss of power due to the addition of variability from including reading times from words that are relatively unaffected by the clausal embedding.

similarity of the NPs causes greater processing difficulty for the object-extracted RCs. This explanation leaves open the question of the critical dimensions that define a "class" of NPs for the relevant purposes of sentence comprehension. We will address that question in the General Discussion.

The second explanation is that the reductions of the object-subject difference in Experiments 2 and 3 relate to specific characteristics of names and pronouns that distinguish them from descriptions. One possibility along these lines has to do with how pronouns and names are taken to make reference. In formal semantics, pronouns and proper names are taken to refer to objects in the domain of discourse that exist and are unique because of how these expressions are mapped onto objects in the universe of discourse; reference is not part of the semantic representation of an utterance. In contrast, the uniqueness of definite descriptions is semantically represented, thus presumably placing a larger burden on memory than either names or pronouns. This explanation is similar to the one advanced by Gibson (1998) in that it relates sentence-complexity effects to the manner in which expressions make reference, though it differs from Gibson with respect to the nature of the crucial characteristic of reference that contributes to sentence complexity.

A second possibility for how specific characteristics of names and pronouns might affect the magnitude of the object-subject difference relates to the fact that neither pronouns nor names can be modified by a restrictive RC. This syntactic constraint is generally taken to be a semantic consequence of the referential characteristics of names and pronouns that were described above.<sup>3</sup> Because of this constraint, a name or pronoun could not be the subject of the main clause for RC sentences like the ones we have studied. In this way, one aspect of integrating the NPs and VPs of the sentences is simplified when the sentences contain a description and either a name or pronoun rather than two descriptions. Of course, knowing which NP is the subject of the matrix clause does not provide information about the assignment of the two NPs to syntactic roles in the embedded clause. That is, it does not provide information about whether a subject-extracted or object-extracted RC is being processed. However, it may reduce the overall complexity of processing the sentence and in that way contribute to reductions in the object-subject difference. It should be noted that this possibility draws on principles that are similar to the ones invoked by the first explanation above. The inability of the name, or pronoun, to serve as the subject of the main clause (when a subject-modifying RC follows) means that even if memory of the order of the expressions is lost, the subject of the main clause can be recovered from other characteristics of the NPs, which simplifies sentence comprehension.

In Experiment 4, we used a different kind of complex sentence, *clefts*, to test predictions generated from the three explanations above. Clefts, as shown in Example 7, contain an NP that is followed by a clause. Like RCs, clefts have a missing argument in the logical-subject or logical-object position within that clause, with the NP adjacent to *was* serving semantically as the missing argument. Clefts can occur in subject-extracted and object-extracted forms just as RCs can. Clefts are different from RCs in that the initial NP can be an expression like a name or pronoun that denotes a unique individual or object in the universe of discourse. The reason for this is that the cleft does not semantically function to help uniquely identify the referent of the first NP.

(7) *It was the barber/John that saw the lawyer/Bill in the parking lot.*  
*It was the barber/John that the lawyer/Bill saw in the parking lot.*

Previous work has shown that object-extracted clefts are more difficult to understand than subject-extracted clefts (Engelkamp & Zimmer, 1982). Most critically for present purposes, clefts allow both descriptions and names to be clefted, thereby allowing us to explore surface syntactic and semantic configurations of types of NPs that we could not investigate using restrictive RCs.

The current experiment examines the processing of subject- and object-extracted clefts for sentences where type of NP is matched (both descriptions or both names) or mismatched (a description followed by a name or a name followed by a description). The first explanation considered above, confusability of NPs, predicts that difficulty of comprehension should be greater with matched NPs than with mismatched NPs. The second explanation considered above, that the object-subject difference in RCs is affected by specific characteristics of names and pronouns, yields different predictions depending on which possible version of the explanation is considered. If an invariant characteristic of names and pronouns, such as the way in which they make reference, causes a reduction in the difficulty of processing object-extracted constructions, then no object-subject difference should be observed in clefts with names. If a characteristic of names and pronouns that is specific to RC structures is responsible for the elimination of the object-subject difference in those constructions, then an object-subject difference should be observed in clefts with mismatched NP types because clefts are not subject to the same constraints as RCs.

### Method

*Participants.* Sixty-eight students from the same population as in Experiment 3 participated in the study.

*Stimuli, design and procedure.* Stimuli for the experimental trials consisted of 24 sentences (listed in Appendix B) where the object of the cleft could either be extracted from the subject or object of the following clause. The sentences used many of the descriptions, names, and actions used for the RC sentences in the preceding experiments. Once again, sentences were constructed so that there was no inherent semantic relation between the roles depicted by the descriptions and the actions depicted by the verbs. Experimental sentences appeared in eight versions given by the combination of three factors: type of cleft (subject-extracted vs. object-extracted), whether the two NPs were matched (i.e., both descriptions or both names), and type of the first NP (description vs. name). Once again, participants saw each experimental sentence only in one condition; across participants, all sentences occurred in all conditions. Otherwise, the design and procedure were the same as in the preceding experiments.

### Results and Discussion

In contrast to the RC sentences of the previous experiments, the cleft sentences have only a single critical word. This occurs because an RC sentence has two meaningful verbs with which the NPs must be integrated, while a cleft sentence has only one

<sup>3</sup> This resistance to modification with a RC is ultimately related to the semantic fact that pronouns and proper names refer to unique individuals. In contrast, descriptions semantically assert that uniqueness when the determiner *the* is chosen. A restrictive RC can then help establish the conditions for referring to a unique object in the universe of discourse.



meaningful verb. For the cleft sentence, the critical word occurs once there are two NPs and a verb. For the sentences given in Example 7, it would be the noun *lawyer* or the name *Bill* in the subject-extracted condition and the verb *saw* in the object-extracted condition. The mean reading times for the critical word are shown in the left panel of Figure 4. There was a significant main effect of type of cleft such that reading times were significantly longer for object-extracted clefts than for subject-extracted clefts,  $F_1(1, 67) = 22.17$ ,  $MSE = 80,274$ ,  $p < .001$ ;  $F_2(1, 23) = 11.01$ ,  $MSE = 57,624$ ,  $p < .005$ . Given how the type of critical word (noun or verb) varies with type of cleft, we cannot unambiguously attribute this effect to type of cleft independent of the inherent characteristics of the word. There was also a significant main effect of NP match such that sentences in which the NPs were matched on type were read more slowly than sentences in which the NPs were mismatched on type,  $F_1(1, 67) = 10.56$ ,  $MSE = 80,171$ ,  $p < .0025$ ,  $F_2(1, 23) = 12.23$ ,  $MSE = 24,642$ ,  $p < .0025$ . This effect of match cannot be attributed to differences between words (nouns vs. verbs) because the same words contribute to the matched and nonmatched conditions. With respect to the interaction of major interest, the effect of type of cleft (object-extracted vs. subject-extracted) was larger when the NPs were matched than when they were mismatched, an effect that was significant by participants but fell short of significance by items,  $F_1(1, 67) = 4.30$ ,  $MSE = 41,482$ ,  $p < .05$ ;  $F_2(1, 23) = 1.30$ ,  $MSE = 49,411$ ,  $p > .25$ . Because of the nature of the match manipulation, this interaction is independent of the contribution of type of word (noun vs. verb). No other interaction approached statistical significance.

The right panel of Figure 4 shows the mean error rate on the comprehension questions for the cleft sentences in the different conditions. The pattern of comprehension performance mirrors that observed in the reading times but is statistically stronger. Higher error rates were observed for object clefts than for subject clefts,  $F_1(1, 67) = 42.99$ ,  $MSE = 298.020$ ,  $p < .001$ ;  $F_2(1, 23) = 92.38$ ,  $MSE = 48,816$ ,  $p < .001$ . There was also a main effect of NP match such that error rate was higher for matched NPs than for unmatched NPs,  $F_1(1, 67) = 21.75$ ,  $MSE = 169.008$ ,  $p < .001$ ;  $F_2(1, 23) = 28.20$ ,  $MSE = 46.000$ ,  $p < .001$ . The effect of

type of cleft (object-extracted vs. subject-extracted) on error rate was higher for matched NPs than for mismatched NPs,  $F_1(1, 67) = 9.36$ ,  $MSE = 174.617$ ,  $p < .005$ ;  $F_2(1, 23) = 11.96$ ,  $MSE = 47.192$ ,  $p < .005$ . The interaction of type of cleft and type of first NP was significant by participants but not by items,  $F_1(1, 67) = 4.82$ ,  $MSE = 286.192$ ,  $p < .05$ ;  $F_2(1, 23) = 3.33$ ,  $MSE = 156.879$ ,  $p > .05$ .

A set of contrasts on the two measures (reading time for the critical word and comprehension accuracy) was conducted to specifically address if an object-subject difference was observed for sentences in the nonmatched condition (sentences containing a description and a name regardless of order). When examining only the nonmatched condition, there was a significant effect of object versus subject for the critical word,  $t_1(67) = 3.11$ ,  $p < .0025$ ;  $t_2(23) = 2.00$ ,  $p < .06$ , and for comprehension accuracy,  $t_1(67) = 4.12$ ,  $p < .001$ ;  $t_2(23) = 3.91$ ,  $p < .001$ .

A critical goal of the current Experiment 4 was to examine whether the object-subject difference was greater when the two NPs in a sentence were both names than when there was a mismatched sequence of NPs. This comparison was not possible with the restrictive RC sentences used in the previous experiments but it was possible here with the clefts. Accordingly, planned contrasts were conducted, comparing the object-subject difference in the two-names condition with the average of that effect in the one-name conditions (description-name and name-description). For reading time on the critical word, the object-subject difference was bigger in the two-names condition than in the one-name conditions, an effect that was significant by participants but not by items;  $t_1(67) = 2.50$ ,  $p < .05$ ;  $t_2(23) = 1.74$ ,  $p < .10$ . For question accuracy, the object-subject difference was bigger in the two-names condition than in the one-name conditions;  $t_1(67) = 5.22$ ,  $p < .001$ ;  $t_2(23) = 4.91$ ,  $p < .001$ .

Four aspects of the results of Experiment 4 are important for understanding how the types of NPs in a sentence influence comprehension processes: (a) There was a main effect of match of NP such that sentence processing was easier when the two NPs were of different types than when they were of the same type. This finding provides general support for processing models in which having NPs of the same type makes sentence comprehension more

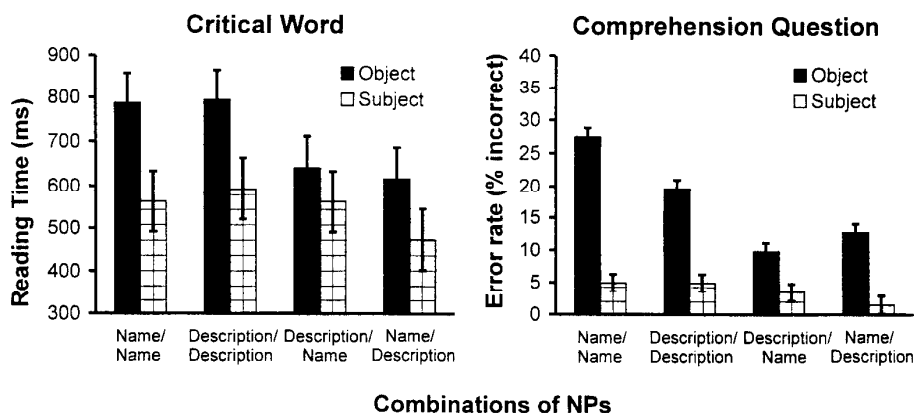


Figure 4. Mean reading time for the critical word and the average error rate (in percent) for the different experimental conditions in Experiment 4. Error bars represent 95% confidence intervals. NP = noun phrase.

difficult, as in the similarity-based interference model discussed above; (b) The object–subject difference was greater when the NPs match than when they do not match, an effect that was more reliable on the accuracy than the reading-time measure. The dependence of the object–subject difference on the match of the NPs provides evidence that sentence complexity effects are influenced by similarity-based interference; (c) The dependence of the object–subject difference on match was present for name–name matches. This indicates that there is nothing special about names that eliminates the object–subject difference; it is a finding that is not consistent with the possibility, outlined above, that an invariant characteristic of names means that they cause the elimination of the object–subject difference; (d) A significant object–subject effect was observed even in the nonmatched NP conditions, a pattern with the cleft sentences that differs from what we observed with the restrictive RCs that were used in Experiments 1–3. This finding is consistent with the idea, articulated above, that the inability of a name (or a pronoun) to serve as the subject of the main clause in a sentence with a subject-modifying restrictive RC may facilitate the processing of sentences with names (or pronouns) as the subjects of object-extracted RCs.

### General Discussion

The experiments reported in this article explore the nature of language comprehension by examining how the processing of a complex sentence is influenced by the types of NPs that occupy critical roles in the sentence. The results show that the well-established finding that sentences with an object-extracted NP are more difficult to process than those with a subject-extracted NP can be substantially reduced or eliminated by mixing names or indexical pronouns with definite descriptions as the NPs in a sentence. Here, we first consider the implications of these results for previous explanations of the processing of complex sentences. Then, we present our own explanation and discuss how it relates to current approaches to working memory and to language processing more generally.

The pattern of results from the experiments would not be expected under most of the previous explanations of the object–subject difference in processing sentences with RCs (for reviews, see Gibson, 1998; MacWhinney & Pleh, 1988). In particular, role-determinant accounts of the difference, as articulated by Bever (1970), MacWhinney (1977), and Sheldon (1974), offer no ready explanation of the reduction or elimination of the effect with a mixture of types of NPs because the mixture has no effect on the changing roles that must be assigned to the NPs. Similarly, general memory-load accounts (see Ford, 1983; MacWhinney, 1987; Waner and Maratsos, 1978) offer no ready explanation of this pattern because the amount of interruption and the degree to which semantically unintegrated sentence fragments must be kept in mind are not influenced by the mixture of types of NPs. However, these general classes of explanations could possibly be augmented by a more fine-grained specification of their mechanisms that can explain how mixtures of NPs influence the difficulty of processing complex sentences.

The models proposed by Bever (1974) and Gibson (1998) offer just such additional specification of the general models discussed above, with Bever (1974) augmenting the double-function version of the role-determinant model and Gibson specifying the nature of

the memory difficulties involved through an appeal to the notion of discourse referents. The current results are relevant to the differing empirical characterizations behind the two models. The results show that the object–subject difference is reduced when a sentence includes either a description and an indexical pronoun as the two critical NPs (Experiment 2) or a description and a name as the two critical NPs (Experiments 3 and 4). This pattern is consistent with Bever's (1974) claim that double-center embedded sentences become grammatically acceptable when they contain NPs of a different surface lexical type. This pattern is not obviously consistent with the finding by Gibson and his colleagues (Gibson, 1998; Gibson & Warren, 1998) that the rated complexity of a double-center embedded sentence is reduced by having an indexical pronoun as the centermost NP but not by having a short name as the centermost NP. One possibility for this inconsistency is that the performance measures that we used (reading time and accuracy of question answering) may tap different processes from those tapped by the intuitive judgment measures used by Gibson and Warren (1998). A second possibility for this inconsistency is that single embeddings and double embeddings involve different processing mechanisms and therefore should be addressed by different theories. While this may be so, most theorists, including Gibson, have considered double-center embeddings to be an extension of single-center embeddings and have addressed them using the same principles.

Our approach to explaining these findings draws on a fundamental property of human memory—its susceptibility to interference during encoding, storage, and retrieval, arising from the similarity of the items being processed (Crowder, 1976). The parsing and semantic interpretation of a sentence require that intermediate representations be held in memory and addressed during comprehension. Object-extracted constructions impose greater demands of this sort than do subject-extracted constructions because they require that two NPs be stored and subsequently accessed while subject-extracted constructions do not. The differing functions of those two NPs are specified by the order in which they appear in the sentence. Memory for order information is impaired when the items to be remembered are similar because the similarity of the items causes interference in retrieving the order information (Lewandowsky & Murdock, 1989; Murdock & Vom Saal, 1967; Naime, 1990).

This similarity-based interference explains why the object–subject difference in processing is affected very substantially by the mix of types of NPs in a sentence. When the NPs are drawn from the same class they are more similar and hence can interfere more with each other's processing. This similarity-based effect might also be able to explain why having NPs of a different type virtually eliminates the object–subject difference in restrictive RCs but only reduces it in clefts. Because a name or pronoun cannot easily be modified by an RC, there is an additional source of information about the roles played by the two NPs when there is a mixture of a name or a pronoun with a description. Thus, having different types of NPs both reduces interference with order information based on similarity and it adds a cue as to which NP is being modified. The clefts do not have this restriction, which results in greater similarity between the NPs, with respect to their possible roles in the sentence, and hence more interference. Alternatively, the difference we observe between RCs and clefts may be due to the fact that the head of the RC serves as the semantic

argument of two verbs whereas the head of the cleft is a semantic argument of one verb. This could give an added cue to the position of the head in the organization of the sentence.

This similarity-based interference model brings to the fore the question that we raised earlier about what constitutes a class of NPs. The forms that we have studied—descriptions, names, and pronouns—have both commonalities and differences. The results of the current experiments do not provide a basis for definitively determining which dimensions of similarity between these forms are critical for the sentence complexity effects that we have observed. However, consideration of the nature of working memory and of the forms themselves offers some insight.

There appears to be general acceptance of the idea that the phonological loop component of working memory participates primarily in cognitive tasks other than online language comprehension (Baddeley, Gathercole, & Papagno, 1998). Instead, online language comprehension draws on working memory that codes language input at a higher level of representation, though there is not clear agreement on the nature of this working memory (Ericsson & Kintsch, 1995; Just & Carpenter, 1992; Waters & Caplan, 1996).

Given the classes of NPs that we have contrasted (descriptions, names, and pronouns), possible sources of similarity-based interference exist on both syntactic and semantic levels of representations. Possible syntactic features of NPs that could contribute to similarity include gender, number, animacy, case, and person. Other syntactic correlates that distinguish names and pronouns from descriptions could also provide a basis of similarity.<sup>4</sup> Semantic features of the representations of these NPs could also provide a basis for similarity-based interference, through either structural-semantic features (e.g., the definite-indefinite contrast) or lexical-semantic features (e.g., semantic fields such as occupations, tools, natural kinds). In addition to syntactic and semantic explanations of the interference effect, it is possible that the different types of NPs differ on some other lexical dimension (e.g., frequency or morphological paradigm) that is not directly related to the syntactic and semantic factors that we have considered and which is responsible for similarity-based interference.

The interference-based explanation of the object-subject difference that we have advanced bears some similarity to the interference model proposed by Lewis (1996, 1999). At an architectural level, the approach advanced by Lewis (1996, 1999) is very similar to the one that we advocate (Gordon & Hendrick, 1998), involving the idea that during language comprehension two representations are incrementally built in memory: a parse tree and a situation model (comparable with a discourse model). Further, Lewis (1996, 1999) stresses the importance of interference in memory as a factor in language processing. However, our view of the nature of interference differs from the formal model advanced by Lewis (1996, 1999).

Lewis (1996, 1999) claimed that interference in the processing of complex sentences emerges from a specific limitation in working memory, that the memory representation of a syntactic relation can index at most two nodes. When a syntactic dependent could satisfy the expectation of more than one syntactic head, interference results. In essence, this formalism allows for one level of center embedding because that does not exceed the capacity of two relations that is a fundamental limitation of short-term memory; it does not allow for two levels of center embedding because that

does exceed the capacity. In this way, Lewis (1996, 1999) accounts for the classic observations of Miller and Chomsky (1963) that a single center embedding is acceptable but a double center embedding is not.<sup>5</sup> In order for Lewis' (1996, 1999) model to explain the difference in ease of processing object-extracted and subject-extracted RCs (both of which are single-embedded structures), it would need to be argued that decrements in processing performance appear as the capacity of short-term memory is approached and do not only appear after it is exceeded. Further, Lewis (1996) explicitly notes (p. 103) that his model does not account for the observation by Bever (1974) that mixing types of NPs substantially enhances the acceptability of double-center embedded sentences, though Lewis (1996, 1999) does note that the phenomenon is consistent at a general level with the importance of interference in language processing. In summary, Lewis' (1996, 1999) formal model states that interference only emerges when the defined limits of syntactic short-term memory are exceeded, though he acknowledges that other kinds of interference phenomena may play a role in language comprehension. In contrast, we argue that interference is a characteristic of the memory used for language processing, and that it can occur regardless of the number of relations involved and regardless of whether there is a specific type of short-term memory involved at the particular level of language processing.

MacDonald and Christiansen (in press) propose an explanation of sentence complexity effects using a type of processing architecture that is very different from the kind that we (or Lewis, 1996, 1999) advocate. They use a simple recurrent network (Christiansen & Chater, 1999b; Elman, 1990) in which learning and processing occur through the connections between simple elements without explicit symbols or rules. They show that the object-subject difference in RCs, and its possible dependence on working memory capacity (King & Just, 1991; Just & Carpenter, 1992; cf. Waters & Caplan, 1996), can emerge through a frequency-by-regularity interaction where the similarity of a subject-extracted RC to the canonical sentence structure of English facilitates its processing as compared with an object-extracted RC, which is less similar to the canonical structure. They argue that very skilled readers overcome this difference because their greater experience with language strengthens the processing connections related to the object-extracted RCs so that the processing of such sentences is influenced less by their (lack of) similarity to canonical structures.

The analysis by MacDonald and Christiansen (in press) provides a strong example of the appeal of connectionist approaches to language comprehension. However, it is also susceptible to a standard concern about such approaches, which is whether demonstrations of success on a limited range of grammatical constructions, such as that of MacDonald and Christiansen, can be expanded to account simultaneously for a broad range of

<sup>4</sup> For example, on one syntactic analysis, a description has two distinct morphemes for the specifier (determiner) position and the common noun position, whereas proper names and pronouns have only a single morpheme for these two syntactic classes.

<sup>5</sup> Lewis (1996) leaves open the question of whether the "magical number" that characterizes the limit is two or three because there are some constructions involving three syntactic dependents of the same sort that seem grammatically acceptable.

generalizations about language (Christiansen & Chater, 1999a). For example, in this article we examined the processing of object-extracted and subject-extracted forms in both RCs (Experiments 1–3) and in clefts (Experiment 4). Most grammars (and automata) that manipulate symbolic representations are able to capture the similarities and differences between the two forms in a straightforward way. Accordingly, we prefer to look toward language-processing mechanisms with explicit rules and symbols (e.g., Joshi, 1990; Rambow & Joshi, 1994) for an understanding of the comprehension of complex sentences. That being said, it is worth noting that the interference effects we observed had their basis in the similarity of expressions. Connectionist networks tend to provide very natural explanations of the processing consequences of the similarity of items, just as they provide very natural explanations of the processing consequences of item frequency. A connectionist approach, or elements drawn from one, may ultimately prove useful in understanding how the mixture of different types of NPs affects the difficulty of processing complex sentences.

Regardless of these questions of formalism, the results of the current experiments support the idea that a well-established characteristic of memory—its susceptibility to interference—is the source of the object–subject asymmetry in RCs and clefts. This suggests that properties of memory interference may play a critical role in explaining a variety of sentence complexity effects.

## References

- Baddeley, A., Gathercole, S., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review*, 105, 158–173.
- Bever, T. G. (1970). The cognitive basis for linguistic structures. In J. R. Hayes (Ed.), *Cognition and the development of language* (pp. 279–362). New York: Wiley.
- Bever, T. G. (1974). The ascent of the specious, or there's a lot we don't know about mirrors. In D. Cohen (Ed.), *Explaining linguistic phenomena* (pp. 173–200). Washington, DC: Hemisphere.
- Caplan, D., Alpert, N., & Waters, G. (1998). Effects of syntactic structure and propositional number on patterns of regional cerebral blood flow. *Journal of Cognitive Neuroscience*, 10, 541–552.
- Caramazza, A., & Zurif, E. (1976). Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia. *Brain and Language*, 3, 572–582.
- Christiansen, M. H., & Chater, N. (1999a). Connectionist natural language processing: The state of the art. *Cognitive Science*, 23, 417–437.
- Christiansen, M. H., & Chater, N. (1999b). Toward a connectionist model of recursion in human linguistic performance. *Cognitive Science*, 23, 157–205.
- Crowder, R. G. (1976). *Principles of learning and memory*. Hillsdale, NJ: Erlbaum.
- Elman, J. L. (1990). Finding structure in time. *Cognitive Science*, 14, 179–211.
- Engelkamp, J., & Zimmer, H. D. (1982). The interaction of subjectivization and concept placement in the processing of cleft sentences. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 34(A), 463–478.
- Ericsson, K. A., & Kintsch, W. (1995). Long-term working memory. *Psychological Review*, 102, 211–245.
- Ford, M. (1983). A method for obtaining measures of local parsing complexity throughout sentences. *Journal of Verbal Learning and Verbal Behavior*, 22, 203–218.
- Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, 68, 1–76.
- Gibson, E., & Warren, T. (1998). *Discourse reference and syntactic complexity*. Manuscript submitted for publication.
- Gordon, P. C., & Hendrick, R. (1998). The representation and processing of coreference in discourse. *Cognitive Science*, 22, 389–424.
- Heim, Irene. (1982). File change semantics and the familiarity theory of definiteness. In B., Rainer, C. Schwartze, & A. von Stechow (Eds.), *Meaning, use and interpretation of language*. Berlin: de Gruyters.
- Joshi, A. V. (1990). Processing crossed and nested dependencies: An automation perspective on the psycholinguistic results. *Language and Cognitive Processes*, 5, 1–27.
- Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, 99, 122–149.
- Just, M. A., Carpenter, P. A., Keller, T. A., Eddy, W. F., & Thulborn, K. R. (1996, October 4). Brain activation modulated by sentence comprehension. *Science*, 274, 114–116.
- King, J., & Just, M. A. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language*, 30, 580–602.
- Lewandowsky, S., & Murdock, B. B., Jr. (1989). Memory for serial order. *Psychological Review*, 96, 25–57.
- Lewis, R. L. (1996). Inference in short-term memory: The magical number two (or three) in sentence processing. *Journal of Psycholinguistic Research*, 25, 93–115.
- Lewis, R. L. (1999). Specifying architectures for language processing: Process, control, and memory in parsing and interpretation. In M. Crocker, M. Pickering, & C. Clifton Jr. (Eds.), *Architectures and mechanisms for language processing* (pp. 56–89). Cambridge, England: Cambridge University Press.
- MacDonald, M. C., & Christiansen, M. H. (in press). Reassessing working memory: A comment on Just and Carpenter and Waters and Caplan. *Psychological Review*.
- MacWhinney, B. (1977). Starting points. *Language*, 53, 152–168.
- MacWhinney, B. (1982). Basic syntactic processes. In S. Kuczaj (Ed.), *Language acquisition: Syntax and semantics* (Vol. 1, 73–136). Hillsdale, NJ: Erlbaum.
- MacWhinney, B. (1987). The competition model. *Mechanisms of language acquisition*. Hillsdale, NJ: Erlbaum.
- MacWhinney, B., & Pleh, C. (1988). The processing of restrictive relative clauses in Hungarian. *Cognition*, 29, 95–141.
- Miller, G. A., & Chomsky, N. (1963). Finitary models of language users. In Luce, D. R., Bush, R. R., & Galanter, E. (Eds.), *Handbook of mathematical psychology* (Vol. 2, pp. 419–492). New York: Wiley.
- Murdock, B. B., Jr., & Vom Saal, W. (1967). Transpositions in short-term memory. *Journal of Experimental Psychology*, 74, 137–143.
- Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition*, 18, 251–269.
- Rambow, O., & Joshi, A. V. (1994). A processing model for free word-order languages. In C. Clifton, Jr., L. Frazier, & K. Rayner (Eds.), *Perspectives on sentence processing* (pp. 267–301). Hillsdale, NJ: Erlbaum.
- Sheldon, A. (1974). On the role of parallel function in the acquisition of relative clauses in English. *Journal of Verbal Learning and Verbal Behavior*, 13, 272–281.
- Steedman, M., (1996). Natural language processing. In M. Boden (Ed.), *Artificial intelligence* (pp. 229–266). San Diego, CA: Academic Press.
- Wanner, E., & Maratsos, M. (1978). An ATN approach to comprehension. In M. Halle, J. Bresnan, & G. Miller (Eds.), *Linguistic theory and psychological reality* (pp. 119–161). Cambridge, MA: MIT Press.
- Waters, G. S., & Caplan, D. (1996). The capacity theory of sentence comprehension: Critique of Just and Carpenter (1992). *Psychological Review*, 103, 761–772.

Appendix A

Appendix B

Stimuli for Experiments 1-3

Stimuli for Experiment 4

The stimuli for Experiments 1-3 are shown below in the object-extracted form. They were also presented in the subject extracted form. The slashes separate the descriptions, the pronoun, and the names that were used to vary the types of noun phrases. Experiment 1 used only descriptions. Experiment 2 used descriptions and the pronoun. Experiment 3 used descriptions and the names.

The stimuli for Experiment 4 are shown below in the object-extracted form. They were also presented in the subject-extracted form. The slashes separate the descriptions and the names that were used to vary the types of noun phrases.

- Fnl 1. The banker that the barber/you/Sue praised climbed the mountain just outside of town before it snowed.<sup>a</sup>
- Fnl 2. The dancer that the reporter/you/Ann phoned cooked the pork chops in their own juices on New Year's Eve.<sup>a</sup>
- Fnl 3. The architect that the fireman/you/Wes liked dominated the conversation while the game was on television.<sup>a</sup>
- Fnl 4. The waiter that the broker/you/Jan despised drove the sports car home from work that evening.<sup>a</sup>
- Fnl 5. The detective that the secretary/you/Ted disliked clipped the coupons out with the dull scissors.<sup>a</sup>
- Fnl 6. The judge that the doctor/you/Tom ignored watched the special about Colombian drug dealers on the nightly news.<sup>a</sup>
- Fnl 7. The robber that the mailman/you/Sam insulted read the newspaper article about the fire.<sup>a</sup>
- Fnl 8. The governor that the comedian/you/Kay admired answered the telephone in the fancy restaurant.<sup>a</sup>
9. The actor that the director/you/Fay thanked worked in many hit movies before 1990.
10. The poet that the painter/you/Ben inspired wrote an autobiography after their friendship became well known.
11. The chef that the cashier/you/Joe distrusted called for help after the restaurant closed.
12. The aunt that the child/you/Kim amused made paper dolls out of the newspaper.
13. The violinist that the conductor/you/Max complimented performed at Carnegie Hall for two weeks.
14. The teacher that the student/you/Bob questioned wrote a long science fiction novel during the summer vacation.
15. The editor that the author/you/Jen recommended changed jobs after a new merger was announced.
16. The tailor that the customer/you/Pam described worked in a small building near the bus station.
17. The admiral that the general/you/Jim advised reminisced nostalgically before the trip got underway.
18. The coach that the referee/you/Eve criticized talked publicly about the incident after the game.
19. The lawyer that the client/you/Ken interviewed had a very small office.
20. The plumber that the electrician/you/Joy called drove a grey truck.
21. The salesman that the accountant/you/Jon contacted spoke very quickly.
22. The clown that the magician/you/Meg entertained was a star.
23. The clerk that the traveler/you/Lou helped worked in a large foreign bank.
24. The gardener that the homeowner/you/Liz envied was very friendly.

1. It was the banker/Sue that the barber/Dee praised just outside of town.
2. It was the dancer/Jill that the reporter/Rose phoned on New Year's Eve.
3. It was the architect/Ted that the fireman/Wes liked before the argument began.
4. It was the waiter/Kay that the broker/Jan despised that evening.
5. It was the detective/Jack that the secretary/Bill disliked during card games.
6. It was the judge/Sam that the doctor/Tom ignored at the party.
7. It was the robber/Luke that the mailman/Mark insulted after reading the newspaper article.
8. It was the governor/Barb that the comedian/Gwen admired in the fancy restaurant.
9. It was the actor/Kim that the director/Fay thanked before the show.
10. It was the poet/Joe that the painter/Ben inspired outside the coffeeshop.
11. It was the chef/Pete that the cashier/Nick distrusted after the restaurant closed.
12. It was the aunt/Gail that the child/Jane amused with the paper dolls.
13. It was the violinist/Bob that the conductor/Max complimented at Carnegie Hall.
14. It was the teacher/Todd that the student/Brad questioned during the summer vacation.
15. It was the editor/Pam that the author/Jen recommended after a new merger was announced.
16. It was the tailor/Reid that the customer/Kate described at the banquet.
17. It was the admiral/Ken that the general/Jim advised before the trip got underway.
18. It was the coach/Joy that the referee/Eve criticized after the game.
19. It was the lawyer/Seth that the client/Greg interviewed in the very small office.
20. It was the plumber/Lynn that the electrician/Beth called from the payphone.
21. It was the salesman/Lou that the accountant/Jon contacted in the morning.
22. It was the clown/Liz that the magician/Meg entertained in the auditorium.
23. It was the clerk/Nate that the traveler/Doug helped after the explosion.
24. It was the gardener/Dawn that the homeowner/Fran envied after the lottery ended.

<sup>a</sup> From "Individual Differences in Syntactic Processing: The Role of Working Memory," by J. King and M. A. Just, 1991, *Journal of Memory and Language*, 30, p. 600. Copyright 1991 by Academic Press. Adapted with permission.