The Nature of Working Memory Operation During The Comprehension of Unambiguous, Complex Sentences

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ABSTRACT

MARCUS LIVINGSTON JOHNSON: The Nature of Working Memory Operation During the Comprehension of Unambiguous, Complex Sentences

(Under the direction of Peter C. Gordon)

The current studies, using eye-tracking methodology, sought to investigate the notion that processing difficulty may occur when reading sentences in which two or more noun phrases are encountered before they are integrated with verbs. This difficulty may be alleviated if the noun phrases are sufficiently dissimilar. Relative clauses (RC) and clefts, which can present readers with two or more noun phrases before the verbs which integrate them into the rest of sentence, were used to test this notion. Evidence for increased processing difficulty was found in Experiments 1 and 2 when two similar, but not dissimilar noun phrases were encountered before any verbs. Additionally, Experiment 3 utilized concurrent load methodology to test the possibility that the working memory responsible for language comprehension is modularized from general working memory. Experiment 3 provided evidence in support of similarity-based working memory and in opposition to the notion of modularized language comprehension working memory.

To my parents, Luther N. Johnson, II and Sue M. Johnson,

without whose support this work would

never have been completed.

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1. Introduction

Readers often report experiencing difficulty and exhibit behavior affirming that difficulty during the comprehension of complex sentences. For some sentences the difficulty that readers experience may be attributed to the resolution of a temporary lexical or syntactic ambiguity that occurs before a correct interpretation of the sentence may be reached. Such difficulty is often experienced during the reading of sentences containing garden path structures such as (1).

(1) *The horse raced past the barn fell.*

Initially, most readers interpret *the horse* to be the subject of the verb *raced*, but must later change their interpretation such that *the horse* is taken to be the object of the verb *raced* in order to correctly understand the meaning of the sentence. It is reasonable to conclude that the difficulty experienced in sentences such as (1) results from the reassessment of the syntactic relationship between a noun phrase (NP) and a verb. For other sentences difficulty stems not from ambiguity resolution, but instead from an over-taxation of the cognitive systems (in particular, memory systems) that are used to determine the meaning of unambiguous, yet complex sentences. Sentences containing doubly-embedded, object-extracted relative clauses (RCs), such as (2), while containing no local ambiguity, often are extremely difficult, if not impossible, to comprehend.

(2) The manager that the employee that the clerk met saw knew the business was in jeopardy.

Although there is no point in a sentence such as (2) where the reader experiences a misleading garden-path with respect to the meaning of the sentence, such sentences nonetheless pose a great challenge to readers. Investigating the nature of the difficulty that readers experience when faced with complex, unambiguous sentences can help us to understand how cognitive systems operate during reading.

Modern research on unambiguous complex sentence comprehension has its origins in the work of Miller and Chomsky (1963). They suggested that one characteristic of grammar systems is that they are capable of producing an infinite number of grammatically acceptable utterances. For instance it is possible for a sentence to be acceptable grammatically while extending in a right-branching manner indefinitely (e.g., The lawyer that knew the client that saw the doctor that treated the patient that called the plumber…). They further noted, that in order to understand how language is used, as opposed to it theoretical capabilities, we must consider that limitations of cognitive systems such as memory restrict the constructions that are actually produced and that are capable of being understood. Their ideas sparked research into the nature of memory operation during language production and comprehension.

Bever (1974) made the observation that the types of NPs present in complex sentences can influence the level of difficulty associated with comprehending the sentences. In particular he noted that sentences containing structures as complex as quadruply-embedded object-extracted relative clauses like (3) and (4) are markedly easier to understand when the NPs related to the relative clauses were superficially distinguishable (as (3) is) than when they were superficially similar (as (4) is).

(3) The banker your portrait the art dealer everyone I met trusts appraised belonged to knows nothing about art.

(4) The cricket the mouse the cat the dog barked at miawed at squeaked at chirped at midnight.

He believed that when the NPs of these types of sentences can be "contradictorily coded by the perceptual mapping rule" the comprehension of them is greatly facilitated. While his observations suggested that certain qualities of the NPs present in complex sentences may be related to the difficulty associated with these sentences, his work did not offer any ideas related to the nature and/or mechanism underlying his observations.

The current research posits working memory to be the cognitive mechanism whose limitations are responsible for the difficulty experienced during unambiguous, complex sentence comprehension. The notion that working memory plays a strong role in language comprehension has been corroborated by many recent studies. Just and Carpenter (1980), in a model of language processing based on eye-movement data, suggested that working memory is the temporary storage facility through which the activated representations of physical features, words, meanings, case roles, clauses, and text units move from perceptual input to long term memory. Also using eye-tracking methodology, Frazier and Rayner (1982) found that readers are able to remember the locations of information in the text relevant to resolving discourse difficulty upon encountering regions of the text that lead to disambiguation. Upon encountering regions requiring a reanalysis of the meaning of sentences, participants in their study quickly moved their eyes to the regions relevant to the reanalysis rather than serially searching backwards from the spot of disambiguation or serially searching forwards from the beginning of the sentence. Lewis (1999) used a simulation approach to understanding how working memory is involved in language comprehension, and concluded that working memory plays a key role in storing information required for syntactic parsing.

Although most accounts of unambiguous, complex sentence comprehension emphasize the involvement of working memory in their comprehension, this is not universally the case. For instance, MacWhinney (1977) did not attribute the difficulty experienced during the reading of certain complex sentences to working memory constraints. In an attempt to explain why sentences containing an object-extracted relative clause (RC), such as (5), are more difficult to read and comprehend than sentences containing a subject-extracted RC, such as (6), MacWhinney suggested that the difference in difficulty lies in a shift in perspective that must occur when reading sentences with object-extracted RCs, but not when reading sentences with subject-extracted RCs.

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

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

He proposed that during the comprehension of sentences with object-extracted RCs (such as (5)) readers initially take on the perspective of the first NP (in this case *the banker*), but upon encountering the RC must switch perspectives from the first NP to the second NP (in this case they must then adopt the perspective of *the barber*) as the second NP is the agent of the RC and the first NP is the patient of the RC. After the RC the reader must switch perspectives back to the first NP as it is the agent of the matrix clause. However, in the case of sentences with subject-extracted RCs the reader maintains the perspective of the first NP throughout the sentence, as it is the agent of both the RC and the matrix clause. MacWhinney's perspective-shift hypothesis does not include working memory at all in its assessment of the difficulty experienced during the comprehension of a difficult sentence like one containing an object-extracted RC.

In addition, MacDonald and Christiansen (2002) also did not include working memory function in their explanation of the differences in difficulty that are commonly observed between sentences containing object-extracted RCs and sentences containing subject-extracted RCs. Using a connectionist framework as the basis of a model designed to explain many language comprehension phenomena, they proposed that the ease of comprehension associated with a certain language stimulus is related to the amount of experience the reader has had with the structure of the stimulus. They suggested that sentences that contain subject-extracted RCs follow the subject, verb, object (SVO) pattern that is common to English sentence structures, and thus present relatively little difficulty to readers (who have had a good deal of experience with the SVO pattern of language). On the other hand, sentences containing object-extracted RCs present the reader with an object, subject, verb (OSV) pattern that is not very canonical in English and thus has not been experienced as frequently for readers as has the SVO pattern. It is this lack of experience with the noun/verb ordering of sentences that contain object-extracted RCs which they proposed to be the source of difficulty in the comprehension of sentences containing object-extracted RCs. As such, their model of language comprehension does not include working memory capabilities in its explanation of the patterns of behavior associated with the reading of sentences containing RCs

In contrast, King and Just sought to test the idea that the comprehension of sentences with relative clauses is related to the working memory capacity of the reader. Using self-paced reading methodology they tested readers who were classified as having either high or low working memory capacities (as measured by the reading span task developed by Daneman and Carpenter, 1980) by presenting them with sentences containing object-extracted RCs and sentences containing subject-extracted RCs. They found that readers who had low working memory capacities performed worse than readers who had high working memory capacities on a comprehension task related to information in the sentence after reading sentences with object-extracted RCs, even though the low span readers took longer to read these sentences. Their findings suggest that working memory does play a role in the comprehension of unambiguous, complex sentences.

Gibson (1998) also attributed the difficulty readers experience while comprehending sentences with an object-extracted RC to working memory constraints, but like Bever (1974) he believed that the types of NPs of the sentence were responsible for the level of difficulty experienced when comprehending the sentence. He examined data from experiments (Warren and Gibson, 1998, cited in Gibson, 1998) in which participants read sentences with doubly-embedded object-extracted RCs that contained various types of NPs.

(7) The student who the professor who the scientist collaborated with had advised copied the article.

(8) The student who the professor who I/you collaborated with had advised copied the article.

(9) The student who the professor who Bill/he collaborated with had advised copied the article.

The participants, after reading the sentences, rated the complexity of them. The complexity ratings of sentences in which the centermost NP was either the indexical pronoun "you" or the indexical pronoun "I" (like (8)) were lower than sentences in which all the NPs were descriptions (like (7)). However, there was no reduction in complexity ratings for sentences that had an embedded name or referential pronoun (like (9)). He used these findings to support a model which he called the Syntactic Prediction Locality Theory (SPLT). Under the SPLT, a discourse entity that is encountered during the reading of a sentence poses a memory cost to the reader until it is integrated with a verb later in the sentence. Greater distances between the input of the discourse entities and their integration points pose more memory cost to the reader. Additionally, distance in the SPLT is measured in the number of discourse entities that are encountered between the input of a discourse entity and its integration point. Thus, the SPLT explains the difference in complexity between sentences with object-extracted RCs and sentences containing subject-extracted RCs by saying that during the reading of a sentence with an object-extracted RC (like (5)) there is a discourse entity (in this example, *the barber*) in between the first NP and its point of integration, but in a sentence with a subject-extracted RC there is no intervening discourse entity. He further explains why difficulty is alleviated when an intervening discourse entity is an indexical pronoun (like in (8)) by saying that the indexical pronouns "you" and "I" are already given in the discourse and therefore pose no memory cost to the reader. While the SPLT seemed to account for many different ratings of sentence complexity, its core claims rested on a narrow base of subjective ratings of very complex sentences.

Gordon, Hendrick, and Johnson (2001), using self-paced reading methodology, found evidence inconsistent with the SPLT. Consistent with the SPLT, they found that readers spent longer reading the critical regions (the last two words of the RC) of sentences containing object-extracted RCs than they spent reading the critical regions of sentences containing subject-extracted RCs when both the NPs of the sentences were descriptions (e.g., the banker). However, they also found that this difference in reading times between sentences with object-extracted RCs and sentences with subject-extracted

RCs was eliminated when the NP embedded in the RC was either the indexical pronoun "you" or a name. While the SPLT would predict this reduction in difference between sentences with object-extracted RCs and sentences with subject-extracted RCs when the embedded NP is "you" (as the SPLT considers this indexical pronoun to be given in the discourse), it would not predict such a reduction in difference for sentences in which the embedded NP is a name. Gordon, et al. attributed the alleviation of difficulty in these cases to a reduction in similarity-based memory interference. They suggested that during the reading of sentences containing object-extracted RCs, but not during the reading of sentences containing subject-extracted RCs, the reader must juggle two NPs in memory before either NP is integrated with a verb. When the two NPs are similar, as is the case when both NPs are descriptions, the reader may get confused as to who is performing the actions specified by the verbs. When the two NPs are distinct then it may be easier for the reader to keep track of which people are performing the actions specified by the verbs, as there is less similarity-based memory interference between the NPs. While the findings of their experiment were consistent with the notion of similarity-based memory interference, Gordon, et al. did not specify what aspects of NPs make them similar to one another.

Warren and Gibson (2002), in order to account for reductions in difficulty in unambiguous, complex sentences that occur when NPs other than indexical pronouns (like names, for instance) are used as the critical NPs, modified the SPLT so that the memory cost imposed by NPs encountered between the introduction of a discourse entity and its integration with a verb depends on how given the NP is in the discourse. They applied a givenness hierarchy to their model, wherein NP types were ordered in terms of how given they are in the following manner (from most given to least given): 1^{st} and 2^{nd}

person pronouns, 3rd person pronouns, first names, full/famous names, definite descriptions, and indefinite descriptions. The complexity ratings and reading time data seemed to indicate that comprehension difficulty depends on how given the NPs of the sentence were in that the more given a NP was in the discourse the less complex the sentence seemed to be.

Gordon, Hendrick, and Johnson (2004) revisited the notion of similarity-based memory interference in an effort to understand what characteristic of NPs may mediate the occurrence of similarity-based memory interference. Again using self-paced reading methodology they manipulated certain structural characteristics of the embedded NPs of sentences containing object-extracted RCs and sentences containing subject-extracted RCs and compared the reading time data to the baseline condition of sentences containing RCs in which both the NPs were definite descriptions (e.g., the barber) in order to see if differences in structural characteristics between the two NPs could reduce similarity-based memory interference. They tested sentences containing RCs in which the NP embedded in the RC was either an indefinite description (e.g., a barber) or a generic (barbers) and found that neither of these conditions resulted in a reduction in difficulty for sentences with object-extracted RCs (the types of sentences in which they believed similarity-based memory interference was occurring). Additionally, they tested sentences containing subject-extracted or object-extracted RCs in which the NP embedded in the RC was “the person” and sentences containing subject-extracted or object-extracted RCs in which the NP being modified by the RC was “the person” (in both cases the other NP was a description involving an occupation or a role) against the baseline conditions in which both NPs were descriptions involving occupations or roles in order to see whether the amount of lexical semantic information associated with the NPs mediates similarity-based memory interference. The NP “the person” may be thought of as having less information associated with it than a description like “the barber”. Again, they found no reductions in difficulty for sentences with object-extracted RCs when “the person” was one of the NPs.

Finally, they tested sentences containing object-extracted or subject-extracted RCs in which the NP embedded in the RC was the pronoun “everyone” against their baseline condition and found that difficulty was reduced for object-extracted RCs when “everyone” was the embedded NP. Combining their results with those of Gordon, et al. (2001) they concluded that common noun status may be mediating similarity-based memory interference. If a noun is a common noun then it means that it can be considered part of a group (for instance, the barber is one of all barbers). Definite descriptions, indefinite descriptions, generics, and “the person” are all common nouns, while the pronoun “you”, names, and the pronoun “everyone” are all not common nouns. They only observed reductions in difficulty for sentences containing object-extracted RCs when one of the NPs was a common noun and the other was not, and thus concluded it may be the mediating factor in similarity-based memory interference.

It should be noted that the work of Gordon et al. assumes that the working memory responsible for mediating similarity-based memory interference effects is not a special, modular memory used only during sentence processing, but instead is the working memory that also is responsible for more general tasks requiring memory resources, and thus operates according to the principles of general working memory. There has been an ongoing debate in language and memory research as to whether the working memory used during sentence comprehension is modular (i.e., separate) from more general working memory processes. While much evidence has been presented from researchers on both sides of the debate (see Waters and Caplan, 1996 and Caplan and Waters, 1999 for arguments for a modularized language resource; see Just and Carpenter, 1992 and Just, Carpenter, and Keller, 1996 for arguments against one), recent research (Gordon, Hendrick, and Levine., 2002) related directly to the similarity-based memory interference hypothesis and the modularity debate has provided evidence that in the domain of complex sentence comprehension working memory is not modularized from general working memory resources. Gordon et al. (2002) used a dual-task methodology in which participants had to remember either three names or three descriptions while reading sentences containing either a subject-extracted or an object-extracted cleft in which the NPs were either both descriptions (as in (10), an object-extracted cleft and (11), a subject-extracted cleft)) or both names (as in (12), an object-extracted cleft and (13), a subject-extracted cleft)).

(10) It was the banker that the barber praised just outside of town.

(11) It was the banker that praised the barber just outside of town.

(12) It was Ben that Mark praised just outside of town.

(13) It was Ben that praised Mark just outside of town.

They found that when the type of NPs of the load task matched the type of NP of the sentence then interference effects emerged, such that comprehension accuracy suffered. This effect was not observed when the NPs of the two tasks did not match. As the load task may be thought of as being mediated by general working memory unrelated to sentence comprehension, the finding that load type influences comprehension abilities suggests that the sentence comprehension task was drawing on the same general working memory mediating the load task.

The research presented in this paper was designed to further explore the nature of working memory operation during complex sentence comprehension. More specifically, it was designed to test the similarity-based memory interference hypothesis using eye-tracking methodology, which allows for an analysis of reading time data that is more sophisticated than that which is possible using self-paced reading methodology while simultaneously enabling participants to read in a more natural manner than is possible using self-paced reading methodology. In particular, it allows for an investigation into the time-course of effects observed during the reading of unambiguous, complex sentences. Experiment 1 was designed to determine if the effects that Gordon, et al. found in their previous self-paced reading research was a result of constraints placed on the participants by the unnatural reading environment that results from self-paced reading methodology. Experiment 2 was designed to explore further the nature of similarity-based memory interference by investigating the possibility that the mediating factor for similarity-based memory interference may be the amount of lexical semantic information associated with the NPs. Experiment 3 was designed to test whether a concurrent load task can influence the reading behavior of participants presented with unambiguous, complex sentences.

2. Experiment 1

The reading time data reported in Gordon, et al. (2001), Warren and Gibson (2002), and Gordon, et al. (2004) were all collected using self-paced reading methodology. In the self-paced reading procedures used by these researchers, participants press a key or button to advance from one word of a sentence to the next. Once these participants had advanced from a word they were unable to regress back to that word. Such a reading environment, in addition to being unnatural, may have forced the participants to rely more heavily on their working memory than they would during normal reading in order to remember the portions of the text beyond which they had already advanced. It is possible that the effects observed by these researchers which were attributed to memory processes were actually a result of this reading environment. Therefore, it may be expected that in a more natural reading environment like that participants experience in an eye-tracking experiment, effects of the type these researchers reported may not be observed.

This experiment tested the reading behavior of participants presented with sentences which contained either an object-extracted RC or a subject-extracted RC and with either both the NPs being descriptions or with the first NP being a description and the NP embedded in the RC being a name by using the same experimental stimuli used by Gordon, et al. (2001), Experiment 3, with the exception that the names were lengthened to minimize the possibility that they would be skipped during reading. If the effects observed in Gordon, et al. (2001) were a result of constraints placed on the participants by the unnatural reading environment, then we would expect to find no reduction in difficulty for sentences containing object-extracted RCs when the embedded NP is a name in this experiment. If the previously reported results could not be attributable to methodological constraints, then we would expect to see a reduced difference between sentences with object-extracted RCs and sentences with subject-extracted RCs when the embedded NP is a name as opposed to when the embedded NP is a description.

Materials

The experimental and filler stimuli were identical to those used in Experiment 3 of Gordon, et al. (2001), except that the names used were longer than the short names they used (to control for possibly confounding length effects). Each experimental sentence contained either an object or subject RC that modified the sentential subject. The sentential subject was always a description and the embedded NP was either a description or a name. NP type was crossed with RC type to make four sentence types. Each participant saw all four types of sentences, thus the design was within-subjects. The condition in which each sentence was presented was counterbalanced across participants to prevent a potentially confounding effect of particular stimuli. The stimuli for Experiment 1 can be found in Appendix 2. A comprehension question related to information in the sentence followed both experimental and filler sentences.

Method

Participants. Participants were 36 introductory psychology students at the University of North Carolina at Chapel Hill. They received course credit for their participation.

Data Collection. A SensiroMotoric Instruments (SMI) EyeLink System eye-tracking device was used to track participants' eye movements while they read the stimuli on a PC. A separate PC was used by the experimenter to calibrate the eye-tracker and to monitor calibration during the experiment. Software created by SMI and later modified by this lab was used to present the stimuli.

Data Analysis. Vertical drift of the eye tracks that is common to the EyeLink system was corrected manually using the TeView software developed by Gary Feng at Duke University. Software developed by the author and the SPSS statistical package was used to analyze the fixations made by participants. Numerous measures of eye-movement data were analyzed. See Appendix 1 for a definition of the measures used in the analysis.

Procedure. After completing a consent form, participants were fitted with the eye-tracker, which was then calibrated. Each trial began with the presentation of a fixation point at a location corresponding to the left-most boundary of where the sentence was to be presented. Participants were instructed to fixate on that point. Once their fixation was judged to be steady and on the point the experimenter triggered the presentation of the sentence. This routine served as a mini-calibration for the device and directed the participant's gaze to the proper location for later stimulus presentation. After the participant finished reading the sentence for comprehension he/she pressed the spacebar. This caused the sentence to disappear and the comprehension question to appear. Each question was true/false in nature and the participant pressed one of two keys to indicate his/her answer. After doing so the next trial began with the fixation point. This procedure continued until the end of the experiment and was interrupted only if the eye-tracker needed to be recalibrated or of the participant became uncomfortable.

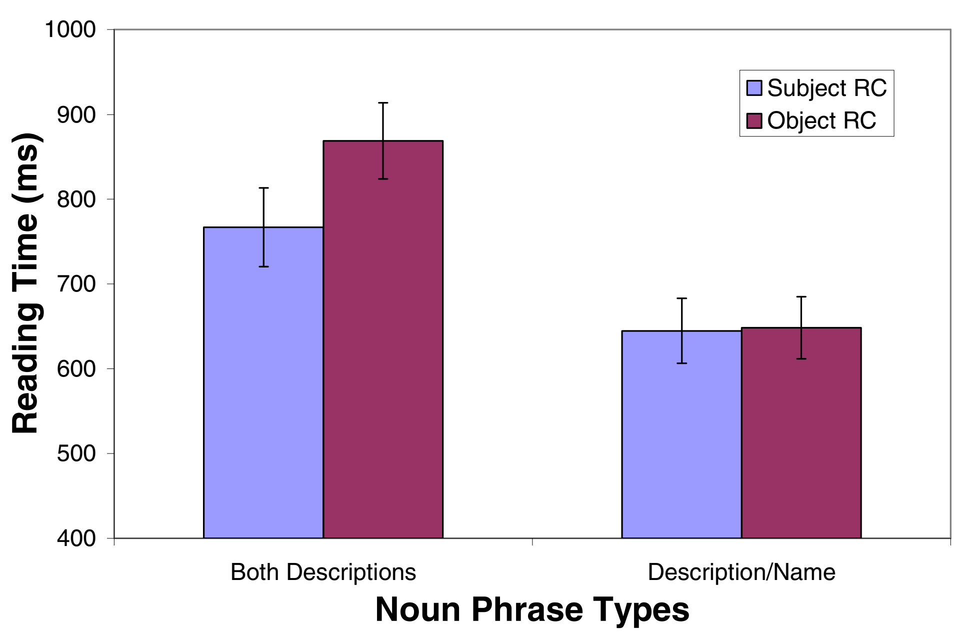
Results

Comprehension Question Accuracies. Table 1 shows accuracies on the comprehension questions. There was a main effect of NP type on comprehension question accuracy such that questions related to sentences with embedded names were answered more accurately (proportion correct = .94) than questions related to sentences with embedded descriptions (proportion correct = .87); $F_1(1,35) = 17.86$, MSE = .06, $p < .001$, $F_2(1,23) = 5.89$, MSE = .18, $p < .025$. There was no effect of RC type on question accuracy ($F_1(1,35) = .06$, MSE = .08, $p > .8$, $F_2(1,23) = .02$, MSE = .29, $p > .9$ and no interaction between RC type and NP type on question accuracy ($F_1(1,35) = .61$, MSE = .07, $p > .43$, $F_2(1,23) = .19$, MSE = .22, $p > .66$).

Analyses of the Critical Region. The critical region of the sentences in Experiment 1 was the embedded RC (all words after "that" and before the matrix verb). Table 2 shows reading time measures for the critical region of the sentence. Gaze duration can be taken to be the measure of earliest processing of a region in our study. There was a main effect of NP type on gaze duration on the critical region, such that longer gaze durations (664 msec) were observed for sentences with embedded descriptions than for sentences with embedded names (530 msec; $F_1(1,35) = 38.06$, MSE = 74084, $p < .001$, $F_2(1,23) = 21.68$, MSE = 121554, $p < .001$). There was no effect of RC type on gaze duration on the critical region ($F_1(1,35) = .00$, MSE = 144250, $p > .97$, $F_2(1,23) = .01$, MSE = 109026, $p > .92$). There was a trend toward an interaction between NP type and RC type, such that the object-subject difference was greater when the NPs were both descriptions, but it did not reach traditional significance levels ($F_1(1,35) = 3.78$, MSE = 105856, $p > .06$, $F_2(1,23) = 2.20$, MSE = 161438, $p > .15$).

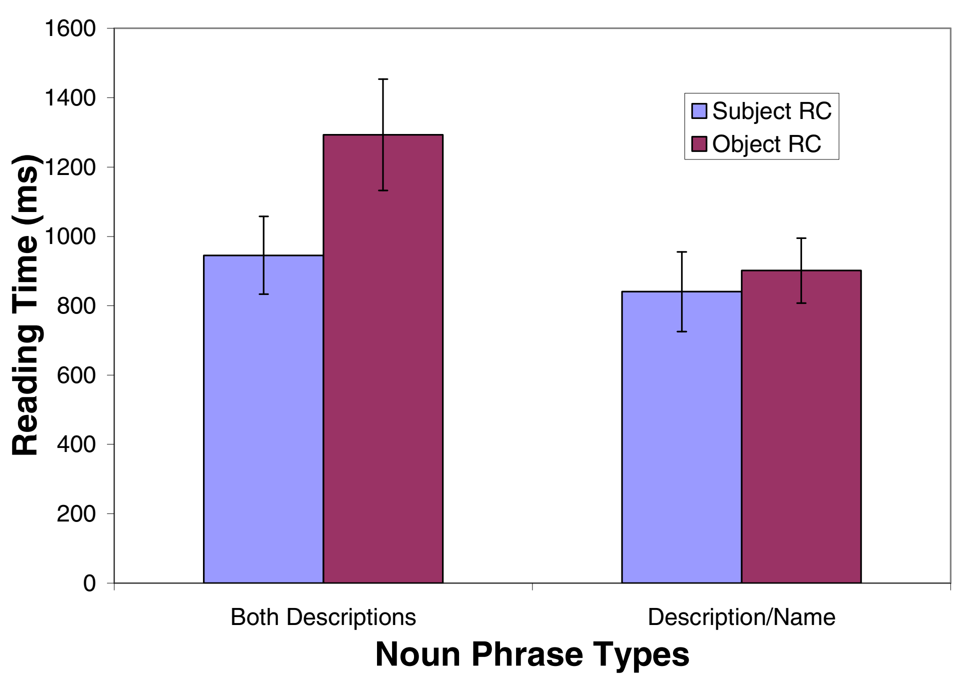
Right-bounded reading of a region can also be considered to be a relatively early measure of processing in our study. There was a significant effect of RC type on right-bounded reading times on the critical region such that the right-bounded time of object RCs (786 msec) was longer than the right-bounded time of subject RCs (708 msec; $F_1(1,35) = 13.20$, MSE = 100688, $p < .002$, $F_2(1,23) = 15.68$, MSE = 80253, $p < .002$). In addition there was an effect of NP type on right-bounded reading times on the critical region. RCs with embedded descriptions were read more slowly (823 msec) than RCs with embedded names (672 msec; $F_1(1,35) = 48.07$, MSE = 105431, $p < .001$, $F_2(1,23) = 38.44$, MSE = 122133, $p < .001$). Most importantly, there was a significant interaction between RC type and NP type with respect to right-bounded reading times of the RC. The difference between object and subject RCs was bigger for RCs with descriptions than for RCs with names ($F_1(1,35) = 19.63$, MSE = 88086, $p < .001$, $F_2(1,23) = 12.06$, MSE = 129251, $p < .003$).

Figure 1: Time Spent on Right-Bounded Reading of the Relative Clause



Rereading can be taken to be a relatively late measure of the processing of a region and total reading time can be taken to be a general measure of processing of a region. Object RCs were read more slowly (1093 msec) than subject RCs (834 msec) during rereading of the RC ($F_1(1,35) = 20.90$, MSE = 695544, $p < .001$, $F_2(1,23) = 10.51$, MSE = 1383612, $p < .005$). Also, RCs with descriptions were read more slowly (1114 msec) than RCs with names (813 msec) during rereading ($F_1(1,35) = 21.69$, MSE = 905576, $p < .001$, $F_2(1,23) = 35.52$, MSE = 552987, $p < .001$). Moreover, there was an interaction between RC type and NP type such that the difference in rereading times for object and subject RCs was more pronounced for RCs with descriptions than for those with names ($F_1(1,35) = 4.30$, MSE = 930478, $p < .05$, $F_2(1,23) = 8.58$, MSE = 466593, $p < .009$).

Figure 2: Time Spent Rereading the Relative Clause



Not surprisingly, there were main effects of RC type and embedded NP type on total RC reading time such that the total time spent fixating object RCs (1701 msec) was longer than the total time spent fixating subject RCs (1430 msec; ($F_1(1,35) = 26.27$, MSE = 597231, $p < .001$, $F_2(1,23) = 12.27$, MSE = 1269764, $p < .003$) and the time spent fixating RCs with descriptions (1776 msec) was longer than the time spent fixating RCs with names (1354 msec; $F_1(1,35) = 40.38$, MSE = 933612, $p < .001$, $F_2(1,23) = 61.73$, MSE = 610828, $p < .001$. There was also a significant interaction between RC type and embedded NP type, such that the object-subject difference was bigger for sentences with embedded descriptions than the difference for sentences with embedded names ($F_1(1,35) = 9.40$, MSE = 767136, $p <.005$, $F_2(1,23) = 10.58$, MSE = 677703, $p < .005$).

Figure 3: Total Time Spent Reading the Relative Clause

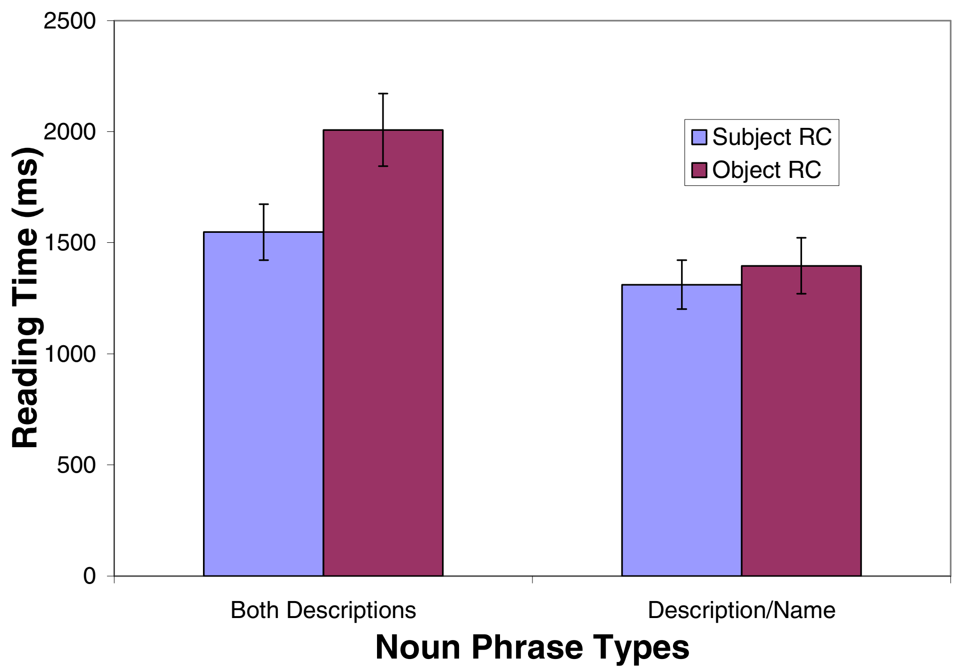
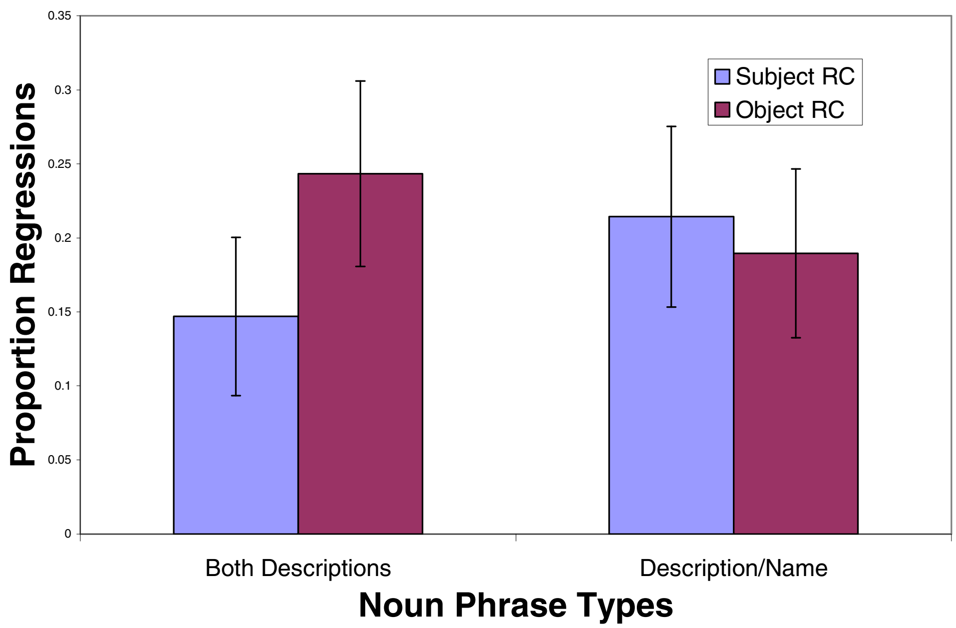


Table 3 shows the regression ratios from the last word of the RC (the word directly before the matrix verb). There were no main effects of RC type ($F_1(1,35) = 1.57$, MSE = .14, $p >.21$, $F_2(1,23) = .87$, MSE = .23, $p < .35$) or NP type ($F_1(1,35) = 0$, MSE = .22, p

> .99, $F_2(1,23) = .09$, MSE = .19, p > .76). However, there was a significant interaction between RC type and NP type such that the difference between regression ratios for object and subject RCs was greater for RCs with descriptions (.24 for object RCs, .15 for subject RCs) than for RCs with names (.19 for object RCs, .21 for subject RCs; $F_1(1,35) = 4.26$, MSE = .25, $p < .05$, $F_2(1,23) = 4.55$, MSE = .15, $p < .045$).

Figure 4: Regression Ratio from Last Word of the Relative Clause



Discussion

The results of Experiment 1 show that the comprehension difficulty associated with sentences containing object-extracted RCs is reduced when the two critical NPs of the sentence are distinct (one is a description and the other is a name). The reduction in complexity observed here suggests that the findings of Gordon, et al. (2001) were not due to constraints placed on their participants by the methodology they used. It also provides evidence in support of the similarity-based memory interference hypothesis, as it predicts that the comprehension difficulty associated with sentences containing object-extracted RCs should be reduced when the two critical NPs of the sentence are distinct. Moreover, the observation that critical differences in processing difficulty were observed relatively early during reading (during right-bounded reading) is consistent with the notion of similarity-based memory interference, in that it is during the period in which the two NPs have been input, but not yet integrated with the sentence in which we would expect such an effect to emerge. Although these effects persisted during rereading, the similarity-based memory interference hypothesis might have been discredited if the effects had not been observed in measures designed to reflect early stages of processing.

3. Experiment 2

Gordon, et al. (2004) found that sentences containing RCs in which one of the critical NPs was a description involving a role or occupation and the other critical NP was "the person" did not show the pattern of reduction of the difference in difficulty between sentences with an object-extracted RC and sentences with a subject-extracted RC that had been shown to occur when one of the critical NPs was a description and the other critical NP was either the indexical pronoun "you", a name, or the pronoun "everyone". However, in the experiment which included the NP "the person", they had two conditions which were being compared against the baseline condition (the baseline condition being that in which both NPs were descriptions involving roles or occupations – like (5) and (6)). One of the conditions of interest (like (14) and (15)) had "the person" as the first NP and a description involving a role or occupation as the NP embedded within the RC. The other condition of interest (like (16) and (17)) had a description involving a role or occupation as the first NP and "the person" as the NP embedded within the RC.

(14) *The person that the barber praised climbed the mountain just outside of town.*

(15) *The person that praised the barber climbed the mountain just outside of town.*

(16) *The banker that the person praised climbed the mountain just outside of town.*

(17) The banker that praised the person climbed the mountain just outside of town.

Gordon, et al. (2004) were attempting to investigate the idea that “the person” may be dissimilar enough from descriptions involving roles or occupations to preclude similarity-based memory interference from occurring, but their results may have been confounded by another potential source of difficulty for readers. In the conditions in which “the person” was the embedded NP (like (16) and (17)), “the person” was modifying an NP that had much more lexical semantic information associated with it than “the person” does. It seems unnatural and unusual to try to restrict a semantically rich descriptive NP with a semantically lean descriptive NP. This unnatural aspect of the stimuli in which “the person” was the embedded NP may have been especially exacerbated in the case of the sentences containing object-extracted RCs (like (16)), because in these cases the embedded NP may have been particularly prominent (as it was the subject of the RC). If this unnaturalness was indeed a problem for readers then it might be expected that the difficulty of object-extracted RCs may not have been diminished when “the person” was the embedded NP, even in the presence of a reduction in similarity-based memory interference. This experiment sought to reexamine the possibility that “the person” and descriptions involving roles or occupations are dissimilar enough to prevent similarity-based memory interference from occurring by excluding the potentially confounding conditions in which “the person” was the embedded NP and compare only conditions in which “the person” was the first NP and the second NP was a description involving a role or occupation to conditions in which both NPs were descriptions involving a role or occupation.

Additionally, this experiment sought to explore the possibility that the mediating factor for similarity-based memory interference is the degree of similarity that the two NPs possess with respect to the amount of lexical semantic information they possess. In previous research Gordon, et al. had found that when the two NPs of sentences containing RCs were a description involving a role or occupation and a name and the pronoun "you", or the pronoun "everyone", then the difference in difficulty between sentences with an object-extracted RC and sentences with a subject-extracted RC was decreased relative to the difference in difficulty between sentences with object-extracted RCs and subject-extracted RCs when these sentences contained two NPs that were descriptions. In all three of these cases, however, the two NPs of the sentences were different with respect to lexical semantic similarity, phonological similarity, and the typical structural semantic role these NPs tend to have in discourses (descriptions tend to introduce new entities while the other three NPs are usually presented in reference to entities present in a discourse either explicitly or implicitly). It is possible that any of these three characteristics of the NPs may have been mediating similarity-based memory interference. In the current experiment, the two NPs of the sentences ("the person" and a description involving a role or occupation) may be thought of as being similar with respect to phonological characteristics (they both have the article "the" followed by a description) and with respect to structural semantics, but as being distinct with respect to the amount of lexical semantic information associated with them. If the level of lexical semantic information associated with the critical NPs is the mediating factor of similarity-based memory interference then we would expect to see a reduction in the difficulty of sentences containing object-extracted RCs when the first NP is "the person". If, on the other hand, similarity-based memory interference is mediated instead by phonological or structural semantic similarities between the NPs or, then we would not expect to see a reduction in difficulty for sentences containing object-extracted RCs when the first NP is "the person".

Finding that the amount of lexical semantic information associated with the critical NPs is what mediates comprehension difficulty in reading sentences that are syntactically complex would certainly be consistent with previous ideas related to sentence comprehension. MacDonald, Pearlmutter, and Seidenberg (1994) suggested that lexical encoding, as opposed to syntactic encoding, drives behavior related even to the disambiguation of complex sentence structures such as garden paths, and that the behavior of readers presented with garden-path sentences can best be explained by the time required for access to word meanings. For example, they suggest that during the comprehension of a sentence like (1) readers initially encode *raced* as a past tense verb, but must later recode it as a past participle. They suggest that it is this initial lexical misinterpretation and the time-course of access to the proper interpretation that mediates the degree of complexity experienced during the comprehension of sentences requiring disambiguation.

This idea stands in marked contrast to theories that emphasize the syntactic nature of ambiguity resolution such as that of Frazier and Rayner (1982), which suggests that syntactic principles such as minimal attachment and late closure control the processing of language input. According to MacDonald, et al. (1994), the root of comprehension difficulty lies in the process of achieving a proper and precise understanding of the meanings of the words in the incoming input. Furthermore, they suggest that lexical access is not an all-or-nothing process, but instead is more like a continuously spreading activation that expands based on learned associations to the material being accessed.

This experiment seeks to investigate the notion that language comprehension difficulties are related to lexical access. Specifically, it seeks to test the idea that the comprehension difficulty associated with complex sentence structures such as object RCs can be alleviated when one of the NPs has little lexical semantic information associated with it and the other one is rich in lexical semantic information (but the two NPs are similar with respect to phonological and structural semantic characteristics).

The notion that lexical processes are of utmost importance to reading behavior is also present in eye-movement modeling research. The EZ-Reader model (Reichle, Rayner, and Pollatsek, in press; Rayner, Reichle, and Pollatsek, 1998; Reichle, et al., 1998) has provided considerable explanatory power to the nature of eye-movements during reading in part by adding a multi-stage process of lexical access to the eye-movement model of Morrison (1984). The fact that incorporating a multi-level process of lexical access to an eye-movement model greatly improves the predictive capability of such a model certainly emphasizes the importance of lexical semantic encoding even at a level as low as eye-movement control during language comprehension.

Materials

The experimental and filler stimuli were identical to those used in Experiment 3 of Gordon, et al. (2004), except that the conditions in which "the person" was the NP embedded in the RC were excluded. Each experimental sentence contained an object-extracted or subject-extracted RC that modified the sentential subject. The sentential subject was either a description involving a role or occupation or "the person" and the NP embedded in the RC was always a description involving a role or occupation. NP type was crossed with RC type to make four sentence types. Each participant saw all four types of sentences, thus the design was within-subjects. The condition in which each sentence was presented was counterbalanced across participants to prevent a potentially confounding effect of particular stimuli. The stimuli for Experiment 2 can be found in Appendix 3. A comprehension question related to information in the sentence followed both experimental and filler sentences.

Method

Participants. Participants were 36 introductory psychology students at the University of North Carolina at Chapel Hill. They received course credit for their participation.

Data Collection. The data in Experiment 2 were conducted in the same manner as the data in Experiment 1.

Data Analysis. The data in Experiment 2 were analyzed in the same manner as the data in Experiment 1.

Procedure. The procedure of Experiment 2 was similar to that of Experiment 1.

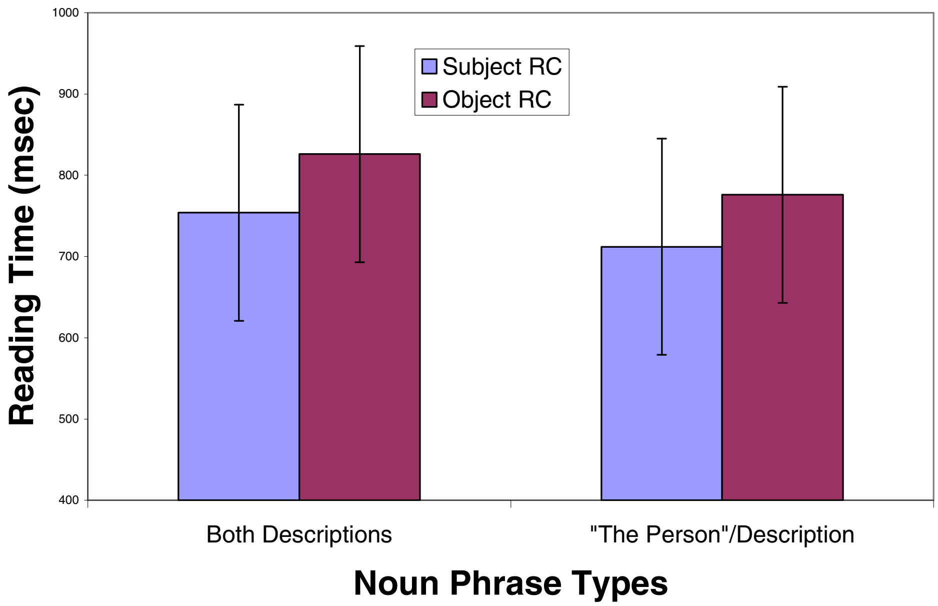
Results

Comprehension Question Accuracies. Table 4 shows accuracies on the comprehension questions. There was no main effect of the type of first NP in the sentence on question accuracy; $F_1(1,35) = 2.00$, MSE = .098, $p > .16$, $F_2(1,23) = .74$, MSE = .266, $p > .39$, no main effect of RC type on question accuracy ($F_1(1,35) = 3.56$, MSE = .094, $p > .1.31$, $F_2(1,23) = .255$, MSE = .29, $p > .26$ and no interaction between RC type and NP type on question accuracy ($F_1(1,35) = .01$, MSE = .108, $p > .91$, $F_2(1,23) = .00$, MSE = .342, $p > .95$).

Analyses of the Critical Region. The critical region of the sentences in Experiment 2 was the embedded RC (all words after “that” and before the matrix verb). Table 5 shows reading time measures for the critical region of the sentence. There was no main effect of the type of RC in the sentence on the early measure of gaze duration, $F_1(1,35) = .00$, $MSE = 187306$, $p > .96$, $F_2(1,23) = .00$, $MSE = 83936$, $p > .94$. There was a trend for the gaze duration of sentences in which the first NP was "the person" to be longer (597 msec) than for the gaze duration of sentences in which the first NP was a description involving a role or occupation (544), but the trend just missed significance, $F_1(1,35) = 4.09$, $MSE = 153536$, $p <.052$, $F_2(1,23) = 4.23$, $MSE = 143914$, $p < .052$. There was no interaction between RC type and the type of first NP in the sentence for gaze duration on the critical region, $F_1(1,35) = .01$, $MSE = 86593$, $p > .93$, $F_2(1,23) = .00$, $MSE = 126723$, $p > .95$.

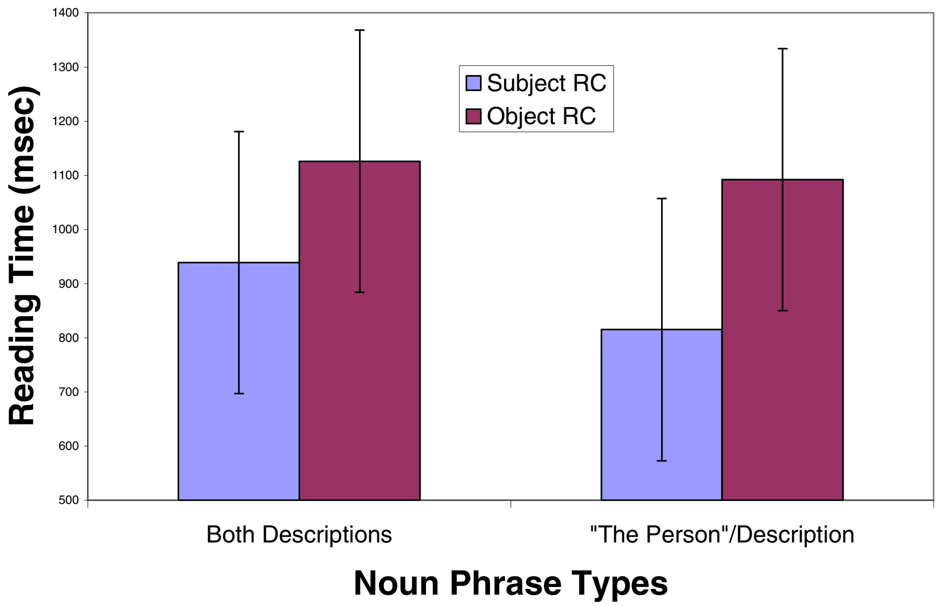
There was a trend toward an effect of RC type on the relatively early measure of right-bounded reading time that reached significance by subjects but not quite by items, such that sentences containing object-extracted RCs showed longer right-bounded durations (801 msec) than did sentences containing subject-extracted RCs (733 msec), $F_1(1,35) = 5.03$, $MSE = 193058$, $p < .032$, $F_2(1,23) = 3.40$, $MSE = 275858$, $p < .079$. There was also a trend that reached significance by subjects but not by items toward longer right-bounded reading times for sentences in which the first NP was a description involving a role or occupation (789 msec) than for sentences in which the first NP was "the person" (744 msec), $F_1(1,35) = 4.18$, $MSE = 99978$, $p < .05$, $F_2(1,23) = 2.19$, $MSE = 191263$, $p > .15$. There was no interaction between RC type and the type of the first NP for right-bounded reading times, $F_1(1,35) = .01$, $MSE = 154278$, $p > .90$, $F_2(1,23) = .02$, $MSE = 119306$, $p > .87$.

Figure 5: Time Spent on Right-Bounded Reading of the Relative Clause



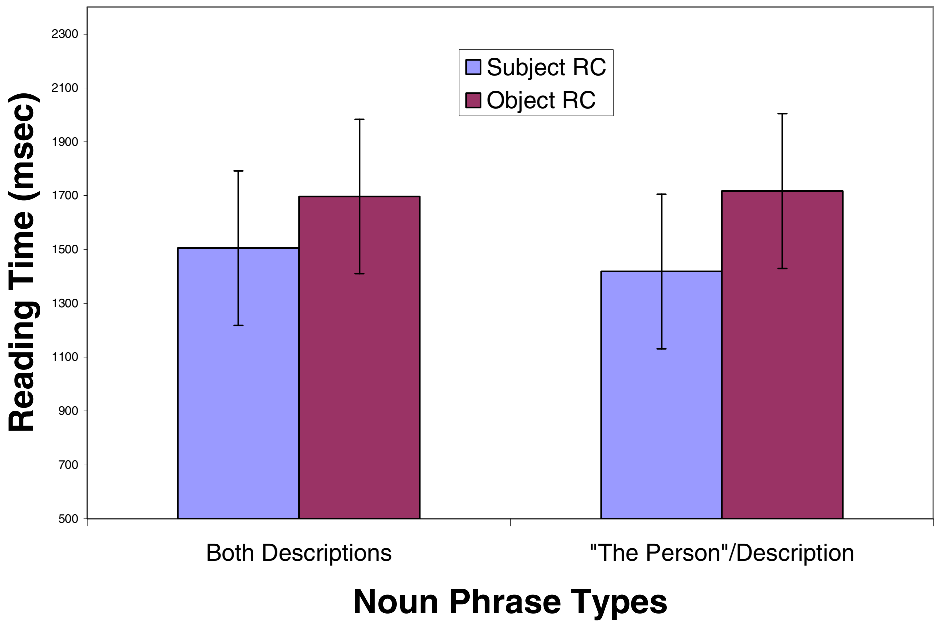
There was a main effect of RC type on the late measure of rereading time such that object-extracted RCs were read more slowly (1109 msec) than subject-extracted RCs (877 msec) during rereading of the RC, $F_1(1,35) = 19.03$, MSE = 610797, $p < .001$, $F_2(1,23) = 9.81$, MSE = 1184979, $p < .006$. There was no main effect of the type of first NP of the sentence on rereading times, $F_1(1,35) = 2.32$, MSE = 579316, $p > .135$, $F_2(1,23) = 3.17$, MSE = 424051, $p > .08$. Also, there was no interaction between RC type and the type of the first NP for rereading times, $F_1(1,35) = .86$, MSE = 512838, $p > .35$, $F_2(1,23) = .65$, MSE = 676705, $p > .42$.

Figure 6: Time Spent Rereading the Relative Clause



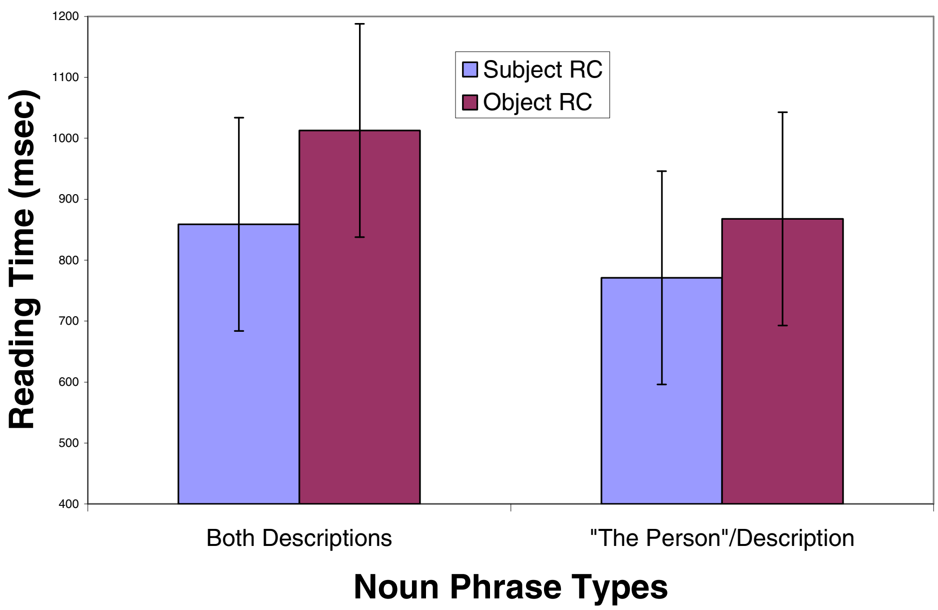
Total time spent reading the RC showed the same patterns as rereading time on the RC. There was a main effect of RC type on total reading time such that object-extracted RCs were read more slowly (1707 msec) than subject-extracted RCs (1461 msec), $F_1(1,35) = 15.08$, MSE = 845703, $p < .001$, $F_2(1,23) = 10.20$, MSE = 1239259, $p < .005$. There was no main effect of the type of first NP of the sentence on total reading times of the RC, $F_1(1,35) = .46$, MSE = 513777, $p > .50$, $F_2(1,23) = .46$, MSE = 558722, $p > .50$. Also, there was no interaction between RC type and the type of the first NP for total RC reading times, $F_1(1,35) = 1.01$, MSE = 721787, $p > .32$, $F_2(1,23) = .85$, MSE = 721042, $p > .36$.

Figure 7: Total Time Spent Reading the Relative Clause



Regression path duration may be considered to be a measure of the time spent integrating the information that has already been encountered in the sentence before progressing to later portions of the sentence. There was a main effect of RC type on regression path duration for the critical region such that the duration was longer for sentences with an object-extracted RC (940 msec) than for sentences with a subject-extracted RC (815 msec), $F_1(1,35) = 11.88$, MSE = 279565, $p < .002$, $F_2(1,23) = 7.40$, MSE = 436499, $p < .02$. There was also a main effect of type of first NP on regression path duration for the critical region such that the duration was longer for sentences with in which the first NP was a description involving a role or occupation (935 msec) than for sentences in which the first NP was "the person" (819 msec), $F_1(1,35) = 13.77$, MSE = 203906, $p < .002$, $F_2(1,23) = 8.47$, MSE = 331829, $p < .01$. However, there was again no interaction between RC type and the type of the first NP for regression path duration on the critical region, $F_1(1,35) = .52$, MSE = 268643, $p > .47$, $F_2(1,23) = .80$, MSE = 189334, $p > .38$.

Figure 8: Regression Path Reading Time from the Relative Clause



Discussion

The results of Experiment 2 showed the expected effect of longer reading times for sentences containing object-extracted RCs than for sentences containing subject-extracted RCs, as measured by total and rereading time on the RC, and regression path duration for the RC (and almost by right-bounded reading time on the RC). Although the type of first NP of the sentence influenced the durations of some reading time measures, these effects were not consistently found and were not consistently in a particular direction. Most crucially, however, was that there was no interaction in any measure between the RC type of the sentence and the type of first NP of the sentence. If it were true that the NP "the person" and descriptions involving roles or occupations were distinct enough to diminish similarity-based memory interference, then we would expect to see an interaction between the RC type of the sentence and the type of first NP of the sentence, such that the reading time differences between sentences containing object-extracted RCs and sentences containing subject-extracted RCs would be diminished when the first NP of the sentence was “the person”. This pattern was not observed, providing support for the notion that the NP “the person” is not distinct enough from descriptions involving roles or occupations to reduce similarity-based memory interference.

Moreover, the findings of this study provide support for the notion that the amount of lexical semantic information associated with the NPs that have the potential to interfere with one another in working memory is not the factor mediating similarity-based memory interference. Given that the NPs used in this study shared phonological and structural semantic characteristics, it cannot be ruled out by this study that either or both of those aspects of NPs contribute to the occurrence of similarity-based memory interference.

4. Experiment 3

This experiment used a dual-task methodology to investigate memory interference in sentences containing the unambiguous, complex sentences structure called clefts. The stimuli were similar to (10), (11), (12), and (13). Sentences containing a cleft structure are similar to those containing RCs, except that they allow the NP that is being modified to be a name and they do not require a matrix verb. Participants read sentences like these and answered comprehension questions related to them in a similar manner to that of Experiment 1, but they also performed a concurrent memory load task in which they were asked to memorize a list of words (which were later to be recalled) before being presented with the sentence/question pairs of the experient. In addition, this experiment had a partial within-subjects and a partial between-subjects design. The manipulation of load type was between-subjects such that for each participant the items in the concurrent load task were either be similar to the critical NPs of the sentence or different from them. The participants who received loads similar to the critical NPs of the sentences were divided into two groups, the name group and the description group. The name group received load items that were names and the NPs of the experimental sentences contained names. The design was similar for the description group except the load items and sentence NPs were descriptions. The participants that received loads different from the NPs in the experimental sentences received digits as loads. Half of the sentences with which these participants were presented had two names as critical NPs and the other half sentences that had two descriptions as critical NPs. Half the sentences for all subjects had object-extracted clefts and the other half had subject-extracted clefts.

If the similarity-based memory interference hypothesis is accurate it may be expected that all participants would exhibit greater difficulty for sentences with object clefts than for sentences with subject clefts. Also, if it were found that matching, but not non-matching, loads do exacerbate the subject-object difference then it would provide evidence that the working memory responsible for language comprehension is not modularized from a more general working memory. If working memory for language comprehension tasks is modularized from more general working memory resources then we would expect the two tasks in this experiment to draw on different cognitive resources. Thus, the resources performing the load task would not be responsible for the performance of the language comprehension task, and therefore the type of load should have no impact on the performance in the language comprehension task. If language working memory were not modularized then the same cognitive resource would be responsible for both tasks and the possibility of similarity-based memory interference would increase in the conditions where the loads are similar to the critical NPs of the sentence.

Materials

There were 48 experimental and 56 filler sentences used in this experiment. The experimental stimuli were taken from Gordon, et al. (2002) and consisted of sentences with either object-extracted or subject-extracted clefts. These clefts either had two names in them or two descriptions. Additionally, three sets of 52 load items were created to serve as fillers. Each set was divided into 13 groups of four items. One of the sets consisted entirely of names, one entirely of descriptions, and the third entirely of one-digit numbers. The ordering of the items for each set was randomized.

Method

Participants. Participants were 64 introductory psychology students at the University of North Carolina at Chapel Hill. They received course credit for their participation.

Data Collection. The data in Experiment 3 were conducted in the same manner as the data in Experiments 1 and 2.

Data Analysis. The data in Experiment 3 were analyzed in the same manner as the data in Experiments 1 and 2.

Procedure. The procedure of Experiment 3 was similar to that of Experiments 1 and 2 except it additionally consisted of a concurrent load task that the participants performed. The experiment was divided into 13 blocks. Before each block, the participant was presented with a set of load items to be remembered for fifteen seconds on the same computer screen which would later present the sentences and comprehension questions. The participant was asked to read the set of items out loud once and then spend the remainder of the fifteen seconds quietly rehearsing the load list. After the fifteen-second memorization period was up the participant was presented with eight sentence/question pairs in a manner similar to Experiments 1 and 2. The first block contained only filler items. The remaining 12 blocks contained four filler items and four experimental items. At the end of each block a screen with the word "Recall" was presented to the participant and he/she was asked to recite the load items for that block. The experimenter checked off the items that were correctly recalled on a score sheet and recorded any items the participant said that were not part of the load list.

Results

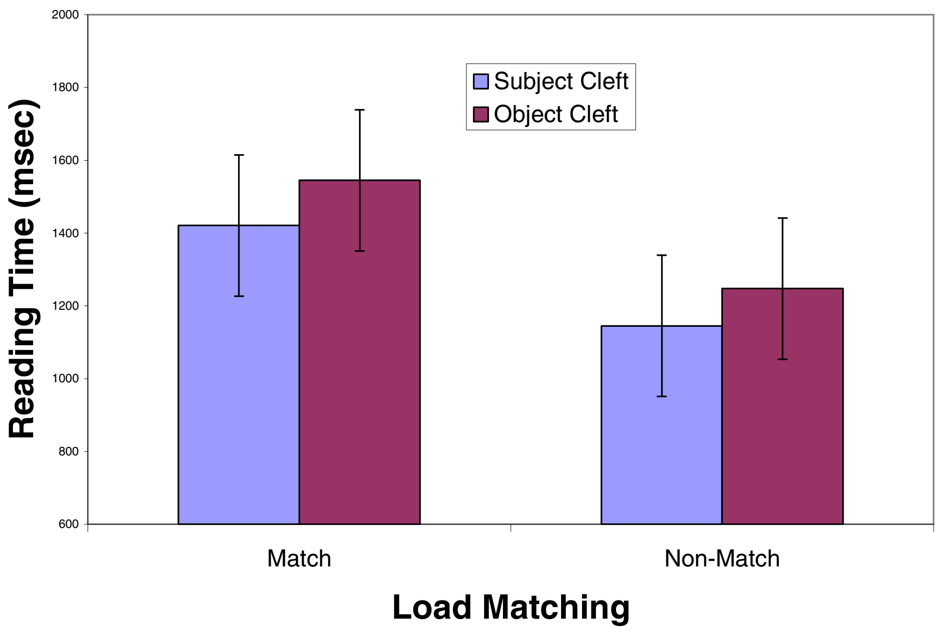
The results of this experiment are presented by grouping the matched conditions (description loads with sentences containing two descriptions and name loads with sentences containing two names) and the non-matched conditions (number loads with sentences containing either two descriptions or two names). Analyses of variance were performed on the dependent measures using the factor of match condition, the factor of cleft type, and the interaction between these two factors. The critical region described in the analyses consists of all the words after "was" through the end of the cleft structure in the sentence.

Comprehension Question Accuracies. Accuracies in response to the comprehension questions following each experimental sentence showed a main effect of cleft type, such that participants responded more accurately to questions related to sentences containing subject-extracted clefts (proportion correct = .97) than they did to object-extracted clefts (proportion correct = .88), $F_1(1,63) = 18.24$, $MSE = .35$, $p < .001$, $F_2(1,47) = 108.13$, $MSE = .06$, $p < .001$. There was also a main effect of load matching, such that participants responded more accurately when the loads did not match the NPs of the sentences (proportion correct = .96) than when the loads did match the NPs of the sentences (proportion correct = .91), $F_1(1,62) = 5.54$, $MSE = .42$, $p < .023$, $F_2(1,47) = 32.31$, $MSE = .07$, $p < .001$. There was a trend toward an interaction for accuracy between load matching and cleft type, such that the difference between object-extracted clefts and subject-extracted clefts was greater when the loads matched the NPs of the sentences that reached significance by items but not by subjects, $F_1(1,62) = 2.03$, $MSE = .34$, $p > .15$, $F_2(1,47) = 10.18$, $MSE = .07$, $p < .004$.

Analyses of the Critical Region. The early measure of gaze duration on the critical region showed a main effect of cleft type, such that the durations for object-extracted clefts were longer (1067 msec) than the durations for subject-extracted clefts (989 msec), $F_1(1,63) = 9.24$, $MSE = 455247$, $p < .004$, $F_2(1,47) = 12.50$, $MSE = 353424$, $p < .002$. There was also a main effect of load matching, such that durations for matching loads were longer (1105 msec) than the durations for non-matching loads (951 msec), $F_1(1,62) = 46.45$, $MSE = 374771$, $p < .001$, $F_2(1,47) = 7.40$, $MSE = 436499$, $p < .02$. There was no significant interaction between cleft type and load matching, $F_1(1,62) = .20$, $MSE = 465710$, $p > .65$, $F_2(1,47) = .33$, $MSE = 350254$, $p > .56$.

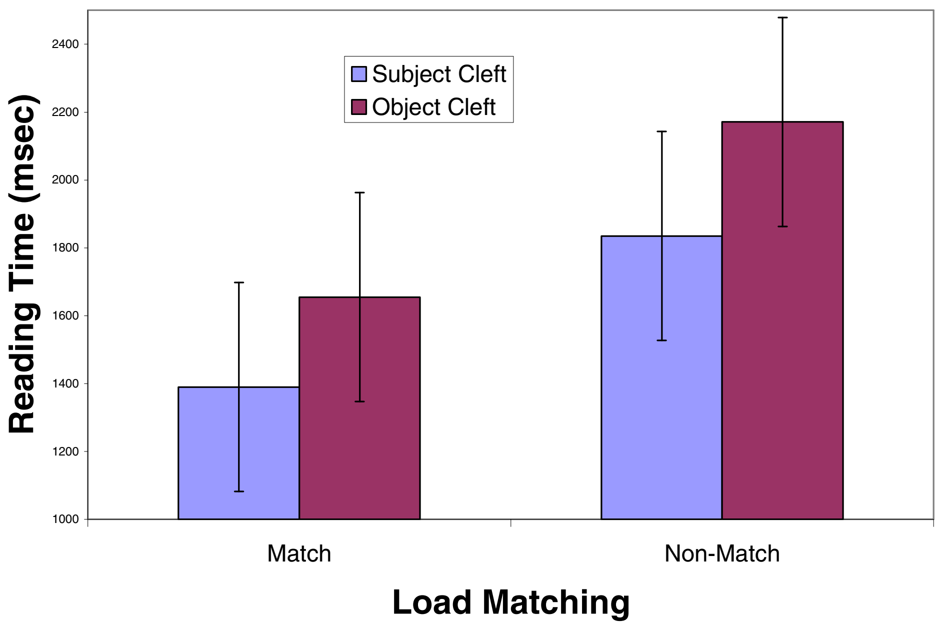
The relatively early measure of right-bounded reading time showed the same pattern as did gaze durations. There was a main effect of cleft type, such that the durations for object-extracted clefts were longer (1397 msec) than the durations for subject-extracted clefts (1283 msec), $F_1(1,63) = 16.35$, $MSE = 576281$, $p < .001$, $F_2(1,47) = 16.66$, $MSE = 572943$, $p < .001$. There was also a main effect of load matching, such that durations for matching loads were longer (1483 msec) than the durations for non-matching loads (1197 msec), $F_1(1,62) = 18.84$, $MSE = 3170026$, $p < .001$, $F_2(1,47) = 154.40$, $MSE = 389769$, $p < .001$. There was no significant interaction between cleft type and load matching, $F_1(1,62) = .12$, $MSE = 585918$, $p > .73$, $F_2(1,47) = .19$, $MSE = 449336$, $p > .66$.

Figure 9: Time Spent on Right-Bounded Reading of the Cleft Region



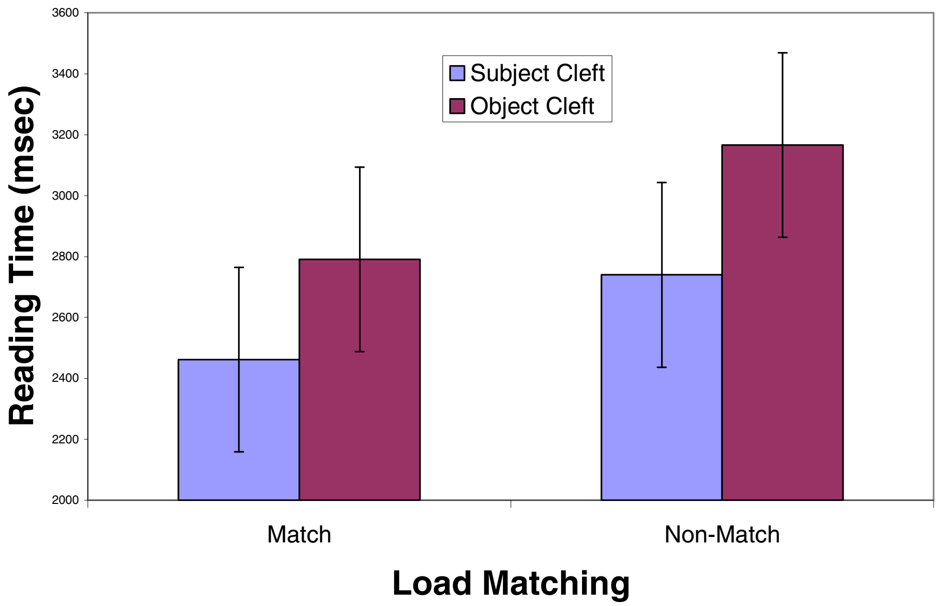
Rereading times also showed a main effect of cleft type, such that the durations for object-extracted clefts were longer (1913 msec) than the durations for subject-extracted clefts (1612 msec), $F_1(1,63) = 44.41$, MSE = 1450132, $p < .001$, $F_2(1,47) = 44.93$, MSE = 1451974, $p < .001$. Interestingly, the patterns observed for the early measures of gaze durations and right-bounded reading times were reversed for rereading times for load matching, such that the durations for matching loads were shorter (1523 msec) than the durations for non-matching loads (2003 msec). This trend reached significance by items but not by subjects, $F_1(1,62) = 2.55$, MSE = 58733191, $p > .114$, $F_2(1,47) = 96.43$, MSE = 1756290, $p < .001$. There was no significant interaction between cleft type and load matching for rereading, $F_1(1,62) = .39$, MSE = 1474681, $p > .53$, $F_2(1,47) = .44$, MSE = 1424263, $p > .50$.

Figure 10: Time Spent Rereading the Cleft Region



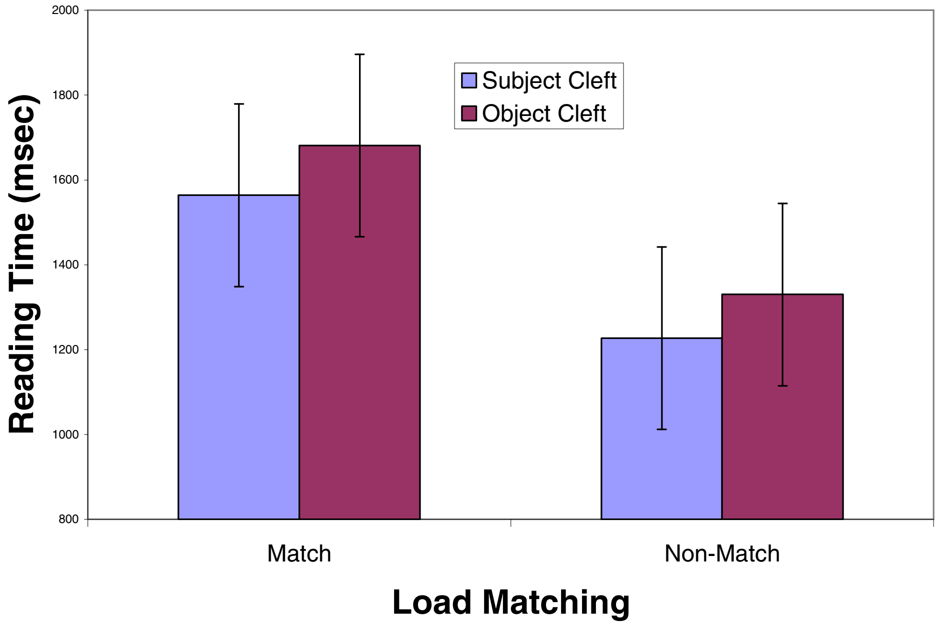
The total reading times on the cleft region showed the same pattern as the rereading times. There was a main effect of cleft type, such that the durations for object-extracted clefts were longer (2979 msec) than the durations for subject-extracted clefts (2601 msec), $F_1(1,63) = 73.13$, MSE = 1382683, $p < .001$, $F_2(1,47) = 71.45$, MSE = 1444032, $p < .001$. The patterns observed for the early measures of gaze durations and right-bounded reading times were also reversed for total reading times for load matching, such that the durations for matching loads were shorter (2627 msec) than the durations for non-matching loads (2953 msec). This trend reached significance by items but not by subjects, $F_1(1,62) = 1.05$, MSE = 59939257, $p > .30$, $F_2(1,47) = 44.84$, MSE = 1735759, $p < .001$. There was no significant interaction between cleft type and load matching, $F_1(1,62) = .82$, MSE = 1421477, $p > .36$, $F_2(1,47) = 1.00$, MSE = 1327690, $p > .32$.

Figure 11: Total Time Spent Reading the Cleft Region



The measure of regression path duration for the cleft region showed patterns similar to that of the early measures of gaze duration and right-bounded reading times, a finding that may be expected in that it includes only times before regions downstream from the target region are fixated (and thus does not include any rereading times). There was a main effect of cleft type for this measure, such that the durations for object-extracted clefts were longer (1506 msec) than the durations for subject-extracted clefts (1396 msec), $F_1(1,63) = 12.91$, MSE = 706236, $p < .002$, $F_2(1,47) = 11.08$, MSE = 812954, $p < .003$. There was also a main effect of load matching, such that durations for matching loads were longer (1623 msec) than the durations for non-matching loads (1279 msec), $F_1(1,62) = 19.43$, MSE = 4384715, $p < .001$, $F_2(1,47) = 148.15$, MSE = 587278, $p < .001$. There was no significant interaction between cleft type and load matching, $F_1(1,62) = .01$, MSE = 715580, $p > .90$, $F_2(1,47) = .04$, MSE = 719219, $p > .83$.

Figure 12: Regression Path Reading Time from the Cleft Region



Discussion

Besides the trend towards an interaction between load matching and cleft type in the question accuracy rates that was significant by items but not by subjects, none of the measures showed an interaction between these two factors. Under the similarity-based memory interference hypothesis, we would expect to observe such an interaction. The similarity-based memory interference hypothesis would predict that memory interference would occur only for object-extracted clefts, as in those structures two NPs must be juggled in memory before being integrated with a verb. In the subject-extracted clefts the first NP is integrated with a verb before the second NP is encountered.

Perhaps the most interesting result is that the reading time measures for early processing all showed a strong effect of load matching. It could be that the load task imposed similarity-based memory interference above and beyond that which would be expected during the reading of object-extracted clefts *and* imposed similarity-based memory interference that would not normally occur in the absence of the additional load task for the reading of subject-extracted clefts. In the matching load conditions the load task introduced similar NPs to be juggled in memory during the reading of all types of clefts, and thus may reasonably have been expected to introduce similarity-based memory interference to all the experimental stimuli, regardless of cleft type.

A finding that is ostensibly incongruous with the similarity-based memory interference hypothesis is the observation that reading times were longer for non-matched load conditions than they were for matched load conditions during rereading. This reversal of the expected pattern carried its effects on into total reading times as well. This finding, however, can be explained by the nature of the design. In Experiment 3 the load matching condition was a between-subjects design, and as it turns out there were three participants who showed mean total sentence reading times more than twice as long as the rest of the participants. All three of these participants were members of the non-matched load condition. When their reading times were removed from the data in an exploratory analysis, the main effect of rereading times for load-matching became non-significant. It is perhaps more interesting that despite the elevated rereading times of these three participants, the early reading-time measures still showed the effects of load-matching in the direction that would be expected if memory interference had the potential to occur. Based on anecdotal experience testing participants, it seems that these three participants were of the type that are often observed reading the sentences over and over again, despite the instructions given to them to read naturally. Such participants have sometimes been encountered during testing by the author. It seems perhaps merely coincidental that they all ended up in the non-matched condition in Experiment 3.

5. General Discussion

The results of the experiments presented here offer some insights into the nature of the characteristics of NPs that is responsible for similarity-based memory interference that may occur during the reading of unambiguous, complex sentences. In addition, these results provide the beginnings of an understanding of the time-course of similarity-based memory interference.

The results of Experiment 1 indicate the results of prior research involving the nature of similarity-based memory interference (Gordon, et al., 2001; Gordon et al. 2002, Gordon, et al. 2004), which were based on self-paced reading methodology, likely did not merely reflect task-specific memory demands placed on the participants in those studies, but instead reflected the more "natural" memory demands that readers experience when trying to resolve relationships between nouns and verbs when they are presented with multiple unintegrated NPs. The use of eye-tracking methodology allows for a much more natural presentation of stimuli to participants than does self-paced reading methodology, and the behaviors that participants exhibit in an eye-tracking setting can be taken as reflections of relatively normal reading processes. The results of Experiment 1 showed that readers experience difficulty when reading sentences that present them with two similar NPs (both descriptions) before either one of the NPs can be integrated with a verb (as is the case in sentences containing object-extracted RCs). This difficulty is alleviated when the two NPs are made to be less similar (one description and one name). Given that these results are consistent with previous self-paced reading research, it can be concluded that similarity-based memory interference, and not task-specific memory demands, is the factor responsible for these findings.

The results of Experiment 2 help to narrow the field of characteristics of NPs that may be responsible for mediating similarity-based memory interference. Experiment 2 used two different sets of NP combinations in unambiguous complex sentences (sentences containing RCs) to test the possibility that the amount of lexical semantic information associated with NPs is responsible for the possibility that two or more integrated NPs may interfere with one another during language comprehension. It was thought that perhaps two NPs with differing levels of lexical semantic information associated with them would not create similarity-based memory interference in readers. In Experiment 2 we examined the reading time data of participants presented with sentences with RCs, the two critical NPs of which either were two descriptions (both rich in terms of lexical semantic information associated with them) or were one description and the NP "the person" (lean in terms of lexical semantic information associated with it). No significant reading time differences were found between the experimental conditions containing two descriptions and the experimental conditions containing one description and the NP "the person". In particular, the sentential condition designed to invoke similarity-based memory interference (sentences with object-extracted RCs) did not lead to different reading patterns across the two NP-combination conditions.

Thus, with respect to the current findings and the idea that the amount of lexical semantic information associated with the critical NPs mediates similarity-based memory interference, two possibilities seem reasonable: 1) the amount of lexical semantic information present in NPs is not the mediating factor for similarity-based memory interference or 2) the manipulation in Experiment 2 was not strong enough to influence similarity-based memory interference. Although we cannot discount entirely either of these possibilities, given that Experiment 2 was designed to control for other factors that might mediate similarity-based memory interference (phonological similarity and structural semantics), it does seem unlikely that semantic similarity at the lexical level *alone* mediates similarity-based memory interference.

The results of Experiment 3, while providing some insight into similarity-based memory interference, also provide further evidence that the working memory that operates during language comprehension is not modularized from more general working memory processes. Although no interaction between load type (matched or non-matched with respect to the NPs of the sentence comprehension task) and sentence type (object-extracted or subject-extracted cleft) was found, a main effect of load type was found, such that clefts that were matched to the load type took longer to read than clefts that did not match load type. This finding is important on two fronts: 1) It provides evidence that similarity-based memory interference can act via a concurrent load task and 2) It provides evidence that general working memory and the working memory responsible for language comprehension are one in the same.

Somewhat similar justifications for these two conclusions can be made. First, if similarity-based memory interference were not acting on the participants in Experiment 3 then there would be no reason for the two load conditions to have differential effects on reading times, as the characteristics of the load items should be irrelevant to the sentence processing task. Similarly, if the working memory responsible for language comprehension were somehow separate from a more general working memory, then there would be no reason to expect that the type of load should influence the sentence comprehension task, as these processes would be carried out by different memory subsystems. Given that performance on the sentence comprehension task was dependent upon load type, however, gives weight both to the similarity-based memory interference hypothesis and a non-modular characterization of the working memory responsible for language comprehension.

In addition to this support for the similarity-based memory interference hypothesis, the current findings also give us insight into the time-course of its effects. The reading time data of the current experiments consistently showed the effect of similarity-based memory interference to occur not in gaze durations, the earliest measure of sentence processing in the current study, but in the slightly later measure of right-bounded reading times. Though there is some overlap between these two measures, a crucial distinction between them may have lead to the difference in the pattern of results these measures exhibited. While right-bounded reading allows for the fixation of information upstream from the target word to occur in between fixations on the target word, gaze durations end when information downstream *or* upstream is fixated. Thus, similarity-based memory interference may not occur during the very first encounter with the critical text, but instead may reflect a further effort required to juggle the critical NPs in working memory when neither of them has been integrated (i.e., readers must look back to remind themselves of the previously encountered NP when presented with an additional unintegrated NP).

Table 1 Question accuracy rates in Experiment 1

	Desc-Object	Desc-Subject	Name-Object	Name-Subject
Accuracy Rates	.88	.86	.94	.94

Table 2 Reading times for the critical region in Experiment 1

Reading Measure	RC Type	NP2	Time(msec)
Gaze Duration	Object	Description	665
	Subject	Description	624
	Object	Name	508
	Subject	Name	552
Right Bounded Reading***	Object	Description	907
	Subject	Description	741
	Object	Name	667
	Subject	Name	677
Rereading***	Object	Description	1312
	Subject	Description	916
	Object	Name	874
	Subject	Name	751
Total reading***	Object	Description	2008
	Subject	Description	1548
	Object	Name	1396
	Subject	Name	1311

Table 3 Regression Ratios from the last word of RC ***

	Object	Subject
Description	.24	.15
Name	.19	.21

*** significant interaction at the .05 level

Table 4 Question Accuracy Rates in Experiment 2

	Desc-Object	Desc-Subject	The Person-Object	The Person-Subject
Accuracy Rates	.88	. 84	.91	.87

Table 5 Reading times for critical region in Experiment 2

Reading Measure	RC Type	NP1	Time(msec)
Gaze Duration	Object	Description	544
	Subject	Description	544
	Object	The Person	597
	Subject	The Person	598
Right Bounded Reading	Object	Description	826
	Subject	Description	754
	Object	The Person	776
	Subject	The Person	712
Rereading	Object	Description	1126
	Subject	Description	939
	Object	The Person	1092
	Subject	The Person	815
Total reading	Object	Description	1697
	Subject	Description	1505
	Object	The Person	1717
	Subject	The Person	1418

Table 6 Regression Path Reading Times for the RC in Experiment 2

	Object	Subject
Description	1013	859
The Person	868	771

Table 7 Question accuracy rates in Experiment 3

	Match-Object	Match-Subject	Non-Match-Object	Non-Match-Subject
Accuracy Rates	.84	.96	.93	.99

Table 8 Reading times for the critical region in Experiment 3

Reading Measure	Cleft Type	Match Condition	Time(msec)
Gaze Duration	Object	Match	1138
	Subject	Match	1071
	Object	Non-Match	996
	Subject	Non-Match	906
Right Bounded Reading	Object	Match	1545
	Subject	Match	1421
	Object	Non-Match	1248
	Subject	Non-Match	1145
Rereading	Object	Match	1655
	Subject	Match	1390
	Object	Non-Match	2171
	Subject	Non-Match	1835
Total reading	Object	Match	2731
	Subject	Match	2432
	Object	Non-Match	3166
	Subject	Non-Match	2740

Table 9 Regression Path Reading Times for the Cleft Region in Experiment 3

	Object	Subject
Match	1682	1564
Non-Match	1330	1227

Appendix 1

Total time spent on a word or region is defined as the sum of all fixations on that word or region.

Right-bounded reading time on a word or region is defined as the sum of all fixations on that word or region until text downstream is fixated (provided text downstream has not been fixated prior to the initial fixation on that word or region).

Gaze duration on a word or region is similar to right-bounded, but fixations that occur after regressive movements from the target word or region will be excluded from the sum.

Rereading time of a word or region is defined as the total reading time minus the right-bounded time for that word or region.

First-pass regression ratio from a word or region is defined as the proportion of all movements from a region that are regressive, instead of progressive, provided text downstream from the word or region has not been fixated.

First pass regression path reading time is defined as the total of all fixations from the first time a word or region is fixated (provided text downstream from the word or region has not been fixated before that initial fixation) until text downstream from the word or region has been fixated.

All these definitions are common to eye-tracking research on language comprehension and are taken from Inhoff and Radach (1998) and Liversedge, Paterson, and Pickering (1998).

Appendix 2

The stimuli from Experiment 1 are shown below in their object-extracted forms. The stimuli were also presented in their subject-extracted forms.

1 The banker that the barber/Sophie praised climbed the mountain just outside of town before it snowed.

2 The dancer that the reporter/Angela phoned cooked the pork chops in their own juices on New Year's Eve.

3 The architect that the fireman/Wesley liked dominated the conversation while the game was on television.

4 The waiter that the broker/Janice despised drove the sports car home from work that evening.

5 The detective that the secretary/Trevor disliked clipped the coupons out with the dull scissors.

6 The judge that the doctor/Daniel ignored watched the special about Colombian drug dealers on the nightly news.

7 The robber that the mailman/Stephen insulted read the newspaper article about the fire.

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

9 The actor that the director/Faith thanked worked in many hit movies before 1990.

10 The poet that the painter/Philip inspired wrote an autobiography after their friendship became well known.

11 The chef that the cashier/Justin distrusted called for help after the restaurant closed.

12 The aunt that the child/Kristen amused made paper dolls out of the newspaper.

13 The violinist that the conductor/Michael complimented performed at Carnegie Hall for two weeks.

14 The teacher that the student/Robert questioned wrote a long science fiction novel during the summer vacation.

15 The editor that the author/Jennifer recommended changed jobs after a new merger was announced.

16 The tailor that the customer/Pamela described worked in a small building near the bus station.

17 The admiral that the general/Jeremy advised reminisced nostalgically before the trip got underway.

18 The coach that the referee/Evelyn criticized talked publicly about the incident after the game.

19 The lawyer that the client/Kenneth interviewed had a very small office.

20 The plumber that the electrician/Joanne called drove a grey truck.

21 The salesman that the accountant/Jonathon contacted spoke very quickly.

22 The clown that the magician/Margaret entertained was a star.

23 The clerk that the traveler/Landon helped worked in a large foreign bank.

24 The gardener that the homeowner/Elizabeth envied was very friendly.

Appendix 3

The stimuli from Experiment 2 are shown below in their object-extracted forms. They were also presented in their subject-extracted forms.

1 The banker/The person that the barber praised climbed the mountain just outside of town before it snowed.

2 The dancer/The person that the reporter phoned cooked the pork chops in their own juices on New Year's Eve.

3 The architect/The person that the fireman liked dominated the conversation while the game was on television.

4 The waiter/The person that the broker despised drove the sports car home from work that evening.

5 The detective/The person that the secretary disliked clipped the coupons out with the dull scissors.

6 The judge/The person that the doctor ignored watched the special about Colombian drug dealers on the nightly news.

7 The robber/The person that the mailman insulted read the newspaper article about the fire.

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

9 The actor/The person that the director thanked worked in many hit movies before 1990.

10 The poet/The person that the painter inspired wrote an autobiography after their friendship became well known.

11 The chef/The person that the cashier distrusted called for help after the restaurant closed.

12 The aunt/The person that the child amused made paper dolls out of the newspaper.

13 The violinist/The person that the conductor complimented performed at Carnegie Hall for two weeks.

14 The teacher/The person that the student questioned wrote a long science fiction novel during the summer vacation.

15 The editor/The person that the author recommended changed jobs after a new merger was announced.

16 The tailor/The person that the customer described worked in a small building near the bus station.

17 The admiral/The person that the general advised reminisced nostalgically before the trip got underway.

18 The coach/The person that the referee criticized talked publicly about the incident after the game.

19 The lawyer/The person that the client interviewed had a very small office.

20 The plumber/The person that the electrician called drove a grey truck.

21 The salesman/The person that the accountant contacted spoke very quickly.

22 The clown/The person that the magician entertained was a star.

23 The clerk/The person that the traveler helped worked in a large foreign bank.

24 The gardener/The person that the homeowner envied was very friendly.

Appendix 4

The stimuli from Experiment 3 are shown below in their object-extracted forms. They were also presented in their subject-extracted forms.

1 It was the dancer/Tony that the fireman/Joey liked before the argument began.

2 It was the detective/Jack that the secretary/Bill disliked during card games.

3 It was the chef/Pete that the cashier/Nick distrusted after the restaurant closed.

4 It was the robber/Luke that the mailman/Mark insulted after reading the newspaper article.

5 It was the banker/Tess that the barber/Elle praised just outside of town.

6 It was the architect/Jill that the reporter/Rose phoned on New Year's Eve.

7 It was the waiter/Kate that the broker/Cora despised in the evening.

8 It was the governor/Barb that the comedian/Gwen admired in the fancy restaurant.

9 It was the judge/Sammy that the doctor/Felix ignored at the party.

10 It was the admiral/Aaron that the general/Jimmy advised before the trip got underway.

11 It was the salesman/Louis that the accountant/Harry contacted in the morning.

12 It was the employee/Henry that the director/Roger evaluated in the old car.

13 It was the actor/Paige that the jeweler/Faith thanked before the show.

14 It was the editor/Patty that the author/Jenna recommended after a new merger was announced.

15 It was the tailor/Janet that the clown/Katie described at the banquet.

16 It was the guitarist/Laura that the magician/Megan entertained in the auditorium.

17 It was the poet/Joel that the painter/Eric inspired outside the coffeeshop.

18 It was the violinist/Mike that the conductor/Hugh complimented at Carnegie Hall.

19 It was the teacher/Todd that the student/Brad questioned during the summer vacation.

20 It was the lawyer/Seth that the client/Greg interviewed in the very small office.

21 It was the aunt/Gail that the child/Jane amused with the paper dolls.

22 It was the coach/Joan that the referee/Ruth criticized after the game.

23 It was the plumber/Lynn that the witness/Beth called from the payphone.

24 It was the gardener/Dawn that the homeowner/Fran envied after the lottery ended.

25 It was the carpenter/Vince that the electrician/Trent pitied outside the new store.

26 It was the manager/Clint that the maid/Bruce punched in the parking garage.

27 It was the producer/Oscar that the translator/Danny offended on the airplane.

28 It was the roofer/Buddy that the biker/Brian kicked during the soccer match.

29 It was the merchant/April that the seamstress/Doris overpaid at the flea market.

30 It was the zookeeper/Helen that the auctioneer/Bobbi idolized after the event.

31 It was the hostess/Wanda that the juror/Cindy flattered on the sidewalk.

32 It was the prosecutor/Sally that the cartoonist/Clara avoided after Monday night.

33 It was the clerk/Nate that the athlete/Doug helped after the explosion.

34 It was the passenger/Rich that the librarian/Carl tutored on the train.

35 It was the traveler/Will that the bartender/Skip saw last weekend.

36 It was the fisherman/Bart that the policeman/John disgusted at the local bar.

37 It was the stewardess/Mary that the diplomat/Lori caught in the classroom.

38 It was the anarchist/Ruby that the professor/Nora tolerated during the protest.

39 It was the boxer/Bess that the swimme/Jean scolded just before dinner.

40 It was the pharmacist/Rita that the engineer/Emma spotted through the window.

41 It was the priest/Butch that the orator/Duane eluded after the big fight.

42 It was the scientist/Jerry that the preacher/Damon rebuked late in the afternoon.

43 It was the pilot/Larry that the private/Jason recognized at the bookstore.

44 It was the farmer/Allan that the writer/Monty quoted in the classroom.

45 It was the puppeteer/Irene that the researcher/Annie noticed during the party.

46 It was the astronomer/Becky that the ballerina/Paula punished on the long trip.

47 It was the zoologist/Carla that the assistant/Holly skirted throughout the fall months.

48 It was the advisor/Candy that the cook/Jenny acknowledged during the traffic jam.

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