The Role of Relative Item Salience in Memory-Taxing Sentence Structures

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ABSTRACT

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(Under the direction of Peter C. Gordon)

Experiments 1 and 2 show that the frequencies of the critical noun phrases (NPs) of sentences containing relative clauses (RCs) can reduce the difference in difficulty experienced when reading sentences containing object-extracted RCs as compared with sentences containing subject-extracted RCs. This reduction in the processing difficulty of the usually burdensome object-extracted RCs, as compared with subject-extracted RCs, only occurs when the head NP is low frequency (LF) and the embedded NP is HF, but not under any other combination of NP frequency. This finding can be attributed to the enhanced salience of LF items as compared with HF items and the impact that this relative salience has on memory processes. Experiment 3 manipulates salience via adjectival modification of the head NP while keeping frequency constant. A reduction in the processing difficulty of object-extracted RCs is found under adjectival modification that mirrors the results of the frequency manipulations. Experiment 4 attempts to determine whether the critical process involved in comprehending RCs is recall of the head NP or recall of the embedded NP. It does so by separating the two loci of retrieval via a multi-lexemic embedded predicate. The results indicate that the presence of multi-lexemic predicates precludes the manifestation of relative salience effects.
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Chapter 1: Overview of Purpose

The skills involved in higher-level language use are among the central qualities that distinguish humans from other animals; because of this any endeavor to understand human cognitive processing should consider the manner in which we process linguistic information to be of primary importance. One particularly important aspect of psycholinguistic research involves the study of how working memory interacts with language processing mechanisms. It has been noted that grammar systems are capable of producing an endless number of grammatically acceptable utterances (Miller & Chomsky, 1963). It has further been noted that certain of these linguistic structures, such as double-embedded object-extracted relative clause structures, like that in (1), place especially heavy, if not impossible, demands on our working memory during their comprehension (Bever, 1974).

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

An analysis of people’s ability to comprehend memory-taxing structures (with a sentence like (1) being an extreme example) may provide us with a glimpse into our unique ability to process higher-level language and into our use of working memory resources as we do so.

The history of working-memory research is replete with efforts to understand more about how characteristics associated with the units of information to be processed may influence general working memory operation (e.g., McDaniel, DeLosh, & Merritt,
In recent years some work of this sort has been done specifically within the domain of language comprehension (e.g., Gibson, 1998; 2000; Warren & Gibson, 2002). Less is known, though, about how the relations between units of information affect the operation of working memory during the language processing.

However, some recent research (King & Just, 1991; Gordon, Hendrick & Johnson, 2001, 2004; Gordon Hendrick, Johnson, & Lee, 2006; Gordon, Hendrick, & Levine, 2002) has shown that the nature of the relations between units of information in memory-taxing sentence structures do play an important role in the difficulty experienced during the comprehension of complex sentences. In particular, sentences with object-extracted relative clauses (RCs) are usually difficult to process (a RC is a subordinate clause that modifies a noun; an object-extracted RC is a subordinate clause that modifies a noun such that the noun it is modifying serves as the object of the subordinate clause). However, this processing difficulty is alleviated when two critical noun phrases (NPs) are made to be dissimilar to one another by making the embedded NP either a name, the indexical pronoun you, or the quantified expression everyone. An illustration of this phenomenon is given in examples (2a) to (2d), all of which contain object-extracted RCs but with various types of NPs embedded in the RC.

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

(2b) The reporter that Allison attacked admitted the error.

(2c) The reporter that you attacked admitted the error.

(2d) The reporter that everyone attacked admitted the error.
Sentences like (2a), which have definite descriptions as both the head NP and the embedded NP, have been shown, through offline measures of sentence comprehension and online measures of reading durations, to be much more difficult for readers to process than sentences like (2b-d), which have a definite description as the head NP and a dissimilar NP as the embedded NP. Thus, the results of such research have suggested that the comprehension difficulty that stems from structures like the object-extracted RC is in some way attributable to the nature of the relations that exist between these two critical NPs. Moreover, the similarity-based memory interference hypothesis (SBMIH) that has followed from these results (Gordon, et al., 2001; 2002; 2004; 2006) has specifically suggested that the key aspect of the relationship between critical NPs responsible for mediating the difficulty of these sentences is the similarity of the NPs to one another.

As Experiments 1 and 2 will show, it seems that the influence of the relations between critical NPs on the difficulty readers experience when reading such structures may be modulated by the memory demands required for the processing of each of the critical NPs (also presented in Johnson, Gordon, & Hendrick, in prep.)\(^1\). This modulation is perhaps best illustrated by a consideration of the examples given in (3a) to (3d), which all consist of sentences containing the usually difficult object-extracted RC structure.

\((3a)\) The painter that the criminal tolerated poured syrup on the french toast.

\((3b)\) The mentor that the barbarian tolerated poured syrup on the french toast.

\((3c)\) The painter that the barbarian tolerated poured syrup on the french toast.

\((3d)\) The mentor that the criminal tolerated poured syrup on the french toast.

\(^1\) As will subsequently be discussed, it is an assumption of the work being presented here and in that described in Johnson, et al., (in prep) that these effects of NP frequency operate via an alteration of the memory demands that these NPs impose during processing. This important assumption will be revisited in a subsequent discussion of theories of complex sentence comprehension, which make this assumption to varying degrees.
In (3a) to (3d) the construction of the items is manipulated in terms of the frequency of natural occurrence of the critical NPs. The English words painter and criminal are high-frequency (HF) words; in contrast, mentor and barbarian are low-frequency (LF) words. As a result, (3a) and (3b) can be considered to have NPs that are matched in frequency, with (3a) having HF NPs and (3b) having LF NPs. In contrast, (3c) and (3d) can be considered to have unmatched NPs, as (3c) has a HF head NP and a LF embedded NP, and (3d) has a LF head NP and a HF embedded NP.

As may be expected from previous work (Gordon, et al., 2001; 2002; 2004; 2006), sentences with matched (and perhaps similar) critical NPs [i.e., (3a) and (3b)] were relatively difficult to process. Interestingly, though, processing difficulty was alleviated when the NPs were unmatched in terms of frequency, but only when the head NP was LF and the embedded NP was HF [as in (3d)], and not when the frequency ordering was reversed [as in (3c)].

This finding, it seems, may be related to the relative memory demands that the head and embedded NPs impose on the reader in the object-extracted RC structure. As it seems that the head NP must be stored in working memory and later retrieved from working memory after some intervening material has been encountered (the beginning of the RC) while the embedded NP must simply be retrieved immediately after being initially encountered, perhaps processing is facilitated only when memory for the head NP is somehow enhanced. It is possible that having a LF head NP enhances its memory trace, but only when the intervening NP is HF, and not when the intervening NP can potentially compete with the memory trace of the head NP, as it may when the embedded NP is also LF.
As will be discussed later, this possibility is supported by findings in the list memory literature that have shown that recall for LF items is enhanced when they are studied in conjunction with HF items but not when they are studied in conjunction with other LF items (Merritt, DeLosh, & McDaniel, 2006; DeLosh & McDaniel, 1996; Van Overschelde, 2002; Duncan, 1974; Gregg, 1976; Gregg, Montgomery, & Castaño, 1980). Such findings support the notion that the relations between critical NPs in complex sentence structures like the object-extracted RC are important; furthermore, they suggest that the reason these relations are important has to do with the way these relations may serve to alter the memory traces of these critical NPs.

As such, it seems that the relative salience of the critical NPs to one another may determine the amount of difficulty experienced when reading structures like the object-extracted RC, which usually seem to tax our working memory structures. When the memory trace of the critical NP that must be held in working memory (the head NP) is enhanced by making it somehow more relatively salient than the other critical NP (the embedded NP), then it may be expected that processing would be enhanced. If so, then it would seem that the difficulty experienced when processing such structures is mediated by a key relation between the critical NPs, specifically that of their relative salience.

Thus, the main purpose of this study is to test prominent theories of complex sentence comprehension in terms of their abilities to explain phenomena involving manipulations of the relative salience of critical NPs. Furthermore, as it seems appropriate to do so, these theories will be put to test in light of a consideration of whether the processing of the critical NPs during the comprehension of complex sentences follows a principle of processing observed in general working memory research. More specifically, its primary aim is to test whether a property of working
memory characterized in the working memory literature, that of enhanced recall of items that are relatively more salient than other concurrently studied items, also affects the comprehension of complex sentences.

It is important to note off-the-bat that the term *salience* has been used in different ways across different types of research. Often in the linguistics literature, the term *salience* is used to refer to an item’s accessibility or givenness in a discourse (e.g., Jaeger & Wasow, 2008; Arnold & Lao, 2008). Here, *salience* is used in a different manner, one more closely related to the way it is used in the list memory literature when it refers to an item’s distinctiveness, or ability to stand out among competitors (e.g., McDaniel, DeLosh, & Merritt, 2000; Serra & Nairne, 1993; Hirshman & Bjork, 1988; Schmidt, 1994; Hunt & Elliot 1980; Merritt, et al., 2006; DeLosh & McDaniel, 1996; Van Overschelde, 2002; Duncan, 1974; Gregg, 1976; Gregg, et al., 1980). This wide variety of converging evidence in the list memory literature has suggested that unusual items are recalled more accurately than common items when the two types of items have been studied together. Though the exact mechanism behind this processing advantage for these unusual distinct or salient – items is not clear, it has been proposed (DeLosh & McDaniel, 1996; Merritt, et al., 2006) that such items draw attentional resources away from other items. This attentional draw in turn leads to an elaboration of item-specific encoding for these salient items, enhancing memory for them. Thus, in this dissertation salience will refer to the ability of an item to gain and hold attention in relation to competitors and to its ability to provoke more elaborate encoding in memory than competing items do. It will not refer to an item’s salience (or prominence) in the discourse as determined by its syntactic or discourse role.
It should also be noted off-the-bat that most prominent theories of complex sentence comprehension have marked difficulty explaining why processing is facilitated in sentences like (3d), which has a LF head NP and a HF embedded NP, but not in sentences like (3a) to (3c). In fact, as will also be discussed below, the theory most closely linked to the notion that the relations between critical NPs plays an important role in mediating processing difficulty (the SBMIH) must be modified to include the notion of relative salience in order to account for these findings. The experiments presented here are designed to further explore the applicability of the relative salience notion to complex sentence processing.

Additionally, the results may provide us with some insight regarding a controversy over whether the working memory involved in language comprehension is modularized from general working memory processes (e.g., Waters and Caplan, 1996; Caplan and Waters, 1999) or indeed involves the use of the same structures and processes that operate during general working memory tasks (e.g., Just and Carpenter, 1992; Just, Carpenter, and Keller, 1996).

This dissertation will be organized in the following manner: Chapter 2 will discuss prominent theories of complex language comprehension and the evidence these theories have used to support their claims. Following the presentation of these theories, Chapter 3 will present the recent NP frequency findings for which all these theories all have difficulty accounting. Chapter 4 will then discuss list-memory research, the findings of which provide insight into the NP frequency sentence processing results and into a reworking of the SBMIH that can account for these findings. This reworking will involve a modification of the SBMIH to de-emphasize item similarity and to include relative salience of the NPs as the key factor responsible for mediating the differences in
processing difficulty that have been observed, enabling it to account for the frequency
effects observed and to make additional predictions for the experiments presented here.
Finally, Chapter 5 will present two additional experiment designed to investigate this
notion of relative salience, discussing the abilities of the results of these studies to answer
questions related to our comprehension of complex sentences, specifically in terms of the
appropriateness of this relative salience notion.
Chapter 2: Theories of Complex Sentence Comprehension

While it is intuitively clear from sentence structures like (1) that certain types of linguistic materials can place heavy demands on our language processing resources, the nature of those demands and the manner in which those demands may be met have yet to be fully understood. Nevertheless, a great deal has been learned in recent years about the operation of our language processing mechanisms during complex sentence comprehension. Perhaps the most well-studied complex sentence structure is the RC. One of the main reasons that RC structures have been so thoroughly studied involves the fact that there are two types of RC structures that can easily be compared with one another; these two types of RC structures, the object-extracted RC (see (4a) for an example) and the subject-extracted RC (see (4b) for an example), contain the exact same words (albeit in a slightly different order) but have different meanings and are associated with very different levels of processing difficulty.

(4a) The senator that the reporter attacked admitted the error.

(4b) The senator that attacked the reporter admitted the error.

Sentences like (4a) are said to contain an object-extracted RC because the subject of the sentence (the senator) is modified by the subordinate clause in such a way that it serves as the object of the clause. In turn, sentences like (4b) are said to contain a subject-extracted RC because the subject of the sentence is modified by the subordinate clause in such a way that it serves as the subject of the clause. What makes these structures so suitable for research involving complex sentence processing is twofold: 1) the two structures can
easily be compared; although they have different meanings, the two structures contain
exactly the same words (albeit in a different order) and 2) sentences containing object-
extracted RCs are typically more difficult to understand than their subject-extracted
counterparts.

However, while it is an interesting observation that object-extracted RCs are more
difficult to process than subject-extracted RCs, it is important to gain an understanding of
why this is the case and how our processing of such structures can shed light on our
language comprehension mechanisms in general. Introspectively, the difficulty in
comprehending a structure like (1) seems to relate to working memory limitations arising
from the need to keep track of who is doing what to whom. However, theories of
complex sentence comprehension have differed in terms of the degree to which working
memory limitations are included as a factor responsible for the amount of difficulty we
experience in processing different structures. A discussion of particularly prominent
theories of complex sentence comprehension follows, presenting these theories in order
of the degree to which they include working memory as a mediating factor of
comprehension (from theories which do not consider working memory to be a factor at
all to those which place working memory at a position of utmost explanatory
prominence).

One theory (MacWhinney, 1977; MacWhinney & Pleh, 1988) has posited that the
reason object-extracted RCs are more difficult than subject-extracted RCs has to do with
a perspective-shift that occurs during the reading of sentences with object-extracted RCs,
but not subject-extracted RCs. This notion of a perspective shift can be illustrated by a
consideration of (4a) and (4b). For (4a), a sentence containing an object-extracted RC,
the reader first takes the perspective of the senator, as in canonical English the subject is
presented first, and as readers tend to take the perspective of subjects. Upon encountering *the reporter* as the agent of the verb *attacked*, however, the reader must shift perspectives from *the senator* to *the reporter* in order to properly understand the sentence. Then, once again, the reader must shift perspective back to *the senator* when the verb *admitted* is encountered, as *the senator* is the agent of the verb *admitted*. In contrast, for (4b), a sentence containing a subject-extracted RC, the reader maintains the perspective of *the senator* throughout the sentence. As *the senator* is the agent of both the verb *attacked* and the verb *admitted*, there is no need for the reader to shift perspectives. This theory suggests that the process of shifting perspectives is somewhat difficult, and that the difficulty experienced during the processing of object-extracted RCs can be attributed to this perspective shift. Moreover, this theory suggests that the difference in comprehension difficulty between these two structures has nothing to do with working memory limitations. Instead, it has only to do adoption of different perspectives by the reader when confronted with object-extracted RCs, but not subject-extracted RCs.

Another theory of complex sentence comprehension has adopted a connectionist approach to language comprehension in proposing that our *experience* with different sentence structures accounts for the difficulty associated with object-extracted RCs as compared with subject-extracted RCs (MacDonald and Christiansen, 2002). The canonical word ordering in English is subject-verb-object (SVO). Other word orderings in English are possible, but they are encountered much less frequently. This experientially-based connectionist theory proposes that we have difficulty with sentences containing object-extracted RCs because the processing of the RC in these structures requires a non-canonical parsing. In contrast, on this view it is easier to read sentences
containing subject-extracted RCs because the processing of the RC in these structures is based on the canonical SVO parsing. This view thus suggests that because we have more experience with structures having canonical word order than with those having non-canonical word order we experience more difficulty when faced with non-canonical structures. As in the perspective-shift theory, this experientially-based theory places little to no emphasis on the role of working memory during complex sentence comprehension (though it should be noted that neither of these theories suggest that working memory does not exist).

Perhaps most relevant to the current research, this experientially-based view can be considered connectionist in that our cognitive resources operate in parallel in order to process linguistic input. The connections between units of information associated with linguistic input become strengthened over time, leading to enhanced processing of structures we have previously encountered or structures that are similar to those we have previously encountered both at the item level and at higher-levels, like those involving syntax. This idea is compelling, but as it is instantiated it is not clear exactly what units of information or connections between units constitute the linguistic input. The purveyors of this connectionist, experientially-based theory suggest that experience can strengthen connections at many different levels but they admit themselves that it is unclear how low-level information may interact with higher-level information in terms of strengthening connections with structures through experience (MacDonald & Christiansen, 2002).

A related explanation of RC processing difficulty proposes that our experience with different RC structures in conjunction with different types of embedded NPs explains the varying amount of difficulty we experience with these structures (Reali &
Christiansen, 2007). This theory is based on a comparison of the frequency of occurrence of object-extracted RCs with the frequency of occurrence of subject-extracted RCs in various linguistic corpora when the embedded NPs of such structures are either a first person pronoun, a second person pronoun, a third person pronoun, a third person impersonal pronoun, or a nominal pronoun. They found that the ratio of object-extracted to subject-extracted RCs in the corpora depended greatly on the type of NP that was embedded in the RC. For some types of embedded NPs (first, second, and third person pronouns) there were many more object-extracted constructions than subject-extracted constructions in the corpora and for the remaining types of embedded NPs there were many more subject-extracted constructions than object-extracted constructions in the corpora. To test whether the frequency of occurrence of these RC type/NP type combinations may be related to the ease of processing associated with these different constructions, they performed self-paced reading experiments using these different RC type/NP type combinations as stimuli. They found that the relative frequency of RC type for a given embedded NP type seemed to predict whether the object-extracted RC construction would be more difficult to process than the subject-extracted RC type or vice versa. This theory seems to put a slight amount of emphasis on working memory’s role in sentence comprehension, in that it seems that working memory would be responsible for encoding and storing connections between item-level information and structurally-based information during initial processing of the linguistic input. Nevertheless, this theory de-emphasizes the role that working memory plays in determining the difficulty in processing sentences, as the constraints working memory is suggested to place on sentence processing are not sufficient for explaining the differences in difficulty that are observed across sentence structures.
While the experientially-based theory related to their research is compelling, the conclusion that the relative frequency of different NP types within different RC structures is able to predict the degree of relative difficulty readers experience when processing object-extracted versus subject-extracted structures seems tenuous. In particular, for the NP types which would predict a reversal in the usual pattern of object-extracted RCs being more difficult than subject-extracted RCs, the magnitude of the differences they found in their reading time data was nowhere near the magnitude of the differences they observed in the frequency counts of the corpora they studied. Additionally, it actually seemed that some regions of these sentences (the main verb in particular) which were purported to show a reversal of the object-extracted/subject-extracted difference actually showed the usual pattern of object-extracted RCs being more difficult than subject-extracted RCs. Finally, their offline measures of comprehension, which consisted of accuracies in response to questions about their RC-containing sentences failed to show the patterns that might be expected from their corpus findings. Nevertheless, their work deserves some consideration as another example of an explanation of complex sentence processing that for the most part excludes working memory limitations as an explanatory factor.

Another line of research that to some degree emphasizes our experience with different language structures has suggested that our experience with the discourse functions that different types of sentence structures serve may be responsible for the difference in processing difficulty between object-extracted RCs and subject-extracted RCs when these sentences are presented in isolation (Roland, et al., 2008; Roland, et al. 2007). They suggest, based on previous research (Fox & Thompson, 1990), that the role of object-extracted RCs is to elaborate on NPs that have been previously introduced in
the discourse. In contrast, they suggest the role of subject-extracted RCs is simply to provide additional information about the nouns they are modifying, whether or not those nouns had been previously introduced in the discourse. They show through self-paced reading data that object-extracted RCs become just as easy to process as subject-extracted RCs when the head of the RC has been previously presented, either topically (Roland, et al. 2007) or simply as a mention (Roland, et al., 2008). Thus, it seems that when object-extracted RCs follow the discourse function in which we normally experience them, processing is facilitated. As readers surely would be expected to keep the previously encountered NP (whether it had been presented topically or merely mentioned) in working memory before encountering it in the target sentence, this theory represents one in which experience (with different roles of RC structures) and working memory are both considered as explanatory factors for relative RC processing difficulty.

Another particularly compelling class of theories that has gained some prominence in recent years involves the suggestion that the amount of processing difficulty we experience when reading complex sentences depends on constraints that information associated with the linguistic input stream places on our interpretation of the meaning of the stream. Although this very interesting set of theories has largely been applied to sentences in which the reader is temporarily faced with some sort of ambiguity before that ambiguity can be resolved (MacDonald, Pearlmutter, & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998; Tabor & Hutchins, 2004; Trueswell, Tanenhaus, & Garnsey, 1994; Vosse & Kempen, 2000) it has also been applied to structures that previously had been considered unambiguous (Gennari & MacDonald, 2008). On this view, in essence, the multiple competing syntactic parses that could end up to be the eventual correct interpretation of a sentence are held in parallel until the
disambiguating region is encountered in a temporarily ambiguous complex sentence. Importantly, readers use any information that is available to them to help their parsing systems make the correct decision about which potential interpretation of the input will be correct.

\[(5a)\] *The witness examined by the lawyer turned out to be unreliable.*

\[(5b)\] *The evidence examined by the lawyer turned out to be unreliable.*

A consideration of (5a) and (5b) provides a simple example of how these constraint-based theories work. In a sentence like (5a) the reader may initially interpret *witness* to be the subject of the verb *examined*, but must later revise that interpretation to determine that *witness* is instead the object of the reduced relative *by the lawyer*. In contrast, this type of revision is much easier when the subject is inanimate like in (5b) (*evidence*). As such it is proposed that readers use cues such as the animacy of the head NP to bolster the strength of certain alternative potential parsings. In this example, as it is quite unlikely that *evidence* can examine anything, readers are able to use that information as guidance in the selection of the proper interpretation. While it may seem that such models rely heavily on working memory processes to maintain the possible alternative parsings, they actually tend to de-emphasize the role working memory plays in complex sentence processing. Instead, they emphasize the importance of the information we use (e.g., syntactic and semantic information) in guiding our parsing systems to correct interpretations. Thus, the maintenance of alternative, potentially correct parsings in working memory is not the critical factor in explaining comprehension difficulty in these theories.

Though these constraint-based theories were initially developed from experiments testing our abilities to read sentences containing temporary ambiguities, recently one
study has sought to apply this type of theory to unreduced RCs, which are typically thought of as being unambiguous (Gennari & MacDonald, 2008). This study was designed to further investigate the finding that the difference in processing difficulty between sentences containing object-extracted RCs and sentences containing subject-extracted RCs is diminished when the head of these sentences is inanimate and the embedded NP is animate (as in (6a) and (6b)), but not when the order of the animacy of the NPs is reversed (as in (6c) and (6d); cf. Traxler, Morris, & Seely, 2002).

(6a) The movie that pleased the director received a prize.
(6b) The movie that the director watched received a prize.
(6c) The director that watched the movie received a prize.
(6d) The director that the movie pleased received a prize.

Under a constraint-based theory, it would be expected that the semantic information associated with the inanimacy of the NP the movie would facilitate processing when it is the head of the sentence and the object of the RC (like in (6b)), as inanimate things are not natural agents, but can be natural patients. Indeed, reading time data suggests that the processing of object-extracted RCs is facilitated when the head of the RC is inanimate and the embedded NP is animate, marking a significant step forward for constraint-based theories of complex sentence comprehension into the domain of explaining how the difficulty in processing unambiguous complex sentences may be determined by certain constraints available to the reader.

As previously mentioned, constraint-based theories of language comprehension de-emphasize the role of working memory during processing (though working memory is never completely abandoned as a key process in language comprehension, and the degree to which these theories de-emphasize working memory varies). Some recent research has
attempted, in a sense, to reconcile differences between theories emphasizing the role of working memory and those emphasizing constraints that usually have to do with experience and non-working memory processes like semantic processing (Van Dyke, 2007; Van Dyke & McElree, 2006). This line of research has investigated two different types of proposed interference, syntactic interference and semantic interference, which pose difficulty to the reader when processing certain structures. Examples of sentences containing various combinations of these two types of interference are illustrated in the sentential components contained in (7a) to (7d).

Sentence beginning: The worker was surprised that the resident...

(7a) who was living near the dangerous warehouse...

(7b) who was living near the dangerous neighbor...

(7c) who said that the warehouse was dangerous...

(7d) who said that the neighbor was dangerous...

Sentence end: was complaining about the investigation.

In all of these sentences, it is proposed that the reader must retrieve the head of the verb was complaining upon encountering the verb. Syntactic interference, it is suggested, occurs when the NP to be recalled has acted in a subject role in the intervening material (as the resident does in (7c) and (7d)), but not when the NP has acted in a different role (the resident acts as the object of a preposition in (7a) and (7b)). Semantic interference, it is suggested, occurs when the NP of the intervening material can also act as the subject of the verb was complaining (as neighbor, but not warehouse can do). It was shown through reading time data and through performance in offline tasks that both types of interference make the correct retrieval of the head of was complaining more difficult. The key suggestion of this study is that cues act to aid retrieval at certain points of
integration in sentences, but that interference from various sources can weaken the cues’ abilities to effectively retrieve the appropriate heads at these points. Thus, such a theory puts forth a concept somewhat similar to constraint-based processing through its proposal of the role of cues (which are to some degree similar to constraints) while still emphasizing the role of working memory retrieval in sentence processing in that the retrieval from working memory of the heads of verbs is the key component mediating the amount of difficulty experienced when reading complex sentences.

Some recent work has presented a model that has attempted to implement some of the claims of cue-based theories of processing (Lewis & Vasishth, 2005). This activation-based model of sentence processing, which is based on the Adaptive Control of Thought – Rational (ACT-R) architecture (Anderson, 2005; Anderson & Lebiere, 1998), operates under two major premises: 1) the activation of elements in memory fluctuates based on natural decay and their history with reactivating structures (like verbs whose heads are the elements being maintained in working memory) and 2) certain cues provide readers with the ability to effectively recall these key elements, but that interference between an antecedent and its point of integration can weaken the strength of those cues. While it seems this model is adept at fitting data from behavioral experiments on the comprehension of complex sentences, it has some admitted weaknesses. The cues on which it is based are solely syntactically-informative in nature. It has been shown (see discussion of Van Dyke, 2007) that other types of information, such as semantics, may serve as cues (or as interference) for comprehension. Additionally, this model has difficulty explaining why the presence of different types of NPs in material intervening between a discourse entity and its point of integration lead to different degrees of processing difficulty. Though some of the difference in processing difficulty across
different NP types may be accounted for by the relative ease of the model’s ability to activate certain types of NPs (e.g., pronouns are more easily activated than full expressions) the model is still not fully able to capture why structures like double center embeddings (like (1)) are made much easier by having mixed NPs in the embeddings (see discussion below of double center embeddings and NP types).

Other approaches to understanding complex sentence comprehension have suggested that working memory operation is the central mediating factor for the degree of difficulty experienced during such comprehension. On these views, processing disruption occurs mainly as a result of the parsing system’s inability to retrieve or store correct information, in one way or another, from/in working memory at certain key points during reading. Interestingly, theories emphasizing working memory’s role in complex sentence processing tend to address, to varying degrees, the role that characteristics associated with critical NPs in sentences play in mediating the processing difficulty associated with the limitations of our working memory systems.

In an important observation that has seemed to inspire much work on the role of working memory in complex sentence processing, Bever (1974) noted that sentences that contain doubly-, triply-, and even quadruply-embedded object-extracted RC structures become much easier to understand when the NPs of these structures are mixed in type rather than all being descriptive terms. This phenomenon can perhaps best be understood by a consideration of the examples given in (8a) and (8b), which contain doubly-embedded object-extracted RC structures.

(8a) The reporter the banker the salesmen knew trusts said the presidential campaign would be interesting this year.

(8b) The reporter everyone I knew trusts said the presidential campaign would be
While readers experience extreme difficulty in parsing and comprehending sentences like (8a), they find that sentences like (8b) are nearly effortlessly understood. It is not clear from the perspective-shift theory (MacWhinney, 1974; MacWhinney & Pleh, 1988) why (8b) would be easier to understand than (8a). Surely perspectives would be expected to shift in both these sentences. Thus it would be expected under the perspective-shift theory that the two sentences would be equally difficult. Simple experientially-based theories (e.g., MacDonald & Christiansen, 2002) also have a difficult time explaining the difference between (8a) and (8b). Experientially-based theories are based on our experience with certain word orderings. While these structures are both non-canonical, it would be expected that both would be equally difficult to comprehend (MacDonald & Christiansen, 2002). Corpus work showing that processing difficulty is related to how often we have encountered certain NP types within certain complex structures (Reali & Christiansen, 2007), provides somewhat more insight into the difference in processing difficulty associated with these structures, but these corpus studies have not included double embeddings. Though experientially-based theories suggest that experience with certain structures helps us with other similar structures, and thus that our experience with single-embeddings should help us with double-embeddings, it could be argued that double-embedded object RCs are qualitatively very different than single-embedded object RCs. While double-embedded object RCs containing definite descriptions as NPs are nearly impossible to understand, single-embedded object RCs containing definite descriptions, while difficult, are still manageable. Finally, while it does seem that constraint-based theories (MacDonald, et al., 1994; McRae, et al., 1998; Tabor & Hutchins, 2004; Trueswell, et al., 1994; Vosse & Kempen, 2000) capture some of the
reduction in processing difficulty associated with (8b) as compared with (8a) (in the least the pronoun I is inherently marked as a subject), a discussion included later in this paper will reveal their shortcomings in accounting for the degree of processing difficulty associated with certain other NP combinations in complex structures.

Theories that emphasize working memory operation in explaining the difference in processing difficulty between object-extracted and subject-extracted RCs have tended to incorporate characteristics related to the head and embedded NPs of such sentences into their theoretical frameworks. Moreover, theories of complex sentence comprehension that emphasize working memory in their frameworks seem particularly well suited to the task of describing differences in comprehension difficulty that are observed when critical NPs are manipulated, as properties related to NPs seem particularly important in working memory-based explanations, but not in other types of explanations. Theories related to perspective-shifts or experience at best tangentially incorporate NP characteristics into their frameworks, and thus seem unable to capture NP-type effects. Theories that are constraint- or cue-based do seem to capture NP-type effects to a degree, in that they suggest that semantics associated with different types of NPs may influence readers’ parsings, but they do not seem to capture all the effects of various NP types on the degree of processing difficulty that different sentences impose on readers.

Two closely related theories of sentence comprehension involving working memory are the syntactic prediction locality theory (SPLT) and the dependence locality theory (DLT) (SPLT: Gibson, 1998; DLT: Gibson, 2000; Warren & Gibson, 2002). Although some of the terms used and some of minor operations proposed by these two theories may differ slightly, they together suggest that two key costs to our processing
system mediate the degree of difficulty we experience when reading sentences. First, a memory cost is incurred whenever an unattached constituent must be maintained in working memory across sentential structures or elements before it can be integrated into the meaning of the sentence. Second, an integration cost is incurred when this integration actually occurs. Most importantly, though, the costs that are incurred (and the resulting difficulty) depend upon the locality of the attachments that must occur. Locality is defined operationally as being inversely related to the number of sentential elements that intervene between an initial encounter with a constituent and its ultimate sentential integration. In terms of the difference in processing difficulty between object-extracted RCs and subject-extracted RCs, these distance-based theories suggest that the difficulty experienced by readers when they encounter object-extracted RCs as compared with subject-extracted RCs may be attributed to the additional cost that is incurred for object-extracted RCs when the reader must maintain the sentential subject across one additional sentential entity before being integrated with a verb. For the previously-given examples (4a) and (4b), the processing of the reader according to these theories can be illustrated as follows. In its object-extracted form (4a), the reader’s memory for the senator must be maintained across the reporter before it can be integrated with any of the verbs of the sentence. In contrast, in its subject-extracted form (4b), the senator can almost immediately be integrated with a verb, the only intervening sentential element being the complementizer that.

Notably, these locality-based theories have been modified to include a givenness hierarchy (cf. Gundel, Hedberg, & Zacharski, 1993) for NPs intervening between a previously encountered NP and its point of integration (Warren & Gibson, 2002). According to this modified view, intervening NPs that are more naturally given (or
referentially accessible) pose less of a cost to readers, thus reducing the difficulty of processing otherwise equal structures. In a test of the modified version of the SPLT/DLT, givenness was manipulated in a reading experiment by using as stimuli sentences containing RCs with the following types of embedded, or intervening, NPs, ordered from most given to least given: (1) first-/second-person pronouns; (2) third-person pronouns; (3) first names; (4) full, famous names; (5) definite descriptions; and (6) indefinite descriptions. Indeed, reading-time data suggested that the difficulty of sentences decreased as the givenness of intervening NPs increased.

However, research related to another working memory-based language comprehension theory has suggested that the difficulty experienced during complex sentence processing involves more than just qualities related to entities that intervene between constituents and their points of integration. The similarity-based memory interference hypothesis (SBMIH) has suggested that the relationships (in terms of similarity) that exist among key NPs in memory-taxing sentence structures play a critical role in determining how difficult sentences are to comprehend (Gordon, et al., 2001; 2002; 2004; 2006). While the SPLT/DLT suggests that characteristics related to intervening NPs may play a role in determining difficulty, the difficulty these characteristics may pose is independent of whatever types of NPs have already been encountered and are being held in working memory. In contrast, the SBMIH proposes that the similarity that NPs have to one another in memory-taxing structures like the object-extracted RC determines how difficult these structures will be. More specifically, it proposes that when critical NPs are similar to one another and must be held in working memory before integration with a verb, there is a greater chance that they will be confusable with one another in working memory during maintenance. Thus, subsequent
correct retrieval of these NPs upon encountering the verbs that will integrate the
constituents into the meaning of the sentence will be made more difficult.

Evidence in support of the SBMIH comes from a series of online reading studies
using self-paced reading and eye-tracking methodology (Gordon, et al., 2001; 2004;
2006). Through online measures of processing time and offline measures of sentence
comprehension, these studies found the usual difference in processing difficulty between
object-extracted RCs and subject-extracted RCs when definite descriptions were used in
the sentence head position and definite descriptions, indefinite descriptions, or generics
(all of which are at least superficially similar to definite descriptions) were used in the
position embedded within the RC. However, this difference in processing difficulty was
found to disappear when a definite description was used as the subject of the sentence
and either a name, the indexical pronoun you, or the quantified expression everyone was
used as the embedded noun. This led us to believe that the similarity of these critical NPs
to one another was mediating the difficulty of object-extracted RCs, as they were found
to be more difficult than subject-extracted RCs only when both NPs were relatively
similar in composition. Moreover, it was proposed that similarity was mediated by
common noun status, in that processing difficulty was not alleviated for object-extracted
RCs when both critical NPs consisted of common nouns, but was alleviated when one of
the critical NPs was a common noun and the other was not. It should be noted, though,
that if it were true that names, the indexical pronoun you, and the quantified expression
everyone were all somehow more given in a discourse than definite descriptions, then
both the SPLT/DLT and the SBMIH provide plausible explanations for these observed
reductions in processing difficulty.
It should be noted that working memory, which some of these prominent theories of complex sentence processing rely heavily on, refers to our use of memory to store and process information in the short term. The most prominent characterization of working memory suggests that it consists of a central executive and three slave systems, the phonological loop, the visuo-spatial sketchpad, and the episodic buffer (Baddeley, 2000; Baddeley & Hitch, 1974). Working memory, as it is used in language comprehension, refers to the way that we temporarily store and process the incoming linguistic stream as we form meaningful syntactic structures. Working memory also can be distinguished from our long term episodic memory, which consists of our memory for specific events and occurrences that we have experienced in the past. However, it is likely that the working memory we may use in language processing does include the episodic buffer, which can serve as a gateway through which information in working memory can make its way to our episodic memory.

A consideration of all these prominent theories of complex sentence comprehension together might at first glance seem to suggest that the true source of processing difficulty has neither been correctly identified nor properly characterized. After all, there are substantial differences in the mechanisms that proposed by these theories. However, the mechanisms underlying complex sentence processing are themselves quite complex. It seems likely that instead of there being a singular source of or singular mechanism responsible for mediating processing complexity, a multitude of cognitive processes contribute to complex sentence processing. Nevertheless, it seems that a practical approach to understanding complex sentence processing should involve attempts at teasing these disparate processes apart so we may characterize them in isolation, at least to the extent that it is possible to do so. The research presented here
represents an attempt to study and improve our understanding of the contribution of working memory to complex sentence comprehension. In the process of doing so, it is imperative to test whether theories of complex sentence comprehension that largely based on working memory processes can explain patterns of comprehension better than other theories that are not so closely linked to working memory. In the end, though, it should remembered that though some patterns of comprehension may be explained better by certain classes of theories, it is likely the case that multiple cognitive processes contribute to complex sentence processing.

This dissertation will return to a discussion of all the theories that have been presented here, both those that are strongly related to working memory and those that rely more heavily on other contributing factors, after the presentation of some recent findings related to complex sentence comprehension and NP frequency. All of these theories have difficulty accounting for these findings which will be presented next, but a discussion of the details of these shortcomings should be reserved until after the findings are made clear.
Chapter 3: Results Related to NP Frequency and Complex Sentences

Results from the first two experiments of the dissertation will now be presented. These experiments serve to set the stage for a reconsideration of some of the most prominent theories of complex sentence comprehension, as the results would not be predicted from any of the theories. The results of these experiments are additionally presented elsewhere (Johnson, et al., in prep).

Experiment 1

Experiment 1 was designed to test whether meaningful differences exist between the way people read and understand sentences with RCs when the critical NPs of these sentences either both naturally occur with high frequency or both naturally occur with low frequency in the lexicon. In connection with Experiment 2, the results may shed light on other prominent theories of complex sentence comprehension. As these theories have already been presented, a discussion of the insights that the results of these two experiments provide will be reserved until after the presentation of the methods and results of both of these experiments.

Experiment 1 compared responses to sentences created by the combination of two independent variables, sentence type and NP type. The sentence types used were object-extracted RCs and subject-extracted RCs. Both of the NP type conditions in this experiment contained similar critical NPs (in terms of NP frequency), but the heads of these NPs were either both HF nouns or both LF nouns.
Methods

Participants. Forty 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 36 sentences, each containing a RC that modified the subject NP of the main clause (NP1). Twenty-four of the sentences were taken from Gordon, et al. (2006); an additional eight sentences were created for this and the next experiment. The stimuli all included definite descriptions in both the sentential-head NP position (NP1) and in the NP position embedded in the RC (NP2). Half of the sentences for each participant contained descriptive critical NPs whose heads were high frequency (HF) in nature in both the sentential-head and RC-embedded positions, and half of the sentences for each participant contained descriptive critical NPs whose heads were low frequency (LF) in nature in both the sentential-head and RC-embedded positions. These conditions may thus be referred to as the HF NP condition and the LF NP condition. Additionally, the ordering of the critical NPs was counterbalanced across participants. The frequency of the head of the NPs was determined by taking into consideration word frequency information from the Celex 2 frequency database. The logarithms of the total number of occurrences per million from this database for the high-frequency descriptions were all greater than 1.3, while the logarithms for the total number of occurrences per million of the low-frequency descriptions were all less than .5. A particular counterbalance is presented in 9a to 9h where 9a-9d contain HF NPs and 9e-9h contain LF NPs, and where 9a, 9c, 9e, and 9g contain object-extracted RCs and 9b, 9d, 9f, and 9h contain subject-extracted RCs.
9a) The painter that the criminal tolerated poured syrup on the French toast.

9b) The painter that tolerated the criminal poured syrup on the French toast.

9c) The criminal that the painter tolerated poured syrup on the French toast.

9d) The criminal that tolerated the painter poured syrup on the French toast.

9e) The mentor that the barbarian tolerated poured syrup on the French toast.

9f) The mentor that tolerated the barbarian poured syrup on the French toast.

9g) The barbarian that the mentor tolerated poured syrup on the French toast.

9h) The barbarian that tolerated the mentor poured syrup on the French toast.

A set of 44 filler sentences was used. The fillers were ideationally complex with a variety of syntactic structures, but they did not include restrictive RC structures.

Design and procedure. Eight counterbalanced lists were created such that each experimental sentence appeared in only one condition in a list. Across lists, each experimental sentence occurred in all conditions (the eight conditions were created by the combination of the factors of RC type and frequency of the head of the NPs and by the counterbalancing of the ordering of the NPs). Each participant was presented with one of these eight lists, which constituted an experimental run. Additionally, each experimental run consisted of four blocks. The first block contained fourteen filler sentences and served as a warm-up block. The next three blocks each contained ten filler sentences and twelve experimental sentences. The order of presentation of sentences was randomized within each block. To end the presentation of each sentence, participants pressed the space bar when they were finished reading the sentences for natural comprehension. To end the presentation of each comprehension question, participants pressed either a key
labeled for a true response or a key labeled for a false response once they had determined their answer.

Throughout the entire experimental run each participant wore an EyeLink system eye-tracking device that was manufactured by SensoMotoric Instruments (SensoMotoric Instruments and SR Research of Berlin, Germany and Osgoode, Canada, respectively). The eye-tracker sampled pupil location at a rate of 250 Hz. In addition, the system parsed the samples into fixations and saccades. After undergoing a routine that calibrated the eye-tracker, participants began the experimental run. The materials of the experiment were presented on a computer screen. Each trial began with the presentation of a fixation point on the screen at the location where the first word of the sentence would later be presented. The presentation of this fixation point served both to direct the gaze of the participant to the location of the beginning of the sentence and to maintain the calibration of the eye-tracker. During the presentation of the fixation point, the experimenter used another computer to monitor the location of the direction of gaze of the participant. When the gaze of the participant was judged to be sufficiently steady on the fixation point the experimenter pressed a button to make the fixation point disappear and the sentence appear. After reading the sentence the participant pressed the spacebar to indicate completion. The sentence then disappeared and the comprehension question relating to that sentence appeared. Then, after the participant pressed the button corresponding to his or her answer to the question, the trial ended and the fixation point for the next trial appeared. During each trial the experimenter could see the location of the eye-position of the participant relative to the location of the words of the trial on the computer the experimenter was using. If the calibration of the eye-tracker appeared inadequate, the experimenter would recalibrate the eye-tracker between trials.
Results

Results for this experiment and for the subsequent experiment will be divided into certain critical regions of text and will be organized so as to focus on: 1) the main effects of NP frequency on early measures of processing, which are presumably associated with low-level stimulus identification and lexical access. 2) The main effect of RC type, which should involve higher-level processing and might be expected to occur early and persist into later measures of processing. And 3) The interaction of NP frequency and RC type (with different RC types presumably being associated with differing levels of memory demands), which would be expected also to occur early and persist to later measures of processing if frequency of the heads of the NPs when the NPs are matched does have an influence on memory processes. Thus, the presentation of results will include measures designed to reflect different components of cognitive processing, in terms of the time-course of these components.

The critical measures presented will be gaze durations, and rereading durations. Gaze durations are defined as the sum of the durations of the initial fixations on a region, provided that no material downstream in the sentence has been viewed. The gaze duration on a region terminates when the gaze is first directed away from the region of interest (regardless of whether the subsequent fixation is progressive or regressive in relation to the region of interest)\(^2\). Rereading durations are defined as the total time spent fixating a region minus the gaze durations on a region.

\(^2\) First-pass reading time has been recommended as an alternative label for gaze duration when the region of interest is greater than a single word (Rayner, in press) though gaze duration is sometimes used for short multi-word regions (Rayner, Warren, Juhasz & Liversedge, 2004). However, because the present analyses use both single-word and multi-word regions, we use the label gaze duration for both so as to avoid using different labels when the same measure is applied to different types of regions.
The regions of interest for this experiment and for the subsequent experiment are the head of NP1, the head of NP2, and the RC region. The RC region consists of the three words after the complementizer “that” and before the matrix verb. This region is chosen as the potential locus of interaction effects, as it is the region in which integration of both NPs with a verb occurs. We also analyzed a region including the RC region and the matrix verb for both Experiment 1 and Experiment 2. The patterns of results were similar to those of the RC region and will not be included here for purposes of brevity.

We also report the offline measure of comprehension question accuracies, which showed a pattern similar to those of reading durations on the RC region.

**NP1 Head**

Figure 1 shows the gaze durations and rereading durations on the NP1 head. Gaze durations showed a strong effect of NP frequency, with HF NP1s being read significantly faster (267 msec) than LF NP1s (329 msec; \(F_1(1,39) = 21.96\) MSE = 6968, \(p < .001\), \(F_2(1,35) = 40.83\) MSE = 3527, \(p < .001\)). There was no effect of RC type on gaze durations on NP1 and no interaction between NP frequency and RC type, findings that would be expected given that no text downstream from NP1 had been fixated yet for these measures, offering no indication to the reader yet of RC type.

Rereading durations of the NP1 head did show an effect of RC type, with NP1s in sentences containing subject-extracted RCs being read more quickly (409 msec) than NP1s in sentences containing object-extracted RCs (492 msec; \(F_1(1,39) = 15.59\) MSE = 17702, \(p < .001\), \(F_2(1,35) = 10.47\) MSE = 26508, \(p < .001\)). The frequency effects observed during gaze durations on NP1 obtained significance during rereading durations by subjects and almost by items in that HF NP1s were read more quickly (423 msec) than LF NP1s (477 msec; \(F_1(1,39) = 14.89\) MSE = 7808, \(p < .001\), \(F_2(1,35) = 3.47\) MSE =
There was no significant interaction between NP frequency and RC type for rereading durations of NP1.

Figure 1: Gaze Durations and Rereading Durations on Head of NP1 for Experiment 1
**NP2 Head**

Figure 2 shows the gaze durations and rereading durations on the NP2 head.

Gaze durations on NP2s showed a strong effect of NP frequency, with HF NP2s being read significantly faster (274 msec) than LF NP2s (323 msec; $F_{1,39} = 28.34$ MSE =

Figure 2: Gaze Durations and Rereading Durations on Head of NP2 for Experiment 1
There was also a strong effect of RC type on NP2 gaze durations where NP2s in object RCs were actually read faster (273 msec) than NP2s in subject RCs (325 msec; F\(_1\)(1,39) = 21.31, MSE = 5119, p < .001, F\(_2\)(1,35) = 76.78, MSE = 1233, p < .001). This main effect of RC type, though, is confounded by the position of the NP2 being different in object RCs and subject RCs. There was no interaction between NP frequency and RC type for gaze durations on NP2.

Rereading durations of the NP2 head also showed an effect of frequency, with HF NP2s being read more quickly (364 msec) than LF NP2s (422 msec; F\(_1\)(1,39) = 8.35, MSE = 16281, p < .007, F\(_2\)(1,35) = 9.61, MSE = 14071, p < .005). Rereading durations of the NP2 head also showed an effect of RC type, such that NP2s in object RCs were actually read faster (354 msec) than NP2s in subject RCs (432 msec; F\(_1\)(1,39) = 16.33, MSE = 14861, p < .001, F\(_2\)(1,35) = 10.19, MSE = 21618, p < .004). Again this main effect of RC type is confounded by the position of the NP2 being different in object RCs and subject RCs. There was no interaction between NP frequency and RC type for rereading durations on NP2.

**RC Region**

Figure 3 shows the gaze durations and rereading durations on the RC region. Gaze durations on the RC region showed a strong main effect of NP frequency, with RCs containing HF NPs being read more quickly (597 msec) than RCs containing LF NPs (676 msec; F\(_1\)(1,39) = 14.60, MSE = 17182, p < .001, F\(_2\)(1,35) = 9.15, MSE = 23244, p < .006). Though there was a trend toward a main effect of RC type of gaze durations on the RC region, with subject RCs being read more quickly (616 msec) than object RCs (656 msec); this trend did not reach significance (F\(_1\)(1,39) = 2.45, MSE = 26006, p > .125,
F$_2$(1,35) = 3.13 MSE = 21623, p > .085). There was no interaction between NP frequency and RC type for gaze durations on the RC region.
Rereading durations on the RC region showed a trend toward a main effect of NP frequency with RCs containing HF NPs being read more quickly (926 msec) than RCs containing LF NPs (1006 msec); this trend did not reach significance ($F_1(1,39) = 3.54$ $MSE = 71385$, $p > .066$, $F_2(1,35) = 3.03$ $MSE = 75938$, $p > .089$). There was a strong effect of RC type on rereading durations of the RC region, with subject RCs being read more quickly (866 msec) than object RCs (1062 msec; $F_1(1,39) = 30.08$ $MSE = 51264$, $p < .001$, $F_2(1,35) = 17.31$ $MSE = 82497$, $p < .001$). There was no interaction of NP frequency and RC type for rereading durations of the RC region.

Comprehension Question Accuracies

The offline measure of comprehension question accuracies showed a main effect of RC type on accuracy, with responses to questions following subject RCs being more accurate (91.4 %) than questions following object RCs (86.4 %; $F_1(1,39) = 5.81$ $MSE = 172.21$, $p < .022$, $F_2(1,35) = 8.18$ $MSE = 110.00$, $p < .008$). There was no main effect of NP frequency on comprehension question accuracies. There was also no interaction between NP frequency and RC type for comprehension question accuracies.
Experiment 2

Experiment 2 was similar to Experiment 1, except the frequencies of the NPs were mixed, such that each sentence contained one HF critical NP and one LF critical NP (where the frequency of the NP again refers to the frequency of the head of the NP). The ordering of the frequency of the NPs was manipulated such that half of the sentences contained a HF NP in the head NP position and a LF NP in the embedded NP position and the other half of the sentences contained a LF NP in the head NP position and a HF NP in the embedded NP position.

Methods

Participants. Forty students from the same population as the previous experiment participated in the study.

Stimuli, design and procedure. The stimuli were similar to those of the previous experiment except that the critical NPs of the experimental sentences were recombined so that each sentence contained one critical NP that was low-frequency in nature and one critical NP that was high-frequency in nature. This recombination consisted of using one of the previously-used high-frequency NPs and one of the previously-used low-frequency NPs from a given experimental sentence (across counterbalances) in Experiment 1 as the critical NPs for a given experimental sentence in the current experiment. The ordering of these NPs with respect to their frequency was additionally counterbalanced so that each recombination of the experimental sentences was presented in either its high/low frequency ordering or its low/high frequency ordering, where the critical NP positions again were the sentential-head and the NP embedded within the RC. Thus, this experiment consisted of eight counterbalanced lists in which the counterbalances were
determined by the combination of the two independent variables: 1) frequency ordering (HF NP1 & LF NP2, 10a, 10b, 10e, & 10f or LF NP1 & HF NP2, 10b, 10c, 10g, & 10h) and 2) and RC condition (object-extracted, 10a, 10c, 10e, & 10g vs. subject extracted, 10b, 10d, 10f, & 10h) and the selection of NPs with respect to their frequency from the stimuli of Experiment 1 (i.e., was the first NP chosen to be the high-frequency NP or was the second). An example of a counterbalancing of a particular experimental stimulus is presented in 10a to 10h:

(10a) The painter that the barbarian tolerated poured syrup on the French toast.
(10b) The painter that tolerated the barbarian poured syrup on the French toast.
(10c) The barbarian that the painter tolerated poured syrup on the French toast.
(10d) The barbarian that tolerated the painter poured syrup on the French toast.
(10e) The criminal that the mentor tolerated poured syrup on the French toast.
(10f) The criminal that tolerated the mentor poured syrup on the French toast.
(10g) The mentor that the criminal tolerated poured syrup on the French toast.
(10h) The mentor that tolerated the criminal poured syrup on the French toast.

Each participant was presented with one of the eight counterbalanced lists of experimental and filler stimuli. All other aspects of the design and procedure were the same as in the preceding experiment.

Results

The presentation of the results of Experiment 2 will be similar to that of Experiment 1 with a focus on gaze durations and rereading durations on the NP1 and
NP2 heads and the RC region. Also, similar to the results of Experiment 1, the accuracies in response to the comprehension questions will be presented.

**NP1 Head**

Figure 4 shows the gaze durations and rereading durations on NP1. Like Experiment 1, NP1 showed large effects of the frequency of NP1 on gaze durations, with HF NP1s being read more quickly (282 msec) than LF NP1s (338 msec; $F_{1}(1,39) = 14.52$, $MSE = 8475$, $p < .001$, $F_{2}(1,35) = 20.17$, $MSE = 5320$, $p < .001$). Also like Experiment 1, as readers should not know whether they are reading a sentence with an object-extracted RC or a subject-extracted RC during gaze durations on NP1 there was no effect of RC type on gaze durations on NP1 and no interaction between NP frequency and RC type for gaze durations on NP1.

There was a trend toward rereading durations for HF NP1s being quicker (449 msec) than LF NP1s (506 msec); this trend fell just short of significance ($F_{1}(1,39) = 3.66$, $MSE = 36301$, $p > .062$, $F_{2}(1,35) = 3.76$, $MSE = 30128$, $p > .060$). Rereading durations on the NP1 head showed a main effect of RC type, with NP1s in sentences with subject–extracted RCs being read more quickly (450 msec) than NPs in sentences with object–extracted RCs (505; $F_{1}(1,39) = 7.26$, $MSE = 16541$, $p < .011$, $F_{2}(1,35) = 6.65$, $MSE = 16701$, $p < .015$). There was no interaction between NP frequency and RC type for rereading durations of NP1.

**NP2 Head**

Figure 5 shows the gaze durations and rereading durations on the NP2 head. Like Experiment 1, gaze durations on NP2 showed a strong effect of NP2 frequency, with HF NP2s being read significantly faster (281 msec) than LF NP2s (319 msec; $F_{1}(1,39) = 16.87$, $MSE = 3315$, $p < .001$, $F_{2}(1,35) = 10.34$, $MSE = 5006$, $p < .004$). There was also a
strong effect of RC type on NP2 gaze durations where, like in Experiment 1, NP2s in 
*object* RCs were actually read faster (275 msec) than NP2s in *subject* RCs (325 msec; 
$F_1(1,39) = 22.06$ MSE = 4638, $p < .001$, $F_2(1,35) = 36.86$ MSE = 2433, $p < .001$). Also 
like Experiment 1, though, this main effect of RC type is confounded by the position of
the different in object RCs and subject RCs. There was no interaction between NP frequency and RC type for gaze durations on NP2.

Figure 5: Gaze Durations and Rereading Durations on Head of NP2 for Experiment 2

NP frequency effects on NP2 disappear by the later reading measure of rereading durations on NP2. However, the RC-type pattern observed for gaze durations on NP2s
was reversed for rereading durations on NP2, with NP2s in subject-extracted RCs being read more quickly (408 msec) than NP2s in object-extracted RC (498 msec; $F_1(1,39) = 9.78 \text{ MSE} = 32575$, $p < .004$, $F_2(1,35) = 13.07 \text{ MSE} = 22078$, $p < .002$). Again, though, RC type effects on NP2 were confounded by the position of NP2 in the sentence. Additionally, an interaction between NP frequency-ordering and RC type is observed in rereading durations on NP2. For sentences with a HF NP1 and a LF NP2 the difference in rereading durations on NP2 between object RCs and subject RCs was 147 msec. In contrast, for sentences with a LF NP1 and a HF NP2 the difference in rereading durations on NP2 between object RCs and subject RCs was only 32 msec. While this first indication of an interaction between NP frequency and RC type was significant ($F_1(1,39) = 5.96 \text{ MSE} = 22168$, $p < .020$, $F_2(1,35) = 8.36 \text{ MSE} = 14315$, $p < .008$), it, like the main effect of RC type, contained the confound of the position of NP2 in the sentence.

**RC Region**

Figure 6 shows gaze durations and rereading durations on the RC region. Gaze durations on the RC region showed a main effect of RC type, with subject-extracted RCs being read more quickly (616 msec) than object-extracted RCs (694 msec; $F_1(1,39) = 14.07 \text{ MSE} = 17142$, $p < .002$, $F_2(1,35) = 12.21 \text{ MSE} = 17516$, $p < .002$). NP frequency did not have a main effect on gaze durations on the RC region. Most importantly, though, a significant interaction between NP frequency-ordering and RC type was observed for gaze durations on the RC region. For sentences with a HF NP1 and a LF NP2 the difference in gaze durations on the RC region between object RCs and subject RCs was 136 msec. In contrast, for sentences with a LF NP1 and a HF NP2 the difference in gaze durations on NP2 between object RCs and subject RCs was only 19 msec. This interaction between NP frequency and RC type was significant ($F_1(1,39) = 10.26 \text{ MSE} =$
13226, $p < .004$, $F_2(1,35) = 5.64$ MSE = 21192, $p < .024$), but can be interpreted differently than the interaction observed for rereading durations on NP2. An analysis of reading durations on the entire RC region contains both a description and a verb across all the experimental conditions. The ordering of these words is different for object-
extracted RCs and subject-extracted RCs, but their position within the sentence as a whole is identical. Thus, the interaction observed for the RC region cannot be attributed to the potential confound of sentential position.

The pattern of results observed for gaze durations on the RC region persisted for rereading durations of the RC region. There was a main effect of RC type on rereading durations of the RC region, with subject-extracted RCs being read more quickly (1006 msec) than object-extracted RCs (1175 msec; $F_1(1,39) = 17.01$ MSE = 67125, $p < .001$, $F_2(1,35) = 13.39$ MSE = 74540, $p < .002$). There also was no effect of NP frequency on rereading durations of the RC region. There was, however, a significant interaction between NP frequency-ordering and RC type for rereading durations of the RC region. For sentences with a HF NP1 and a LF NP2 the difference in rereading durations on the RC region between object-extracted RCs and subject-extracted RCs was 294 msec. In contrast, for sentences with a LF NP1 and a HF NP2 the difference in rereading durations on NP2 between object RCs and subject RCs was only 43 msec. This interaction between NP frequency and RC type was significant ($F_1(1,39) = 5.94$ MSE = 106098, $p < .020$, $F_2(1,35) = 8.16$ MSE = 67106, $p < .008$). Again, this interaction is not confounded by position in the sentence.

Comprehension Question Accuracies

It could be possible to argue that a speed/accuracy tradeoff existed for readers that may have accounted for the effects observed in the online reading duration measures. However, this seems unlikely as the pattern seen in the offline measure of accuracy in response to questions designed to test an understanding of the noun-verb relations in the sentences closely resemble those of the reading duration measures. There was a trend toward an effect of RC type on accuracies, with performance being better in response to
questions following sentences with subject RCs (91.9\%) than in response to questions following sentences with object RCs (88.1\%); this effect just missed significance (F_{1}(1,39) = 3.08 \text{ MSE} = 196.58, p > .086, F_{2}(1,35) = 8.27 \text{ MSE} = 65.87, p < .008).

The fact that the RC type effect on accuracies just missed significance is probably related to the existence of a main effect of NP frequency-ordering on question accuracies and the existence of a significant interaction between NP frequency-ordering and RC type for question accuracies. Accuracies were higher for questions following sentences with a LF NP1 and a HF NP2 (92.1\%) than they were for questions following sentences with a HF NP1 and a LF NP2 (87.9\%; F_{1}(1,39) = 8.01 \text{ MSE} = 86.66, p < .008, F_{2}(1,35) = 7.23 \text{ MSE} = 86.43, p < .012). Moreover, the interaction between NP frequency-ordering and RC type for accuracies was significant. The difference in accuracies between questions following sentences with object-extracted RCs and questions following sentences with subject-extracted RCs for sentences with a HF NP1 and a LF NP2 was 7.5\%. In contrast, the difference in accuracies between questions following sentences with object-extracted RCs and questions following sentences with subject-extracted RCs for sentences with a LF NP1 and a HF NP2 was only 0.3\%. This interaction was significant (F_{1}(1,39) = 5.73 \text{ MSE} = 91.09, p < .023, F_{2}(1,35) = 5.91 \text{ MSE} = 79.44, p < .021).

Thus it seems that a speed-accuracy tradeoff is not responsible for the pattern of results observed in the reading duration measures.
Discussion of Results of Experiments 1 and 2

Using subject-extracted and object-extracted RC structures all containing definite descriptions as the critical NPs, it was shown that the processing difficulty associated with object-extracted RCs as compared with subject-extracted RCs depends upon the frequencies of the critical NPs in these sentences. This finding has been illustrated through examples (3a) to (3d), which are repeated here for clarity.

(3a) The painter that the criminal tolerated poured syrup on the french toast.

(3b) The mentor that the barbarian tolerated poured syrup on the french toast.

(3c) The painter that the barbarian tolerated poured syrup on the french toast.

(3d) The mentor that the criminal tolerated poured syrup on the french toast.

A comparison of the processing difficulty of these object-extracted structures with their subject-extracted counterparts (in which the head NP of the sentence is made to be the subject of the RC and the embedded NP is made to be the object of the RC) revealed that processing was facilitated when the head NP was low frequency (LF) and the embedded NP was high frequency (HF), as in (3d), but not in any of the other frequency combinations (HF head NP, HF embedded NP in (3a); LF head NP, LF embedded NP in (3b); or HF head NP, LF embedded NP in (3c)).

The perspective-shift account (MacWhinney, 1977; MacWhinney & Pleh, 1988) offers no explanation as to why this frequency manipulation changes the processing difficulty of object-extracted RCs. If shifting perspectives is what mediates processing difficulty, then there is no reason to believe that processing would be facilitated in the frequency combination of (3d) but in none of the other frequency combinations. The same shift in perspective would be expected to occur in all frequency combinations, so each of the object-extracted constructions should be more difficult to process than its
subject-extracted counterpart; thus, a shift in perspective cannot be the sole cause for the
difference in processing difficulty that is usually observed between object-extracted RCs
and subject-extracted RCs.

Also, the accounts of complex sentence processing that are based on our
experience with different types of constructions have not offered any reason to expect
processing for object-extracted RCs to be facilitated when the head NP is LF and the
embedded NP is HF. While some researchers have proffered that our relative degrees of
experience with certain NP types within certain sentence structures mediate the amount
of difficulty we experience with these structure/NP type combinations (Reali &
Christiansen, 2007) or that the discourse functions normally served by different types of
RCs mediate processing difficulty (Roland, et al., 2007; 2008), these accounts neither
suggest that the frequency of the critical NPs is related to our experience with these
structures nor that the frequency of the NPs is related to the discourse function of the
different RC types. In fact, under both of these theories, it might be expected that the
condition in which the head NP is LF and the embedded NP is also LF (as in (3b)) would
be the most difficult to process and the condition in which the head NP is HF and the
embedded NP is also HF (as in (3a)) would be the easiest to process. Most likely we
would be expected to have the least experience, both in a rote experiential way and in
terms of experience with certain types of discourse functioning, with sentences
containing two critical LF NPs, and we would be expected to have the most experience
with sentences containing two critical HF NPs. These theories, therefore, would seem to
predict that our lack of experience with these LF NPs would lead us to experience greater
processing difficulty when presented with sentences in which the two critical NPs are LF.
It should be noted, however, that a specific analysis of the frequency of occurrence of HF
definite descriptions and LF definite descriptions in RC structures has not been completed. It is possible, though it seems intuitively unlikely, that the patterns of results observed in Experiments 1 and 2 could follow patterns that potentially may be observed in a corpus analysis of RC structures designed to distinguish definite descriptions in these RC structures based on their frequency of natural occurrence in the language.

Constraint-based and cue-based theories (MacDonald, et al., 1994; McRae, et al., 1998; Tabor & Hutchins, 2004; Trueswell, et al., 1994; Vosse & Kempen, 2000; Gennari & MacDonald, 2008; Van Dyke, 2007; Van Dyke & McElree, 2006) also have difficulty explaining these NP frequency effects on the difference in processing difficulty between object-extracted and subject-extracted RCs. Both of these classes of theories purport that certain types of information (whether this information is referred to as constraints or cues) lead the reader to adopt certain sentential parses. Though these theories differ in that cue-based theories emphasize that this information is particularly important during the retrieval of verb heads from working memory while constraint-based theories emphasize that readers dynamically consider competing alternative parses based on this same type of information, both of these theories seem to agree that the information readers use to adopt certain parsings is mainly syntactic and semantic in nature. As an illustration, both of these theories would agree that the existence of alternative possible meanings for the verb *tossed*, which is present in (11a) (*tossed*, if considered only locally, could be either a past-tense verb or a verb embedded in a reduced RC), as opposed to the existence of only one possible interpretation of the verb *thrown*, which is present in (11b) (*thrown* can only be a verb embedded in a reduced RC), leads readers to experience more difficulty with (11a) than (11b) (Tabor, Galantucci, & Richardson, 2004; Van Dyke, 2007).
(11a) The coach smiled at the player tossed a Frisbee by the opposing team.

(11b) The coach smiled at the player thrown a Frisbee by the opposing team.

However, neither of these classes of theories have suggested anything resembling the notion that a reader, upon encountering a sentence with an object-extracted RC whose head NP is LF and whose embedded NP is HF (like (3d)), could use information related to the frequencies of the NPs either to predict that the sentence indeed contains an object-extracted RC or to somehow assist his or her parsing system in determining who was doing what to whom. Thus, it seems that constraint-based and cue-based theories of complex sentence comprehension, in their current forms, fail to predict the NP frequency results described above.

Theories that emphasize the limitations of working memory as being the mediator of the difficulty we experience when reading complex sentences also have trouble explaining such results. Even if the frequency of the NPs somehow relates to givenness, the SPLT/DLT (Gibson, 1998; Gibson, 2000; Warren & Gibson, 2002) fails to account for these NP frequency findings. Under the SPLT/DLT, it could be expected that high frequency NPs are somehow more given than low frequency NPs, which could explain why object-extracted RCs are made easier in the LF head NP/HF embedded NP condition (as the potentially more given embedded and intervening HF NP may incur less processing cost to the reader). However, the SPLT/DLT would also expect this reduction in processing difficulty in the condition in which both NPs are HF, as processing cost is influenced only by the givenness of intervening NPs in that theory (i.e., it should not matter what the characteristics of the sentential head NP are). As no reduction in processing difficulty is observed for object-extracted RCs whose head is HF and whose
embedded NP is also HF, the SPLT/DLT does not seem capable of explaining these results.

Finally, in its present form, the SBMIH (Gordon, et al. 2001; 2002; 2004; 2006) does not predict these findings. In particular it has difficulty explaining why processing difficulty is attenuated when an object-extracted RC has a LF head NP and a HF embedded NP, but not when an object-extracted RC has a HF head NP and a LF embedded NP. The SBMIH is based on the notion that the similarity of the critical NPs mediates the degree of processing difficulty experienced for object-extracted RCs. If degree of frequency is indeed a factor that is able to produce similarity or dissimilarity, then the order of NPs that differ in frequency should not be a factor in determining difficulty. Processing should be facilitated anytime the NPs are dissimilar in terms of frequency, no matter what the ordering is.

However, while a simple version of the SBMIH would predict a reduction in processing difficulty for sentences containing object-extracted RCs and mixed frequency NPs regardless of the order in which the NPs are presented, it seems that a careful reconsideration of the processes involved in reading these RCs could lead to a retooling of the SBMIH that would make it adept at explaining the results of the RC/NP frequency studies described above. In light of the surprising results of these experiments, it seems that this reconsideration should include some attention to the findings of working memory research involving manipulations of the content of lists of words, especially manipulations involving the frequency of words. Thus, a review of this subset of working memory research will be provided before the presentation of a modified version of the SBMIH, which will be able to account for the results of these RC/NP frequency studies and which can be further tested via the experiments being currently presented.
Chapter 4: List Memory, Relative Salience, and a Modified SBMIH

The SBMIH proposes that interference between critical NPs in working memory is responsible for the processing difficulty associated with sentences containing object-extracted RCs. Additionally, as the results described above illustrate, the similarity of the frequency of these critical NPs seems to be a property that may contribute to the level of difficulty experienced in processing such sentences. In the manner that the SBMIH has previously been proposed, it seems inappropriate to suggest that word frequency is a factor that can contribute to similarity (common noun status was proposed as the factor mediating potential similarity, and the frequency of a definite description has no impact on its common noun status). Word frequency, while intuitively seeming relevant to our parsing systems, does not change the lexical class to which a word belongs. As the results of the frequency studies described above are inconsistent with the current instantiation of the SBMIH it seems necessary to: 1) reevaluate the SBMIH and 2) to do so through a consideration of what research geared towards understanding the role of word frequency in memory operation has shown so it can be better understood how working memory may operate in these complex sentences.

It seems particularly relevant to the current line of research that much work in the list memory literature has been devoted to determining the effect of list composition (i.e., “pure” vs. “mixed” lists) on the subsequent recall of different types of items of the lists, as the SBMIH is based on the critical NPs being similar to one another (or “pure”, as the list memory literature refers to them) or not (or “mixed”, as the list memory literature
refers to them). A typical experiment in this type of list memory research would involve a manipulation of list composition such that the items in a list are either pure, (i.e., of the same type) or mixed (i.e., of two different types). Different dimensions have been used in dividing the items of these lists into types (bizarre vs. non-bizarre items, McDaniel, DeLosh, & Merritt, 2000; generated vs. read items, Mulligan, 2002; Serra & Nairne, 1993; Hirshman & Bjork, 1988; perceptually degraded vs. intact items, Mulligan, 1999; humorous vs. non-humorous items, Schmidt, 1994; orthographically distinct vs. orthographically common items, Hunt & Elliot 1980; and infrequent vs. frequent items, Merritt, et al., 2006; DeLosh & McDaniel, 1996; Van Overschelde, 2002; Duncan, 1974; Gregg, 1976; Gregg, et al., 1980).

Importantly, in all of these manipulations, items that stood out in some way, or were distinct (items that were bizarre, generated, perceptually degraded, humorous, orthographically distinct, or infrequent) from their more normal counterparts showed higher recall after study when the items were presented in mixed lists, but not when the items were presented in pure lists, both when these items were compared with recall levels of concurrently-studied, less distinct-items in mixed lists and when they were compared with recall levels of the exact same items when those items had been studied in pure lists. Particularly relevant to the findings of the study utilizing the NP frequency manipulation in RCs is the pattern of results in the list memory literature showing that infrequent words are recalled better than frequent words following the presentation of these words in mixed lists (Merritt, et al., 2006; DeLosh & McDaniel, 1996; Van Overschelde, 2002; Duncan, 1974; Gregg, 1976; Gregg, et al., 1980).

In order to generalize the implications of the results of such list memory research to the processes involved in sentence comprehension, attention should be given to the
locus of the recall of these NPs in sentence structures. It seems intuitively likely that the key process leading to the successful comprehension of sentences containing object-extracted RCs is the ability to correctly recall the head of the RC after the intervening preverbal parts of the RC have been read, and theories that suggest that working memory plays an important role in complex sentence processing also tend to suggest that recall of the heads of verbs at their points of integration is the mediating factor in processing difficulty (Gibson 1998, 2000; Warren & Gibson, 2002; Lewis & Vasishth, 2005; Van Dyke, 2007; Van Dyke & McElree, 2006). If this notion is indeed true, then it seems that situations that enhance recall for the head of the RC would attenuate the amount of difficulty experienced in processing object-extracted RCs. Additionally, if the same processes that operate in list memory paradigms operate during language processing, then it seems that having mixed-frequency NPs as the critical NPs in an object-extracted RC construction and having the NP whose recall is of paramount importance (the head of the RC) be LF, then it seems processing would be facilitated. The finding of the NP frequency/RC experiments that processing is facilitated in exactly that condition seems consistent with the findings of the list memory literature.

Another quite interesting suggestion from the list memory research may also be related to the processes that occur when reading object-extracted RCs. Recent research (Merritt, et al., 2006; DeLosh & McDaniel, 1996) has suggested that the processing advantage for distinct items in mixed lists may be related to attention to item-specific information associated with those distinct items at the expense of other information. In particular, these studies suggest that memory for order-based information (i.e., the order in which items were studied or encountered) is sacrificed during the processing of distinct

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3 A test of this assumption is the subject of Experiment 4
items in mixed lists. Object-extracted RCs present the critical NPs in a reverse ordering of their canonical word ordering in English. Perhaps the loss of ordering information associated with processing a distinct head NP when paired with a less-distinct embedded NP actually helps readers in that it may reduce confusion related to the processing (or, better said, the lack of processing) of canonical word order violations. This suggestion is speculative, but remains a possibility.

Thus it seems that some revision of the SBMIH may be in order. Gordon, et al. (2004), in an attempt to identify the factor determining whether critical NPs in complex sentences are similar or dissimilar, suggested that common-noun status was the factor by which similarity could be determined. This conclusion was reached after a consideration of all the conditions in which processing of object-extracted RCs was facilitated (when the head NP was a definite description and the embedded NP was a name, you, or everyone) and all the conditions in which processing of object-extracted RCs was not facilitated (when the head NP was a definite description and the embedded NP was also a definite description, an indefinite description, or a generic). For all the cases in which processing was facilitated, the head NP was a common noun and the embedded NP was not a common noun, and for all the cases in which processing was not facilitated both the head NP and the embedded NP were common nouns. However, the common-noun status suggestion cannot explain the reduction in processing difficulty for object-extracted RCs that occurs when the head NP is a LF definite description and the embedded NP is a HF definite description, as both of these NPs are common nouns.

Instead, the results of memory research on pure lists vs. mixed lists seem to shed light on what may be occurring in all of the results obtained in the studies related to the SBMIH (Gordon, et al., 2001; 2002; 2004; 2006; Johnson & Gordon, 2007; Johnson, et
al., in prep.). The list memory research seems to suggest that when items that are in some way distinctive occur in a stimulus with more ordinary items, the relative salience of the distinctive items enhances their subsequent recall. A consideration of conditions in which the processing of object-extracted RCs is facilitated ((12a) to (12d)), as compared to conditions in which the processing of object-extracted RCs is not facilitated ((12e) to (120j)) suggests that processing is only facilitated when the head NP has greater salience than the embedded NP on some dimension.

(12a) The senator that you attacked admitted the error.
(12b) The senator that Robert attacked admitted the error.
(12c) The senator that everyone attacked admitted the error.
(12d) The mentor that the criminal tolerated poured syrup on the french toast.
(12e) The painter that the criminal tolerated poured syrup on the french toast.
(12f) The mentor that the barbarian tolerated poured syrup on the french toast.
(12g) The painter that the barbarian tolerated poured syrup on the french toast.
(12h) The senator that the reporter attacked admitted the error.
(12i) The senator that a reporter attacked admitted the error.
(12j) The senator that reporters attacked admitted the error.

In (12a) to (12c) it seems that the degree of semantic information associated with the definite description head as compared with a name or a pronoun being used as the embedded NP makes the head NP relatively more salient than the embedded NP. In (12d) it seems the LF status of the head NP makes it relatively more salient than the HF embedded NP. Thus, in (12a) to (12d) a relative saliency account would correctly predict that processing is facilitated. In (12e) to (12f) the head NP and the embedded NP are equal in frequency (whether HF or LF), making neither NP more relatively salient than
the other. Thus, a relative saliency account would correctly predict that processing should not be facilitated in these cases. In (12g) the head NP is HF and the embedded NP is LF, but as it seems that recall of the head NP at the verbal regions is of paramount importance, processing should not be facilitated, because recall of the embedded NP, and not the head NP, should be enhanced. Thus, a relative saliency account would correctly predict that processing should not be facilitated in this case. Finally, though the NPs in (12h) to (12j) are superficially dissimilar in terms of their morphological construction, they still consist of lexemes that are similar in frequency and relative salience. Thus, a relative salience account would correctly predict that no processing facilitation should be observed in these cases.

When the results of all of these RC studies are taken together, it seems that common noun status is not the factor determining whether NPs are considered similar or not by our parsing systems. Instead it seems that a modification of the SBMIH can explain the differences in processing difficulty that are experienced across these different NP combinations. This modification can be summarized as follows: 1) The relative salience of the head NP as compared with the embedded NP determines the degree of difficulty experienced when processing object-extracted RC constructions, 2) When the head NP is relatively more salient than the embedded NP its memory trace is enhanced and the possibility of interference from the embedded, less salient NP, is reduced; therefore recall of the head NP at the verbal regions is facilitated, and 3) When the head NP is equal in salience to or less salient than the embedded NP, the possibility of interference for the memory trace for the head NP is increased upon encountering the embedded NP; therefore, recall of the head NP at the verbal regions may be disrupted (whether this disruption results from a distraction/forgetting of the original memory trace
or from an overburdening of our memory system’s capacity limitations), leading to comprehension difficulty.

In their present forms, other theoretical approaches to the processing of complex sentences cannot account for the results of Experiments 1 and 2. However, it is important to note that constraint- and cue-based theories as well as theories emphasizing linguistic experience might also be elaborated in such a way that they could explain the pattern of results in those experiments. Theories emphasizing constraints, cues, or our experience with different items have not directly suggested that information associated with the frequency of items within different syntactic structures can guide us in determining the correct parsing of such structures. However, the results of one study (Reali & Christiansen, 2007) have indirectly suggested, at least to some degree, that the relative frequency of NPs in object-extracted RC structures may be related to our ability to comprehend such structures. Though the study was not designed to test for effects of the relative frequency of NPs within RC structures, they found, through corpus analysis, that when RC structures contained a description as the head of the RC and a personal pronoun as the embedded NP object-extracted RCs occurred more often than subject-extracted RCs. This NP composition is actually one in which the head NP is relatively lower in frequency than the embedded NP (personal pronouns are some of the most common words in English). It is possible that readers are able to use their experience with object-extracted structures in which the head NP is relatively low frequency and the embedded NP is relatively high frequency in a a cue- or constraint-based manner to aid them in processing object-extracted RCs.

Experiments 3 is designed to further test the validity of the relative salience view against the view that relative word frequency can act as a cue- or constraint to the reader.
Experiment 4 is designed to determine where the locus of working memory-based effects occur in the processing of object-extracted RCs. Before these two experiments are presented, though, a brief discussion of a recent debate regarding the modularization of the working memory used during language comprehension is presented, as the results of the Experiments 3 and 4 may shed some light on this debate. This discussion is not of central importance to the current research, but as the results of the current research may provide insight into this important psycholinguistic debate, a brief discussion of this debate is warranted.

*Modularized vs. Non-Modularized Working Memory in Language Comprehension*

In recent years a debate regarding the nature of the working memory used during language comprehension has led to the formation of two camps which disagree as to whether this working memory is modularized or not. The first camp suggests that the working memory resources that are utilized during language comprehension are somehow modularized, or specialized for operations involving linguistic material, and are therefore distinct from our general working memory resources (see Waters and Caplan, 1996 and Caplan and Waters, 1999 for arguments for this modularized view of language-related working memory). The second camp suggests that the working memory that operates during language comprehension is the same as that which operates more generally (see Just and Carpenter, 1992 and Just, Carpenter, and Keller, 1996 for arguments for this non-modularized view of language-related working memory).

While the results of the current experiments will surely not resolve this debate, if additional evidence for the applicability of the relative salience principle of list memory research to complex sentence processing is found, then the results will support a non-
modularized view of language-based working memory. Likewise, if the processing of the complex sentences presented here does not seem to follow the relative salience principle of list memory research, then the results will support a modularized view of language-based working memory.
Chapter 5: Experiments Designed to Further Investigate Relative Salience

Experiment 3

It seems that current theories of complex sentence comprehension have difficulty explaining the results of the NP frequency/RC experiments in which processing was facilitated for object-extracted RCs with a LF head NP and HF embedded NP. However, it is possible that constraint-based and cue-based theories (and possibly even experientially-based theories) could be modified to suggest that readers use frequency information associated with NPs to determine the roles they are likely to play in sentences. Perhaps, upon encountering a LF NP, readers tend to expect that NP to serve in an object role. Similarly, perhaps, upon encountering a HF NP, readers tend to expect that NP to serve in a subject role. If this were the case, then constraint-based and cue-based theories would predict processing facilitation for object-extracted RCs in which the head NP is LF and the embedded NP is HF. In an object-extracted RC the head NP actually becomes the object of the RC and the embedded NP becomes the subject of the RC. Although the role of the head NP later must switch back to that of the subject, perhaps the processing of such sentences is at least temporarily enhanced if frequency information also conveys cue- or constraint-based information to the reader. It follows then that if readers are somehow able to use frequency information to guide them in determining the syntactic structure that may be expected, and this frequency information
guides them in the manner described above, then the only NP frequency combination in
which processing would be expected to be facilitated would be the LF head NP/HF
embedded NP condition.

However, in a manner similar to that suggested by list memory research, it is also
possible that the relative salience of the lexical-semantic information associated with NPs
plays the critical role in determining the processing difficulty associated with object-
extracted RCs. Such an explanation would predict the same pattern of results of the NP
frequency/RC experiments described above as that derived from a potential cue- or
constraint-based explanation. One way of testing which of these two accounts better
explains the findings of the NP frequency/RC study is to manipulate the relative salience
of the NPs while maintaining consistent NP frequencies, or at least consistent frequencies
of the head of the NPs. It seems the most straightforward way to accomplish such a
manipulation is to use HF NPs in both the head NP and embedded NP positions, but to
vary the relative salience of the head NP by manipulating whether the NP contains an
adjectival modification or not. Adding an adjectival modification to the head NP enables
an increase in the amount of lexical-semantic information associated with the NP without
altering the actual frequency of the NP head. This increase in lexical-semantic
information would be expected to increase the relative salience of the NP head without
altering the frequency of the head.

As such, under the possible constraint-based and cue-based explanations
described above, the difficulty of object-extracted RCs should be unaffected by the
inclusion of the adjectival modification of the head NP. In contrast, under the relative
salience modification of the SBMIH, increasing the amount of lexical-semantic
information associated with the head NP should increase its salience relative to the
embedded NP, decreasing the embedded NP’s ability to interfere with the memory trace for the head NP. In turn, processing of object-extracted RCs should be facilitated when the head NP is modified.

A further consideration in modifying the head NP with an adjective involves the manner in which the head NP should be modified. The feature-weighting account of NP modification has suggested, through experiments probing participants’ typicality ratings in response to modified NPs, that modifying a NP with an adjective that is related to real-world experience with that NP increases the salience of that particular aspect of the NP being modified (Murphy, 1988). Additionally, if this modification meets expectations associated with qualities of the NP then it can be considered to be positively diagnostic and can be expected to *increase* the likelihood that the NP at hand is a true representation of the concept underlying the NP (e.g., educated teacher). Conversely, if the modification contradicts expectations associated with qualities of the NP then it can be considered to be negatively diagnostic and can be expected to *decrease* the likelihood that the NP at hand is a true representation of the concept underlying the NP (e.g., ignorant teacher) (Smith & Osherson, 1984). As a goal of the current experiment is to control the frequency of the NPs, it is relevant to consider the possibility that adjectives that might highlight or contradict our expectations associated with these NPs may increase or decrease, respectively, our sense of the frequency of the concepts underlying the NPs. As such, adjectives that are orthogonal to our expectations associated with the NPs (or non-diagnostic adjectives; Smith & Osherson, 1984) have been chosen to modify the NPs (e.g., hungry teacher)\(^4\). These non-diagnostic adjectives should increase the

\(^4\) It should additionally be noted that little work has been done investigating the role that adjectives play in RC constructions. However, it has been shown that NPs containing adjectives involving a uniqueness claim, such as superlatives or the word *only* (e.g., the ugliest shoes; the only meal) co-occur with object-extracted RC constructions at high rates (Wasow, Jaeger, & Orr, in progress). Furthermore, it has been
salience of the NPs while leaving our sense of the frequency associated with the NPs unaltered.

The current experiment compares the patterns of comprehension for sentences containing object-extracted RCs with those of sentences containing subject-extracted RCs when the head NP of these sentences is either modified by a non-diagnostic adjective or is unmodified. A complete counterbalancing of a particular experimental stimulus is presented in (13a) to (13h) as an example.

(13a) The student that the doctor praised climbed the mountain just outside of town before it snowed.

(13b) The student that praised the doctor climbed the mountain just outside of town before it snowed.

(13c) The doctor that the student praised climbed the mountain just outside of town before it snowed.

(13d) The doctor that praised the student climbed the mountain just outside of town before it snowed.

(13e) The sleepy student that the doctor praised climbed the mountain just outside of town before it snowed.

(13f) The sleepy student that praised the doctor climbed the mountain just outside of town before it snowed.

(13g) The sleepy doctor that the student praised climbed the mountain just outside of town before it snowed.

(13h) The sleepy doctor that praised the student climbed the mountain just outside of town before it snowed.

noted that NPs containing such adjectives often sound incomplete without a subsequent RC (Fox & Thompson, in press). Such adjectives were not used in the current study.
Methods

Participants

Thirty-six participants were recruited from the Introductory Psychology Participant Pool at the University of North Carolina at Chapel Hill. They received credit towards a requirement of an Introductory Psychology course for their participation in the experiment. Additionally, four participants were recruited from fliers advertising the study and were paid $10 each for their participation. These participants did not receive any course credit for their participation.

Experimental Paradigm

The experimental paradigm was similar to that of Experiments 1 and 2, except that two separate eye-tracking devices were used in data collection\(^5\). The eye movements of twenty of the participants were tracked using an EyeLink system eye-tracking device (SensoMotoric Instruments and SR Research of Berlin, Germany and Osgoode, Canada, respectively) while they read sentences and answered questions related to the information in those sentences. This eye-tracking device was fitted to the participant’s head and sampled the gaze location of the pupil on a computer screen at a rate of 250Hz and parsed the time record of the tracks into fixations and saccades based on the displacement, velocity, and acceleration of the eyes. EyeLink eye-tracking devices, though having excellent horizontal accuracy, are less accurate in the vertical direction. As such, the tracks of all experimental trials were inspected via the TeView software package developed by Gary Feng. If, upon inspection, a track had been clearly dislocated vertically, the locations of the fixations were relocated via the TeView software, in a

\(^5\) It should be noted that a separate set of analysis was performed in order to determine whether the results vis à vis each of the two eye-tracking devices could be considered comparable. This set of analysis included all the measures reported here, but divided the results based on which eye-tracking device was used in data collection. The pattern of results was similar across the two devices.
vertical direction only, to the words which were evidently the target of the participant’s gaze. Software developed by the author then matched the coordinates of the participants’ fixations to the locations of the words of the stimuli and calculated various fixation measures (discussed below). The eye movements of the other twenty participants were tracked using an EyeLink 1000 system eye-tracking device (SR Research of Osgoode Canada). This eye-tracking device monitored the eye movements of participants via a camera that was mounted on the desktop in front of the participants. It sampled the gaze location of the pupil on a computer screen at a rate of 1000Hz, and, in a manner similar to that of the EyeLink system, parsed the time record of the tracks into fixations and saccades. The tracks of the fixations recorded by the EyeLink 1000 were relocated to their evident location in a manner similar to that which was used for the EyeLink data (in combination with the TeView software) via the DataViewer software developed by SR Research.

It should be noted that the use of eye-tracking methodology allows sentences to be presented in their entirety (as opposed to self-paced reading methodology, which typically presents participants with one word or region of words at a time). Thus, eye tracking methodology provides a measure of processing as it occurs during relatively normal reading and has been successfully exploited to study many issues in language processing (Rayner, 1998).

Materials

Materials for Experiment 3 are given in Appendix 1. Each experimental run consisted of 40 experimental sentences and 58 filler sentences. The experimental sentences were created by modifying the experimental sentences of Gordon, et al., 2001; 2004; 2006; 2007. Each contained either an object-extracted RC or a subject-extracted
RC with a definite description as the head of the sentence (and RC). This sentence head consisted of either a HF definite description NP that was modified in a non-diagnostic manner (e.g., the hungry teacher) or an unmodified HF definite description (e.g., the teacher). As the NPs in the experiment all consisted of definite descriptions, adjectives that could potentially be used to describe all the heads of the critical NPs in the study in a non-diagnostic manner were chosen as modifiers. Each experimental sentence was presented in all four possible conditions (as determined by crossing RC type and head NP type) across participants, but each participant saw only one version of each experimental sentence. Eight lists counterbalancing the experimental conditions of each sentence and the ordering of the NPs (such that the position within the sentence of the NPs within each pair of critical NPs was swapped across counterbalancings) were created, and each participant was presented with one of these lists. Thus, each participant was presented with ten sentences in each experimental condition. The filler sentences conveyed complex ideas but did not contain RCs. Forty-eight of the fillers served as experimental sentences for a study unrelated to the current study. A true/false comprehension question followed the presentation of each sentence. Two-thirds of the questions following the experimental sentences referred to the relationship between the head NP and the embedded NP and one-third referred to the action represented by the matrix verb. The questions following the filler sentences referred to the complex ideas conveyed by those sentences. Half of the answers to the comprehension questions were true and half were false.

Procedure

Each experimental run consisted of five blocks. The first block contained ten filler sentences and served as a warm-up block for the participants. The next four blocks
each contained twelve filler sentences and ten experimental sentences. The order of presentation of the sentences was randomized within each block. To end the presentation of each sentence, participants pressed either the space bar (EyeLink system participants) or a button on a control pad (EyeLink 1000 system participants) when they were finished reading the sentence for comprehension. To end the presentation of each comprehension question, participants pressed either a key labeled for a true response or a key labeled for a false response using either a keyboard (EyeLink system participants) or a control pad (EyeLink 1000 system participants) once they had determined their answer.

Each experimental run proceeded as follows and was similar across eye-tracking devices: After undergoing a routine that calibrated the eye-tracking device, participants began the experimental run. Each trial began with the presentation of a fixation point on the screen at the location where the first word of the sentence would later be presented. The presentation of this fixation point served both to direct the gaze of the participant to the location of the beginning of the sentence and to maintain the calibration of the eye-tracker. During the presentation of the fixation point, the experimenter used another computer to monitor the location of the direction of the gaze of the participant. When the gaze of the participant was judged to be sufficiently steady on the fixation point the experimenter pressed a button that made the fixation point disappear and the sentence of the trial appear. After the participant read the sentence and pressed the spacebar (EyeLink system) or a button on a control pad (EyeLink 1000 system) to signify completion, the sentence disappeared and the comprehension question relating to that sentence appeared. Then, after the participant pressed a button corresponding to his or her answer, the trial ended and the fixation point for the next trial appeared. During each trial the experimenter was able to see the location of the fixation of the participant.
relative to the location of the words of the trial as determined by the eye-tracking device. If the calibration of the eye-tracking device appeared inadequate, the experimenter recalibrated the device between trials.

**Results**

The results of the current experiment and the subsequent experiment will focus on two types of critical measures of processing difficulty. The first type is the offline measure of accuracy in response to the comprehension questions following each experimental sentence. The second type relates to online measures of processing difficulty and consists of the gaze durations of participants on certain critical regions of the experimental sentences and the total amount of time participants spent on these critical regions of the experimental sentences. Gaze duration refers to the sum of the durations of the initial fixations on a region, provided that no material downstream in the sentence has been viewed. The gaze duration on a region terminates when the gaze is first directed away from the region of interest (regardless of whether the subsequent fixation is progressive or regressive in relation to the region of interest). As such, gaze durations provide insight into participants’ initial processing of a region of text. The total time on a region is simply the sum of all fixations on a region during reading. Total times provide insight into the overall amount of difficulty a certain region of text poses to participants. The choice of these measures is based on a number of authoritative reviews of eye-tracking measures for reading studies (Inhoff & Radach, 1998; Liversedge, Paterson, & Pickering, 1998; Rayner, 1998).

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6 The online measure of rereading duration, which reflects late processing of a region, will not be reported in this or in the subsequent experiment. The total times on regions of text in this and in the subsequent experiment exhibit the same patterns as rereading durations. Thus, for the sake of brevity and clarity only gaze durations and total times will be reported.
The critical regions of the experimental sentences of Experiment 3 consist of the NP serving as the head of the sentence and the RC region. Though not directly of interest to the hypotheses being tested here, the head NP is of interest in that it is the NP being manipulated across experimental conditions. The RC region, consisting of all the words after the complementizer *that* and before the matrix verb (e.g., the doctor praised/praised the doctor) is of particular interest as it is the region in which effects of NP type emerged in Experiments 1 and 2 and in which, in addition to comprehension question accuracy patterns, effects might be expected to emerge in the current experiment if modification of the head NP indeed has an impact on processing difficulty. As in Experiments 1 and 2, we also analyzed a region including the RC region and the matrix verb. The patterns of results for that region were similar to those of reading durations on the RC region, and will not be included here for purposes of brevity.

Figure 7: Comprehension Question Accuracies for Experiment 3

![Comprehension Question Accuracies](image)
Comprehension Question Accuracies

Figure 7 shows accuracies in response to comprehension questions for Experiment 3. There was a trend towards a main effect of RC type on comprehension question accuracies such that responses to questions following sentences containing subject-extracted RCs were more accurate (92.1%) than responses to questions following sentences containing object-extracted RCs (89.3%). This effect was significant by subjects, but fell short of significance by items ($F_1(1,39) = 4.38$ MSE $= 75.50$, $p < .044$, $F_2(1,39) = 3.10$ MSE $= 100.38$, $p > .085$). There was not a significant main effect of head NP modification on comprehension question accuracy. However, critical to the hypotheses being tested, there was a significant interaction between RC type and head NP modification on comprehension question accuracy ($F_1(1,39) = 4.24$ MSE $= 78.06$, $p < .047$, $F_2(1,39) = 6.20$ MSE $= 63.33$, $p < .018$). For questions following sentences with an unmodified head NP there was a difference between those relating to sentences containing subject-extracted RCs (93.2%) and those relating to sentences containing object-extracted RCs (87.5%). In contrast, for questions following sentences with a modified head NP there was no difference between those relating to sentences containing subject-extracted RCs (91.0%) and those relating to sentences containing object-extracted RCs (91.0%).

Reading Duration Measures

Figure 8 shows the reading patterns in terms of gaze durations and Figure 9 shows the reading patterns in terms of total times for the various regions of the experimental sentences. The top panel of each of these figures contains conditions in which the head
Figure 8: Gaze Durations by Region for Experiment 3

No Adjective - Gaze Durations

Adjective - Gaze Durations

NP was unmodified. The bottom panel of each of these figures contains conditions in which the head NP was modified with an adjective. The presentation of the results of
each critical region will begin with the findings related to gaze durations on that region and will follow with the findings related to the total times spent on that region.

*Head NP Region*

The head NP region consisted of the determiner *the*, the head of the NP, and an adjective, if it was modified by one.

**Gaze Durations.** It is not surprising that there was a main effect of head NP modification on gaze durations on the head NP region. Head NPs that were modified by an adjective were read more slowly during gaze durations (874 msec) than head NPs that were unmodified (493 msec), as the presence of an adjective makes the region longer \( F_1(1,39) = 469.95 \text{ MSE} = 12589, p < .001, F_2(1,39) = 492.88 \text{ MSE} = 11833, p < .001 \). There was also an almost-significant main effect of RC type on at the head NP region, such that head NP regions preceding object-extracted RCs were read more slowly during gaze durations (700 msec) than head NP regions preceding subject-extracted RCs (666 msec). This effect fell short of significance by subjects, but was significant by items \( F_1(1,39) = 3.51 \text{ MSE} = 12562, p > .068, F_2(1,39) = 4.29 \text{ MSE} = 10106, p < .046 \). Though this finding is surprising in that the RC region could not have yet been fixated by the participants during gaze durations on the head NP region, it likely reflects parafoveal preview effects that result from readers being able to gather some information from words slightly downstream from currently fixated regions. There was no interaction between RC type and head NP modification for gaze durations on the head NP region.

**Total times.** Total times on the head NP region showed a similar pattern as gaze durations on that region, with the exception of an increased significance level of the main effect of RC type. Head NP regions preceding object-extracted RCs showed longer total
Figure 9: Total Times by Region for Experiment 3

No Adjective - Total Times

Adjective - Total Times

times (1809 msec) than head NP regions preceding subject-extracted RCs (1677 msec;
F₁(1,39) = 9.61 MSE = 72533, p < .005, F₂(1,39) = 9.84 MSE = 75884, p < .004). The increase in the significance of this effect would be expected, as total times include the rereading of that region that would occur after the participants had also read the RC region. As object-extracted RCs pose more difficulty to readers than subject-extracted RCs, it would be expected that participants would revisit previously read regions to help them resolve this difficulty. Head NPs that were modified by an adjective showed longer total times (2309 msec) than head NPs that were unmodified (1177 msec; F₁(1,39) = 217.47 MSE = 235557, p < .001, F₂(1,39) = 332.38 MSE = 154400, p < .001). There was no interaction between RC type and head NP modification for total times on the head NP region.

**RC Region**

The RC region consisted of the words after the complementizer *that* and before the matrix verb.

**Gaze Durations.** There was a main effect of RC type on gaze durations on the RC region such that object-extracted RC regions showed longer gaze durations (619 msec) than subject-extracted RC regions (569 msec; F₁(1,39) = 7.23 MSE = 13951, p < .012, F₂(1,39) = 4.17 MSE = 22993, p < .049). There was no main effect of head NP modification on gaze durations on the RC region. There was also no interaction between RC type and head NP modification for gaze durations on the RC region.

**Total Times.** A somewhat different pattern emerged for total times on the RC region. A main effect of RC type persisted and increased in its significance level for total times on the RC region. Object-extracted RCs showed longer total times (2220 msec) than subject-extracted RC regions (1990 msec; F₁(1,39) = 19.71 MSE = 107637, p < .001,
F₂(1,39) = 20.59 MSE = 105983, p < .001). Additionally, a main effect of head NP modification emerged for total times on the RC region, such that RC regions following unmodified head NPs showed longer total times (2273 msec) than RC regions following modified head NPs (1937 msec; F₁(1,39) = 35.28 MSE = 128459, p < .001, F₂(1,39) = 13.87 MSE = 312979, p < .002). Finally, a trend towards an interaction between RC type and head NP modification emerged in total times. The pattern of the interaction for total times on the RC region resembled the pattern of the interaction for comprehension question accuracies. For unmodified head NPs, object-extracted RC regions showed much longer total times (2457 msec) than subject-extracted RC regions (2124 msec). For modified head NPs the difference in total times on the RC region across RC types was diminished (2029 msec for object-extracted RC regions; 1895 for subject-extracted RC regions). This trend fell just short of significance (F₁(1,39) = 3.66 MSE = 100761, p > .062, F₂(1,39) = 3.13 MSE = 126392, p > .084). This pattern, though not quite significant, is consistent with the notion that modifying the head NP with an adjective increases reader’s ability’s to process object-extracted RC structures.

Discussion

Experiment 3 tested the hypothesis that the relative salience of the critical NPs to be processed in memory-taxing, complex sentence structures has an impact on our ability to successfully comprehend such challenging sentence structures. The results provided evidence supporting this hypothesis. Comprehension seems to be facilitated when we read structures that demand that we recall NPs that are more salient than other NPs being simultaneously held in working memory before the integration of either NP with a verb. The relative salience of the critical NPs in sentences containing RC structures was manipulated in Experiment 1 via an adjectival modification of the head NP while keeping
the relative frequency of these NPs constant. Comprehension of the particularly challenging object-extracted RC structure was facilitated when the head NP (which, it is suggested, is the critical NP whose recall mediates comprehension difficulty in such structures) was modified with an adjective, thus making it more salient than the other critical NP.

Data on comprehension question accuracies showed that head NP modification improved the comprehension of object-extracted RCs as compared with subject-extracted RCs. When the head NP was unmodified there was a comprehension advantage for sentences containing subject-extracted RCs as compared with sentences containing object-extracted RCs. When the head NP was modified by an adjective, this typical subject-extracted comprehension advantage disappeared, and questions referring to sentences containing object-extracted RCs were answered at accuracy levels similar to those of questions referring to sentences containing subject-extracted RCs.

Additionally, the total time measure of processing for the RC region of these sentences complemented the pattern found in comprehension question accuracies, though this pattern was not quite significant statistically. When the head NP was unmodified there was a large difference in the total time participants spent fixating the RC region, such that they spent a longer time fixating object-extracted RC regions than they did fixating subject-extracted RC regions. When the head NP was modified by an adjective this difference in total times spent fixating the RC region was diminished, such that the amount of time participants spent fixating object-extracted RC regions was closer to the amount of time they spent fixating subject-extracted RC regions.

Taken together, the results related to patterns of comprehension question accuracies and those related to total time spent reading the RC region suggest that
modifying the head NP of sentences containing RCs reduces the difference in difficulty between object-extracted and subject-extracted RCs.

It should be noted that though reading time data did not show a significant interaction between RC type and head NP modification, the fact that comprehension question accuracies did show a statistically significant interaction mirrors the patterns that have been found in previous studies. In previous studies the object-extracted/subject-extracted difference was reduced when the embedded NP consisted of the embedded pronoun you, a name, or the quantified expression everyone (Gordon, Hendrick, & Johnson, 2001; 2004). In all of these cases in which the object-extracted/subject-extracted processing difference was reduced in reading time data, a complementary interaction was found in comprehension question accuracies. Thus, it seems that processing effects are distributed across different measures. Though the reading time data in the current experiment did not quite reach statistical significance, the trend in the direction predicted by the relative salience notion, together with the significant interaction for the comprehension question accuracies, show that processing of object-extracted RCs was facilitated by adjectival modification of the head NP.

The frequencies of both the head NP and the embedded NP were held constant in the current experiment so that both NPs were HF. It seems unlikely, then, that readers gained insight about the kind of RC structure they might expect to encounter upon reading modified head NPs as compared with unmodified head NPs, as the frequency of the nouns were held constant across these conditions. Thus, it seems that theories of complex sentence processing that suggest that we use cues or constraints related to sentence components we encounter during processing to determine which structures we may expect to subsequently encounter (MacDonald, et al., 1994; McRae, et al., 1998;
Tabor & Hutchins, 2004; Trueswell, et al. 1994; Vosse & Kempen, 2000; Gennari & MacDonald, 2008; Van Dyke, 2007; Van Dyke & McElree, 2006) seem unable to capture the entirety of the processes involved in such complex sentence processing.

Instead, it seems more likely that working memory processes account for the pattern of effects observed in the current experiment. It seems that the memory trace for the head NP is enhanced when the head NP is modified by an adjective, as such modification may enhance the salience of that NP as compared with the potentially competitive embedded NP. In sentences that require the maintenance in working memory of multiple NPs before those NPs can be integrated with the verbs of the sentence, processing would, as is found in the current experiment, be enhanced when the NP whose retrieval is of particular importance is made more salient in working memory as compared with concurrently held NPs.

Experiment 4

An assumption of the proposed revision of the relative-salience model is that it is the retrieval of the head NP at the first verb of sentences containing object-extracted RCs that determines the amount of difficulty experienced when reading these sentences. When retrieval of the head NP is facilitated, difficulty is reduced. This assumption is consistent with previous theoretical accounts (Gibson 1998, 2000; Warren & Gibson, 2002; Lewis & Vasishth, 2005; Van Dyke, 2007; Van Dyke & McElree, 2006) but has not been tested empirically. In the examples given so far it is reasonable to expect that this retrieval of the head NP is required upon encountering the verb embedded in an object-extracted RC, as the head NP serves as the object of the embedded verb. However, it also seems reasonable that the embedded NP would also need to be retrieved upon
encountering the verb embedded in an object-extracted RC, as the embedded NP serves as the subject of the embedded verb.

Therefore, it is possible that the results of Experiments 1 and 2 in which the frequency of the NPs was manipulated and other experiments in which the type of embedded NP was manipulated could be explained by suggesting that certain NP combinations lead to enhanced retrieval of the embedded NP upon encountering the embedded verb. If the critical process determining the difficulty of object-extracted RCs involves retrieval of the embedded NP upon encountering the embedded verb then the relative salience principle would seem invalid. As retrieval of both the head NP and the embedded NP seem to be required for successful integration of sentential meaning at the embedded verb, it is difficult to determine whether the critical process mediating the difficulty associated with object-extracted RCs involves retrieval of the head NP or the embedded NP. For example, perhaps the retrieval of HF NPs (and not LF NPs) is actually enhanced when these HF NPs are paired with LF NPs. The results of the Experiments 1 and 2 described above would be predicted by such a possibility. As so, the possibility that the frequency of NPs is associated with the strength of the memory trace of the NP in a positive manner, so that the higher the frequency of the NP the higher the strength of the memory trace, cannot be ruled out.

In fact, the SPLT/DLT theory of complex sentence comprehension (Gibson, 1998; DLT: Gibson, 2000; Warren & Gibson, 2002) seems to suggest that the more given a NP (where givenness could also be positively related to NP frequency), the less cost it imposes on a reader, perhaps by virtue of it representing a stronger entity in the discourse, which may increase its given memory trace. If such a take on the givenness notion of NPs is valid, then it could be expected that increasing the frequency of NPs increases
their memory trace. If it is also valid that the critical process involved in comprehending object-extracted RCs is retrieval of the embedded NP then processing should be facilitated when the embedded NP is HF. It should be noted, though, that if this alternative view on the processes involved in processing sentences containing object-extracted RCs is valid, it must still hold that the strength of the memory trace of the embedded NP (which may under this view be critical) hinges on its relation to the trace of the head NP. If it did not hinge on such a relation, this alternative view would predict no difference between the condition in which the head NP is LF and the embedded NP is HF and the condition in which both NPs are HF.

Experiment 4 is designed to test this alternative characterization of the critical process involved in the comprehension of sentences containing RCs by separating the locus of retrieval of the head NP from the locus of retrieval of the embedded NP. The manner in which it may do so is best illustrated through a consideration of examples of the stimuli used in the experiment given in (14a) to (14h).

(14a) The artist that the servant ran [T1] in the race with [T2] read the newspaper article about the fire.

(14b) The servant that the artist ran [T1] in the race with [T2] read the newspaper article about the fire.

(14c) The artist that the simpleton ran [T1] in the race with [T2] read the newspaper article about the fire.

(14d) The servant that the lifeguard ran [T1] in the race with [T2] read the newspaper article about the fire.
(14e) The simpleton that the servant ran [T1] in the race with [T2] read the newspaper article about the fire.

(14f) The lifeguard that the servant ran [T1] in the race with [T2] read the newspaper article about the fire.

(14g) The simpleton that the lifeguard ran [T1] in the race with [T2] read the newspaper article about the fire.

(14h) The lifeguard that the simpleton ran [T1] in the race with [T2] read the newspaper article about the fire.

The sentences used in Experiment 4 are similar to those of Experiments 1 and 2 with some modifications. Most importantly, the embedded verbs have been modified so that the locus at which retrieval of the head NP would be expected to occur (at the end of the prepositional phrase, illustrated by with in the example) has been shifted away from the locus at which retrieval of the embedded NP would be expected to occur (at the start of the embedded verb, illustrated by ran in the example). Separating the loci at which the head and embedded NPs would be expected to be retrieved may allow for a test of which retrieval process is being facilitated when the frequencies of these NPs (or perhaps better said, the combination of the frequencies of the NPs) are manipulated.

Additionally, only sentences containing object-extracted RCs are used in the current experiment. The critical issue to be resolved by this experiment involves determining the point at which difficulty is alleviated by certain NP frequency combinations in the object-extracted RC. Therefore, there is no need to include subject-extracted RCs as baselines. Instead, the baseline conditions are comprised of sentences containing object-extracted RCs in which the NPs are matched in frequency, so that one
baseline consists of sentences containing object-extracted RCs where both of the critical NPs are HF and the other baseline consists of sentences containing object-extracted RCs where both of the critical NPs are LF. As such, a careful analysis of the data that will be collected may provide a test of whether the critical process determining the difficulty of object-extracted RCs involves retrieval of the embedded NP or the head NP.

If the critical process involves retrieval of the embedded NP then we may find a reduction in the difference in processing difficulty between the baseline conditions and the condition containing a LF head NP and a HF embedded NP at [T1], the point at which retrieval of the embedded NP would be expected to occur. If, on the other hand, the critical process involves retrieval of the head NP then we may find a reduction in the difference in processing difficulty between the baseline conditions and the condition containing a LF head NP and a HF embedded NP at [T2], the point at which retrieval of the head NP would be expected to occur.

Methods

Participants

Twenty six participants were recruited from the Introductory Psychology Participant Pool at the University of North Carolina at Chapel Hill. They received credit towards a requirement of an Introductory Psychology course for their participation in the experiment. Additionally, fourteen participants were recruited from fliers advertising the study and were paid $10 each for their participation. These participants did not receive any course credit for their participation.

Experimental Paradigm

The experimental paradigm was similar to that of Experiment 3 with the exception that all participants were tested using the EyeLink 1000 system. Thus, testing
procedures and analysis procedures were similar to those described for the portion of participants tested using the EyeLink 1000 device in Experiment 3.

**Materials**

Materials for Experiment 4 are given in Appendix 2. The materials were similar to Experiments 1 and 2, except each sentence contained an object-extracted RC, and the frequency of the head NP and the embedded NP were manipulated independently (so that the frequency pairings were HF/HF, LF/LF, HF/LF, and LF/HF). Additionally, the ordering of the descriptions was counterbalanced so that each description appeared in both NP positions across all types of frequency combinations. Finally, the embedded verbs were modified so as to make the embedded predicate multi-lexemic rather than mono-lexemic. All embedded predicates were four to six words in length.

**Procedure**

The procedure was similar to that described for participants tested using the EyeLink 1000 system in Experiment 3.

**Results**

The measures of processing difficulty were similar to those of Experiment 3 in that they included comprehension question accuracies, gaze durations on critical regions, and total times on critical regions. The critical regions differed from Experiment 3, though, in that they were defined so as to reflect the regions at which retrieval of the head NP and the embedded NP, respectively, might be expected to occur. Thus, the first critical region (the T1 region) was defined as the region at which retrieval of the embedded NP might be expected to occur and consisted of the first verb in the sentence (which was also the first word of the multi-lexemic predicate). The second critical region (the T2 region) was defined as the region at which retrieval of the head NP would be
expected to occur, and consisted of the last word of the embedded multi-lexemic predicate.

Figure 10: Comprehension Question Accuracies for Experiment 4

Comprehension Question Accuracies

Figure 10 shows accuracies in response to comprehension questions for Experiment 4. There was no main effect of head NP frequency on comprehension question accuracies. There also was no main effect of embedded NP frequency on comprehension question accuracies. Finally and most critically, there was no interaction between head NP frequency and embedded NP frequency for comprehension question accuracies.
Figure 11: Gaze Durations by Region for Experiment 4

High Frequency Embedded NP - Gaze Durations

Low Frequency Embedded NP - Gaze Durations

The artist/The lifeguard
that the servant ran in the race with read the newspaper article...

The simpleton ran in the race with read the newspaper article...
Figure 12: Total Times by Region for Experiment 4

High Frequency Embedded NP - Total Times

Low Frequency Embedded NP - Total Times
Reading Duration Measures

Figure 11 shows the reading patterns in terms of gaze durations and Figure 12 shows the reading patterns in terms of total times for the various regions of the experimental sentences. The top panel of each of these figures contains conditions in which the embedded NP was HF. The bottom panel of each of these figures contains conditions in which the embedded NP was LF. The presentation of the results of each region will begin with the findings related to gaze durations on that region and will follow with the findings related to the total times spent on that region.

T1 Region

The T1 region consisted of the first word of the multi-lexemic predicate (the verb immediately following the embedded NP).

Gaze Durations. There was a nearly-significant main effect of head NP frequency on gaze durations at the T1 region, such that gaze durations at the T1 region following a LF head NP (301 msec) were longer than those following a HF head NP (286 msec). This effect did not attain significance by subjects but was significant by items ($F_1(1,39) = 3.97$ MSE = 2366, $p > .052$, $F_2(1,39) = 6.43$ MSE = 1840, $p < .016$). There was no main effect of embedded NP frequency on gaze durations at the T1 region. Additionally there was no interaction between head NP frequency and embedded NP frequency for gaze durations at the T1 region.

Total Times. Interestingly, total times showed a reversal of the pattern that gaze durations showed for the main effect of head NP frequency at the T1 region. Total times at the T1 region following a LF head NP (955 msec) were shorter than those following a HF head NP (1021 msec; $F_1(1,39) = 6.57$ MSE = 26707, $p < .015$, $F_2(1,39) = 5.16$ MSE =
This reversal suggests that readers initially show some spillover of the difficulty of processing LF head NPs at the T1 region as compared with HF head NPs, but that overall the presence of a LF head NP actually helps readers process object-extracted RCs. There was no main effect of embedded NP frequency on total times at the T1 region. Additionally there was no interaction between head NP frequency and embedded NP frequency for total times at the T1 region.

**T2 Region**

The T2 region consisted of the last word of the multi-lexemic predicate (the word immediately preceding the matrix verb).

**Gaze Durations.** There was no main effect of head NP frequency on gaze durations at the T2 region. There was also no main effect of embedded NP frequency on gaze durations at the T2 region. Finally, there was no interaction between head NP frequency and embedded NP frequency for gaze durations at the T2 region.

**Total Times.** A similar lack of effects was observed for total times at the T2 region. There was no main effect of head NP frequency on total times at the T2 region. There was also no main effect of embedded NP frequency on total times at the T2 region. Finally, there was no interaction between head NP frequency and embedded NP frequency for total times at the T2 region.

**Discussion**

Experiment 4 was designed to test whether the critical process responsible for the difficulty associated with sentences containing object-extracted RCs is the retrieval of the head NP or the retrieval of the embedded NP. It attempted to do so by using multi-
lexemic embedded predicates in sentences containing object-extracted RCs to separate the locus of retrieval of the head NP from the locus of retrieval of the embedded NP.

The most striking aspect of the results of Experiment 4 is that there was a lack of any evidence of an interaction following the pattern found in the frequency studies described in Experiments 1 and 2. Experiments 1 and 2 showed that the processing of sentences containing object-extracted RCs is facilitated when the head NP of such sentences is LF and the embedded NP is HF as compared with when the NPs match in frequency or when the head NP is HF and the embedded NP is LF. The sentences of Experiment 4 all contained object-extracted RCs and varied in terms of the frequency composition of the two critical NPs. The difference between the sentences of Experiment 4 and the sentences containing object-extracted RCs in Experiments 1 and 2 is that instead of having one word embedded predicates, the sentences of Experiment 4 had multi-lexemic embedded predicates. It was expected that these multi-lexemic predicates would separate the locus of retrieval of the head NP from that of the embedded NP and would thus reveal the critical memory process involved in the processing of object-extracted RCs.

Instead, the results seem to suggest that embedding multi-lexemic predicates in object-extracted RC structures precludes (or obscures) the emergence of processing facilitation that can occur when the head NP is made more salient than the embedded NP. Evidence for the notion that the relative salience of the NPs had little impact on processing difficulty can be seen in the pattern of comprehension question accuracies (the length of the predicates of Experiment 4 makes it infeasible to compare reading time data of Experiment 4 with reading time data of other experiments that found processing facilitation for sentences with object-extracted RCs and various critical NP combinations,
like in Gordon, et al., 2001; 2004; 2006). The comprehension question accuracies of all the conditions of Experiment 4 resemble the levels of accuracy found in the baseline conditions of previous experiments for which the processing of object-extracted RCs was not facilitated (Gordon, et al., 2001; 2004; 2006). In fact, there seems to be no evidence that having a LF head NP and a HF embedded NP facilitates the comprehension of sentences containing object-extracted RCs with multi-lexemic embedded predicates. As such, the results seem unable to shed light on the critical memory process involved in the processing of sentences containing object-extracted RCs.

However, the results of Experiment 4 are interesting in that they suggest that it is likely that multiple factors contribute to the processing difficulty associated with object-extracted RC constructions.

First, the results seem to suggest that some degree of cue- or constraint-based information is conveyed to the reader through the frequency of NPs. Though no interaction between head NP frequency and embedded NP frequency was found in any of the measures, there was a main effect of head NP frequency on the T1 region total reading times (the first word of the multi-lexemic predicate), such that this region was read more quickly when it followed a LF head NP than when it followed a HF head NP. This pattern seems to suggest that perhaps readers to some extent may be able to use the frequency of the head NP as a cue or constraint (MacDonald, et al., 1994; McRae, et al., 1998; Tabor & Hutchins, 2004; Trueswell, et al., 1994; Vosse & Kempen, 2000; Gennari & MacDonald, 2008; Van Dyke, 2007; Van Dyke & McElree, 2006) indicating that they might soon encounter an object-extracted RC. One study in particular has shown that frequency of the critical NPs is associated with the occurrence of types of RC structures in corpora such that relatively LF head NPs tend to be associated with object-extracted
RCs (Reali & Christiansen, 2007). Perhaps readers take advantage of this information, and use it to predict (at least to some degree) that an object-extracted RC may be forthcoming when they encounter a LF NP.

Second, the results seem to suggest that the distance between a NP and its point of integration with the sentence also contributes to comprehension difficulty. The fact that lengthening the embedded predicate seems to contribute to the amount of difficulty experienced in processing object-extracted RCs is consistent with accounts of complex sentence processing emphasizing the role that the distance of a referent to its point of integration plays in determining processing difficulty (Gibson, 1998; 2000; Warren & Gibson, 2002). When the predicates of object-extracted RCs are lengthened, it seems to preclude the possibility that processing difficulty can be influenced by manipulating the frequency of the NPs. Though the relative salience-based SBMIH account might suggest that a multi-lexemic predicate would add to difficulty in that extra NPs are sometimes included in such predicates (e.g., the morning in ran in the morning with), it seems to be somewhat of a stretch to suggest that the extra NPs compete in memory with the critical NPs when recall of the critical NPs is required (i.e., NPs like the morning cannot act as agents of the verbs of such structures). Instead, accounts emphasizing distance across intervening material seem to better capture this particular phenomenon.
General Discussion of Experiments Designed to Further Investigate Relative Salience

The results of Experiments 3 suggest that the relative salience of critical NPs in complex sentence structures is a factor that can mediate the amount of difficulty readers experience when processing sentences containing object-extracted RCs. The results of Experiment 4, however, suggest that the relative salience of these critical NPs is not the only factor responsible for such difficulty.

It light of the current findings it is reasonable to conclude that the relative salience of the critical NPs is a significant mediating factor in the amount of difficulty associated with sentences containing object-extracted RCs. When sentences containing object-extracted RCs are presented such that the head NP is more salient than the embedded NP, processing is facilitated, as measured by comprehension question accuracy and critical region reading durations. Moreover, when frequency of the critical NPs is controlled and relative salience is manipulated via adjectival modification of the head NP this processing facilitation persists.

It is difficult for most prominent theories of complex sentence processing to explain such findings. The perspective shift hypothesis (MacWhinney, 1977; MacWhinney & Pleh, 1988), which does not include working memory processes in its explanation of factors contributing to the processing difficulty associated with object-extracted RCs is particularly unable to account for such results. The perspective shift account would predict that object-extracted RCs would always be as difficult as subject-extracted RCs, as an extra shift in perspective is always required in the processing of object-extracted RCs as compared with subject-extracted RCs.
Theories that suggest that the difficulty we experience when reading object-extracted RCs as compared with subject-extracted RCs may be attributed to our relative experience with these different structures (MacDonald & Christiansen, 2002) or to our experience with classes of NPs within these different structures (Reali & Christiansen, 2007) also have difficulty accounting for the current findings. Experiment 3 controlled not only the class of the NPs but also the frequency of the NPs and found that facilitation of object-extracted RCs occurred when the head NP was made more salient than the embedded NP through adjectival modification rather than frequency.

Theories suggesting that information associated with items or structures that readers process provide cues or constraints to them as to what they may expect to encounter next (MacDonald, et al., 1994; McRae, et al., & Tanenhaus, 1998; Tabor & Hutchins, 2004; Trueswell, et al., 1994; Vosse & Kempen, 2000; Gennari & MacDonald, 2008; Van Dyke, 2007; Van Dyke & McElree, 2006) also have difficulty accounting for the findings of Experiment 3, as the potential cue or constraint of word frequency was controlled in that experiment. Although the results of Experiments 1 and 2, which manipulated word frequency, could lead to a modified cue- or constraint-based theory in which the relative frequency of NPs could aid readers in parsing object-extracted RCs, this seems unlikely given the results of Experiment 3.

Theories emphasizing that the distance between a referent and its point of integration mediates processing difficulty and that qualities associated with the intervening material (i.e., givenness) can alter processing difficulty (Gibson, 1998; 2000; Warren & Gibson, 2002) also fail to account for the findings of Experiment 3, as the intervening material was constant across conditions where processing difficulty differed.
It seems then, that the SBMIH of complex sentence comprehension (Gordon, et al. 2001; 2002; 2004; 2006) best accounts for the results of Experiment 3, but that the SBMIH requires a modification so that the factor responsible for mediating interference in complex sentences is the relative salience of the critical NPs (and not common noun status). Under this theory, if the head NP is made to be more salient than the embedded NP then the embedded NP becomes less able to interfere with the memory trace for the head NP in a sentence with an object-extracted RC. In turn, recall of the head NP is enhanced upon encountering the verbs of the sentence.\(^7\)

However, the results of Experiment 4 seem to suggest that the relative salience of the critical NPs is not the only factor mediating the processing difficulty associated with object-extracted RCs. The processing of multi-lexemic embedded predicates did seem to be somewhat facilitated (as reflected in shorter total times at the first word of the predicate) when the predicate followed a LF head NP as compared with when it followed a HF head NP. Such a finding is consistent with the notion that LF NPs may provide more of a cue or a constraint to readers than HF NPs that an object-extracted RC may be forthcoming (MacDonald & Christiansen, 2002; Reali & Christiansen, 2007; MacDonald, et al., 1994; McRae, et al., 1998; Tabor & Hutchins, 2004; Trueswell, et al., 1994; Vosse & Kempen, 2000; Gennari & MacDonald, 2008; Van Dyke, 2007; Van Dyke & McElree, 2006).

Additionally, the finding that lengthening the predicate of an object-extracted RC seems to reinstate the difficulty that had previously been observed to be reduced when the head NP was relatively more salient than the embedded NP suggests that distance-based

\(^7\) Actually, it could be that recall of the embedded NP is somehow enhanced when the head NP is more salient than the embedded NP, but the results of extensive list memory research seem less consistent with this possibility than with the possibility that recall of the head NP is enhanced.
theories of complex sentence comprehension are adept at explaining some processing phenomena (Gibson, 1998; 2000; Warren & Gibson, 2002).

Altogether, the results of the current study indicate that it is likely that many factors contribute to the amount of difficulty readers experience when they are faced with complex sentences. Though it seems likely that the relative salience of the critical NPs in such structures plays an important role in determining difficulty, it is clearly not the only factor responsible for doing so.
Appendix 1

The stimuli from Experiment 3 are shown below in the condition consisting of a modified head NP followed by an subject-extracted RC. They were also presented with unmodified head NPs and in forms in which the head NP was followed by an object-extracted RC.

1. The sleepy doctor that praised the student climbed the mountain just outside of town before it snowed.
2. The attractive teacher that phoned the officer cooked the pork chops in barbecue sauce on New Year's Eve.
3. The uncomfortable leader that liked the husband dominated the conversation while the game was on television.
4. The intelligent minister that despised the brother drove the sports car home from work that evening.
5. The hungry president that disliked the daughter clipped the coupons out with the dull scissors.
6. The talented official that ignored the professor watched the special about Colombian drugs on the nightly news.
7. The confused artist that insulted the servant read the newspaper article about the fire.
8. The thoughtful soldier that admired the farmer answered the telephone in the fancy restaurant.
9. The accomplished writer that thanked the colonel consulted for many hit movies before 1990.
10. The outgoing secretary that inspired the director wrote an autobiography after their friendship became well known.
11 The exhausted captain that distrusted the reader called for help after the restaurant closed.

12 The thirsty scientist that amused the owner made paper dolls out of the newspaper.

13 The animated chief that complimented the player declined a television interview respectfully.

14 The hopeful patient that questioned the general wrote a long science fiction novel during the summer vacation.

15 The grumpy lawyer that recommended the visitor changed jobs after the announcement of a new merger.

16 The surprised politician that described the guest worked in a small building near the bus station.

17 The restless employer that advised the chairman recalled the event before the trip got underway.

18 The curious driver that criticized the victim talked publicly about the incident after the game.

19 The moody colleague that interviewed the judge had a very small office.

20 The tired manager that called the gentleman drove a gray truck.

21 The irritated neighbor that contacted the prisoner spoke very quickly.

22 The worried partner that entertained the author behaved with dignity.

23 The quiet priest that helped the expert worked in a large foreign bank.

24 The adventurous citizen that envied the stranger descended the staircase.

25 The cheerful assistant that recruited the engineer dragged a heavy suitcase through the crowded airport.
26 The nervous consumer that serenaded the peasant visited several family members last Tuesday.

27 The confident supporter that taught the passenger constructed a tower of playing cards.

28 The talkative employee that tutored the specialist carved the turkey at Thanksgiving dinner.

29 The happy socialist that adored the reporter purchased a pair of shoes.

30 The disgruntled governor that idolized the speaker eavesdropped through the open door.

31 The infuriated producer that evaluated the commander shivered in the cool wind.

32 The bored criminal that tolerated the painter poured syrup on the French toast.

33 The cautious sergeant that pitied the traveler coached little league baseball.

34 The calm waiter that scolded the economist blinked due to a sudden gust of dusty wind.

35 The excited detective that flattered the foreigner appreciated the exhibit at the museum.

36 The jealous designer that frightened the guardian chuckled about the scare in retrospect.

37 The sick aunt that belittled the coach slept in the hammock in the late afternoon.

38 The depressed actor that respected the nurse swam in the ocean during high tide.

39 The amused journalist that defeated the pilot bought a gallon of milk on the way home.

40 The groggy psychiatrist that believed the parent joked about the current state of the economy.
Appendix 2

The stimuli from Experiment 4 are shown below. Both high and low frequency NPs are shown at the head NP position and the embedded NP position and are separated by slashes with the high frequency NP being the first in each pair.

1. The student/beautician that the doctor/hustler walked in front of climbed the mountain just outside of town before it snowed.

2. The officer/jurist that the teacher/bookworm dined in the evening with cooked the pork chops in barbecue sauce on New Year's Eve.

3. The husband/overseer that the leader/shoplifter sat in close proximity to dominated the conversation while the game was on television.

4. The brother/peddler that the minister/mailman hiked in the morning with drove the sports car home from work that evening.

5. The president/jester that the daughter/hijacker sang in the choir with clipped the coupons out with the dull scissors.

6. The professor/jogger that the official/swindler drove in the lane next to watched the special about Colombian drugs on the nightly news.

7. The servant/simpleton that the artist/lifeguard ran in the race with read the newspaper article about the fire.

8. The farmer/navigator that the soldier/bellboy went to the movies with answered the telephone in the fancy restaurant.

9. The colonel/dietician that the writer/cobbler shopped at the mall for consulted for many hit movies before 1990.

10. The director/nominee that the secretary/ferryman vacationed at the beach with wrote an autobiography after their friendship became well known.
11 The reader/mugger that the captain/organist swam in the triathlon with called for help after the restaurant closed.

12 The owner/anchorman that the scientist/gladiator strolled along the path with made paper dolls out of the newspaper.

13 The player/psychic that the chief/gymnast attended the event with declined a television interview respectfully.

14 The general/finalist that the patient/moderator performed in the band with wrote a long science fiction novel during the summer vacation.

15 The visitor/bicyclist that the lawyer/baritone played the board game with changed jobs after the announcement a new merger.

16 The guest/handyman that the politician/machinist practiced for the game with worked in a small building near the bus station.

17 The chairman/samurai that the employer/looter worked in the office with recalled the event before the trip got underway.

18 The victim/impostor that the driver/trumpeter jumped off the diving board before talked publicly about the incident after the game.

19 The judge/fiddler that the colleague/innkeeper relaxed by the pool with had a very small office.

20 The gentleman/kidnapper that the manager/lobbyist joined the club with drove a gray truck.

21 The prisoner/abbot that the neighbor/gunsmith visited the museum with spoke very quickly.

22 The author/cripple that the partner/suitor traveled the region with behaved with dignity.
23 The expert/bowler that the priest/censor argued in support of worked in a large foreign bank.

24 The stranger/playmate that the citizen/choirboy asked for assistance from envied descended the staircase.

25 The engineer/hooker that the assistant/mariner hid in the shadows from dragged a heavy suitcase through the crowded airport.

26 The peasant that the consumer rode on the train with visited several family members last Tuesday.

27 The passenger/teller that the supporter/rapist started the society with constructed a tower of playing cards.

28 The specialist/wrestler that the employee/fugitive competed for the title against carved the turkey at Thanksgiving dinner.

29 The reporter/botanist that the socialist/skeptic joked about the issue with purchased a pair of shoes.

30 The speaker/skipper that the governor/heretic discussed the details with eavesdropped through the open door.

31 The commander/custodian that the producer/envoy begged for forgiveness from shivered in the cool wind.

32 The painter/mentor that the criminal/barbarian rehearsed for the play with poured syrup on the French toast.

33 The traveler/surveyor that the sergeant/cadet explored the coast with coached little league baseball.

34 The economist/rescuer that the waiter/economist expected a raise from blinked due to a sudden gust of dusty wind.
35 The foreigner/cashier that the detective/forger lost the final game to appreciated the exhibit at the museum.

36 The guardian/defector that the designer/shopper made the arrangements with chuckled about the scare in retrospect.

37 The coach/minion that the aunt/copyist marched in the parade with slept in the hammock in the late afternoon.

38 The nurse/whaler that the actor/hurdler exercised in the gym with swam in the ocean during high tide.

39 The pilot/humorist that the journalist/colonist participated in the event with bought a gallon of milk on the way home.

40 The parent/braggart that the psychiatrist/marksman bowled in the tournament against joked about the current state of the economy.
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