Available online at www.sciencedirect.com
ScienceDirect

Journal of Memory and Language 56 (2007) 270–290

Journal of Memory and Language

www.elsevier.com/locate/jml

Interactions of meaning and syntax: Implications for models of sentence comprehension ☆

Gail McKoon *, Roger Ratcliff

Department of Psychology, The Ohio State University, Columbus, OH 43210, USA

Received 9 January 2006; revision received 17 July 2006
Available online 22 September 2006

Abstract

A reduced relative—main clause ambiguity occurs in sentences that begin with reduced relative clauses, as in *The hangman executed by the government was convicted of treason*. This ambiguity has often been the focus of research designed to investigate the processes by which syntactic structures are built during sentence comprehension. Reading time differences between more difficult and less difficult reduced relative sentences (e.g., *The hangman executed by the government was convicted of treason* vs. *The martyr executed by the government was convicted of treason*) have been interpreted as reflecting syntactic disambiguation processes. In this article, we point out that there exists a possible alternative interpretation of the differences, namely, that reading times are longer for the more difficult sentences because the information in their relative clauses mismatches a reader's general knowledge of how events typically occur in the world or how they are typically referenced in discourse. Under this interpretation, the differences in reading times do not have their bases in disambiguation processing.

Keywords: Sentence comprehension; Syntax processing; Sentence meaning

From the earliest beginnings of modern psycholinguistics (Fodor, Bever, & Garrett, 1974), much of the research that has investigated the representations and processes by which humans understand language has focused on syntax. Central questions have been what kinds of syntactic information are available to the processing system, how does the system produce the syntactic structures that are necessary for comprehension, and what form do these structures take. More recently, considerations of meaning have begun to enter syntax research agendas and questions about the interactions of meaning with syntax have become salient in many discussions. However, in this article, we argue that there are crucial types of meaning that have large effects on comprehension processes that have not yet been sufficiently taken into account.

The types of meaning on which we focus arise from interactions among all the parts of a sentence with each other, with contextual information, and with the general knowledge of a comprehender. Many types of meaning fall under this large umbrella, but they all originate in interactions among various sorts of information and so, to emphasize their interactiveness, we give them the general label "holistic." Drawing on text processing research in psycholinguistics, we include in this class

☆ Preparation of this article was supported by NIMH Grants R37-MH44640 and K05-MH01891, and by NIDCD Grant R01-DC01240.
* Corresponding author. Fax: +1 614 688 3984.

0749-596X/$ - see front matter
doi:10.1016/j.jml.2006.07.006

the interactions among the concepts expressed by the words of a sentence that form propositions, and interactions among concepts and propositions and a comprehender's general knowledge and real-world situation. Also, drawing on construction grammar approaches in linguistics as well as on text processing research, we assume that syntactic and discourse structures have meanings, and that the meanings of concepts and propositions depend on and interact with the meanings of the syntactic and discourse structures in which they are expressed. The emphasis on holistic types of meaning involving interactions among concepts and propositions and how they are situated in syntactic and larger real-world, discourse, and general knowledge contexts is basic to the ''Meaning through Syntax'' (''MTS'') theoretical framework presented by Levin and Rappaport Hovav (2005, 2005). The goal for the framework is to bring interactions between syntactic information and holistic sorts of meaning to the forefront of psycholinguistic research.

The investigations in this article address an issue central to current models of syntactic processing, the processing of ambiguous sentences. In particular, the investigations are concerned with the frequently studied reduced relative—main clause ambiguity (e.g., Ferreira & Clifton, 1986), the ambiguity that occurs when the initial words of a sentence can continue either as a reduced relative clause or a main clause (e.g., *The elephant devoured...*). We discuss two types of holistic meaning that are relevant to this ambiguity, first, the discourse meaning of the reduced relative clause construction and, second, the interactions between the concepts and propositions expressed in sentences and a comprehender's general knowledge. Discussion of these two types of meaning is formulated in the context of an experimental design that has been used in recent studies of the reduced relative—main clause ambiguity, and so we begin by describing that design.

Experimental design

In the design used by, for example, Clifton et al. (2003), McRae, Spivey-Knowlton, and Tanenhaus (1998), and Trueswell, Tanenhaus, and Garnsey (1994), there are four types of sentences, exemplified below. The first and third sentences begin with reduced relative clauses for which the head of the clause (*The meat* or *The elephant*) is the object of the verb in the clause. The first six words of these sentences (*The meat devoured by the snake* and *The elephant devoured by the snake*) are ambiguous in their syntax between a reduced relative clause interpretation and a main clause interpretation. The second and fourth sentences do not have this ambiguity because they begin with nonreduced relative clauses.

The meat devoured by the snake provided much needed nourishment.
The meat that was devoured by the snake provided much needed nourishment.
The elephant devoured by the snake provided much needed nourishment.
The elephant that was devoured by the snake provided much needed nourishment.

Currently, there are two main classes of theories that attempt to explain the processing of sentences like these. Constraint based theories (e.g., MacDonald, 1994; Spivey-Knowlton, Trueswell, & Tanenhaus, 1993) assume that multiple kinds of information, including some kinds of meaning information, interact immediately and simultaneously to choose the appropriate syntactic structure for the words of a sentence. In contrast, models like Frazier, Clifton, and Rayner's ''garden path'' model (Frazier, 1987, 1979; Frazier & Clifton, 1996; Frazier & Rayner, 1982; Rayner, Carlson, & Frazier, 1983) assume that there are two stages of processing. The first is an encapsulated module for syntactic processing that is influenced only by syntactic information. Meaning information enters processing only at the second stage.

The motivation for experiments using the design illustrated by the sentences above has been that the constraint based and two stage models have been thought to make different predictions for reading times. It has been assumed that the key difference between the pairs of sentences is that *The elephant* refers to an entity that is rated by subjects as more typically an agent than a patient of the clausal verb *devour*, whereas *The meat* refers to an entity that is rated as more typically a patient than an agent of *devour*. In the sentences above, *the meat* and *the elephant* are patients of *devour*. *The meat* is more in accord with this role than *The elephant* is, and so it is expected that comprehending ''meat being devoured'' is easier than comprehending ''elephant being devoured.''

For the two stage model, the first words of both the ''meat'' and the ''elephant'' reduced relative sentences are initially interpreted as main clauses despite *meat* being a more likely patient than agent of *devour*. Only the later, second stage, processes can make use of agent-verb and patient-verb typicalities, and therefore it is only in second stage processes that the *meat* reduced relative can become easier than the *elephant* reduced relative. In contrast, for constraint based models, agent-verb and patient-verb typicalities come into play immediately.

To test the models against each other, the effects of agent/patient typicality for reduced relative sentences have been compared to the effects for nonreduced relative sentences. Usually it has been found that reading times slow for reduced relative sentences compared to nonreduced relative sentences, with the slowdown larger when the head of the relative clause is a typical agent than when it is a typical patient.[1] The nonreduced relative sentences have been used to control for all possible differences between the reduced relatives with typical agent versus typical patient heads except those involved with syntactic disambiguation. In other words, the assumption has often been that the nonreduced versions of the *meat* and *elephant* sentences control for all the differences between the *meat* and *elephant* reduced relatives except those that interact with syntactic disambiguation.

Generally, it has been considered that empirical results favor the constraint based models. Hare, McRae, and Elman (2004, p. 184) have rejected the two stage model, saying that recent research has demonstrated that information like agent and patient typicality is used immediately, not delayed as would be predicted by the two stage model. For example, Trueswell et al. (1994, Experiment 2, first pass reading times) found a significant disruption in reading times for reduced relatives with typically agent heads compared to their nonreduced counterparts, but no significant disruption for reduced relatives with typically patient heads. As Clifton et al. (2003) put it, speaking of researchers *other* than themselves, ''many cognitive psychologists judge that constraint based models have carried the day'' (page 318). However, significant problems with this conclusion have been raised (e.g., Clifton et al., 2003; Frazier, 1995). In this article, we take a neutral position. We examine how both types of model might explain the data we present.

Questioning underlying assumptions

The focus of this article is not on testing the constraint based and two stage models against each other, nor is it on the processes by which the ambiguity of sentences that begin with reduced relative clauses might be resolved. We take no stand on whether or how this ambiguity is involved in sentence processing. Instead, we address two core assumptions that the models have shared. The first is that the reduced and nonreduced versions of a clause differ only in their ambiguity. This assumption entails that reading times are slower for reduced than nonreduced versions of a relative clause—the typical finding—only because the first words of the reduced versions are ambiguous between relative clause and main clause syntactic structures. This is a strong assumption because it means that, after subtracting out the effects that any variable has on reading times for nonreduced relatives, all of the remaining effects that the variable has on reading times for reduced relatives can be attributed to interactions between the variable and syntactic processing.

We question whether the only reason for a sentence like *The elephant that was devoured by the snake*... being read faster than *The elephant devoured by the snake*... is that syntactic processing is easier. Intuition suggests that the proposition ''snake devours elephant'' is such an unlikely event that it should lead to large disruptions in reading times whether the syntactic structure in which it is expressed is ambiguous or not. The extreme improbability of a snake devouring an elephant should, we suggest, swamp any effects of easier syntactic processing for nonreduced than reduced relative clauses. In principle, a snake could, given a few years, devour an elephant, but it would be a highly unusual event.

The intuitive difficulty of the ''snake devours elephant'' proposition arises, we believe, from the interaction of all three elements, *snake*, *devour*, and *elephant*, with each other to form the proposition. The reason that the proposition is difficult is that it mismatches general knowledge. This brings into question a second assumption upon which research on the reduced relative—main clause ambiguity has often been based, the assumption that sentences like *the meat* and *the elephant* sentences differ only in the typicalities of their elements as agent-verb and verb-patient pairs: ''meat devouring,'' ''elephants devouring,'' ''snakes devouring,'' ''meat being devoured,'' ''elephants being devoured,'' and ''snakes being devoured.'' In contrast, the MTS emphasis on holistic meanings draws attention to the combinations of meanings that form propositions and to the interactions of concepts, combinations of concepts, and propositions with general knowledge. In the example, ''snake devours meat'' is an event consistent with general knowledge but ''snake devours elephant'' is not. The inconsistency might arise simply because elephants are rarely devoured, but this is not the case: dead elephants can be devoured by animals and birds that eat carrion (usually several animals or birds). What is so unlikely is the devouring being done by a snake.

In this article, we argue in favor of intuition and against the models' assumptions. First, in the next section, we review evidence that reduced and nonreduced relative clauses differ not only in their ambiguity but also in their meanings (McKoon & Ratcliff, 2003). The difference in meaning that we propose provides an explanation for why the difference in reading time between propositions like ''snake devours elephant'' and ''snake devours meat'' is larger when they are expressed as reduced than nonreduced relative clauses. The conclusion we draw is that nonreduced relative clauses cannot

[1] With typical patients as heads, the slowdown in reading times for reduced compared to nonreduced relative clauses has often been greatly reduced or eliminated. However, Clifton et al. (2003) found that, on some measures, the slowdown for reduced relative compared to nonreduced relative sentences was as great when the clause heads were typical patients as when they were typical agents.

be used to control for all differences among reduced relatives except those that are involved in ambiguity resolution.

Second, we review past research that demonstrates the effects of real-world knowledge on comprehension processing, research that supports the prediction that "snake devours elephant" should lead to large disruptions in reading times even when it is expressed in unambiguous constructions. Third, Experiments 1 through 8 test this prediction using unambiguous versions of the sentences that were used in two previous studies of the reduced relative—main clause ambiguity (McRae et al., 1998; Trueswell et al., 1994; also Clifton et al., 2003). The results show that propositions like "snake devours elephant" slow reading times when they are expressed in simple unambiguous sentences like *The snake devoured the elephant* as well as when they are expressed in sentences with the reduced relative—main clause ambiguity. Our conclusion is that in McRae et al.'s and Trueswell et al.'s studies, the reduced relatives with typical agent heads differed from the reduced relatives with typical patient heads not only in their agent-verb and verb-patient typicalities but also in the relations of their meanings to general knowledge.

The findings from Experiments 1 through 8 that processing times differ between reduced relatives like *the elephant devoured by the snake* and *the meat devoured by the snake* even when the propositions are expressed in unambiguous structures leads to our overall conclusion: the differences in processing times between reduced relatives like *the elephant devoured by the snake* and *the meat devoured by the snake* cannot be uniquely tied to processes that disambiguate syntactic structures. In the General Discussion, we suggest how models might explain both the results from Experiments 1 through 8 and the results from previous experiments on the reduced relative—main clause ambiguity. In other words, we suggest how the models might include processes that deal with meanings like the mismatch between "snake devours elephant" and general knowledge, in addition to processes that disambiguate syntactic structures.

The nonreduced relative clause construction

The MTS framework (McKoon & Ratcliff, 2003, 2005) follows research in discourse processing and linguistics in assuming that syntactic constructions carry meaning, different meanings for different constructions (e.g., Anderson, 1971; Bolinger, 1968; Borkin, 1974; Fillmore, 1968; Givon, 1985; Goldberg, 1995, 1997; Kintsch, 1974; Wierzbicka, 1988). For reduced and nonreduced relative clauses, the MTS proposal is that the two constructions differ in their meanings in that a reduced relative clause places a single entry into the discourse, an entry that can be represented as $f(x)$, while a nonreduced relative clause places two entries into the discourse, an entity x and the information in the clause about x, represented as $g(x)$. The difference between a single discourse entry, $f(x)$, and two entries, x and $g(x)$, is that the former conveys a stronger connection between the head and the information in the clause than the latter. For example, for the reduced relative sentence *the meat devoured by the snake provided nourishment*, the propositional representation might be (provide, meat, nourishment) and (devour, snake, meat), with "meat" encoded as being the same entity in both propositions. In contrast, for the nonreduced version, *the meat that was devoured by the snake provided nourishment*, the representation might be (provide, meat, nourishment) and (devour, snake, X), where X points to "meat" in the (provide, meat, nourishment) proposition. In the reduced case, "meat" is explicitly represented in the "devouring" proposition. In the nonreduced case, it is represented in the "devouring" proposition only indirectly.

The assumption that the concepts and propositions of sentences and texts vary in the strengths of the connections among them is standard in text processing models. In an early demonstration of the propositional structures of sentences, Ratcliff and McKoon (1978) examined priming in item recognition between pairs of words from sentences like *The mausoleum that enshrined the tsar overlooked the square. Mausoleum* primed recognition of *square* more than *tsar* did, indicating that *square* was more strongly connected to *mausoleum* than to *tsar*, presumably because *mausoleum* and *square* are in the same proposition, while *tsar* and *square* are not in the same proposition. In another demonstration, again with item recognition, this time with seven sentence paragraphs, McKoon and Ratcliff (1980) found larger priming effects between pairs of words that were closely connected in the propositional structures of the paragraphs than between pairs of words that were farther apart. Variation in the strengths with which the concepts and propositions of sentences and texts are connected has now become basic to text processing models (e.g., Anderson, Budiu, & Reder, 2001; Kintsch, 1988).

For reduced and nonreduced relative clauses, McKoon and Ratcliff (2003) provided several lines of evidence for the MTS proposal about their meanings. One experiment supported the general notion that the perceived meanings are different. Subjects were asked to rate how well sentences with reduced and nonreduced relative clauses were written. The sentences were taken from a large corpus of naturally produced text (e.g., articles from The New York Times, transcripts of Larry King Live). The sentences were rated either in the form in which they had appeared in the corpus, or with their reduced relative clauses switched to nonreduced or vice versa. For example, the sentence *The subject most frequently debated by the Fergie followers on Fleet Street is the royal figure* was either tested in the form just given, as it appeared in the corpus, or it was switched to *The subject that is most frequently debated by the Fergie followers on Fleet Street is the royal figure*. Although the effect was small, subjects rated the sentences as significantly better when they were in the form in which they naturally occurred. Even when the naturally occurring form was a reduced relative, subjects significantly preferred it over the other, nonreduced form. This is just what would be expected if the two constructions are understood to have different meanings: whichever form the speaker or writer used, reduced or nonreduced, would be the one for which its meaning best conformed with the meaning of the sentence as a whole.

In two other experiments, McKoon and Ratcliff (2003) used cued recall to directly test the notion that the head of a relative clause is less strongly connected to the information in the clause for a nonreduced relative than for a reduced relative. Subjects read sentences that contained either reduced or nonreduced relative clauses. After reading a list of sentences, they were given all of each sentence except for the head and the clause information as a cue for recall. Conditionalized on recall of the head, more of the information in a clause was recalled if it had been read in reduced form than if it had been read in nonreduced form. This finding is exactly what would be expected if the head-to-clause connection is weaker for nonreduced than reduced relatives.

If the MTS proposal about the difference in meaning between reduced and nonreduced relative clauses is correct, then (for investigations of reduced relative—main clause ambiguity processing) nonreduced relative clauses cannot provide a proper control against which to test reading times for reduced relatives. In previous research, longer processing times for reduced relative clauses than for their nonreduced counterparts have been attributed solely to the reduced relatives' ambiguity. *The elephant devoured by the snake provided...* is read more slowly than *the elephant that was devoured by the snake provided...* because the former must be disambiguated. The MTS proposal is that there is another factor at work: the reduced relative takes longer to read because the head of the clause, *the elephant*, is more strongly connected to the information in the clause, *devoured by the snake*, and therefore the difficulty with its meaning is more apparent to the processing system. Thus, with the MTS proposal, there exist two possible explanations for longer processing times for reduced than nonreduced relative clauses. One is that the larger processing time differences come about only because there is difficulty with the meaning expressed by the clause and this difficulty is mitigated for the nonreduced version. The second is that the longer processing times come about *both* because the reduced relative is more affected than the nonreduced relative by meaning difficulty *and* because it must be disambiguated. Currently, there is no way to distinguish between these two possible explanations and so nonreduced relatives do not provide an adequate control for testing reduced relatives.

In this article, we focus on the problem that if nonreduced relative clauses do not control for all the factors that might affect comprehension of reduced relatives except ambiguity, then some other method of control must be found. One possibility is to use other sorts of unambiguous constructions, a possibility pursued in Experiments 1 through 8.

Interactions between new knowledge and prior knowledge

In this section, we review research that supports the prediction that information like "snake devours elephant" should lead to large disruptions in reading times even when it is expressed in unambiguous constructions. Investigations of mismatches between information being read and expectations from general knowledge have long been part of text processing research. Beginning in the early 1970s with researchers like Bransford, Barclay, and Franks (1972), Kintsch (1974), and Norman and Rumelhart (1975), this domain has focused on the meanings conveyed by sentences, larger discourses, and their interactions with a reader's knowledge. The empirical issues that have been addressed concern many of the types of meaning that we have grouped under the label holistic: the psychological reality of propositions as units of meaning, the connections that organize and relate to each other the concepts and propositions of a text, the inferences that are drawn from the explicit propositions of a text, and the extent to which the concepts and propositions of a text can be connected to and are consistent with discourse and real-world information.

The latter considerations from this literature seem especially relevant to the sentences that have been used in research on the reduced relative—main clause ambiguity. Both the extent to which information is consistent with a reader's general knowledge and the extent to which information can be connected to general knowledge already known to the reader might be at work in these sentences. Consider the following sentences, from the items on which Experiments 1 through 8 below were based. The first pair is from McRae et al. (1998) and the second pair is from Trueswell et al. (1994):

> The hangman executed by the government had been convicted of treason.
> The martyr executed by the government had been convicted of treason.
> The man towed by the garage was parked illegally.
> The car towed by the garage was parked illegally.

The first sentence of each pair was designed to have the head of the reduced relative clause be a typical agent of the verb in the clause and the second sentence of each pair was designed to have the head be a typical patient. In other words, a hangman is a typical agent for the verb *execute* whereas a martyr is a typical patient, and a man is a typical agent for the verb *tow* whereas a car is a typical patient.

The potential problem with pairs of sentences like these, as with the *elephant* and *meat* pair, concerns the extent to which the two sentences of a pair match background knowledge. For the *execution* sentences, a government executing a hangman is inconsistent with the usual execution script in which it is a hangman who does the executing (e.g., Schank & Abelson, 1977). In contrast, a government executing a martyr is consistent with the way execution events often happen.

Note, crucially, that it is interactions with general knowledge that are at issue. It might be that pairs of sentences differ in this respect in their concepts or in combinations of their concepts. First, at the level of single concepts, *the satyr executed by the government* might be more difficult than *the martyr executed by the government* simply because readers have less knowledge of satyrs than martyrs. Second, at the level of combining concepts, it might be that combining *hangman* with *execute* in *the hangman executed by the government* is more difficult than combining *martyr* with *execute* in *the martyr executed by the government* because, in a typical script, hangmen are usually executors whereas martyrs are usually executees. Third, at the level of propositions, it might be that it is only when all the concepts of a proposition are put together that differences appear. While it is likely that hangmen do the executing in some scripts, there are others in which they might not. *The hangman executed by the government* might mismatch general knowledge and therefore be difficult to read, but *the hangman executed by the rebels* might match general knowledge and therefore present no difficulty. In both cases, *the hangman* is combined with *execute*; the difference in difficulty lies in the full propositions, (execute, government, and hangman) (execute, rebels, hangman).

Other pairs of McRae et al.'s sentences are also problematic with respect to interactions with general knowledge. For example, for the sentences *The juror convicted by the judge*... and *The criminal convicted by the judge*..., judges are much more likely to convict criminals than jurors. Whether this kind of problem applies to all of the sentences used by McRae et al., and those used by Trueswell et al. is uncertain. The examples just given seem to provide clear cases, but it is not always possible to know the extent to which prior expectations are or are not met because expectations from general knowledge can be extremely subtle.

The connections between the information in a sentence and information already known to a reader can be even more subtle. Usually, a discourse moves from mention of one entity to mention of another by relating each next entity to the previous ones or to other entities already known to the reader, or both, a phenomenon called grounding. The single isolated sentences often used in psycholinguistic research usually do not provide proper grounding. *The hangman*, for example, is probably not properly grounded by its sentence because there is no obvious relation or connection a reader can construct between a specific, already-known entity and *the hangman*. For McRae et al.'s and Trueswell et al.'s sentences, the concern is that the grounding problem might be worse for the reduced relatives with typical agent heads than for the reduced relatives with typical patient heads. The *towing* sentence, for example, says that a man was towed by a garage but this would almost never happen literally. Although we might say, in an appropriate and fully specified context, that a man was towed by a garage, we would mean that the man's car was towed. A man being towed by a garage would make sense, that is, it would be properly grounded, as long as the discourse context provided information that allowed *the man* to be understood as referring to his car. But in an isolated sentence in an experiment, there is no appropriate discourse context. Thus, comprehension of *The man towed by the garage*... would likely be more difficult than comprehension of *The car towed by the garage*.... However, it must be stressed that, like the extent to which information in sentences meets prior expectations, the extent to which information is well-grounded is difficult to judge. It is difficult to judge whether, overall, McRae et al.'s and Trueswell et al.'s sentences differed in that the reduced relatives with typically patient heads were better grounded than the reduced relatives with typically agentive heads. Some support for this possibility is given in a study by Fox and Thompson (1990) that showed that the linguistic mechanisms speakers use to ground people are different than the mechanisms used to ground other entities, but there is currently no general and explicit way to measure groundedness.

In this section, we gave background for the proposal that, in previous experiments such as McRae et al.'s (1998) and Trueswell et al.'s (1994), relative clauses with typically agent versus typically patient heads differed not only in their agent/patient typicality but also in their meanings, that is, the extent to which the events they describe match expectations from general knowledge and the extent to which the events can be grounded in general knowledge. The results of the experiments below provide support for this proposal.

Experiments 1 through 8

Experiments 1 through 8 were designed to demonstrate the interactions of sentences' meanings with general knowledge using materials from two studies of reduced relative—main clause ambiguity processing, McRae et al. (1998) and Trueswell et al. (Experiment 2, 1994). Both studies found the standard result that reading times are slower for sentences with a reduced relative—main clause ambiguity when the head of the reduced relative is a typical agent than when it is a typical patient. The study by McRae et al. (1998) has been influential because it combined empirical results with a detailed simulation model that accounted for those results. Trueswell et al.'s (1994) earlier study has also been influential. It was one of the first efforts to make explicit the constraints postulated by constraint based models and to empirically investigate them, and it was the topic of recent new studies by Clifton et al. (2003).

McRae et al. (1998) and Trueswell et al. (1994) gave the constraint based explanation of their findings that was outlined above: the difference in processing times between the reduced and nonreduced versions of a relative clause is larger when the clause is headed by a typical agent than a typical patient because typicality interacts with syntactic disambiguation processes. Specifically, the typical patient is more in accord with the syntactic role it must assume as the head of a reduced relative than is the typical agent. This makes it easier for the processing system to choose the reduced relative construction over the main clause construction for the typical patient than for the typical agent. In other words, *the meat devoured...* is easier to process as a reduced relative than *the elephant devoured...* because *the meat* is a better patient of *devour*.

The purpose of Experiments 1 through 8 was to provide evidence for the alternative possible explanation of their findings that was put forward above. To reiterate, according to this alternative explanation, the difference in processing times between reduced relative clauses with typical agent versus typical patient heads is due to differences in the interactions between their meanings and general knowledge. The difference in processing times is not due to agent-verb and verb-patient typicalities interacting with syntactic disambiguation processes. Processing times for nonreduced relatives are set aside because they have different meanings than reduced relatives and so cannot serve as a control for all factors that might influence processing times other than ambiguity.

For Experiments 1 through 8, the propositions of the relative clauses used by McRae et al. and Trueswell et al. were rewritten into new sentences that are not ambiguous. Three different unambiguous constructions were tested. Table 1 shows examples of the original sentences from McRae et al. and Trueswell et al. and the new sentences. For McRae et al.'s and Trueswell et al.'s original sentences, McKoon and Ratcliff (2003) replicated their findings of longer reading times for the sentences with typically agent heads. These data are shown in the table along with the data from Experiments 1 through 8.

The first unambiguous construction was a simple main clause sentence. The nouns that were the heads of the reduced relatives in McRae et al.'s and Trueswell et al.'s sentences became main clause objects (Experiments 1 and 5 in Table 1). The two sentences of a pair (e.g., *The government executed the hangman* and *The government executed the martyr*) differ only in the final noun. At the point at which this noun is processed, it is apparent that it is the final noun of its sentence, and there is no syntactic ambiguity.

In the second unambiguous construction (Experiments 2 and 6, Table 1), the reduced relative from each of the original sentences was moved to a position in which either it was the object of the sentence's main verb or it was the object of a preposition. In *The nuns mourned the hangman executed by the government*, for example, the noun phrase made up of the reduced relative and its head is the object of the verb *mourned*. At the point at which the head and verb of the reduced relative are processed (e.g., when *the hangman executed* is processed), there is no syntactic ambiguity between the head of the reduced relative being an agent versus a patient. There may be other possible syntactic structures when only the head has been processed, but these occur rarely and are eliminated once the verb is processed. At the verb, there is no possible syntactic structure for which the head is an agent.

In the third unambiguous construction (Experiment 4, Table 1), the relative clauses in object positions were changed from reduced to nonreduced. According to the MTS proposal about the meanings of reduced and nonreduced relative clauses, the nonreduced construction leads to a weaker connection between the head of the clause and the information in the clause. Therefore, difficulty with the meaning of the proposition should be mitigated, as has been demonstrated with nonreduced relatives in sentence subject positions. Specifically, the difference in reading times that has been found between *The hangman executed by the government...* and *The martyr executed by the government...* tends to be smaller when the clauses are nonreduced (*The hangman/martyr who was executed by the government...*). Experiment 4 was designed to replicate this finding with nonreduced relatives in object position.

In the fourth unambiguous construction (Experiment 8, Table 1), the propositions of the original reduced relatives and their heads were expressed in main clause, passive sentences. With the passive verb, there is no ambiguity between whether the subject noun is an agent or patient.

Overall, the aim of Experiments 1 through 8 was to show that there are differences in meaning between the pairs of propositions used in the reduced relative sentences of McRae et al.'s and Trueswell et al.'s experiments that are not tied to syntactic disambiguation processes. To anticipate, the results matched expecta-

Table 1
Sentence reading times

Experiment	Sentences	Reading times (ms)	Difference in means	95% Confidence interval on difference in means
Materials based on sentences used by McRae et al. (1998)				
McKoon and Ratcliff (2003)	The hangman executed by the government had been convicted of treason.	3056		
	The martyr executed by the government had been convicted of treason.	2639	417*	
Experiment 1	The government executed the hangman.	1403		
	The government executed the martyr.	1331	72*	±61 ms
Experiment 2	The nuns mourned the hangman executed by the government.	3023		
	The nuns mourned the martyr executed by the government.	2762	261*	±210 ms
Experiment 3	The nuns mourned the hangman.	1350		
	The nuns mourned the martyr.	1380	−30	±83 ms
Experiment 4	The nuns mourned the hangman who was executed by the government.	2680		
	The nuns mourned the martyr who was executed by the government.	2630	50	±59 ms
Materials based on sentences used by Trueswell et al. (1994)				
McKoon and Ratcliff (2003)	The man towed by the garage was parked illegally.	2407		
	The car towed by the garage was parked illegally.	2084	323*	
Experiment 5	The garage towed the man.	1486		
	The garage towed the car.	1393	93*	±76 ms
Experiment 5 replication	The garage towed the man.	1334		
	The garage towed the car.	1258	76*	±65 ms
Experiment 6	The attendant could not find the man towed by the garage.	2750		
	The attendant could not find the car towed by the garage.	2515	235*	±132 ms
Experiment 7	The attendant could not find the man.	1813		
	The attendant could not find the car.	1833	−20	±127 ms
Experiment 8	The man was towed by the garage.	1414		
	The car was towed by the garage.	1288	126*	±81 ms

Note: * Indicates a significant difference.

tions: The propositions with typical agents took longer to read than the propositions with typical patients when they were expressed unambiguously in simple main clause sentences, in object-position reduced relatives, and in simple passives.

Method

Materials

For Experiments 1 through 4, the materials were based on the 40 pairs of sentences used by McRae et al. (1998). Like the example in the first two rows of Table 1, the beginning of each of these sentences was the main subject of the sentence, a noun phrase modified by a reduced relative clause. The heads of the reduced relatives were always animate entities, and for one sentence of each pair, this was an entity that was rated a typical agent of the verb in the reduced relative and for the other sentence, it was an entity that was rated a typical patient. Typicality values were determined by McRae et al. (1998) from subjects' ratings. The typical agent nouns' average ratings were 5.3 as agents and 1.5 as patients (on a scale of 1–7), and the typical patient nouns' averages were 1.0 as agents and 5.0 as patients. The mean frequencies of the typical agent and typical patient heads were 27 and 29, respectively (Francis & Kucera, 1982). Their mean numbers of syllables were 2.3 and 2.2, respectively.

McKoon and Ratcliff (2003) replicated McRae et al.'s finding of significantly longer reading times for the reduced relative sentences with typical agent heads, measuring reading times for the first lines of the sentences, which averaged 10 words in length and always included the reduced relative and the main verb of the sentence. The mean reading times from McKoon and Ratcliff's study are shown in the first two rows of Table 1.

For Experiments 1 through 4, new sentences were formed from McRae et al.'s materials, as shown in Table 1. For each experiment, there were 40 pairs of sentences, the two sentences of a pair differing in the same critical nouns, one a typical agent and the other a typical patient, as the original pairs. For Experiment 1, the relative clauses and their heads were used to form new sentences with the noun phrase that had been the object of the *by* phrase in the original sentence used as the subject of the new sentence, and the noun phrase that had been the head of the reduced relative used as the object of the new sentence. All the sentences were exactly five words in length.

For Experiment 2, the relative clauses and their heads from McRae et al.'s sentences were placed in object positions in new sentences, like the example in Table 1. A clause and its head made up either the direct object of the main verb of the sentence or the object of a prepositional phrase that immediately followed the main verb. The reduced relative and its head were worded exactly as in the original sentence, and the words of the clause were always the last words of the sentence. The head and clause were preceded by the noun phrase that was the subject of the sentence, the main verb of the sentence, and sometimes a preposition, the same words for both versions of a sentence. The number of words preceding the head of the relative clause averaged 3.4.

Experiment 3 was included to control for the possibility that the words preceding the heads of the reduced relatives in the sentences of Experiment 2 differed in some way in their relations to the typical agent versus typical patient heads, some way that would affect processing time. For Experiment 3, the relative clauses were deleted from the sentences of Experiment 2 (see example in Table 1). The words of the sentences were identical to those used in Experiment 3, with the exception of the deleted clauses.

In Experiment 4, the relative clauses in object positions were changed from reduced to nonreduced. The reading time difference found between subject-position reduced relative clauses with typical agent versus typical patient heads has tended to be smaller with nonreduced relatives and Experiment 4 was designed to replicate the finding with nonreduced relatives in object position. The words of the sentences were identical to those used in Experiment 2 except that the words *that was* (for inanimate heads) or *who was* (for animate heads) were added to turn the relative clauses from reduced to nonreduced. Since it was possible we would find no significant difference in reading times between the two versions of the nonreduced relatives, we also included in Experiment 4 sentences for which we predicted a significant difference, the same sentences as were used in Experiment 5.

For Experiments 5 through 8, the sentences were based on the 16 pairs of sentences used by Trueswell et al. (Experiment 2; 1994). All of these sentences began with a noun phrase modified by a reduced relative. For one sentence of each pair, the head of the reduced relative was an animate entity, and for the other, it was inanimate, as in the examples in Table 1. The sentences averaged 9.8 words in length. The mean word frequency for the animate heads was 354 and the mean frequency for the inanimate heads was 132 (Francis & Kucera, 1982). The mean numbers of syllables were 2.0 and 2.1, respectively. The reading times for McKoon and Ratcliff's (2003) replication are shown in Table 1.

For Experiments 5, 6, and 7, new sentences were formed from Trueswell et al.'s sentences in exactly the same way as was done for Experiments 1, 2, and 3 for McRae et al.'s sentences. For each experiment, there were 16 pairs of sentences, the two sentences of a pair differing in the same animate and inanimate nouns as the original pairs. For Experiment 6, the mean number of words preceding the reduced relative and its head was 5.2.

For Experiment 8, the sentences were passive versions of the sentences used in Experiment 5. All sentences used the passive auxiliary *was* or *were*. Just as for the sentences of Experiments 5 and 6, the sentences of Experiment 8 have no ambiguity of structure: in *the man was towed by the garage*, the passive auxiliary is consistent only with a syntactic structure in which *man* is a patient of *towed*.

For each of Experiments 1 through 4, there were 80 filler sentences; for each of Experiments 5, 6, and 8, there were 256, and for Experiment 7, there were 128. The filler sentences varied in length, none containing reduced relative clauses.

Procedure

The sentences were displayed on the screen of a PC computer, and reading times were measured for each sentence. Measuring reading times for whole sentences differs from the paradigms most frequently used in research with reduced relative clauses, paradigms in which reading time is measured for each word of a sentence or each phrase. For the purposes of this article, the choice of paradigm is not crucial. In Experiments 1 and 5, the critical manipulation (typical agent versus typical patient) occurred at the final word of the sentence. In Experiments 2 and 6, the final words of the sentence (e.g., *by the government*) were words on which the effect of the agent/patient manipulation has been observed in previous experiments with word-by-word reading times. If we had used a word-by-word reading time measure, all of the differences between the sentences would, necessarily, have occurred at the final words of the sentences because that is where the sentences differed.

Each experiment began with a block of 20 practice sentences, followed by the experimental sentences mixed in random order with the filler sentences. Two-thirds of the sentences were immediately followed by a true/false test sentence to check for comprehension; for about half of them, the correct response was "true."

Subjects controlled the reading time for each sentence by pressing the space bar on the PC keyboard when they were finished with a sentence and ready for the next item (either another sentence to read or a true/false test). Test sentences were marked with the label "TRUE OR FALSE." Subjects were instructed to press the ?/ key if a test sentence was true according to the sentence just read and to press the *z* key if not. Subjects were encouraged to read the sentences as quickly as possible while keeping their accuracy on the true/false tests high.

Design and subjects

A counterbalanced design was used for each experiment, with the two sentences of each pair, two sets of sentence pairs, and two groups of subjects as the factors. All of the subjects were undergraduates at Northwestern University, participating for credit in an introductory psychology class. The number of subjects for each experiment is shown in Table 2.

Results

Mean reading times were calculated for each of the experimental sentences and means of these means are reported in Table 1, along with 95% confidence intervals on the differences between the means. Other summary statistics are reported in Table 2. For all eight experiments, reading times longer than 2.5 standard deviations above the mean (about 2% of the data on average) were eliminated from the analyses (Ratcliff, 1993).

The results of the experiments support the hypothesis put forward in this article: the propositions of the reduced relatives used by McRae et al. (1998) and Trueswell et al. (1994) differ such that the meanings of the propositions that included typical agent heads are more difficult to comprehend than the meanings of the propositions that included typical patient heads. In Experiments 1, 2, 5, 6, and 8 (and in the replication of Experiment 5 that was included in Experiment 4), none of the sentences contained a reduced relative—main clause ambiguity yet in every case, reading times were significantly longer for the sentences with typical agents than the sentences with typical patients (see Table 2; $p < .05$ throughout this article). Note that the size of the difference between the sentences with typical agents and the sentences with typical patients varied across the experiments as the baseline reading times varied. For example, in Experiment 1, the difference was 72 ms with a baseline of 1331 ms, whereas in Experiment 2, the difference was 261 ms with a baseline of 2762 ms. In percentage terms, the differences varied from 5% of baseline to 10% of baseline.

Experiments 3 and 7 were designed as checks that there was no differential difficulty introduced in the sentences of Experiments 2 and 7 by the new, main clause, subjects and verbs. It was expected that there would be no significant differences between the two versions of the sentences and there were none.

In previous research, the reading time differences that have been obtained between reduced relative clauses with typical agent heads and reduced relative clauses with typical patient heads have often been significantly smaller when the clauses were switched to nonreduced. Previous

Table 2
Experiment summaries

Experiment	Number of subjects	Filler items		F value for reading time differences between the two experimental conditions
		% Correct, true tests	% Correct, false tests	*F* value
Experiment 1	24	95	92	$F(1,24) = 4.5$
Experiment 2	16	97	96	$F(1,15) = 8.4$
Experiment 3	16	96	93	$F < 1.0$
Experiment 4	32	95	93	$F < 1.0$
Experiment 5	44	96	88	$F(1,43) = 5.3$
Experiment 5 replication	32	95	93	$F(1,31) = 4.8$
Experiment 6	16	91	72	$F(1,15) = 11.5$
Experiment 7	16	95	90	$F(1,15) < 1.0$
Experiment 8	22	91	91	$F(1,21) = 8.9$

Note: Because the experiments were designed only to examine the materials used by Trueswell et al. (1994) and McRae et al. (1998), only analyses of variance with subjects as the random variable are reported.

research usually used nonreduced relative clauses in subject positions of sentences. In Experiment 4, the nonreduced relatives were in object positions. There was no significant effect of agent/patient typicality.

In Experiments 2 and 6, a reduced relative clause occurred in an object position, as in *The attendant couldn't find the man towed by the car.* Sentences like these have been studied previously by Tabor, Galantucci, and Richardson (2004). They found the same result we did: For reduced but not for nonreduced relatives, reading times were slowed when the head of the clause was a typical agent compared to a typical patient. Tabor et al.'s studies are somewhat problematic because many sentences were judged by subjects as ungrammatical and because reading times were slow (over 400 ms per word on average). In comparison, most of the sentences in our studies were judged grammatical (84% by an independent group of subjects) and reading times averaged about 285 ms per word. Nevertheless, our finding replicates Tabor et al.'s, and underlines the significance of their discussion of how various sentence processing models might handle interactions between meaning and the processes that construct sentences' syntactic structures.

Discussion of experiments 1 through 8

In motivating Experiments 1 through 8, we outlined the reasoning behind earlier experiments on reduced relative—main clause ambiguities. The reasoning has relied on two assumptions. The first is that the only difference to the sentence processing system between reduced and nonreduced relative clauses is a syntactic one: reduced relatives require disambiguation but nonreduced relatives do not. McKoon and Ratcliff (2003) showed that this assumption is incorrect, and argued that, when there are difficulties with the meaning of the clause, then they are more apparent to the processing system if the clause is reduced than if it is not. The difficulty with the meaning of "snake devours elephant," specifically its mismatch with general knowledge, is more disruptive to processing if the information is expressed in a reduced relative than a nonreduced relative.

The assumption that reduced and nonreduced relatives differ only in ambiguity has been crucial in previous research. It allowed nonreduced relatives to serve as controls for everything that might affect comprehension processing for reduced relatives except disambiguation processes and variables that interact with them. Thus, when the difference in processing times between reduced and nonreduced relatives was larger when the head of a clause was a typical agent of the clausal verb than when it was a typical patient, it was argued that agent/patient typicality was a significant factor in disambiguation.

Setting aside nonreduced relatives as a control brings into question exactly what the contrast has been between the two types of reduced relatives that were used in McRae et al.'s, 1998 and Trueswell et al.'s (1994) experiments, reduced relatives with typical agent heads and reduced relatives with typical patient heads. The claims have been that agent/patient typicality is, in fact, the key difference between them and that agent/patient typicality is implicated in syntactic disambiguation processes. In other words, *meat* is a more typical patient of *devour* and that makes disambiguation of *the meat devoured…* easier than disambiguation of *the elephant devoured….* For Experiments 1 through 8, we argued that agent/patient typicality was not the only important difference. The elements of the relative clauses must be considered in terms of how they combine to make up propositions and how the information in the propositions relates to general knowledge. "Snake devours elephant" mismatches general knowledge in a way that "snake devours meat" does not. If this is correct, then larger disruptions in processing that occur for *The elephant devoured by the snake…* than *the meat devoured by the snake…* might be attributable to processes other than syntactic disambiguation. If so, then "snake devours elephant" should disrupt processing compared to "snake devours meat" even in sentences that are not ambiguous. Using unambiguous sentences constructed from the materials used in previous studies, this is exactly what Experiments 1 through 8 demonstrated.

In the General Discussion, we discuss the implications of these conclusions for the two stage and constraint based models. First, however, we explore a different kind of control condition that has been sometimes used to investigate disambiguation difficulties for reduced relative clauses.

Reduced relative clauses with unambiguous past participles

Spivey-Knowlton and Tanenhaus (1998), Spivey-Knowlton et al. (1993), and MacDonald (1994) compared two types of reduced relative clauses: those for which the verbs were ambiguous between their active past tense and passive past participle forms and those with unambiguously passive participle forms. For example, they compared sentences like *The actress selected by the director believed that her performance was perfect* to sentences like *The actress chosen by the director believed that her performance was perfect. Selected* is ambiguous whereas *chosen* is not.

This experimental manipulation becomes crucial in light of the arguments we have presented so far in this article. According to both the two stage and the constraint based models, processing should be slower for ambiguous than unambiguous relative clauses because ambiguity makes choosing the relative clause structure difficult. If, as we propose, nonreduced relatives must be set aside because they do not adequately control for factors other than those involved in disambiguation, then the only other unambiguous relative clauses against which reduced relatives with ambiguous verbs have been compared are those used in the studies just described. Spivey-Knowlton and Tanenhaus (1998), Spivey-Knowlton et al. (1993), and MacDonald (1994) all found that reading times were faster for reduced relatives with unambiguous passive participle verbs than reduced relatives with ambiguous verbs.

The authors of the studies interpreted this finding in the framework of constraint based models. For such models, the relative difficulty of processing a potentially ambiguous sentence depends on the probabilities with which the elements and possible structures of the sentence occur in the language. The interpretation was that reduced relatives with unambiguous verbs are read faster because there is no ambiguity to slow processing. Although not explicitly spelled out, this interpretation appears to depend on the following reasoning: an unambiguous verb like *chosen* in the sentence above cannot be the verb of a main clause; therefore the probability of a reduced relative is zero, and therefore no other probabilities are relevant to processing. In other words, probabilities usually assumed relevant to processing like the probability of *chosen* being active or passive, the probability of an actress being an agent or a patient of *choose*, the probability that a *by* prepositional phrase contains the agent in a reduced relative clause, and the *a priori* probabilities of reduced relative versus main clause structures all become irrelevant with an unambiguous verb.

It does not seem to us that this reasoning is necessarily consistent with the general framework of constraint based models. Instead, it seems possible that processing of all types of syntactic constructions should depend on the probabilities with which they and their elements occur in the language, regardless of whether they or their elements are ambiguous. If this is correct, then a direct comparison of processing for the two *actress* sentences depends on the two sentences differing in only one respect: the probability that *chosen* is passive participle is 1.0 whereas the probability that *selected* is passive participle is less than 1.0.

To test whether the ambiguous and unambiguous verbs used in the studies by Spivey-Knowlton, MacDonald, and colleagues (MacDonald, 1994; Spivey-Knowlton et al., 1993; Spivey-Knowlton & Tanenhaus, 1998) differ only in this one respect, we examined sentences from a corpus of 280 million words of naturally produced texts. The corpus includes newspaper and magazine articles, transcripts of television shows, and children's and adults' fiction and nonfiction. For each verb, we calculated four probabilities. The first was the probability that it occurs in a reduced relative clause of the appropriate type (i.e., a clause for which the head is the object of the clausal verb). The second two were the probability that a verb occurs in active versus passive voice and the probability that a *by* phrase immediately following the verb contains the agent of the verb. Fourth, we calculated the probability that the verb occurs in a nonreduced relative clause. For each of these probabilities except the *by* phrase, we examined a large enough number of randomly chosen sentences for each verb such that the standard errors in the probabilities for the verbs were less than .0003. For the *by* phrase probability, we examined all the sentences in which each verb occurs in a 23 million word subset of the corpus. In a constraint based model that depends on probabilities, there should be no significant differences between the ambiguous and unambiguous verbs in any of these probabilities. They should differ only in the probability that they are passive participles.

Corpus study 1

In the materials used by Spivey-Knowlton and Tanenhaus (Experiment 1, 1998) and Spivey, Trueswell, and Tanenhaus (Experiments 2 and 3, 1993), there were 32 sentences with reduced relative - main clause ambiguities in sentence-initial position, like the *actress* sentences above. For 16 of the sentences, the clausal verb was ambiguous between its past tense and passive participle forms and for 16, the verb was unambiguously passive participle. For our study, two of the verbs, *woken* and *forsaken*, were eliminated from analyses because there were too few tokens of them in the corpus. *Abandoned*, *taken*, *beaten*, *chosen*, and *shown* were each used twice in Spivey et al.'s sentences, and the other 20 verbs were: *presented*, *killed*, *watched*, *removed*, *battered*, *identified*, *robbed*, *admitted*, *punished*, *selected*, *covered*, *criticized*, *recognized*, *raised*, *slain*, *seen*, *forgotten*, *hidden*, *known*, and *grown*. For statistical analyses of the corpus data, we included the same verbs twice as in Spivey et al.'s studies, and we substituted mean values for the two verbs that we eliminated.

The results, displayed in Table 3, show a significant difference between the ambiguous and unambiguous verbs in the probabilities with which they occur in reduced relative clauses.

Corpus study 2

In this study, 18 verbs used by MacDonald (Experiment 1, 1994) were examined. For 6 verbs, the passive participle is unambiguous (*overthrown, shown, drawn, chosen, seen*, and *eaten*), and for 12, the passive participle and past tense forms are the same (*captured, admired, presented, selected, found, devoured, fought, raced, painted, applauded, watched,* and *attacked*). The verbs were used in sentences like *The ruthless dictator overthrown/*

captured/fought in the coup was hated throughout the country. In the corpus, the unambiguous verbs occur in reduced relative clauses with a significantly higher probability than the ambiguous verbs and they occur in the passive voice with a significantly higher probability (Table 3).

Corpus study 3

For the third study, we examined the 24 verbs from MacDonald's (1994) Experiment 3: 8 ambiguous (*overthrown, shown, drawn, chosen, seen, driven, taken*, and *overtaken*) and 16 unambiguous (*chased*, *noticed*, *painted*, *criticized*, *heard*, *pushed*, *passed*, *attacked*, *fought*, *raced*, *studied*, *lectured*, *watched*, *moved*, *marched*, and *surrendered*). In MacDonald's experiment, these verbs were placed in reduced relative clauses in sentences like *The rancher could see that the nervous cattle driven/pushed/moved into the crowded pen were afraid of the cowboys.* In the corpus, the unambiguous verbs occur in reduced relative clauses with a significantly higher probability than the ambiguous verbs, and they are significantly more likely to occur in passive voice (Table 3).

Corpus study 4

In the experiments by Spivey-Knowlton and colleagues (1993; 1998) and MacDonald (1994), reading times were directly compared for reduced relative sentences with ambiguous verbs and reduced relative sentences with unambiguous verbs (*the nervous cattle pushed into the pen*... versus *the nervous cattle driven into the pen*...). Trueswell et al. (1994) used a different design. For both ambiguous and unambiguous verbs, reading times for reduced relative clauses were compared to reading times for nonreduced relative clauses. For example, *The evidence examined by the lawyer turned out to be unreliable* was compared to *The evidence that was examined by the lawyer turned out to be unreliable*, and *The poster drawn by the illustrator was used for a magazine cover* was compared to *The poster that was drawn by the illustrator was used for a magazine cover*. There were 16 ambiguous verbs (*examined*, *transported*, *loved*, *lifted*, *graded*, *selected*, *requested*, *identified*, *captured*, *attacked*, *studied*, *described*, *expected*, *scratched*, *recognized*, and *wanted*) and 12 unambiguous verbs (*taken*, *drawn*, *done*, *thrown*, *grown*, *written*, *broken*, *chosen*, *shown*, *seen*, *stolen*, and *eaten*). The unambiguous verbs are more likely to occur in reduced relative clauses in the corpus than the ambiguous verbs (Table 3).

Discussion of corpus studies 1 through 4

In all four corpus studies, verbs like *eaten* that have unambiguously passive participle forms were significantly more likely to occur in reduced relative clauses than verbs like *devoured* that are ambiguous between their participle and past tense forms. In two of the studies, the unambiguously participle verbs were also significantly more likely to occur in the passive than the active voice. Thus, the two types of verbs that were used in the studies differ in other factors besides their ambiguity. We do not know whether there exist ambiguous and unambiguous verbs that could be matched on their probabilities of occurrence in various model-relevant forms and structures.

Spivey-Knowlton and colleagues (1993; 1998), MacDonald (1994), and Trueswell et al. (1994) interpreted

Table 3
Ambiguous and unambiguous verbs: probabilities of occurrence

Study	Verb	Reduced relative	Passive	"By" phrase contains agent	Nonreduced relative
Spivey-Knowlton and Tanenhaus, Experiment 1; Spivey-Knowlton, Trueswell, and Tanenhaus, Experiments 2 and 3	Ambiguous	.05	.59	.53	.02
	Unambiguous	.09	.66	.49	.02
		$F(1,15) = 5.9^*$	$F(1,15) = 1.9$	$F < 1.0$	$F < 1.0$
MacDonald, Experiment 1	Ambiguous	.04	.40	.76	.04
	Unambiguous	.10	.65	.69	.02
		$F(1,10) = 39.3^*$	$F(1,10) = 31.3^*$	$F < 1.0$	$F(1,10) = 1.6$
MacDonald, Experiment 3	Ambiguous	.02	.23	.45	.01
	Unambiguous	.10	.65	.53	.03
		$F(1,14) = 70.0^*$	$F(1,14) = 227.9^*$	$F(1,14) = 1.3$	$F < 1.0$
Trueswell et al. (Welch two sample *t*-tests)	Ambiguous	.04	.49	.56	.02
	Unambiguous	.10	.62	.51	.03
		$t(18) = 3.7^*$	$t(30) = 1.7$	$t(24) = .41$	$t(23) = 1.2$

Note: * Indicates significant at $p < .05$.

Table 4
Sentence types

Pair		Sentences
1***	Subject position reduced relative clauses	The meat devoured by the snake provided much needed nourishment.
		The elephant devoured by the snake provided much needed nourishment.
2	Subject position nonreduced relative clauses	The meat that was devoured by the snake provided much needed nourishment.
		The elephant that was devoured by the snake provided much needed nourishment.
3???	Subject position reduced relative clauses	The meat eaten by the snake provided much needed nourishment.
		The elephant eaten by the snake provided much needed nourishment.
4	Subject position nonreduced relative clauses	The meat that was eaten by the snake provided much needed nourishment.
		The elephant that was eaten by the snake provided much needed nourishment.
5***	Active main clauses	The snake devoured the meat.
		The snake devoured the elephant.
6***	Object position reduced relative clauses	The hunter saw the meat devoured by the snake.
		The hunter saw the elephant devoured by the snake.
7	Object position nonreduced relative clauses	The hunter saw the meat that was devoured by the snake.
		The hunter saw the elephant that was devoured by the snake.
8***	Passive main clauses	The meat was devoured by the snake.
		The elephant was devoured by the snake.

*** Indicates significant difference in reading times between the two sentences.

their findings as consistent with the constraint based model framework. However, it is difficult to know whether such a model would work, given the results of the corpus studies. Earlier, we listed two possibilities. One is that an unambiguous passive participle immediately rules out a main clause interpretation: *The actress chosen...* is immediately processed as a reduced relative and the usual constraint based probabilities do not affect processing time. However, this does not seem to fit the spirit of constraint based processing. Moreover, in implementations of constraint based models, the weight given to verb information is low (e.g., .12 by McRae et al., 1998). The other possibility is that all the usual constraint based probabilities do affect processing even with an unambiguous verb like *chosen*. In this case, a model would have to be developed to attempt to fit the data. The data from the corpus studies show that, for the verbs used in previous experiments, the reduced relative occurs about twice as often with the unambiguous verbs as with the ambiguous verbs. Given that construction probabilities have been rated as the strongest constraints in implemented models (e.g., .51 in McRae et al.), then it is likely that it is construction probabilities that would account for faster reading times when the verb in a reduced relative was unambiguous. However, this account is speculative; as we stress below, a model would need to be explicitly implemented and tested against data.

General discussion

Table 4 shows the eight types of sentences under consideration, with asterisks indicating those pairs for which processing times are slower for the sentence with the typical agent than the sentence with the typical patient. For current models of syntactic disambiguation processing, the questions are whether and how they can accommodate data for all these types of sentences.

The sentences of most interest in previous research have been sentences like the first pair, reduced relative clauses with typical patient and typical agent heads. Given the results of Experiments 1 through 8, there are (at least) three possible explanations for the usual finding that the sentences with typical agent heads take longer to read. One is that the slower reading time is due *only* to extra difficulty with the meaning of the proposition with the typical agent; the slower reading time does not at all reflect syntactic disambiguation processes. A second explanation is that the slower reading time reflects *both* extra difficulty in meaning *and* disambiguation processes of the sort proposed by the two stage model. A third explanation is that the slower time reflects both extra difficulty in meaning and disambiguation processes of the sort proposed by constraint based models.

Below, we first review the two stage and constraint based theories that have been applied to sentences with the reduced relative—main clause ambiguity and discuss how, at a qualitative level, both might account for data for all the sentence types in Table 4. Whether they could also account for the data quantitatively and, at the same time, extend to other types of ambiguities are open questions.

The two stage model

In this section, we examine, in more detail than has been done previously, the various aspects of meaning that can influence second stage processing. The first, syntactic, stage always produces the simplest analysis for a string of words, the one that places the least burden on cognitive resources. For strings of words that are ambiguous between reduced relative and main clause readings, the main clause is simplest. If the simplest analysis becomes syntactically untenable at some word in the sentence, reanalysis is required. For example, for *The elephant devoured by the snake provided...*, if a main clause structure is maintained through the end of the prepositional phrase *by the snake*, then syntactic processes cannot fit the verb *provided* into the developing syntactic structure and so reanalysis is triggered.

Syntactic reanalysis can also be triggered by failure of second stage, meaning processes. When the first stage forwards its syntactic analysis to the second stage, all the other kinds of information involved in comprehension come into play, including general knowledge and discourse information. It is the job of second stage processes to make sense out of whatever syntactic structure is produced by the first stage, and if they fail, the first stage must produce a new syntactic structure.

Consider the first sentence in Table 4, *The meat devoured by the snake provided...*. The first stage begins with a main clause analysis. Second stage processes could encounter difficulty with this analysis at (at least) two different points: the verb *devoured* because inanimate entities like *meat* do not usually engage in devouring; and the prepositional phrase *by the snake* because it is difficult to find a meaning for the prepositional phrase that ties it into a main clause meaning with *The meat* as subject and *devoured* as verb. If either of these meaning difficulties is large enough, the second stage triggers reanalysis. The meaning already constructed up to that point in the sentence must be discarded, the first stage must construct a new syntactic analysis (a reduced relative clause), and the second stage must construct meaning for the new syntactic analysis. Constructing a meaning for the reduced relative structure is relatively easy because the parts of meaning are reasonable—meat can be devoured and snakes can devour—and the meaning of the whole is reasonable: the combination of meat being devoured and a snake being the entity to do the devouring makes a proposition that represents an event that is consistent with a comprehender's general knowledge about events that can happen in the world.

For the nonreduced relative that begins with *the meat*, no reanalysis is required to distinguish it from a main clause. The reduced relative structure is signaled by the pronoun and auxiliary (*that was*) and the elements and combinations of meaning for the relative clause structure are reasonable just as they are for the reduced relative.

Comparing the reduced and nonreduced versions of the *meat* sentences, there are multiple sequences of processing that would lead to slower reading times for the reduced version. Reanalysis from a main clause structure to a reduced relative structure could be triggered by meaning difficulties at the verb *devoured* or at the prepositional phrase *by the snake*, or reanalysis could be triggered syntactically at the verb *provided*. At which point reanalysis occurs depends on whether the meanings at *devour* and *by the snake* are sufficiently difficult to trigger reanalysis. For any particular experimental set of sentences, average processing time at the three regions, *devour*, *by the snake*, and *provided*, would depend on the proportion of sentences reanalyzed at each region. Predictions would also depend on whether reanalyses resulting from meaning difficulties were assumed to take the same or different amounts of time as reanalyses resulting from syntactic difficulties.

Processing for the second reduced relative in Table 4, *The elephant devoured...*, begins in the same way as for the *meat* reduced relative, with first stage processes producing a main clause structure. Unlike *the meat*, an elephant is an entity that can devour things, so second stage processes should not encounter difficulties with the meaning of *The elephant devoured*. At the prepositional phrase and the verb *provided*, the same difficulties arise as for the *meat* sentence: problems with tieing a meaning for the prepositional phrase into a main clause interpretation of *The elephant devoured* and the inability of syntactic processes to produce a main clause analysis for *The elephant devoured by the snake* at the verb *provided*.

Whenever reanalysis does occur, there is a difficulty for the *elephant* sentence beyond the difficulties that occur for the *meat* sentence, namely the meaning, taken as a whole, of the relative clause, "snake devours elephant." This extra difficulty could add to processing time at the prepositional phrase *by the snake* or at the main verb *provided*. Overall, processing times would be slower for the *elephant* reduced relative than the *meat* reduced relative. But how much slower would depend on the proportion of sentences reanalyzed at each region in the sentence, the relative amounts of time taken by meaning-triggered versus syntax-triggered reanalyses, and the amount of extra time taken by difficulties with the meaning of "snake devours elephant."

If the idea of a snake devouring an elephant is difficult in a reduced relative clause, then, in the absence of any further assumptions, it should be difficult in a nonreduced relative as well. However, if the MTS hypothesis about the nonreduced relative construction is correct and could be incorporated into the model, then problems with the meaning of the proposition would be mitigated for *The elephant that was devoured by the snake*.

For the reduced relatives with *eaten* in Table 4, the verb is unambiguously a passive participle. The questions are whether information about tense ambiguity is available to first stage, syntactic, processes and whether links between tense information and possible syntactic structures are available. In other words, does first stage processing know that *eaten* in a sequence of words like *the meat eaten* must be a passive participle, and does it know that a passive participle immediately following a noun phrase signals a reduced relative clause? Or, if this information is not available to first stage processes, it is possible that the differences among verbs in probabilities of occurrence in reduced relatives and passive constructions are reflections of second stage, meaning differences, a possibility that would need further research.

Whether the processing system finds the appropriate syntactic structures for *the meat eaten*... and *the elephant eaten*... on the basis of first stage, syntactic tense information or second stage, meaning information, the meaning of the proposition "snake eats elephant" should be more difficult than the meaning of "snake eats meat." Whether this difference in difficulty is sufficiently large to significantly affect reading times would depend on the relative speeds of the processes involving the verb *eaten* and the processes involving the meanings of the propositions. In Table 4, we have indicated (with question marks) that data on this difference are not currently available. However large the difference, it should be smaller for the nonreduced versions of the sentences, just as for the sentences with *devour*.

For all the remaining sentences in Table 4, their syntactic structures are unambiguous. In each case, reading times should be slower for the "elephant" than the "meat" sentences because of the difficulty in the holistic meaning of "snake devours elephant," with the slowdown mitigated for the nonreduced relative sentences.

In sum, although we have provided only a sketch of possibilities, and details would need to be worked out and tested, we conclude that the two stage model could potentially be consistent with the relative reading times of all the pairs of sentences in Table 4.

Constraint based models

Constraint based models are connectionist models in which multiple kinds of information ("constraints") are all assumed to interact simultaneously during sentence processing to produce the syntactic structure for a sentence. Each word in the lexicon is assumed to have stored with it its own syntactic, semantic, discourse, and general knowledge information. For an input string of words, the various kinds of information for all the words interact to produce candidate syntactic representations of the input. The candidates are ranked by probabilities of occurrence in the language, and some of the sources of information that contribute to deciding which is most likely to be correct are more strongly weighted than others.

For the reduced relative—main clause ambiguity, implementations of constraint based models like McRae et al.'s (1998; e.g., Spivey-Knowlton & Tanenhaus, 1998) have been designed to decide whether strings of words like *The elephant devoured by the snake* are main clauses or reduced relative clauses. For these models, the processing system is assumed to have available to it five probabilities. The first two are the probability that the verb occurs in the active as opposed to passive voice and the probability that the verb occurs in the past tense as opposed to past participle tense. In a main clause, the verb is active and past, and in a reduced relative, the verb is passive and past participle. McKoon and Ratcliff (2003, 2005) showed that for the verbs used in some investigations of the reduced relative—main clause ambiguity, their probability of being passive and past participle is higher than their probability of being active and past. Thus, verb probabilities have tended to favor a reduced relative clause interpretation.

The third probability that the processing system is assumed to have available to it is the probability of occurrence of a main clause compared to a reduced relative clause, and the fourth is the probability that a *by* prepositional phrase contains the agent of a verb in a reduced relative clause. These two probabilities are assumed to be constant across sentences, that is, they are constant no matter what the words that make up the candidate syntactic structures. The probability of a main clause is much higher than the probability of a reduced relative clause, .92 by McKoon and Ratcliff's (2003) estimate, and the probability of a *by* phrase containing an agent is also high, .80 by McRae et al.'s (1998) estimate.

The fifth probability is the only one that represents meaning information, and it is the probability with which a noun occurs as an agent as opposed to a patient of a verb. In some implementations, this probability is higher by the same amount for all animate than all inanimate nouns and in other implementations, the relative probability depends on the individual noun-verb pair. For example, the probability of *meat* being an agent of *devour* is much lower than the probability of it being a patient.

Implemented constraint based models like McRae et al.'s (1998) and Spivey-Knowlton and Tanenhaus's (1998) do not construct syntactic structures; instead, they simply choose between structures. For strings like *The elephant devoured by the snake*, they choose between a main clause structure and a reduced relative structure. The words of a sentence, or sometimes short phrases, are processed incrementally. At each next word or phrase, an overall probability is calculated for the main clause being the best candidate and for the reduced relative being the best candidate. The two probabilities are calculated by integrating the individual probabilities relevant for that word or phrase and the probabilities of the structures that resulted from processing the previous words or phrases of the sentence. Each of the probabilities is weighted according to its assumed importance. Integration proceeds (via a simple algebraic connectionist competition algorithm) until the probability of one of the alternative structures exceeds the other by a criterion amount. At that point, processing proceeds to the next word or phrase.

To provide concreteness, consider the sentences in Table 4. In implementations of constraint based models like those discussed here, nonreduced relative clauses are considered to be unambiguous. Agent/patient typicality plays a role only in the processing of ambiguity, and so it does not affect reading times for nonreduced relatives. That is, reading times should not be different for *The elephant that was devoured by the snake*... than for *The meat that was devoured by the snake*....

The models generate predictions for how much slower reading times should be for reduced than nonreduced versions of sentences. For the *meat* reduced relative, at *The meat devoured*, the best candidate for the string of words is a reduced relative. The higher probability of a main clause than a reduced relative is overridden by the higher probability of *meat* being a patient of *devour* than an agent and the higher probability of *devoured* being passive and past participle than active and past. Overriding the high probability of a main clause takes extra processing time compared to the *meat* nonreduced relative. At the next region of the sentence, the prepositional phrase *by the snake*, the reduced relative is still the best candidate but less processing time is required than for the first region because of the high probability of a *by* phrase containing the agent of a reduced relative and the high probability of *the snake* being an agent for *devoured*. At the verb *provided*, it is assumed that the processing system has access to the information that the verb is a main clause verb. The probability of *The meat devoured by the snake* being a main clause is set to zero and the probability of it being a reduced relative clause is set to one, with the consequence that the verb is read about as quickly for the reduced relative sentence as for the nonreduced relative sentence (McRae et al., 1998).

For *The elephant devoured by the snake*, the situation is different. At *the elephant devoured*, the probability of *The elephant* being an agent of *devoured* is high, joining with the main clause advantage to produce a relatively short processing time for the main clause as the best candidate. However, at *by the snake*, processing time slows because of the high probability of a *by* prepositional phrase containing the agent of a reduced relative and the high probability of *the snake* being an agent for *devoured*. At the verb *provided*, the assumption is the same as for the *meat* reduced relative: the system as access to the information that *provided* is a main clause verb, which means that the probability of *The elephant devoured by the snake* being a main clause is set to zero and the probability that it is a reduced relative is set to one. The system must override its earlier best candidate to switch to the reduced relative and it takes extra processing time to do so.

Overall, implementations of constraint based models like McRae et al.'s (1998) have done well in accounting for data from experiments with sentences like the first two pairs in Table 4 (but see Clifton et al., 2003). The differences in processing times between reduced relatives with typical agent heads and reduced relatives with typical patient heads have been explained with just one factor: early in a reduced relative clause, a typical agent favors the incorrect main clause reading but a typical patient favors the correct reduced relative reading.

For reduced relatives with unambiguous verbs like *eaten*, we mentioned two possible constraint based explanations of MacDonald, Spivey-Knowlton, and colleagues' findings that they have shorter reading times than reduced relatives with ambiguous verbs like *devour*. One is the one implied by MacDonald, Spivey-Knowlton, and colleagues, that the shorter reading times are due to lack of ambiguity. By this explanation, an unambiguous passive participle means that there is no choice for the processing system to make between a reduced relative structure and a main clause structure. Immediately upon encountering a verb, the processing system has access to information about whether or not the verb is ambiguous between its past tense and passive participle forms, and also that the only two possible structures are a reduced relative clause and a main clause. For an unambiguous verb, only the reduced relative structure is viable, and so the probability of a reduced relative clause is set to one and all other probabilities are ruled out of consideration. That is, no other probabilities can affect processing times. With these assumptions, shorter processing times are predicted for reduced relatives with unambiguous than ambiguous verbs, and equal processing times are predicted for *the meat eaten by the snake*... and *the elephant eaten by the snake*....

The second possible constraint based explanation of MacDonald, Spivey-Knowlton, and colleagues' findings that we mentioned is that the processing system chooses a reduced relative over a main clause interpretation with unambiguous verbs in the same way that it does with ambiguous verbs. Under this explanation, the choice depends on the relative probabilities of the elements of the sentences, including the different probabilities that an ambiguous versus an unambiguous verb occurs in reduced relatives, and how the various probabilities are weighted.

The crucial results for the constraint based models under consideration are the results from Experiments 1 through 8. The active main clause sentences, the object position reduced relative sentences, and the passive main clause sentences are all unambiguous yet they all showed shorter reading times when the verb's patient was a typical patient of the verb than when it was atypical. The shorter reading times cannot be the result of interactions between pair-wise noun-verb typicality relations and syntactic ambiguity. Therefore, like the two stage model, they must add consideration of how the meanings of concepts and propositions relate to general knowledge.

Adding these considerations to a constraint based model might lead to a model that could be consistent with all the data summarized in Table 3. Here, we offer one possible scenario. Under this scenario, sentence-initial reduced relative clauses are always processed first as main clauses. For both *The meat devoured* and *The elephant devoured*, the system initially chooses a main clause because the probability of a main clause is much higher than the probability of a reduced relative. Processing time is longer for *The meat devoured* than *The elephant devoured* because a proposition denoting an event in which meat devours something is improbable with respect to general knowledge, whereas the match between an elephant devouring something and general knowledge is much stronger. Second, at the prepositional phrase, for the *meat* sentence, the high probability of the *by* phrase containing the agent of a reduced relative and the strong match between "snake devours meat" and general knowledge combine to switch the favored interpretation from a main clause to a reduced relative. For the *elephant* sentence, the high probability of the *by* phrase containing the agent of a reduced relative favors a reduced relative interpretation but it is overridden by the mismatch between "snake devours elephant" and general knowledge, and so the system continues with a main clause interpretation, although it takes extra processing time to do so. For the *elephant* sentence, the switch to the reduced relative interpretation occurs only when it is forced by the main clause verb *provided*, and it takes significant processing time because of the implausibility of "snake devours elephant". To explain why the effect of the mismatch between "snake devours elephant" and general knowledge is smaller for the nonreduced relative sentence, there would have to be some means by which the nonreduced relative construction lessened the difficulty of the meaning of "snake devours elephant."

The most noteworthy point of this exercise is that the slower processing times for the *elephant* than the *meat* reduced relatives are explained in terms of meanings interacting with syntactic choices, rather than agent-verb and patient-verb typicality values interacting with syntactic choices. With this scenario, the models could explain the data from Experiments 1 through 8. They could explain why reading times are shorter not only for *The car towed by the garage was parked illegally* than *The man towed by the garage was parked illegally*, but also shorter for *The garage towed the car* than *The garage towed the man*, shorter for *The attendant couldn't find the car towed by the garage* than *The attendant couldn't find the man towed by the garage*, and shorter for *The car was towed by the garage* than *The man was towed by the garage*. Whether a constraint based model could actually be implemented to simultaneously cover all the data for all the sentence structures in Table 3 is an open question. Moreover, it appears to us that the gain in predictive ability could come at a cost. Under the scenario just outlined—with reduced relative clauses always first analyzed as main clauses—it might not be possible to distinguish empirically between the constraint based model and the two stage model. The central problem raised by the results of Experiments 1 through 8 is that both sorts of models must incorporate consideration of how meanings relate to general knowledge.

Discourse reference theory, the competitive attachment parser, and MTS

Besides the two stage and constraint based models, there are three other approaches to the reduced relative—main clause ambiguity. One, discourse reference theory, has been proposed by Altmann, Crain, and Steedman (Altmann & Steedman, 1988; Crain & Steedman, 1985; Ni, Crain, & Shankweiler, 1996). In their view, a reduced relative clause serves the discourse function of denoting a subset of entities out of a larger set of possibilities. For example, *devoured by the snake* should pick the meat for which this event occurred from the set of all meats under consideration in the current discourse. However, the reduced relatives usually used in experimental situations have no discourse context, which means that there is no appropriate set of discourse entities from which the reduced relative can denote a subset, and so the processing of reduced relative clauses should be slowed relative to nonreduced relatives. It has been a problem for discourse reference theory to explain why the absence of discourse context should be more troublesome for sentences like *The elephant devoured by the snake provided much needed nourishment* than for *The meat devoured by the snake provided much needed nourishment*. The research in this article provides a possible solution. The difference between the two types of relative clauses lies outside the general problem that the heads of reduced relatives are not properly grounded in a discourse context; instead, the two types of clauses are differentially difficult in how consistent their meanings are with background and discourse knowledge.

The two stage model, constraint based models, and discourse reference theory all assume that sentences that begin with reduced relative clauses are grammatical in that they obey the rules of English grammar, and so the cognitive system should be able to parse them into their correct syntactic representations. According to two newer approaches (McKoon & Ratcliff, 2003, 2005; Stevenson & Merlo, 1997), some reduced relatives, specifically those like the *The horse raced past the barn fell*, are ungrammatical. In Stevenson and Merlo's (1997) competitive attachment parser, manner of motion verbs like *race* do not have the lexical structure necessary for a reduced relative. In *race*'s lexical structure, any entity engaged in racing must have the syntactic position of an agent, but the reduced relative requires its head to have the syntactic position of a patient. The parser cannot resolve the clash between these two requirements and so it cannot achieve a complete syntactic representation for the sentence. While this approach explains difficulties with reduced relatives with manner of motion verbs, it does not address the difficulties that have been found with reduced relatives with other types of verbs. The competitive attachment parser should be able to construct a syntactic representation for any verb for which the head of a reduced relative is a syntactic patient, and there has been no explanation for why this should be more difficult for some reduced relatives (e.g., *The elephant devoured...*) than for others (e.g., *The meat devoured...*). However, the parser deals only with the construction of syntactic representations. If the difference between *The elephant devoured...* and *The meat devoured...* lies outside this domain, that is, in the domain of meaning, then the differential reading times are not problematic.

In Stevenson and Merlo's (1997) competitive attachment parser, the difficulty with manner of motion verbs is a syntactic one. In McKoon and Ratcliff's MTS (2003, 2005) view, the difficulty has to do with meaning. Manner of motion verbs are part of a larger group of verbs for which their meaning is inappropriate in terms of causality for the reduced relative construction. For this group of verbs, their lexical semantic structure denotes events for which the cause is marked as internal to the entity engaging in the activity, whereas the lexical structures of many other verbs allow denotation of events for which the cause is external to the entity undergoing the activity. Verbs that denote internally caused events are prohibited in reduced relatives like *The horse raced past the barn fell* because, according to MTS, the reduced relative construction denotes an entity that participates in an event caused by some force or entity external to itself. For example, in the acceptable reduced relative *The snowflakes sent by the good witch*, the head of the clause is *the snowflakes* and the snowflakes are caused to participate in the event of the clause, the "sending" event, by the witch, who is an entity external to themselves. The problem with reduced relatives like the one in *The horse raced past the barn fell* is that *race*'s lexical semantic structure specifies that the causality of the racing event is internal to the horse, which clashes with the reduced relative's requirement of external causality. McKoon and Ratcliff (2003) presented a number of corpus studies of naturally produced sentences and a number of psycholinguistic experiments in support of the MTS view of reduced relatives with internal cause verbs. For classes of verbs for which the denoted event can be externally caused, the only predictions MTS currently makes about the difficulty with which they are processed in relative clauses are predictions that have to do with meaning and interactions of meaning with discourse, situational, and general knowledge information.

None of the approaches we have discussed—the two stage model, constraint based models, the competitive attachment processor, discourse reference theory, or the MTS framework—provides an explanation for why unambiguously past participle verbs like *eaten* are more likely to occur in reduced relative clauses than other verbs or why they are more likely to occur in passive voice. We think that such an explanation may require a deeper understanding of their lexical semantics (Levin & Rappaport Hovav, 2005).

Conclusions

In this article, we have questioned two assumptions that have been made when constraint based and two stage theories have been used to explore comprehension of sentences with the reduced relative—main clause ambiguity. First, on the basis of data from McKoon and Ratcliff (2003), we argued that reduced and nonreduced relative clauses do not differ only in ambiguity, they also differ in meaning. Previous investigations of the ambiguity have been interested in the differences in processing time that remain between two reduced relatives after subtracting out the differences in processing time between their nonreduced counterparts. The assumption has been that the remaining differences are entirely due to syntactic disambiguation processes. However, this assumption is incorrect according to McKoon and Ratcliff's data. *The hangman executed by the government* does not convey the same thing as *The hangman who was executed by the government*. The mismatch between "government executes hangman" and the general hanging script causes less difficulty for the nonreduced than the reduced relative construction.

If nonreduced relatives must be set aside as controls for all the factors that might affect comprehension processes other than ambiguity then, for the research literature of concern in this article, the issue becomes how to explain the slower processing times for reduced relatives with typical agent heads than reduced relatives with typical patient heads. One possibility is that they are slower only because they mismatch general knowledge; their slower processing times have nothing to do with disambiguation. Another possibility is that they are slower both because of the mismatch with general knowledge and because of interactions between the mismatch and disambiguation processes. We suggested that this latter possibility might be instantiated in either the two stage or the constraint based models.

Over the past 30 years, psycholinguistics has been split, in the main, between researchers interested in how syntactic structures are processed and researchers interested in how conceptual and propositional meanings are processed. Theoretical and empirical interactions between the two domains have been infrequent. Issues such as how propositions and the syntactic structures in which they are expressed influence and reflect each other, where and how they meet in the language processing system, and how they can be separated in psycholinguistic investigations are rarely addressed. We hope that the experiments reported in this article lead to further consideration of these questions.

References

Altmann, G. T. M., & Steedman, M. (1988). Interaction with context during human sentence processing. *Cognition, 30*, 191–238.

Anderson, J. R., Budiu, R., & Reder, L. (2001). A theory of sentence memory as part of a general theory of memory. *Journal of Memory and Language, 45*, 337–367.

Anderson, S. R. (1971). On the role of the deep structure in semantic interpretation. *Foundations of Language, 6*, 197–219.

Bolinger, D. L. (1968). Entailment and the meaning of structures. *Glossa, 2*, 119–127.

Borkin, A. (1974). *Problems in form and function.* Ph.D., dissertation, University of Michigan. Published, Norwood, NJ: Ablex Publishing, 1984.

Bransford, J. D., Barclay, J. R., & Franks, J. J. (1972). Sentence memory: a constructive versus interpretive approach. *Cognitive Psychology, 3*, 193–209.

Clifton, C., Jr., Traxler, M. J., Mohamed, M. T., Williams, R. S., Morris, R. K., & Rayner, K. (2003). The use of thematic role information in parsing: Syntactic processing autonomy revisited. *Journal of Memory and Language, 49*, 317–334.

Crain, S., & Steedman, M. (1985). On not being led up the garden path: the use of context by the psychological syntax processor. In D. R. Dowty, L. Karttunen, & A. M. Zwicky (Eds.), *Natural language parsing* (pp. 320–358). Cambridge, England: Cambridge University Press.

Ferreira, F., & Clifton, C. (1986). The independence of syntactic processing. *Journal of Memory and Language, 25*, 348–368.

Fillmore, C. J. (1968). The case for case. In E. Bach & R. T. Harms (Eds.), *Universals in linguistic theory* (pp. 1–88). New York, NY: Holt, Rinehart and Winston.

Fodor, J. A., Bever, T. G., & Garrett, M. F. (1974). *The psychology of language: An introduction to psycholinguistics and generative grammar*. St. Louis: McGraw-Hill Book Co.

Fox, B. A., & Thompson, S. A. (1990). A discourse explanation of the grammar of relative clauses in English conversation. *Language, 66*, 297–316.

Francis, W. N., & Kucera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar*. Boston: Houghton-Mifflin.

Frazier, L. (1979). *On comprehending sentences: Syntactic parsing strategies*. Bloomington, IN: Indiana University Linguistics Club.

Frazier, L. (1987). Theories of syntactic processing. In J. L. Garfield (Ed.), *Modularity in knowledge representation and natural language processing*. Cambridge, MA: MIT Press.

Frazier, L. (1995). Constraint satisfaction as a theory of sentence processing. *Journal of Psycholinguistic Research, 24*, 437–468.

Frazier, L., & Clifton, C. (1996). *Construal*. Cambridge, MA: The MIT Press.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: eye movements in analysis of structurally ambiguous sentences. *Cognitive Psychology, 14*, 178–210.

Givon, T. (1985). Function structure and language acquisition. In D. I. Slobin (Ed.), *The crosslinguistic study of language acquisition* (pp. 1005–1028). Hillsdale, NJ: Lawrence Erlbaum Associates.

Goldberg, A. E. (1995). *A construction grammar approach to argument structure: Constructions*. Chicago: University of Chicago Press.

Goldberg, A. (1997). The relationships between verbs and constructions. In M. Verspoor, K. D. Lee, & E. Sweetner (Eds.), *Lexical and syntactical constructions and the construction of meaning*. Amsterdam: J. Benjamins.

Hare, M., McRae, K., & Elman, J. (2004). Admitting that admitting verb sense into corpus analyses makes sense. *Language and Cognitive Processes, 19*, 181–224.

Kintsch, W. (1974). *The representation of meaning in memory*. Hillsdale, NJ: Erlbaum.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: a construction–integration model. *Psychological Review, 95*, 163–182.

Levin, B., & Rappaport Hovav, M. (2005). *Argument realization, research surveys in Linguistics series*. Cambridge, UK: Cambridge University Press.

McKoon, G., & Ratcliff, R. (1980). Priming in item recognition: the organization of propositions in memory for text. *Journal of Verbal Learning and Verbal Behavior, 19*, 369–386.

MacDonald, M. C. (1994). Probabilistic constraints and syntactic ambiguity resolution. *Language and Cognitive Processes, 9*, 157–201.

McKoon, G., & Ratcliff, R. (2003). Meaning through syntax: language comprehension and the reduced relative clause construction. *Psychological Review, 110*, 490–525.

McKoon, G., & Ratcliff, R. (2005). Meaning through Syntax in sentence production and comprehension. *Psychological Review, 112*, 1032–1039.

McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language, 38*, 283–312.

Ni, W., Crain, S., & Shankweiler, D. (1996). Sidestepping garden paths: assessing the contributions of syntax, semantics and plausibility in resolving ambiguities. *Language and Cognitive Processes, 11*, 283–334.

Norman, D. A., Rumelhart, D. E., & LNR Research Group. (1975). *Explorations in cognition*, San Francisco: Freeman.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114*, 510–532.

Ratcliff, R., & McKoon, G. (1978). Priming in item recognition: evidence for the propositional structure of sentences. *Journal of Verbal Learning and Verbal Behavior, 17*, 403–417.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior, 22*, 358–374.

Schank, R. C., & Abelson, R. P. (1977). *Scripts, plans, goals, and understanding*. Hillsdale, NJ: Erlbaum.

Spivey-Knowlton, M., & Tanenhaus, M. (1998). Syntactic ambiguity resolution in discourse: modeling the effects of referential context and lexical frequency. *Journal of Experimental Psychology, 24*, 1521–1543.

Spivey-Knowlton, M., Trueswell, J., & Tanenhaus, M. K. (1993). Context effects in syntactic ambiguity resolution: discourse and semantic influences in parsing reduced relative clauses. *Canadian Journal of Experimental Psychology, 47*, 276–309.

Stevenson, S., & Merlo, P. (1997). Lexical structure and parsing complexity. *Language and Cognitive Processes, 12*, 349–399.

Tabor, W., Galantucci, B., & Richardson, D. (2004). Effects of merely local syntactic coherence on sentence processing. *Journal of Memory and Language, 50*, 355–370.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: use of thematic role information in syntactic ambiguity resolution. *Journal of Memory and Language, 33*, 285–318.

Wierzbicka, A. (1988). *The semantics of grammar*. Amsterdam: John Benjamins.