



The influence of contextual contrast on syntactic processing: evidence for strong-interaction in sentence comprehension

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Abstract

The present study compares the processing of unambiguous restrictive and non-restrictive relative clauses (RCs) within both a null context and a supportive discourse using a self-paced reading methodology. Individuals read restrictive RCs more slowly than non-restrictive RCs in a null context, but processed restrictive RCs faster than non-restrictive RCs in supportive context, resulting in an interaction between context and RC type. These results provide evidence for two theoretical points. First, principles analogous to those in referential theory [Altmann G. T. M., & Steedman, M. (1988). Interaction with context during human sentence processing. *Cognition*, 30, 191–238; Crain, S., & Steedman, M. (1985). On not being led up the garden path: The use of context by the psychological parser. In D. Dowty, L. Karttunen, A. Zwicky (Eds.), *Natural language parsing*. Cambridge, UK: Cambridge University Press] apply not only in resolving ambiguity but also in processing unambiguous sentences. Second, the discourse context can guide and facilitate interpretive processing. This result suggests that intrasentential factors such as syntax are not autonomous from contextual processing, contrary to the modularity hypothesis [Fodor, J. A. (1983). *Modularity of mind*. Cambridge, MA: MIT Press].

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1. Introduction

To understand a sentence, it is crucial to situate its meaning within an appropriate discourse context. Yet, until recently, investigations into the cognitive underpinnings of sentence comprehension have often divorced sentences from their context, choosing instead to focus on intrasentential factors like syntactic complexity or thematic plausibility. A prominent exception is a line of research that has come to be known as the referential theory. This theory holds that the referential function of language affects how individuals resolve certain semantic and structural ambiguities (Altmann & Steedman 1988; Crain & Steedman, 1985; Ni & Crain, 1989). Work in this area hinges on the observation that alternative interpretations of an ambiguous utterance generally have different discourse properties. As a result, one reading is usually more consistent with the immediate discourse.

To illustrate, consider how the referential theory explains parsing behavior for sentences such as (1) (adapted from Crain & Steedman, 1985).

- (1) A psychologist told the woman that he was having trouble with...
- a. ...her husband.
 - b. ... to leave.

Up to the preposition “with”, the clause initiated by “that” can be analyzed either as a sentential complement (SC) of the verb “told” as in (1a) or as a relative clause (RC) modifying “The woman” as in (1b). Individuals experience intuitive difficulty with continuations such as (1b) relative to those like (1a) indicating a preference for the SC analysis when strings like (1) are presented in a null context.

The referential theory explains this preference by appealing to the disparate referential properties of SC and RC constructions. In a null context neither reading is entirely felicitous because the use of the definite determiner requires the prior existence of a unique referent corresponding to the denotation of the NP, “the woman.” No woman has been established prior to encountering this NP, hence “the woman” is an infelicitous description. In addition, the restrictive RC modifier implicates the existence of a contrast set corresponding to the denotation of the head noun, but differing in the property expressed by the modifier. In (1b), the implication is that there are multiple women in the context, only one of whom can be distinguished by virtue of being troublesome to the psychologist.

Referential theory explains the preference for the SC analysis by appeal to the principle of Parsimony: Choose the candidate reading associated with the fewest unsatisfied presuppositions¹ (Crain & Steedman, 1985). The SC interpretation does not carry the implication of a contrast set and is therefore preferred in the null context. Parsimony has

¹ A number of researchers have argued or assumed that the projection of a contrast arises from the conventional meaning of restrictively modified definite NPs via formal presupposition or some other mechanism (Spivey-Knowlton & Sedivy, 1995; Steedman & Altmann, 1989). However, recent evidence indicates that the source of the contrast is Gricean in nature (Clifton & Ferreira, 1989; Sedivy, 2003). We assume the latter position in this paper. Except where explicitly stated otherwise, nothing in what follows hinges on this distinction.

been used to explain why individuals prefer to leave NPs unmodified across a number of ambiguous constructions (e.g. Crain & Steedman, 1985; Ni, Crain, & Shankweiler, 1996; Sedivy, 2002; Spivey-Knowlton & Sedivy, 1995).

Parsimony leads to the prediction that varying the discourse context can affect preferences in ambiguity resolution. This has been borne out in empirical studies. By introducing a contrast set in the linguistic or non-linguistic context, structural preferences can be affected. In a context with two women as in (2), where the presuppositions of the RC reading are satisfied, the preference for the SC reading is diminished (Crain & Steedman, 1985).

(2) A psychologist was counseling two women. He was worried about one of them, but not the other.

Because there is more than one woman here, “the woman” does not pick out a unique referent. Preference for modifying the noun in this context follows from the principle of Referential Support: An NP analysis which is referentially supported will be favored over one that is not (Altmann & Steedman, 1988). Evidence for Referential Support comes from studies where an unmodified definite NP would introduce a referential ambiguity (e.g. Altmann, Garnham, & Dennis, 1992; Altmann & Steedman, 1988; Spivey-Knowlton & Tanenhaus, 1994). If left unmodified, these cases violate the uniqueness presupposition associated with definites.

Notably, referential theory as stated does not apply in processing language that is unambiguous or felicitous. The principles of referential theory claim only that in the face of ambiguity the perceiver selects the least infelicitous reading among the alternatives. But, surely even felicitous and unambiguous utterances interact with discourse. In fact, it is hard to conceive of a naturalistic sentence that does not exhibit a referential function. Thus, the scope of referential theory is severely limited. The primary purpose of this paper is to explore the ways in which referential theory might be extended to encompass sentence comprehension in general. Below we introduce three hypotheses regarding the influence of discourse context on intrasentential processing. Each of these paints a distinct portrait of the architecture of the sentence processing mechanism.

1.1. Three ways to extend referential theory

The first possibility is that Parsimony and Referential Support only apply in adjudicating between alternative analyses of an ambiguous string. We refer to this hypothesis as the Ambiguity Only Hypothesis.

(3) Ambiguity Only Hypothesis

The discourse is consulted only in the face of ambiguity. The processing mechanism interprets an ambiguous utterance so as to make the background assumptions of the utterance consonant with a relevant model of the discourse context.

An alternative approach is that Parsimony and Referential Support are not specialized to deal with infelicity, but rather emerge from fundamental properties of how we access and update mental models of discourse. For instance, a number of studies suggest that constructing discourse structure consumes computational resources (e.g. Garrod & Sanford, 1977, 1982, 1994; Halliday & Hasan, 1976; Haviland & Clark, 1974; Murphy,

1984; Warren & Gibson, 2001). Parsimony might be a specific reflection of this property. The accommodation of unsupported presuppositions could be a special case of augmenting the discourse model in general. Modified NPs would create difficulty, at least in part, because increasing the number of presuppositions increases the complexity of building a corresponding mental model. There are two architectures that might support this type of interaction between context and other sources of information. One of these is given in (4).

(4) Weakly-Interactive Mental Models Hypothesis

Sentences are parsed using intrasentential criteria, such as syntactic knowledge. The resultant analysis (or analyses in the case of ambiguity) is then evaluated against the context, and changes are incrementally made to the current discourse model. These changes can incur costs that interfere with interpretive processes and lead to comprehension difficulty.

On this view, context does not direct the structure building operations of the parser, but there are potentially “frequent and immediate appeals from structure to semantics and context.” (Crain & Steedman, 1985, p. 326; also see Altmann & Steedman, 1988; Fodor, 1983). The second mental models account holds that the interaction between processes that interpret a sentence and those that manipulate the discourse model is bidirectional:

(5) Strongly-Interactive Mental Models Hypothesis

The discourse model is constantly updated and accessed in the comprehension of a sentence. Sometimes the sentence causes the construction of discourse structure. Othertimes the discourse model directs interpretive processes and projects syntactic structures.

This view represents a radical departure from the other two hypotheses. It posits a much more intimate relationship between referential context and parsing, hypothesizing that the effects of discourse context on intrasentential constructive processes are ubiquitous. According to (5), in cases where a particular syntactic form is highly predictable given the context, context can guide the construction of representations in support of that form. On this view, evidence for Referential Support in ambiguity resolution might be an instantiation of a broader principle: the parser might project modifying structures that anticipate the identification of a particular referent *whenever* an NP fails to refer. For instance, the parser might project representations compatible with a restrictive RC or prepositional phrase (PP) when a partial NP does not select among several potential referents in the context.

Studies of structural ambiguity resolution have provided the primary means to explore the relationship between referential context and the processes that assign a structure to an input word string. Generally, this work shows that manipulating the discourse or other non-syntactic information can affect parsing preferences in structural ambiguity resolution (e.g. Altmann & Steedman, 1988; Britt, 1994; Chambers, Tanenhaus, & Magnuson, in press; Ni et al., 1996; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Unfortunately, this method is inherently limited in its ability to distinguish strong and weak interaction. Even if it is found that these manipulations affect the preferred analysis of an ambiguity, one can never be sure whether extrasentential factors are guiding the initial parse, or whether syntactic processes propose multiple candidates in parallel and one of these is rapidly selected on the basis of non-syntactic criteria.

1.2. Restrictive and non-restrictive RCs

To establish whether referential principles are specialized for adjudicating between infelicitous analyses of an ambiguous string or apply more generally in language comprehension, the present study examined sentential structures with similar referential properties to those investigated in previous work, but which are unambiguous and felicitous. Restrictive and non-restrictive RCs, such as those given in (6), were chosen because they are structurally and lexically identical apart from the relativizing word, but serve different discourse functions.

- (6) a. The boy that studied for the exam aced the test.
 b. Mary, who studied for the exam, aced the test.

Restrictive modifiers (e.g. (6a)) serve to identify a particular referent from among a group of entities that contrast along the dimension denoted by the modifier. This function arises because restrictively modified NPs are interpreted by intersecting the properties denoted by the head and the modifier (Partee, 1973). The modifier focuses attention on a subset of the entities denoted by the head. This implicates a non-empty complement set of competitor referents that match the head property, but differ along the dimension indicated by the modification. In contrast, non-restrictively relativized NPs (e.g. (6b)) do not get their meaning through set intersection, but rather refer to the concept denoted by the head noun via discourse anaphora (Sells, 1985). The RC does not focus attention on a subset of the entities denoted by the head noun, and no contrast set is implicated. As a consequence, non-restrictive RCs can be used to modify nominal heads that do not permit contrast (cf. (7)).

- (7) a. My father, who ate ham this morning, became extremely ill.
 b. The sun, which rises in the east, can be used to orient oneself.

As (8) illustrates, the contrastive function of restrictive RCs bars them from such constructions. (For most American English speakers, the overt complementizer “that” cannot be used in a non-restrictive RC and therefore unambiguously signals a restrictive RC.)

- (8) a. *My father that ate ham this morning became extremely ill.
 b. *The sun that rises in the east can be used to orient oneself.

(* indicates unacceptability.)

By situating restrictive and non-restrictive relative clauses in different contexts the present study investigates whether principles analogous to those of the referential theory apply in processing unambiguous sentences. If Parsimony and Referential Support only apply in ambiguity resolution, then there is no cause to expect referential effects for these constructions. However, if these principles are specific instances of more general properties of discourse processing, then manipulating context should have an impact on processing.

2. Experiment 1

Using a self-paced reading task, we examined processing behavior for subject modifying non-restrictive and restrictive RCs in a supportive context and in a null context. Two central issues were addressed.

First, if Parsimony arises because constructing referents in a mental model of a discourse consumes resources, then syntactic structures that induce a more elaborate discourse model should elicit greater difficulty in a null context. The discourse model associated with a restrictively relativized NP is more complicated than a non-restrictively modified NP because the former asserts the existence of a reference set and implicates the existence of a second set. The analogous model for a non-restrictively modified NP is simpler, containing only a single referential set. The first two conditions in the experiment compared restrictive and non-restrictive RCs in a null context as in (9):

(9) Null Context

a. Restrictive RC

A postman that a dog bit on the leg needed seventeen stitches and had a permanent scar from the injury.

b. Non-Restrictive RC²

A postman, who a dog bit on the leg, needed seventeen stitches and had a permanent scar from the injury.

If discourse complexity impinges on sentence comprehension in unambiguous structures as depicted in the Mental Models Hypotheses (4) and (5), restrictive RCs, such as (9a), should be read more slowly than non-restrictive RCs, as in (9b), in a null context. This would demonstrate that the construction of a contrast set consumes resources. If instead Parsimony only operates in the face of ambiguity as hypothesis (3) claims, then there is no cause to think that these minimally different structures should be processed differently.

Second, in a context containing multiple potential referents for a definite NP, a modifier is necessary to identify the intended referent. Referential Support was invoked to explain a preference to attach an ambiguous constituent to a nominal head in order to resolve such referential ambiguities. If a similar principle applies to unambiguous language processing as the Strongly-Interactive Mental Models Hypothesis claims, then comprehenders should anticipate modification in the face of referential ambiguity even when a modifying constituent can only be attached in one way. The present study investigated whether an unambiguous clause that serves an identifying function would be easier to process than a clause that has an identical structure but does not identify a referent. Restrictive and

² There is a prescriptive requirement to use “whom” in place of “who” in object-extracted RCs such as this one. However, it is unlikely that this affected the present results. American English speakers rarely adhere to this prescription, and none of our participants noticed this violation in post-experimental debriefing. Further, there was no particular difficulty observed with the non-restrictive conditions.

non-restrictive RCs were each presented as the second sentence within supportive discourses as in (10).

(10) Supportive Context

a. Restrictive RC

A vicious guard dog bit a postman on the leg and another postman on the arm.
The postman that the dog bit on the leg needed seventeen stitches and had a permanent scar from the injury.

b. Non-Restrictive RC

A vicious guard dog bit a postman and a garbage man.
The postman, who the dog bit on the leg, needed seventeen stitches and had a permanent scar from the injury.

The context for the restrictive condition introduces two referents compatible with the denotation of the subject noun of the target sentence (e.g. postmen in (10a)). The non-restrictive condition only introduces one such referent (e.g. a single postman in (10b)). For both conditions, the subject is specified with a singular definite determiner. This arrangement presupposes that only a single entity matching the denotation of the NP is salient in the discourse. Upon seeing the partial NP up to the head (e.g. “The postman...”), the two-referent condition (10a), requires a modifier to pick out the referent of interest. No modifier is necessary in the one-referent context (10b) because the partial subject already refers successfully. If context can direct constructive interpretive processes, as predicted by the Strongly Interactive Mental Models Hypothesis, then processing a modifier should be facilitated for the restrictive RC condition when the context contains two candidate referents, compared to a non-restrictive in a context containing a single referent. This is because the two-referent context demands a modifier to follow the noun, whereas the one-referent context merely permits it. When there is a discourse-based requirement for a syntactic structure given the current partial input, strong-interaction says that structures which can potentially satisfy this requirement will be facilitated. Critically, interpretive processing should be facilitated even *before the discourse requirement is satisfied*. For (10a), processing over the embedded clause should be facilitated prior to encountering the PP where the material necessary to identify the intended referent is encountered. None of the other hypotheses in (3)–(4) make this prediction.

It is important to note that this difference is not predicted by a weakly-interactive model, where discourse context acts as a filter to evaluate interpretations proposed on the basis of intrasentential criteria. This is because the restrictive and non-restrictive conditions are each presented within a supportive discourse. Comparing the resulting parse against the context would not induce a penalty in either condition, because the modifier is equally consistent with the context in each case. To be clear, weak interaction predicts that discourse processing might be facilitated over the identifying material in the PP, because this is where the discourse requirement is satisfied. However, processing of the restrictive modifier should not be influenced prior to encountering the identifying material. By definition, the weakly-interactive model does not permit discourse processes to influence syntactic ones.

To summarize, if the processing mechanism exhibits strong interaction between discourse context and intrasentential information, then restrictive and non-restrictive RCs should be processed differently in and out of context. Non-restrictive RCs should be easier to process in a null context than restrictive RCs, and restrictive RCs should be easier to process in a supportive context than non-restrictive RCs. Thus this view predicts an interaction between context and RC type.

2.1. Methods

2.1.1. Participants

Fifty-six native English-speaking adults from the Massachusetts Institute of Technology and surrounding community took part in the present study.

2.1.2. Materials

Twenty items containing non-restrictive and restrictive RCs were prepared (see Appendix A). Restrictive RCs were created by introducing the RC with “that”. Non-restrictives were created by inserting a comma immediately after the matrix subject and employing a *wh*-pronoun (e.g. “who”) to introduce the embedded clause. All RCs modified sentential subjects and contained object gaps. Target sentences were either presented at the onset of a passage (9), or were situated within a supportive discourse context (10). In order to avoid presupposition failure, NPs were introduced with indefinite articles in the null context conditions. Thus all readings are equally felicitous.

In the supportive context conditions, the target sentences were the second sentence in the passage. All the material in the embedded clause of the target, up to and including the verb, was information stated in the previous sentence. The identifying information in the restrictive condition and the new information in the non-restrictive condition were contained in the ensuing prepositional phrase.

Stimuli were separated into four lists so that each condition was equally represented and no two conditions from the same item appeared in the same list. Each participant saw a different list. Stimuli were pseudo-randomly intermixed with 20 fillers consisting of multiple sentence passages and containing a variety of syntactic forms.

2.1.3. Apparatus and procedure

Sentences were presented using a non-cumulative, self-paced, word-by-word display on a Macintosh computer running purpose-built software. Each trial began with dashes standing in for all non white space characters in a passage. Participants pressed the space bar to replace the next series of dashes with the word they concealed. With the exception of the first press, this action caused the previous word to disappear. Commas were displayed with the previous word. A yes-or-no comprehension question followed each passage. Participants were instructed to read at a normal rate in a manner that would enable them to answer the comprehension questions. The computer recorded the time between button presses to the nearest millisecond. To ensure that regions of interest would appear at the same point on the screen across the context and null-context conditions, each sentence in a passage started on a new line.

2.2. Results

2.2.1. Performance on comprehension questions

Overall, participants accurately responded to 84.5% of comprehension questions after experimental items. A 2×2 ANOVA crossing context (supportive or null) and RC type (restrictive or non-restrictive) did not reveal any main effects or interactions ($F_s < 1$).

2.2.2. Reading times

The effects of context and structure were evaluated by analyzing reading times over the embedded subject noun and verb for each condition (e.g. “dog bit”). This region was chosen because it did not immediately follow the comma, which was present in the non-restrictive conditions, and because it contained information that was mentioned previously in both supportive context conditions. Thus comparisons of interest did not include the ensuing prepositional phrase, which contained information that was old to discourse for the supportive context restrictive RCs and contained information that was new to discourse for the supportive context non-restrictive RCs.

Data from one participant was excluded from reading time analyses because their accuracy on comprehension questions was at chance. All other participants were at 70% or above. One item was excluded from analyses because of a typographical error in one condition. Following Ferreira and Clifton (1986) analyses were performed on the residual reading times after the variance due to word length as a linear predictor was subtracted. In addition, values beyond 5 SD away from the condition mean for each region were omitted from analyses. This excluded .7% of the data. Table 1 contains the mean residual reading times per word over the embedded verb and preceding noun for each condition. Raw reading times patterned similarly. Appendix B lists raw and residual reading times across all four conditions.

A 2×2 ANOVA crossing context (supportive or null) and RC type (restrictive or non-restrictive) revealed a main effect of context; overall reading times were faster in supportive, rather than null, contexts ($F(1,54) = 16.6$, $MSe = 6770$, $P < 0.001$; $F(1,18) = 17.3$, $MSe = 2120$, $P < 0.001$). There was also significant interaction between context and RC type, demonstrating that supportive contexts conferred a stronger benefit for restrictive than non-restrictive modifiers ($F(1,54) = 9.8$, $MSe = 2440$, $P < 0.01$; $F(1,18) = 9.1$, $MSe = 860$, $P < 0.001$). There was no main effect of RC type ($F_s < 1$).

Critical tests involved planned comparisons across RC type within each level of context. For the null context conditions, reading times for restrictive RCs were elevated over non-restrictive RCs ($t(54) = 4.4$, $MSe = 3600$, $P < 0.05$; $t(18) = 4.3$, $MSe = 1050$, $P < 0.05$). This is consistent with either of the Mental Models Hypotheses ((4) and (5)), but

Table 1
Residual reading times in ms per word over the embedded subject noun and verb in Experiment 1

Context/RC type	Restrictive	Non-restrictive
Supportive	−61.0 (10.8)	−43.4 (11.1)
Null	5.0 (9.4)	−19.0 (8.7)

Standard errors in parentheses.

was not predicted by the Ambiguity Only Hypothesis. Within the supportive context conditions, the trend reversed; processing times were significantly shorter for restrictives than non-restrictives ($t(54)=3.1$, $MSe=2740$, $P<0.05$; $t(18)=4.4$, $MSe=760$, $P<0.05$). This is as expected if the processor is strongly-interactive, but not if it is weakly-interactive.

2.3. Discussion

The predictions of the strongly-interactive model were borne out. Restrictive RCs were harder to process in a null context than non-restrictive RCs, but non-restrictive RCs were harder to process in a supportive context than restrictive RCs. The null context results lend support to the hypothesis that the construction of a referential contrast is costly. The difference between RC types in the supportive context indicates that discourse exigencies can guide syntactic processing.

One important caveat is in order. The null context result might be an artifact of the fact that indefinite NPs are harder to modify restrictively. This is because indefinite NPs normally serve to set up an entity in the discourse model, but restrictive relative clauses normally serve to select among entities, which are already established in the discourse. The clash between the functions of the indefinite article and the restrictive modifier may have led to increased complexity and elevated reading times. To examine this possibility, Experiment 2 used stimuli where null context conditions were introduced with definite NPs.

3. Experiment 2

3.1. Methods

3.1.1. Participants

Fifty-one native English-speaking adults from the Massachusetts Institute of Technology and surrounding community took part in the present study.

3.1.2. Materials, apparatus, and procedure

The 20 stimulus items from Experiment 1 were altered so that all NPs were introduced by definite articles. Though this violates the existence presupposition associated with definiteness, reading experiments typically contain such stimuli. These stimuli do not elicit particular difficulty, suggesting that individuals readily accommodate the existential presupposition in contexts where it is repeatedly violated.³ Stimuli were presented

³ It is important to note that the violation of the existence presupposition differs from the case of positing a contrastive entity. When either an definitely- or indefinitely-specified NP is introduced in a null context, a new referent must be introduced to the discourse model. In contrast, the use of a restrictive modifier conjures one more referent (the contrastive entity) than the use of a non-restrictive modifier. One possible explanation for why definites do not appear to cause special difficulty is that individuals are prepared to accommodate presuppositions associated with existence or discourse salience when sentences or short passages are presented in a null context. The unsupported definites in Experiment 2 are the only examples of infelicitous constructions used in either experiment.

Table 2
Residual reading times in ms per word over the embedded subject noun and verb in Experiment 2

Context/RC type	Restrictive	Non-restrictive
Supportive	–45.8 (7.3)	–25.4 (8.7)
Null	6.4 (11.4)	–15.2 (13.0)

Standard errors in parentheses.

pseudorandomly with 35 filler passages, many of which also contained definite NPs without explicit antecedents. The procedure was identical to that of Experiment 1.

3.2. Results

3.2.1. Performance on comprehension questions

Overall, participants accurately responded to 84.9% of comprehension questions after experimental items. A 2×2 ANOVA crossing context (supportive or null) and RC type (restrictive or non-restrictive) did not reveal any main effects or interactions ($F_s < 1$).

3.2.2. Reading times

As in Experiment 1, length-corrected residual reading times were analyzed over the region containing the embedded subject noun and verb. Data from one participant was excluded for comprehension accuracy below 70%. Values over 5 SD away from the condition mean for each word were omitted from analyses. This excluded .6% of the data. Table 2 contains the mean residual reading times per word over the embedded verb and preceding noun for each condition. Raw reading times patterned similarly. Appendix B lists raw and residual reading times across all four conditions.

A 2×2 ANOVA crossing context (supportive or null) and RC type (restrictive or non-restrictive) revealed a main effect of context ($F(1,49)=6.2$, $MSe=7840$, $P<0.05$; $F(1,19)=18.1$, $MSe=1230$, $P<.001$) and an interaction between context and RC type ($F(1,49)=6.8$, $MSe=3230$, $P<0.05$; $F(1,19)=6.4$, $MSe=1430$, $P<0.05$). There was no main effect of RC type ($F_s < 1$).

Planned comparisons replicated the pattern observed in Experiment 1. In a null context, the restrictive condition was reliably slower than the non-restrictive in the participant analysis ($t(49)=3.1$, $MSe=3740$, $P<0.05$), and marginally slower in the items analysis ($t(19)=2.4$, $MSe=1940$, $P=0.07$).⁴ Within the supportive context, the restrictive condition was read faster than the non-restrictive condition over the critical region ($t(49)=4.9$, $MSe=2120$, $P<0.05$; $t(19)=6.1$, $MSe=750$, $P<0.05$).

⁴ When the next word (the preposition) was included in the critical region, the difference across RC type was fully reliable ($t(49)=5.8$, $MSe=2510$, $P<0.05$; $t(19)=4.9$, $MSe=1130$, $P<0.05$). Indeed, all differences reported in this section (and for Experiment 1) were larger and more reliable when the preposition was included in the analysis region.

3.3. Discussion

Experiment 2 replicated the results of Experiment 1 for sentences where all NPs were introduced with definites rather than indefinites. The differences observed between restrictive and non-restrictive RCs in and out of context in this experiment cannot be related to the definiteness of the determiner. This strengthens the case that the present effects are driven by the disparate discourse functions of restrictive and non-restrictive RCs.

A possible objection to the present interpretation of results is that there may have been a penalty in the supportive context for non-restrictive RC over the critical region. This is because the content of that region is a repetition from the context, and non-restrictive RCs generally serve to convey new material. Thus the content of the critical region does not satisfy the discourse function of the non-restrictive RC. This may have led to a reading anomaly and elevated reading times relative to the supportive context restrictive RC condition.

It was critical to our design that the discourse functions of neither the non-restrictive nor restrictive RC were satisfied over the critical region in the supportive context conditions. Thus the material in the critical region is also at odds with the discourse function of the restrictive RCs. Specifically, restrictive RCs serve to identify a unique member of the set denoted by the head. The material in the critical region did not select among the candidates in the discourse. In fact, the discourse requirement for identifying material in restrictive supportive context conditions is multiply determined. The preceding discourse, the syntactic form of the partial NP, and the discourse function associated with restrictive RCs all support the expectation that identifying material should appear at the point of encountering the critical region. The identifying material must select one of the referents that has already been established in the discourse. This is a more specific expectation than that for the non-restrictive condition, which merely demands parenthetical material. The fact that the restrictive condition is processed more quickly despite violating the more specific discourse expectation implies that syntactic processing is being facilitated.

Further, it is worth noting that the absolute speed of reading times is not consistent with a penalty arising from a reading anomaly in the critical region of the non-restrictives. Residual reading times for each supportive context condition were numerically faster in the critical two word region than over any other two-word region of the target sentence, and also as fast or faster than every two-word region of the corresponding null-context sentence (except the first region of the non-restrictive RC condition in Experiment 2, which is fast because it is the initial region of a trial).

4. General discussion

Both experiments confirmed the pattern anticipated if discourse-level processes and structure building processes influence one another bidirectionally. First, restrictive RCs elicited more difficulty than non-restrictives in a null context. This suggests that intrasentential interpretive processes can engender costly updates to the current discourse model. In particular, structures that support restrictive modification cause costly discourse structure to be constructed. This parallels findings in ambiguity resolution, which suggest

that the parser prefers syntactic structures associated with fewer unsupported presuppositions. The present result is expected if the addition of discourse contrast consumes resources, and if similar referential principles govern the processing of all sentences regardless of the existence of ambiguity or presupposition failure.

To our knowledge this is the first direct evidence that entities which are implicated by a particular syntactic arrangement (i.e. those in the contrast set) introduce a processing cost. All previous work demonstrating such costs in unambiguous structures has examined referential descriptions which either presuppose the existence of a new referent (Garrod & Sanford, 1977, 1982, 1994; Halliday & Hasan, 1976; Haviland & Clark, 1974; Warren & Gibson, 2001) or assert it directly (e.g. Murphy, 1985). In both cases, the referents conjured by the description influence the truth conditions of the utterance. Implicated entities are not critical to the truth conditional content of an utterance. Thus, there is no logical need to construct them on the fly. A lazy processor could wait until the end of a sentence rather than committing to a costly implicature that might be retracted later. Our results suggest that the comprehension system is not judicious in this way.

Second, the restrictive modifier was read more quickly than a non-restrictive modifier when the utterance containing it was embedded in a supportive discourse. This finding indicates that the current discourse model can guide structure-building processes within the sentence. This is analogous to findings that ambiguous phrases are more likely to be interpreted as restrictive modifiers in the face of a referential ambiguity. In the present experiment, properties of the discourse model induced a structural expectation for an identifying modifier. The comprehension of that modifier was facilitated even before the identifying information contained in the modifier was encountered.

Note that comparisons were across modifiers that are extremely similar lexically and syntactically. No theory of structural complexity predicts a difference between the processing of non-restrictive and restrictive RCs (see e.g. Frazier, 1999; Gibson, 1991, 1998; Gorrell, 1995; Pritchett, 1988). Note also that the effects of discourse were observed in the midst of processing the dependent clauses, not at the onset of the modifiers where lexical and syntactic differences are thought to exist. Further, a structural explanation would be unable to explain why restrictive RCs are harder to process in a null context, but non-restrictives are harder in a supportive context. Thus, disparate semantic and discourse properties must be playing a role in the present effects. The differential effects across the conditions indicate that discourse context is used to interpret and evaluate partial sentential structures as they are incrementally constructed.

The second result above is particularly intriguing. Models that postulate strong interaction between structural and non-structural constraints have been dismissed as computationally intractable because non-structural information is a potentially unbounded information source (Altmann & Steedman, 1988; Crain & Steedman, 1985; Fodor, 1983). As an argument for the functional autonomy of *syntactic* knowledge, this reasoning fails to be convincing. There are many ways to limit the amount and types of information consulted in assigning structure to a sentence. Positing an a priori distinction between constraints that are syntactic and non-syntactic, or intrasentential and extrasentential, is not necessary. Nor do these divisions comport well with the existing evidence. Various non-syntactic and referential constraints are considered by the sentence processing mechanism extremely rapidly (e.g. Altmann & Kamide, 1999; Marslen-Wilson & Tyler,

1987; Tanenhaus et al., 1995). We believe the most serious criticism of a strongly-interactive model is forwarded by Altmann and Steedman (1988). They claim that non-structural criteria cannot direct intrasentential parsing decisions because they cannot be used to predict a syntactic structure with 100% certainty. For instance, it is generally difficult to predict in advance what structural arrangement will be used to refer to an object in a given context. However, in the case where a partial description introduces a referential ambiguity, there is a strong contingency between the referential context and a restrictive modifier. Such an example does not require consulting unbounded information sources and is therefore a good candidate for strong interaction. The strongly-interactive model that we advocate predicts context will be used to project syntactic structure whenever syntax is predictable from the context.

5. Summary and conclusions

The present work illuminates the interaction of discourse contrast and reading difficulty by generalizing the results from ambiguous and infelicitous sentences to encompass all circumstances. Two principles emerge from this work. First, the complexity of the discourse model evoked by a construction influences how difficult that construction is to process. In particular, the process of constructing a contrast set increases the processing difficulty associated with a restrictive modifier. Second, situations where there is more than one candidate referent for a definite expression set up the expectation for contrast. Processing is facilitated for material that can serve this contrastive function.

The present studies revealed effects of discourse contrast in unambiguous sentences. We conclude that the principles of referential theory are specific instantiations of broader principles. Parsimony results because building discourse structure consumes resources. Referential Support results because individuals expect restriction when a definite fails to refer. Uncovering the precise nature and scope of these broader principles promises to be an intriguing area of future inquiry.

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Appendix A. Experimental stimuli for Experiment 1

The four conditions for each of 20 items employed as stimuli in Experiment 1 are given below. Conditions (a), (b), (c), and (d) were the supportive context-restrictive RC, supportive context-non-restrictive RC, null context-restrictive RC conditions, and null context-non-restrictive RC conditions, respectively. Slashes indicate line breaks which occurred between sentences.

- 1a. A group of film critics praised a director at a banquet and another director at a film premiere. The director that the critics praised at a banquet announced that he was retiring to make room for young talent in the industry.
- 1b. A group of film critics praised a director and a producer for lifetime achievement. The director, who the critics praised at a banquet, announced that he was retiring to make room for young talent in the industry.
- 1c. A director that critics praised at a banquet announced that he was retiring to make room for young talent in the industry. Many of his colleagues were shocked by his decision to stop making films.
- 1d. A director, who critics praised at a banquet, announced that he was retiring to make room for young talent in the industry. Many of his colleagues were shocked by his decision to stop making films.

- 2a. A vicious guard dog bit a postman on the leg and another postman on the arm. The postman that the dog bit on the leg needed seventeen stitches and had a permanent scar from the injury.
- 2b. A vicious guard dog bit a postman and a garbage man. The postman, who the dog bit on the leg, needed seventeen stitches and had a permanent scar from the injury.
- 2c. A postman that a dog bit on the leg needed seventeen stitches and had a permanent scar from the injury. It took a few hours for the police to find the dog that was terrorizing the neighborhood.
- 2d. A postman, who a dog bit on the leg, needed seventeen stitches and had a permanent scar from the injury. It took a few hours for the police to find the dog that was terrorizing the neighborhood.

- 3a. A literary agent signed a novelist at a conference and a novelist at a poetry seminar. The novelist that the agent signed at a conference refused to participate in book talks or other promotional events.
- 3b. A literary agent signed a novelist and a poet to big contracts. The novelist, who the agent signed at a conference, refused to participate in book talks or other promotional events.
- 3c. A novelist that an agent signed at a conference refused to participate in book talks or other promotional events. The agent tried to convince him that appearances were important, but eventually gave up.
- 3d. A novelist, who an agent signed at a conference, refused to participate in book talks or other promotional events. The agent tried to convince him that appearances were important, but eventually gave up.

- 4a. A mental hospital rewarded a psychiatrist with a promotion and another psychiatrist with a raise. The psychiatrist that the hospital rewarded with a promotion enjoyed the prestige of his new position.
- 4b. A mental hospital rewarded a psychiatrist and a nurse for their outstanding performance. The psychiatrist, who the hospital rewarded with a promotion, enjoyed the prestige of his new position.

- 4c. A psychiatrist that a hospital rewarded with a promotion enjoyed the prestige of his new position. He often bragged about how important he was to fellow staff members which made him very unpopular.
- 4d. A psychiatrist, who a hospital rewarded with a promotion, enjoyed the prestige of his new position. He often bragged about how important he was to fellow staff members which made him very unpopular.
- 5a. A painter sketched a flower with a pencil and a flower with a stick of charcoal. The flower that the painter sketched with a pencil began to fade before the artist could paint over the figure.
- 5b. A painter sketched a flower and a maiden. The flower, which the painter sketched with a pencil, began to fade before the artist could paint over the figure.
- 5c. A flower that a painter sketched with a pencil began to fade before the artist could paint over the figure. He was angry, but eventually decided to change the theme of the painting.
- 5d. A flower, which a painter sketched with a pencil, began to fade before the artist could paint over the figure. He was angry, but eventually decided to change the theme of the painting.
- 6a. An anthropology professor read a manuscript in the library and a manuscript in the faculty lounge. The manuscript that the professor read in the library questioned the central thesis of his life's work.
- 6b. An anthropology professor read a manuscript and a draft of a book review. The manuscript, which the professor read in the library, questioned the central thesis of his life's work.
- 6c. A manuscript that a professor read in a library questioned the central thesis of his life's work. He looked up some of the sources in the paper to check its validity, and they were accurate.
- 6d. A manuscript, which a professor read in a library, questioned the central thesis of his life's work. He looked up some of the sources in the paper to check its validity, and they were accurate.
- 7a. An 18th century British admiral captured a pirate off the coast and another pirate near an island. The pirate that the admiral captured off the coast had been responsible for several attacks on American ships.
- 7b. An 18th century British admiral captured a pirate and a band of rogues. The pirate, who the admiral captured off the coast, had been responsible for several attacks on American ships.
- 7c. A pirate that an admiral captured off the coast had been responsible for several attacks on American ships. At sea, the pirate would raise a distress flag to lure unsuspecting ships into a trap.
- 7d. A pirate, who an admiral captured off the coast, had been responsible for several attacks on American ships. At sea, the pirate would raise a distress flag to lure unsuspecting ships into a trap.

- 8a. A master thief opened a safe with an explosive and a second safe by cracking the combination. The safe that the thief opened with an explosive was demolished and its contents were completely burned.
- 8b. A master thief opened a safe and a strongbox containing payroll slips. The safe, which the thief opened with an explosive, was demolished and its contents were completely burned.
- 8c. A safe that a thief opened with an explosive was demolished and its contents were completely burned. The smoke produced from the fire set off the alarm to the building, and the thief was caught.
- 8d. A safe, which a thief opened with an explosive, was demolished and its contents were completely burned. The smoke produced from the fire set off the alarm to the building, and the thief was caught.

- 9a. A clumsy waiter annoyed a businessman at a luncheon and another at a dinner party. The businessman that the waiter annoyed at a luncheon threatened to sue the hotel.
- 9b. A clumsy waiter annoyed a businessman and a wealthy diner in the same day. The businessman, who the waiter annoyed at a luncheon, threatened to sue the hotel.
- 9c. A businessman that a waiter annoyed at a luncheon threatened to sue the hotel. Since the waiter knew that he was in danger of losing his job, he tried to make amends.
- 9d. A businessman, who a waiter annoyed at a luncheon, threatened to sue the hotel. Since the waiter knew that he was in danger of losing his job, he tried to make amends.

- 10a. A golf amateur beat a professional in a tournament and another professional in a friendly match. The professional that the amateur beat in a tournament suffered tremendous humiliation after the defeat.
- 10b. A golf amateur beat both a professional and a fellow member of his country club. The professional, who the amateur beat in a tournament, suffered tremendous humiliation after the defeat.
- 10c. A professional that an amateur beat in a tournament suffered tremendous humiliation after the defeat. He threw his golf clubs into the pond and demanded a rematch.
- 10d. A professional, who an amateur beat in a tournament, suffered tremendous humiliation after the defeat. He threw his golf clubs into the pond and demanded a rematch.

- 11a. An evil villain imprisoned a superhero in a fortress and another superhero in his hideout. The superhero that the villain imprisoned in a fortress escaped by using her magic powers and quick wits.
- 11b. An evil villain imprisoned a superhero and a police chief. The superhero, who the villain imprisoned in a fortress, escaped by using her magic powers and quick wits.
- 11c. A superhero that a villain imprisoned in a fortress escaped by using her magic powers and quick wits. Once she had gotten away, she tried to figure out what evil plot the villain had planned.

- 11d. A superhero, who a villain imprisoned in a fortress, escaped by using her magic powers and quick wits. Once she had gotten away, she tried to figure out what evil plot the villain had planned.
- 12a. A Hollywood studio sued a producer over a contract and another producer over a budget dispute. The producer that the studio sued over a contract denied signing any agreement prior to production.
- 12b. A Hollywood studio sued a producer and a director. The producer, who the studio sued over a contract, denied signing any agreement prior to production.
- 12c. A producer that a studio sued over a contract denied signing any agreement prior to beginning production on an action film. He lost the lawsuit despite having a team of high priced lawyers.
- 12d. A producer, who a studio sued over a contract, denied signing any agreement prior to beginning production on an action film. He lost the lawsuit despite having a team of high priced lawyers.
- 13a. A college dean misquoted a philosopher at a reception and another philosopher at commencement. The philosopher that the dean misquoted at a reception wrote about the ethical treatment of animals.
- 13b. A college dean misquoted a philosopher and a famous novelist. The philosopher, who the dean misquoted at a reception, wrote about the ethical treatment of animals.
- 13c. A philosopher that a dean misquoted at a reception wrote about the ethical treatment of animals. During the speech, the philosopher politely ignored the mistake.
- 13d. A philosopher, who a dean misquoted at a reception, wrote about the ethical treatment of animals. During the speech, the philosopher politely ignored the mistake.
- 14a. A young woman carried a child in her arms and a child with a toy on her back. The child that the woman carried in her arms cried loudly because she wanted to ride on the woman's back.
- 14b. A young woman carried a child and a backpack full of toys through the airport. The child, who the woman carried in her arms, cried loudly because she wanted to ride on the woman's back.
- 14c. A child that a woman carried in her arms cried loudly because she wanted to ride on the woman's back. Unfortunately, the woman was carrying a backpack full of toys so there was no room for the child.
- 14d. A child, who a woman carried in her arms, cried loudly because she wanted to ride on the woman's back. Unfortunately, the woman was carrying a backpack full of toys so there was no room for the child.
- 15a. An exhibitionist attended a party without a shirt and another party without pants. The party that the exhibitionist attended without a shirt ended shortly after his arrival.
- 15b. An exhibitionist attended a party and a wedding in the same week. The party, which the exhibitionist attended without a shirt, ended shortly after his arrival.

- 15c. A party that an exhibitionist attended without a shirt ended shortly after his arrival.\The host asked the man to leave.\When that didn't work, he threatened to call the police.
- 15d. A party, which an exhibitionist attended without a shirt, ended shortly after his arrival.\The host asked the man to leave.\When that didn't work, he threatened to call the police.
- 16a. A stewardess stowed a valise under a seat and another valise in the plane's cockpit.\The valise that the stewardess stowed in the cockpit was mistaken for a bomb and the plane had to be evacuated.
- 16b. A stewardess stowed a valise and computer for a lazy passenger.\The valise, which the stewardess stowed in the cockpit, was mistaken for a bomb and the plane had to be evacuated.
- 16c. A valise that a stewardess stowed in the cockpit was mistaken for a bomb and the plane had to be evacuated.\The bomb squad came and exploded the valise in the middle of the runway.
- 16d. A valise, which a stewardess stowed in the cockpit, was mistaken for a bomb and the plane had to be evacuated.\The bomb squad came and exploded the valise in the middle of the runway.
- 17a. A wealthy arts patron commissioned a sculptor for a fountain and another for a large bust of himself.\The sculptor that the patron commissioned for a fountain resented the project because he hated his employer.
- 17b. A wealthy arts patron commissioned a sculptor and a landscaper.\The sculptor, who the patron commissioned for a fountain, resented the project because he hated his employer.
- 17c. A sculptor that a wealthy arts patron commissioned for a fountain resented the project because he hated his employer.\He felt that a classical sculpture would go better with the landscape.
- 17d. A sculptor, who a wealthy arts patron commissioned for a fountain, resented the project because he hated his employer.\He felt that a classical sculpture would go well with the landscape.
- 18a. A bully hit one student with a rock and another student with a binder.\The student that the bully hit with a rock registered an official complaint with the school board.
- 18b. A bully hit both a student and a teacher after eating too much sugar.\The student, who the bully hit with a rock, registered an official complaint with the school board.
- 18c. A student that a bully hit with a rock registered an official complaint with the school board.\The bully was suspended for a few days and was forced to give a formal apology.
- 18d. A student, who a bully hit with a rock, registered an official complaint with the school board.\The bully was suspended for a few days and was forced to give a formal apology.

- 19a. A janitor cleaned one bathroom with a mop and another bathroom with a sponge.\The bathroom that the janitor cleaned with a mop smelled better than the bathroom cleaned with a sponge.
- 19b. A janitor cleaned a bathroom and a supply closet.\The bathroom, which the janitor cleaned with a mop, smelled better than the bathroom cleaned with a sponge.
- 19c. A bathroom that a janitor cleaned with a mop smelled better than it had smelled when he used a sponge.\After making this discovery, the janitor asked his boss if he could have a new mop.
- 19d. A bathroom, which a janitor cleaned with a mop, smelled better than it had smelled when he used a sponge.\After making this discovery, the janitor asked his boss if he could have a new mop.
- 20a. An astronomer discovered a comet with binoculars and another with the telephoto lens of his camera.\The comet that the astronomer discovered with binoculars was the largest known comet of its kind.
- 20b. An astronomer discovered a comet and an asteroid in similar orbits.\The comet, which the astronomer discovered with binoculars, was the largest known comet of its kind.
- 20c. A comet that an astronomer discovered with binoculars was the largest known comet of its kind.\He immediately called the observatory to report his discovery.
- 20d. A comet, which an astronomer discovered with binoculars, was the largest known comet of its kind.\He immediately called the observatory to report his discovery.

Appendix B. Residual and raw reading times across target sentences

Table B1

Residual (and raw) reading times per word in milliseconds for Experiment 1 trimmed at 5 SD

Region	Condition			
	Null context		Supportive context	
	Non-restrictive	Restrictive	Non-restrictive	Restrictive
A/The	−4.2 (325.9)	2.9 (331.4)	143.7 (495.7)	145.9 (496.8)
postman(.)	14.6 (437.7)	−7.0 (401.4)	−57.0 (361.5)	−41.0 (365.7)
who/that	38.7 (401.3)	24.5 (388.8)	2.1 (362.2)	−12.0 (349.9)
a/the	12.9 (348.8)	29.7 (360.8)	−27.6 (323.8)	−20.8 (329.8)
dog	−47.1 (355.8)	−13.4 (383.9)	−51.3 (345.2)	−66.0 (331.0)
bit	9.6 (406.9)	21.1 (414.3)	−32.5 (358.7)	−55.4 (340.5)
on	24.1 (380.1)	32.0 (383.4)	1.8 (352.3)	−22.4 (329.7)
the	−2.9 (332.2)	−3.5 (332.4)	−9.3 (326.0)	−27.8 (305.7)
leg	−19.3 (392.3)	−34.4 (360.6)	−35.1 (375.0)	−28.3 (371.5)
needed	22.2 (413.1)	5.9 (399.0)	0.4 (392.4)	−11.1 (376.4)
seventeen	−1.7 (376.2)	−26.3 (349.4)	−15.0 (360.3)	−30.8 (341.8)
stitches	−33.6 (358.2)	−39.8 (350.4)	−41.6 (343.2)	−26.5 (355.5)
and	−6.4 (358.3)	−24.8 (340.7)	−17.6 (349.6)	−17.5 (346.3)
had	−21.3 (356.1)	−21.4 (354.5)	−23.9 (354.5)	−17.6 (361.3)

Table B2

Residual (and raw) reading times per word in milliseconds for Experiment 2 trimmed at 5 SD

Region	Condition			
	Null context		Supportive context	
	Non-restrictive	Restrictive	Non-restrictive	Restrictive
The	–22.4 (290.9)	–14.2 (299.7)	117.9 (432.4)	104.5 (424.6)
postman(,)	–37.8 (328.1)	–16.6 (339.2)	–31.3 (335.0)	–36.0 (322.0)
who/that	22.8 (343.2)	21.9 (345.0)	–8.8 (310.6)	–28.7 (294.4)
the	–10.0 (304.1)	8.0 (322.1)	–34.8 (279.0)	–21.8 (292.2)
dog	–16.8 (325.8)	–4.9 (344.8)	–41.8 (305.4)	–47.4 (302.9)
bit	–17.3 (331.3)	18.1 (361.4)	–10.6 (337.6)	–41.6 (306.5)
on	1.5 (316.0)	28.6 (352.2)	8.3 (322.3)	–13.9 (299.6)
the	–12.5 (292.1)	–6.7 (299.4)	–10.5 (294.8)	–7.9 (297.1)
leg	11.9 (368.1)	3.9 (355.1)	–9.4 (344.4)	–23.6 (322.5)
needed	44.4 (381.1)	39.3 (381.3)	6.0 (355.1)	–32.6 (311.4)
seventeen	–11.4 (319.7)	23.0 (361.7)	6.2 (338.7)	–20.7 (312.0)
stitches	–31.5 (302.7)	6.4 (346.2)	–9.1 (338.5)	–21.4 (317.9)
and	–17.4 (307.8)	–7.2 (316.6)	–19.3 (306.4)	–17.1 (310.2)
had	–16.3 (315.7)	–5.8 (328.9)	–0.8 (325.0)	–7.1 (322.8)

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