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Immediate Effects of Discourse and Semantic Context in Syntactic Processing: Evidence from Eye-Tracking

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Abstract¹

We monitored readers' eye-movements to examine the time-course of discourse and semantic influences in syntactic ambiguity resolution. Our results indicate immediate and simultaneous influences of referential context and local semantic fit in the reading of reduced relative clauses (i.e., *The horse raced past the barn fell.*). These results support a model of sentence processing in which alternatives of a syntactic ambiguity are differentially activated by the bottom-up input, and syntactically-relevant contextual constraints simultaneously add activation to their supported alternatives. Competition between comparably active alternatives may then cause slowed reading times in regions of ambiguity.

Introduction

Recent constraint-based models of syntactic ambiguity resolution propose that multiple syntactic alternatives are at least partially available at points of local ambiguity. Ambiguity resolution is viewed as a continuous process with local and contextual constraints providing support for the competing alternatives. The initial availability of the alternatives will be strongly determined by a variety of local syntactic constraints (MacDonald, Pearlmutter & Seidenberg, 1994). Correlated constraints from the context provide evidence in support of the competing alternatives (e.g., Bates & MacWhinney, 1989; McClelland, St. John & Taraban, 1989; MacDonald, in press; MacDonald et al, 1994; Spivey-Knowlton, Trueswell & Tanenhaus, 1993; Trueswell, Tanenhaus & Gamsey, in press).

Constraint-based approaches can be contrasted with two-stage models in which initial syntactic commitments are made using only a restricted domain of syntactic information [e.g., the garden-path model (Frazier & Rayner, 1982)]. In these models, initial commitments are made on the basis of structurally-based parsing principles such as Minimal Attachment. Non-syntactic constraints are used only to evaluate and, if necessary, help revise the initial syntactic analysis constructed by an autonomous syntactic processor (e.g., Rayner, Carlson & Frazier, 1983).

Sentences with reduced relative clauses such as Bever's (1970) famous sentence in (1) have emerged as an important tool for contrasting the predictions made by constraint-based and two-stage models:

1. The horse raced past the barn fell.

These sentences typically result in "garden-paths" because readers initially assume a main clause structure rather than a reduced relative clause structure. According to two-stage models, the main clause structure is always chosen initially because it is syntactically simpler. In contrast, constraint-based models propose that there is a conspiracy of factors that typically result in the main clause preference. More specifically, the reduced relative clause requires a relatively rare conjunction of a verb in a passive voice not preceded by a "be" form, and a transitive argument structure (see MacDonald et al, 1994, for discussion).

In a reduced relative clause, the subject noun phrase is the Patient of the verb, whereas in a main clause it plays the role of Agent. Thus, a noun phrase that is a poor Agent and a good Patient for the ambiguous verb, as in (2), should provide strong support for a reduced relative clause. If the system can make immediate use of semantic constraints, then the reader should not experience a "garden-path" in sentence (2). In fact, several recent studies have confirmed this prediction made by the constraint-based approach to syntactic ambiguity resolution.

2. The evidence examined by the judge turned out to be unreliable.

In an experiment in which eye-movements were monitored, Trueswell et al (in press) showed that the typical processing difficulty observed for reduced relatives is sharply attenuated with materials such as those in (2). With the most constraining materials, temporarily ambiguous reduced relatives were no more difficult than unambiguous controls. MacDonald (in press) and Pearlmutter and MacDonald (1992) have found similar results. In addition, MacDonald has shown that thematic constraints interact with verb argument structure as well as past-participle frequency (MacDonald et al, 1994). Finally, Burgess (1991) has shown that the parafoveal availability of a word that supports a reduced relative (e.g., "by") interacts with the effect of semantic constraint.

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These studies strongly suggest that local semantic constraints, in particular the semantic fit between a noun phrase and a potential argument position, have immediate effects on syntactic ambiguity resolution under conditions where multiple syntactic alternatives are available. However, it remains unclear whether constraints from discourse context can also influence initial syntactic ambiguity resolution.

Discourse context is, in principle, a rich source of constraint for syntactic ambiguity resolution. Incremental updating of a discourse model during sentence processing would make available a variety of constraints that could be used to rapidly evaluate contextually-dependent expressions, including referential expressions (e.g., anaphors) and other expressions that can be viewed as discourse operators such as verb tense (Trueswell & Tanenhaus, 1991).

In this paper, we used relative clauses to investigate the use of referential constraints provided by discourse context, under conditions similar to those in which thematic context effects have been documented. Crain and Steedman (1985) argued that the initial preference for the main clause interpretation in the reduced relative ambiguity is due to the bias toward interpreting the subject noun phrase (NP) as a simple (unmodified) NP when the context is consistent with there being a single unique referent for that NP. They point out that a simple definite NP presupposes a unique referent in discourse, but a complex definite NP (i.e., "the actress selected by the director") presupposes a *set of referents* in discourse. Thus, if a set of actresses existed in the discourse context, readers would initially prefer the reduced relative interpretation, and exhibit no processing difficulty. The literature on whether such referential constraints can affect initial syntactic processing has been largely inconclusive (cf. Altmann, Garnham & Dennis, 1992; Mitchell, Corley & Garnham, 1992; for a review, see Spivey-Knowlton & Tanenhaus, 1994). In previous work, we have argued that this is because the effectiveness of a discourse constraint depends both on the *strength* of the constraint and the *availability* of the biased syntactic alternatives (Spivey-Knowlton et al., 1993).

We report two eye-movement experiments which demonstrate that, contrary to previous claims in the literature, referential constraints can have immediate effects on syntactic ambiguity resolution. We further show that discourse-based contextual constraints operate in concert with local semantic constraints involving thematic roles.

Experiment 1

Sixteen sentences were preceded by contexts that contained either a single referent for the initial NP in the target sentence (i.e., one actress) or a pair of referents for the initial NP (i.e., two actresses). Stimuli were taken from Spivey-Knowlton et al. (1993). Example stimuli are shown in (3):

3. a. 1 NP Referent Context:

An actress and the producer's niece were auditioning for a play. The director selected the actress but not the niece.

Reduced Relative Target:

The actress selected by the director believed that her performance was perfect.

b. 2 NP Referent Context:

Two actresses were auditioning for a play. The director selected one of the actresses but not the other.

Unreduced Relative Target:

The actress who was selected by the director believed that her performance was perfect.

Additionally, a rating task was conducted on 20 subjects to obtain ratings for the typicality of the initial NP being an Agent of the given verb (i.e., "On a scale from 1 to 7, how typical is it for an actress to select someone or something?").

Eye movements and fixation durations were recorded from a different set of 20 subjects reading one version of each stimulus (from the 2 X 2 factorial of Context by Target Sentence), among 32 filler stimuli.

For eye-movement analysis, the target sentences were segmented into four regions: Initial NP / verb / "by"-phrase / main verb + one word /. The verb region is the point ambiguity. The "by"-phrase provides strong probabilistic disambiguation, but is still formally syntactically ambiguous (the sentence could be an intransitive main clause with a locative "by"-phrase). Finally, the main verb region completely resolves the ambiguity as a reduced relative.

Figure 1 shows the total time that the eyes spent in the recording regions, including regressive fixations. Clearly, the syntactic ambiguity in the reduced relative produced processing difficulty in the 1NP referent context, but not in the 2NP referent context. However, it may be that including regressive fixations in calculating reading times conflates initial processing effects with evaluative "second-stage" processing effects.

Therefore, it is necessary to separate reading times for the first pass through a region from reading times of regressive (second pass) eye-movements. In both contexts, the second pass reading times showed small nonsignificant elevations in reading time due to syntactic ambiguity. However, first pass reading times at the "by"-phrase (Figure 2) showed a reliable interaction of Referential Context X Target Sentence; $F(1,16)=9.02$, $p<.01$; $F(1,12)=5.21$, $p<.05$.

This result shows a clear influence of referential context in the initial processing of a syntactic ambiguity. In a context that referentially supports a relative clause structure, reading times for the relative-clause-supporting "by"-phrase show no difficulty in processing, despite to the presence of syntactic ambiguity. In contrast, in a context that referentially supports a main clause structure, reading times for the "by"-phrase show considerable processing difficulty due to the presence of syntactic ambiguity.

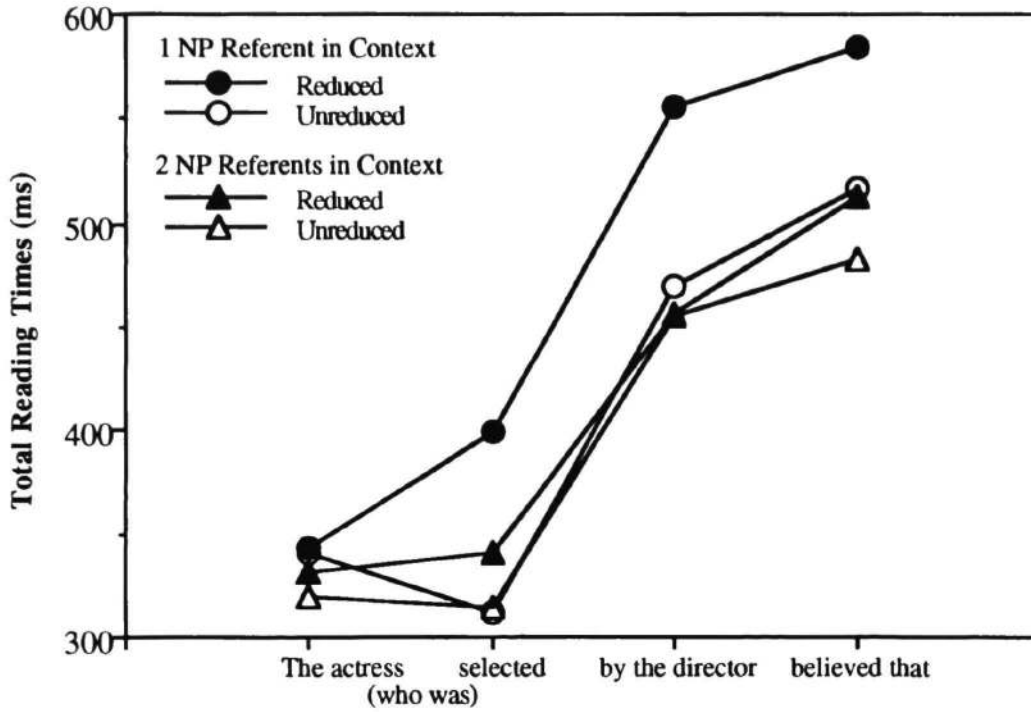


Figure 1. Total reading times for the recording regions of the reduced and unreduced relative clause target sentences in two different referential contexts. The 1NP referent context (circles) shows considerable processing difficulty due to the syntactic ambiguity, whereas the 2NP referent context (triangles) alleviates this processing difficulty.

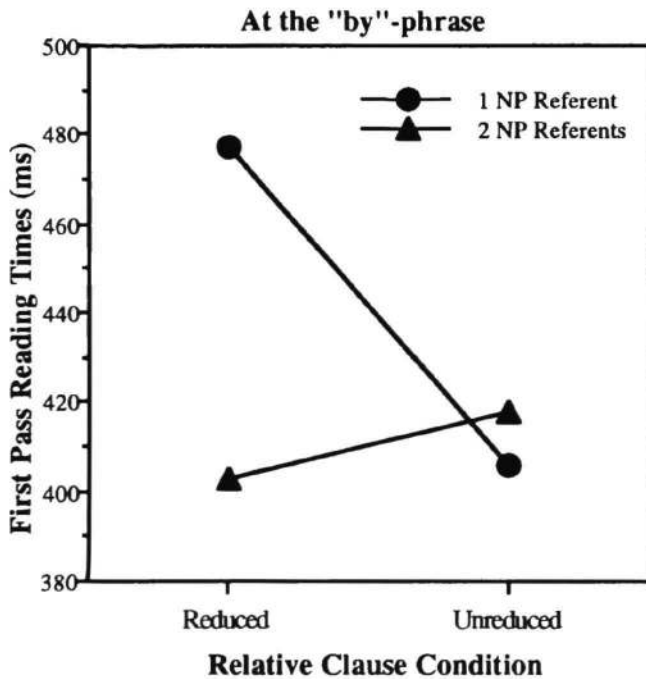


Figure 2. In the 1NP referent context (circles), the syntactic ambiguity in the reduced relative produced considerable processing difficulty in first pass reading times of the "by"-phrase. However, in the 2NP referent context (triangles), no such processing difficulty was observed.

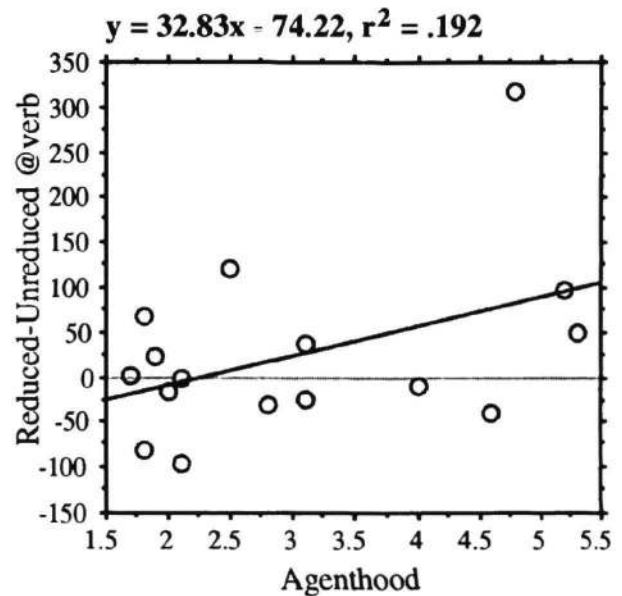


Figure 3. As the typicality of the subject NP being an Agent of the ambiguous verb increases from 1.7 to 5.3, degree of processing difficulty due to the syntactic ambiguity increases.

In addition to an early influence of discourse context in syntactic processing, this experiment was also aimed at testing for an early influence of local semantic context. For example, if the local semantic constraint provides strong support for the main clause structure (i.e., the subject NP is a highly typical Agent for the verb) while the referential context provides strong support for the reduced relative structure (2 NP referents), competition between these two supported alternatives will result in slowed processing in that sentence region.

Agenthood ratings (from 1 to 7, see above) for each stimulus item were entered into a regression analysis to predict the magnitude of processing difficulty (reduced relative first pass reading time minus unreduced relative first pass reading time) at the verb region in the 2 NP referent context only. Figure 3 shows the degree of correlation between Agenthood and processing difficulty at the verb for the sixteen stimuli. (Statistically, this correlation is merely suggestive: $p=.08$.)

Experiment 2

This experiment used the same contexts and reduced relative sentences but with different unambiguous control sentences, such as the following:

- The actress chosen by the director believed that her performance was perfect.

In this control sentence (4), the critical verb (*chosen*) is morphologically unambiguous as a past participle, thus

ruling out a main clause structure and forcing a relative clause interpretation.

As before, eye movements were monitored while 20 subjects read the contexts and sentences. Total reading times are shown in Figure 4.

First Pass reading times of the "by"-phrase (Figure 5) show an interaction of Referential Context X Target Sentence that is very similar to that in Figure 2; $F1(1,16)=5.20$, $p<.05$; $F2(1,12)=7.86$, $p<.02$. When the context contained only a single NP referent, readers exhibited substantial processing difficulty at the "by"-phrase due to the syntactic ambiguity. In contrast, when the context contained two NP referents, readers exhibited no such processing difficulty.

Moreover, Figure 6 shows the regression analysis for Agenthood predicting the degree of processing difficulty (with about the same slope as in Figure 3) to be quite reliable ($p<.005$). As the Agenthood of the subject increases, so does support for the main clause alternative, and greater competition (indexed by processing difficulty) ensues between the discourse-supported relative clause and the semantically-supported main clause.

These results mirror those of Experiment 1. The influence of referential context is clearly visible in first pass reading times at the "by"-phrase (Figure 5). A single NP referent in context causes processing difficulty with the syntactic ambiguity, whereas 2 NP referents alleviates that processing difficulty. Likewise, the influence of local semantic context is clearly visible in first pass reading times at the verb (Figure 6). When the initial NP is a typical Agent of the verb, the competition

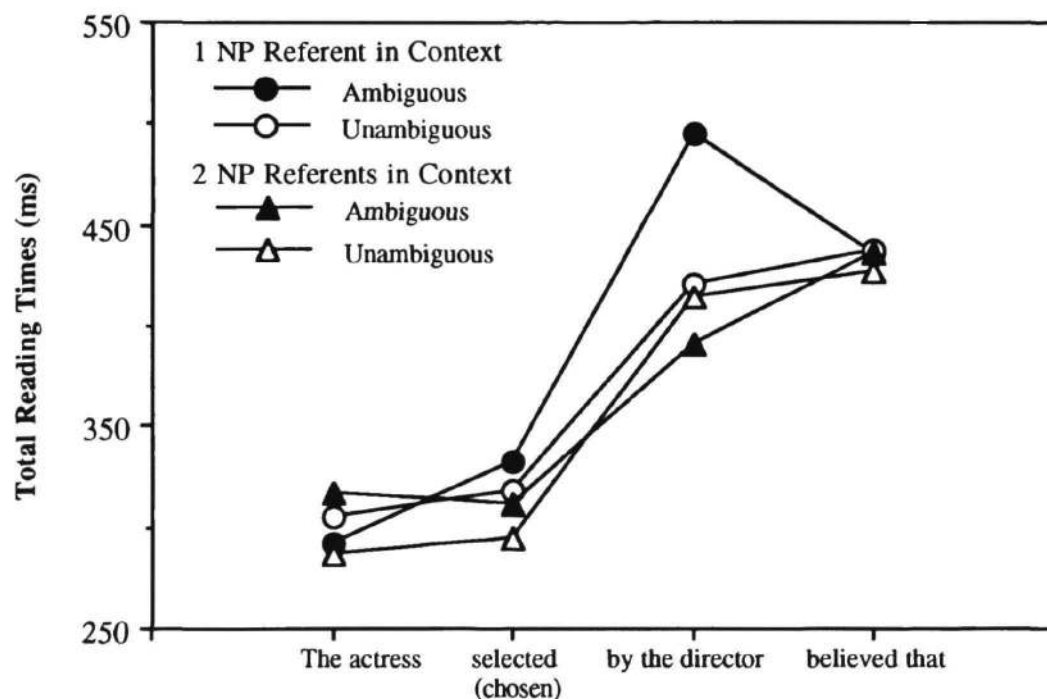


Figure 4. Total reading times for the recording regions of the ambiguous and unambiguous relative clause target sentences in two different referential contexts. The 1NP referent context (circles) shows processing difficulty due to the syntactic ambiguity, whereas the 2NP referent context (triangles) alleviates this processing difficulty.

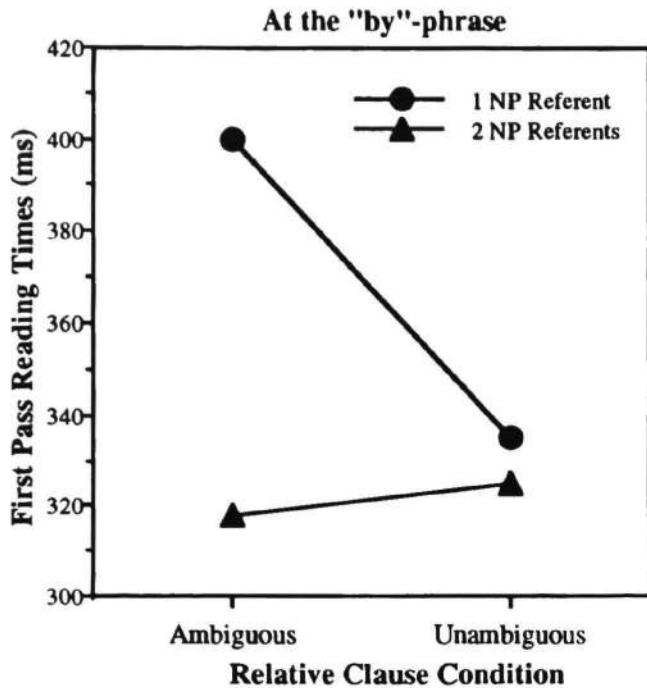


Figure 5. First pass reading times of the "by"-phrase for ambiguous and unambiguous relative clauses in both referential contexts. Note the similarity between this interaction and that of Experiment 1 (Figure 2).

between syntactic alternatives (one supported by local semantics, the other by referential context) produces slowed processing. In contrast, when the initial NP is a non-typical Agent of the verb, there is little competition between alternatives because both contextual constraints support the same syntactic alternative (the reduced relative).

General Discussion

These immediate effects of referential and semantic context are inconsistent with the notion of an informationally-encapsulated parsing module that makes syntactic commitments without recourse to knowledge-based information (e.g., Frazier & Rayner, 1982). Rather, they are best accommodated by a model of sentence processing that allows for a number of contextual constraints to impose immediate influences in initial syntactic commitments, i.e., a constraint-based model. An important facet of the constraint-based approach to syntactic ambiguity resolution is that slowed processing can be seen as the result of competition between active alternatives of the ambiguity (cf. Spivey-Knowlton, 1994), rather than as the result of syntactic misanalysis. If the various constraints [such as verb argument structure frequency (e.g., Juliano & Tanenhaus, 1993; MacDonald, in press), semantic fit between noun and verb (e.g., Pearlmutter & MacDonald, 1992), referential context (e.g., Spivey-Knowlton & Tanenhaus, in press), and temporal cohesion of discourse (Trueswell & Tanenhaus, 1991)] are split over which alternative they support, those two active alternatives will delay further processing while

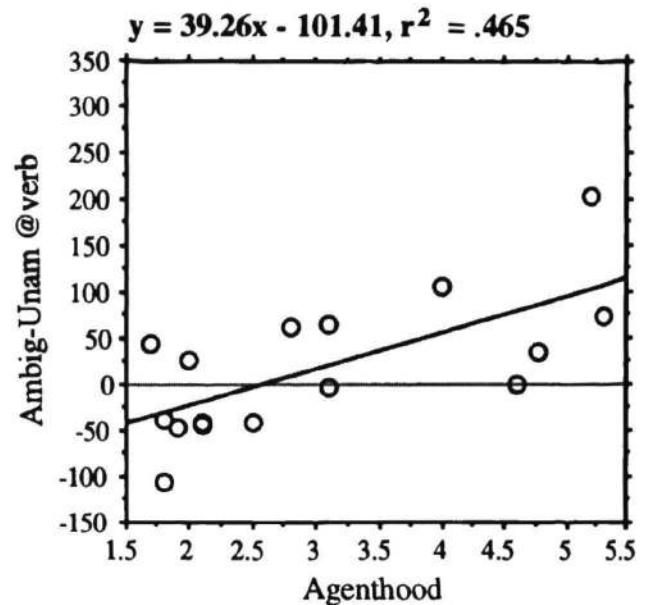


Figure 6. Agenthood of the initial NP predicts degree of processing difficulty at the verb, for sentences in the 2NP referent context. Note the similarity between the slope of this regression and that of Experiment 1 (Figure 3).

they compete with one another in the ambiguous region of the sentence. However, if all of the constraints support only one alternative, no competition will take place.

The present evidence, as well as other recent work, is consistent with this constraint-based approach to sentence processing. However, further experimentation is needed to uncover the relative importance (or weights) given to the relevant constraints on interpretation. This will in turn provide the necessary parameters to facilitate explicit computational models of syntactic ambiguity resolution that will explore and further develop the claims of the constraint-based approach.

As an example of a first step toward modeling constraint-based syntactic ambiguity resolution, Spivey-Knowlton (1994) computed a linear combination of verb-form frequency information (from a corpus), Agenthood and Patienthood typicality between noun and verb (from rating tasks), and referential context bias toward main clause or relative clause (from sentence completions) to produce activation levels of the main clause and relative clause alternatives for each stimulus item. These two syntactic alternatives decremented one another, via a competition algorithm, until one was greater in activation by a set criterion. The number of competition cycles to reach this steady state correlated with the degree of reading-time delay exhibited by subjects across all the stimulus items.

Connectionist architectures have also been used to approach this problem. Pearlmutter, Daugherty, MacDonald & Seidenberg (1993) trained a feedforward network with a corpus of natural English usage. The model received input consisting of a verb and the animacy of its preceding NP. Based on the distribution of that verb's usage in the training set, the model produced an

output consisting of a preferred thematic relation between the NP and the verb. When the subject NP was animate, the model usually assigned it the thematic role of Agent, implying a main clause structure. In contrast, when the subject NP was *inanimate*, the model usually assigned it the role of Patient, corresponding to a relative clause structure.

Along similar lines, Juliano & Tanenhaus (1994) trained a *recurrent* connectionist network on a corpus of English usage, with the inputs being a verb and its *subsequent* word. Its output predicted what type of verb complement would follow the verb (e.g., NP, prepositional phrase, sentence complement, etc.). Across a range of verbs, the model showed verb complement preferences that were analogous to those exhibited by human subjects in reading-time and sentence-completion tasks.

The existing computational models oversimplify the problem and are of small scale. Nonetheless, these models, and the constraint-based approach to syntactic ambiguity resolution, have met with encouraging success in matching empirical data, and promise a more detailed understanding of sentence processing in general.

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