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Anticipating explanations in relative clause processing

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ABSTRACT

We show that comprehenders' expectations about upcoming discourse coherence relations influence the resolution of local structural ambiguity. We employ cases in which two clauses share both a syntactic relationship and a discourse relationship, and hence in which syntactic and discourse processing might be expected to interact. An off-line sentence-completion study and an on-line self-paced reading study examined readers' expectations for high/low relative-clause attachments following implicit-causality and non-implicit causality verbs (*John detests/babysits the children of the musician who*...). In the off-line study, the widely reported low-attachment preference for English is observed in the non-implicit causality condition, but this preference gives way to more high attachments in the implicit-causality condition in cases in which (i) the verb's causally implicated referent occupies the high-attachment position and (ii) the relative clause provides an explanation for the event described by the matrix clause (e.g., ...*who are arrogant and rude*). In the on-line study, a similar preference for high attachment emerges in the implicit-causality context—crucially, before the occurrence of any linguistic evidence that the RC does in fact provide an explanation—whereas the low-attachment preference is consistent elsewhere. These findings constitute the first demonstration that expectations about ensuing discourse coherence relationships can elicit full reversals in syntactic attachment preferences, and that these discourse-level expectations can affect on-line disambiguation as rapidly as lexical and morphosyntactic cues.

1. Introduction

As cognitive agents attempting to comprehend their world, people do not merely gather information through their senses about the situations they encounter. They also draw inferences necessary to interpret these situations as coherent. For example, if one encountered a scene in which an individual is lying dead on the floor and another is standing nearby with a gun, one would likely infer that the death was caused by the second individual having shot the first, despite not having witnessed the event firsthand. One might not reach the same conclusion if the individual standing nearby was instead holding a stethoscope, suggesting other possible causal connections, e.g., that a doctor is trying to help the person on the floor.

Interpreting natural language discourses that *describe* such situations triggers the same type of inferential processes. For instance, upon hearing (1):

(1) John detests his coworkers. They are arrogant and rude.

A comprehender will typically not be content to merely interpret the two sentences as independent statements about the world, but will instead infer that the coworkers' arrogance and rudeness are the *reasons why* John detests them. This inference comes naturally despite the fact that no linguistic material in the passage explicitly cues a

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causal relationship. Our comprehender might be confused, on the other hand, by the similarly unremarkable sentences in passage (2):

(2) John detests his coworkers. They like curry.

People typically detest other people for a reason, and hence this passage might lead our comprehender to wonder why liking curry would cause someone to detest someone else. The lack of an obvious causal connection might even lead the comprehender to construct a possible scenario by which the passage would become coherent: perhaps John does not like the smell of curry, and his coworkers regularly have it for lunch in cubicles proximal to his, for example. As pointed out by Hobbs (1979), the very fact that comprehenders are driven to entertain such scenarios demonstrates that they actively seek to establish the coherence of discourses. Despite the fact that no linguistic element in (2) signals a causal relationship, it nonetheless seems that comprehenders have an *expectation* that such a relation exists—particularly so, as we will subsequently argue, with so-called IMPLICIT-CAUSALITY (IC) verbs like *detest*—and will consider making additional assumptions about the state of the world to support the inference of this relation.

Such facts have led a number of researchers (Hobbs, 1979; Kehler, 2002; Asher & Lascarides, 2003, inter alia) to argue that the establishment of such relevancy relations—henceforth, COHERENCE RELATIONS, of which the causal EXPLANATION relation in (1) is one example—is a fundamental and ubiquitous aspect of discourse interpretation. That is, just as comprehenders seek to recover the implicit syntactic structure of a sequence of words in a sentence, they likewise attempt to recover the implicit "coherence structure" of a sequence of utterances in a discourse. If comprehenders establish such coherence relations and, as has been posited to occur for syntactic relations, generate expectations about what relations are likely to ensue based on the current context, one can ask whether the impact of such expectations extends beyond discourse to the level of syntactic structure building. Such an effect would, in addition to providing strong evidence of the pervasiveness of comprehenders' coherence-driven expectations in language processing, also contribute a novel example to the existing literature documenting the sensitivity of syntactic processing to discourse-level pragmatic inferences (Crain & Steedman, 1985; Altmann & Steedman, 1988, inter alia).

We investigate this question through two experiments involving the well-studied phenomenon of relative clause (RC) attachment, which, as we will argue, gives rise to situations in which two clauses share both a syntactic relationship and a discourse relationship, and hence in which syntactic and discourse processing might be expected to interact. We capitalize on a discourse-level property of RCs that has not, to our knowledge, previously been utilized in psycholinguistic work: the ability of an RC to provide an explanation of the eventuality described in the matrix clause. Consider (3):

(3) John detests the coworkers who are arrogant and rude.

In addition to serving the usual function of restricting the reference of the noun phrase (NP) it modifies (*the coworkers*), in typical contexts the RC in (3) also generates the same inference[1] that we witnessed for (1): that the coworkers' arrogance and rudeness constitute reasons why John detests them.

Our experimental design combines this insight with two previously-established facts concerning OBJECT-BIASED IC verbs like *detest*: (i) that they generate a greater-than-usual expectation for an ensuing explanation of the eventuality they denote, and (ii) that their direct object is expected to be the locus of this explanation. With this in mind, we consider the problem of RC attachment ambiguity, with reference to the sentence fragments in (4) and (5).

(4) John babysits the children of the musician who...
(5) John detests the children of the musician who...

The ensuing RC headed by *who* can be attached to two positions: the HIGH NP, headed by *children*, or the LOW NP, headed by *musician*. Previous studies have shown convincingly that English typically displays a low-attachment bias. However, we can ask what we would expect to happen if comprehenders are able to utilize the above types of pragmatic knowledge when making a syntactic attachment decision. If IC verbs like *detest* generate a greater-than-usual expectation for an ensuing explanation (as compared to non-IC verbs like *babysit* in (4), for example), *and* comprehenders are implicitly aware that RCs can describe such an explanation, *and* this explanation is likely to be about the direct object, then we might expect a greater bias for the RC to attach to the direct object in (5) than in (4), *which, crucially, is the high attachment point for the RC*. This reasoning only goes through, of course, if all three of these types of pragmatic information are utilized in concert during the normal course of syntactic processing.

In this article, we demonstrate, by way of an off-line sentence completion study and an on-line self-paced reading time study, that this prediction is borne out. The next section reviews previous work that has addressed the use of pragmatic information in syntactic processing, and describes the logic of our experimental design and predictions in greater detail. As this discussion will make clear, our results are distinguished from previous work in showing the effect of general discourse processing mechanisms beyond the specific case of referential ambiguity, and in demonstrating the role of pragmatic expectations in a scenario in which utterance felicity is not at stake. Sections 3

[1] This inference has the hallmarks of a conversational implicature (Grice, 1975), in that it can be canceled without contradiction (i) and reinforced without excessive redundancy (ii), establishing that the causal relationship is not entailed:

(i) John detests the coworkers who are arrogant and rude. Being arrogant and rude himself, his coworkers' behavior does not bother him, but he is appalled by their pretense of obsequiousness to the boss.
(ii) John detests the coworkers who are arrogant and rude. It is precisely their arrogance and rudeness that causes him to hate them so much.

See e.g., Geis and Zwicky (1971), Horn (2000), inter alia for further discussion.

and 4 describe our sentence-completion and self-paced reading studies respectively. The general discussion in Section 5 describes the implications of our results for existing models of on-line syntactic comprehension, as well as for the ongoing debate between IMMEDIATE FOCUSING and CLAUSAL INTEGRATION accounts of discourse comprehension. Section 6 concludes.

2. Background and motivation

At first blush, it might seem unlikely that pragmatic processing—of the sort underlying the computation of the type of conversational implicatures that are witnessed in (1) and (3), for instance—would have a pervasive impact on decisions made at the syntactic level. After all, inference at the pragmatic level presumably first requires the computation of the semantic representations it operates over, which in turn requires the construction of the corresponding syntactic analyses.[2] However, a line of inquiry initiated by Crain and Steedman (1985) and Altmann and Steedman (1988) has aimed to demonstrate that discourse-level interpretation processes do in fact impact on-line sentence comprehension. Their work on the Referential Theory focused on the ability of NP postmodifiers to restrict the domain of possible reference of the modified NP. According to this theory, an NP with a restrictive postmodifier such as *the horse raced past the barn* can, in a typical discourse context, be taken not only to presuppose the existence of a horse that was raced past a barn, but also to conversationally implicate the existence of a horse that was not. This implicature results, according to Gricean reasoning, from the fact that if there were only one horse in the context, the speaker would be expected to have chosen the less informative and less prolix NP *the horse*. As a result, when there is ambiguity as to whether material after a given NP constitutes a postmodifier of that NP, the postmodifier analysis should be favored when the preceding context implies that the NP would otherwise be referentially ambiguous. Crain and Steedman (1985) showed that an appropriate referential context can eliminate syntactic garden paths: For example, comprehenders are more likely to accept the grammaticality of sentences like *The horse raced past the barn fell* in a discourse that has previously introduced more than one horse. Likewise, Altmann and Steedman (1988) demonstrated that prepositional phrases that violate the principle of minimal attachment by modifying an NP are read more quickly than those that obey the principle by modifying a VP if the context is 'NP-supporting', i.e., the sentence *the burglar blew open the safe with the new lock* is read more quickly than *the burglar blew open the safe with the dynamite* if, crucially, there has been more than one safe introduced in the discourse context.

Various studies have since provided additional on-line support for the assertion that the relationship between a referential NP and the number of compatible discourse referents influences syntactic attachment decisions. For example, it has been shown by Ni, Crain, and Shankweiler (1996) and Sedivy (2002) that invoking implicit referential contrast sets can affect main-verb/reduced-relative ambiguity resolution in garden-path sentences. Similarly, in a Dutch-language ERP experiment, Van Berkum, Brown, and Hagoort (1999) showed that comprehenders reading sentence onsets of the type *David told the girl that...*, where *that* is ambiguous between introducing a complement clause versus a relative clause, had stronger relative-clause expectations in an ambiguous (two-girl) referential context than in an unambiguous (one-girl) referential context.

The predictions of the Referential Theory also apply to sentences that involve RC attachment ambiguity, as in the classic example in (6).

(6) Someone shot the servant of the actress who was on the balcony.

As predicted by the principle of Late Closure (Frazier, 1978), an RC low-attachment bias has been confirmed in off-line studies with questionnaires and completion tasks and in most on-line studies (Frazier & Clifton, 1996; Carreiras & Clifton, 1999; Fernandez, 2003; but see also Traxler, Pickering, & Clifton, 1998).[3] The Referential Theory predicts, however, that such attachment preferences will be sensitive to the referential status of definite NPs, such that attachment to a definite NP should be preferred when the NP would be referentially ambiguous (and hence infelicitous) without a postmodifier. For example, a low-attachment bias is predicted in a context with multiple actresses as in (7), while a high-attachment bias is predicted in a context with multiple servants as in (8):

(7) There was a servant working for two actresses. Someone shot the servant of *the actress* who was on the balcony.

(8) There were two servants working for a famous actress. Someone shot *the servant* of the actress who was on the balcony.

Offline evidence in a variety of languages supports this prediction (French: Zagar, Pynte, & Rativeau, 1997; Dutch: Desmet, De Baecke, & Brysbaert, 2002; Greek: Papadopoulou & Clahsen, 2006). The evidence for on-line effects has been more mixed. Papadopoulou and Clahsen report significant effects with self-paced reading, but the Zagar et al. and Desmet et al. studies find no significant effects using eye-tracking.

These works have been instrumental in demonstrating that certain discourse interpretation processes—specifically, the establishment of discourse reference—start before the full syntactic structure of the sentence is computed. The results are limited, however, in showing the effect of a single interpretative process (reference) coupled with a single predictive information source (availability of

[2] In the following quote, Clifton and Ferreira (1989) express precisely this rationale: "To make a conversational implicature, a listener must have already parsed the sentence, assigned it its literal interpretation, realised that additional inferences must be added to make it conform to the Gricean maxim, and determined what these inferences are. Such activity could not reasonably affect the initial steps of parsing."

[3] More recent research, however, has made clear that the attachment-preference picture is in fact considerably more complex, and depends on lexico-syntactic details of the ambiguity in question. We defer further discussion of these issues to Section 5.

compatible referents). Further, the contexts involved are all ones in which utterance felicity is at stake, as the felicity of the referential NP hinges on the RC's role in identifying the intended referent. It remains an open question whether such effects can be demonstrated more generally, in situations requiring the integration of multiple, heterogeneous information sources, and in which utterance felicity is not at stake.

The research described in this paper answers this question in the affirmative. To accomplish this, we utilize the set of independent properties of IC verbs and RCs that were mentioned in the introduction, which we combine to establish the predictions of our design. The first property is already well-known in the literature: that IC verbs impute causality primarily to one of the participants of the eventuality they denote, creating a strong bias toward mentioning that participant in any ensuing explanation (Garvey & Caramazza, 1974; Brown & Fish, 1983; Au, 1986; McKoon, Greene, & Ratcliff, 1993). Some verbs, like *detest* in (9), are object-biased, meaning that it is the direct object that comprehenders expect to hear mentioned again in an explanation: If John detests Mary, then the cause is likely to originate from a property of Mary. On the other hand, verbs like *annoy* in (10) are subject-biased: If John annoys Mary, then the cause presumably originates from a property of John. Non-IC verbs, such as *babysit* in (11), are reported to have weaker and less consistent biases.

(9) John detests Mary because... [OBJ-BIAS IC VERB]
...she is rude and arrogant.
(10) John annoys Mary because... [SUBJ-BIAS IC VERB]
...he is rude and arrogant.
(11) John babysits Mary because... [NON-IC VERB]
...he needs the money./...she is too young to be left alone.

Second, we take advantage of the fact that different contexts create different expectations regarding what type of coherence relation will ensue. Kehler, Kertz, Rohde, and Elman (2008) conducted a passage completion study that examined the types of discourse continuations that participants produce when prompted with different context types, specifically comparing IC and non-IC verbs, as in (12) and (13).

(12) John detests Mary. _____. [IC VERB]
(13) John babysits Mary. _____. [NON-IC VERB]

The results showed that IC verbs yield far more Explanation relation continuations than do context sentences with non-IC verbs. At an intuitive level, the lexical semantics of verbs like *detest* appear to lead the comprehender to ask *Why?* in a way that verbs like *babysit* do not.[4] Recent studies by Rohde, Kehler, and Elman (2006, 2007) and Kehler et al. (2008) provide evidence that comprehenders not only generate expectations concerning what coherence relations are likely to ensue based on the current context, but also that any successful model of coreference necessarily must incorporate those expectations.

[4] Unless, of course, the cause of the eventuality has previously been provided in the discourse (cf. Simner & Pickering, 2005).

For the experiments described in this paper, we couple these two IC biases with the fact that RCs can implicate explanations in order to test whether discourse biases can influence syntactic attachment. Consider the matrix clauses of (14)–(15), with sample RCs shown below in (a–b):

(14) John babysits the children of the musician who...
a. ...lives in La Jolla. [low]
b. ...are students at a private school. [high]
(15) John detests the children of the musician who...
a. ...lives in La Jolla. [low]
b. ...are arrogant and rude. [high]

The matrix clauses in these examples differ only in the verb: *detests* is an object-biased IC verb, whereas *babysits* is non-IC. The default low-attachment preference attested in English predicts uniform biases across (14)–(15); for instance, in a passage completion experiment, we would expect to see more low-attaching completions (like (14a) and (15a)) than high-attaching ones (like (14b) and (15b)). We would likewise expect the RC verb *lives* in (14a) and (15a), which agrees in number with the lower NP, to be easier to process on-line than the verb *are* in (14b) and (15b), which agrees with the higher NP.

However, if comprehenders utilize coherence-based pragmatic knowledge as they syntactically process a sentence, the bias toward high attachments should be greater in (15) than in (14). Here's why. As we have mentioned, IC verbs such as *detest* in (15) create a strong expectation for an ensuing explanation. This explanation can be delivered via an immediately-following RC. Finally, if an explanation were to follow, an object-biased verb like *detest* creates a strong expectation that the explanation will re-mention the verb's direct object, which is the high attachment point for the relative clause. With a non-IC verb (14), however, there is a reduced expectation for an upcoming explanation and, even if an explanation were to occur, it would have a reduced next-mention bias to the object. For non-IC prompts, therefore, we predict that the relevant coherence-driven biases will result in a preference for low attachment similar to that found in previous studies.

A demonstration that supports these predictions would go beyond previously-established results in several respects. First, it would demonstrate conclusively that discourse coherence expectations influence not only discourse-dependent expressions such as pronouns (Rohde et al., 2006, 2007; Kehler et al., 2008), but also local syntactic processing decisions within a sentence. It would therefore constitute a fairly radical demonstration of the range of information sources that are brought to bear in on-line syntactic comprehension, as no previous work on sentence processing has utilized coherence relations to similar effect. This design therefore affords a new opportunity to examine a set of strong predictions concerning the potential effects of pragmatic biases on incremental syntactic analysis.

Second, a positive result would show that the effect of discourse processing on syntactic comprehension goes well beyond referential ambiguity, since there is no such ambiguity in these passages. It would also refute any model that attempts to limit the role of discourse information to instances in which utterance felicity is at stake. Note that any modulation of attachment preferences that might be observed in our study could not be reduced to a simple bias against infelicity in definite descriptions (or in any other aspect of the sentence). For example, (15a), repeated below as (16), is in no way infelicitous despite the fact that the RC does not provide an explanation of the detesting; the need for an explanation can easily be satisfied by a subsequent sentence (17).

(16) John detests the children of the musician who lives in La Jolla.
(17) The children are arrogant and rude.

That is, even though an explanation RC continuation is not *required* by the matrix clause in (16) for utterance felicity, this context nevertheless induces an *expectation* that the RC will in fact be an explanation, which in turn is predicted to induce a high RC attachment preference associated with effects that can be measured both off-line and on-line. Such a result would suggest that coherence-driven factors are as important as, and fully integrated with, lexical and morphosyntactic cues during the resolution of ambiguity.

Finally, a positive result would also inform current theories of discourse processing, arguing particularly against clausal integration accounts (Garnham, Traxler, Oakhill, & Gernsbacher, 1996; Stewart, Pickering, & Sanford, 2000). In such accounts, the construction of the discourse relationship between two clauses begins only after each clause has individually been processed in full. Such theories straightforwardly predict that there should be no on-line, mid-sentence effect of coherence relations during the processing of the very clauses over which coherence will ultimately be established.

The remainder of this paper presents two experiments that test the hypothesis we have set forth. If comprehenders are indeed using coherence-driven biases mid-sentence, then one would expect to see effects with respect to the types of RC completions they generate following IC matrix-clause verbs (Experiment 1, a sentence-completion study). If these biases contribute to on-line processing, then one would expect to see processing difficulty associated with those RC attachments that violate the biases introduced by the matrix-clause verb (Experiment 2, a self-paced reading study).

3. Experiment 1: Sentence completions

This experiment uses an off-line sentence-completion task to test the hypothesis that RC attachment preferences are sensitive to comprehenders' expectations about the role that an upcoming clause can play in coherence-biasing IC contexts.

3.1. Methodology

3.1.1. Participants

Fifty-two monolingual English-speaking UCSD undergraduates participated in the study for course credit in Linguistics courses.

3.1.2. Materials

Stimuli consisted of twenty-one pairs of completion prompts differing only in the IC status of the matrix verb, as in (18)–(19). This manipulation is henceforth referred to as 'verbtype'. The complete stimuli can be found in Appendix A.1.

(18) [NON-IC PROMPT] John babysits the children of the musician who...
(19) [IC PROMPT] John detests the children of the musician who...

The subject of the matrix verb was a proper name, and the direct object consisted of a complex NP containing two NPs connected by the genitive marker *of*. Both NPs denoted human referents so that participants could plausibly interpret the relative pronoun prompt *who* as modifying either NP. The complex NP consisted of a singular NP and a plural NP so that in cases in which participants' completions contained an embedded verb marked with number agreement, judges could use that information to determine the attachment height unambiguously. The order of singular and plural was balanced across stimuli (10 singular–plural, 11 plural–singular). The verb in the matrix clause was either an object-biased IC verb or a non-IC verb. IC verbs were selected from two lexical semantic categories that Levin (1993) labels 'psych' and 'judgment' verbs. We adapted the non-IC verbs from those identified by McKoon et al. (1993) in their study of IC and pronoun interpretation. For our stimuli, psych verbs appeared in the present tense since they describe non-eventive states (e.g., *detest, adore*), whereas judgment verbs appeared in the simple past (e.g., *scolded, praised*). Each pair of IC and non-IC verbs was matched for tense as in (18)-(19).

Verbtype was manipulated within participants and within items, with 4 randomizations for each list. In addition to the experimental items, the experiment included 21 fillers and 21 additional stimuli for an unrelated experiment.[5] The additional fillers consisted of sentences with non-IC, non-transfer verbs and a variety of prompts as well as sentences with complex NPs and unambiguous RC prompts. The unambiguous RC prompts used the relative pronoun *who* in contexts in which only one of the two nouns in the complex NP was animate. Half of the unambiguous RC fillers enforced a low attachment and half enforced a high attachment.

[5] The stimuli for the interleaved experiment contained sentences with transfer-of-possession verbs followed either by a full stop and a completion prompt or a full stop and an ambiguous pronoun prompt: *Matt passed a sandwich to David. (He)...*

3.1.3. Procedure

Sentence completions were collected via a web-based interface that participants could access from their own computer. Each item appeared on a page by itself with a text box in which participants were instructed to write their completion. The entire experiment took roughly thirty minutes, but participants were encouraged to have an hour available so that the experiment could be completed in one session. (Participants could leave and return at a later time by identifying themselves with an ID number.) They were instructed to imagine a natural sentence completion for each prompt, writing the first completion that came to mind and avoiding humor.

3.1.4. Evaluation and analysis

Two trained judges—the first author of this paper and an undergraduate Linguistics student—annotated all responses for the RC's intended attachment site (low or high) and the relationship that could be inferred to hold between the RC and the matrix clause ('explanation' and 'non-explanation'). The judges assessed the intended attachment site in light of the matrix clause context and the elicited RC. The judges assessed the RC relationship by asking whether the eventuality denoted by the RC would normally be inferred to give a cause or reason for the eventuality denoted by the matrix clause. To assist in making this assessment, they were told that they could construct variants with *because* clauses: if the sentence *John detests the children of the musician who are arrogant and rude* led annotators to believe that *John hates the children of the musician* <u>*because*</u> *they are arrogant and rude*, then the example would be annotated as an explanation RC. Disagreements were resolved through discussion. An RC was excluded from the analysis if at least one judge assessed its attachment height to be ambiguous, as well as in the few cases in which the judges disagreed about the intended attachment site. Examples (20)–(21) show all possible annotations.[6]

(20) [NON-IC PROMPT]: John babysits the children of the musician who...
  a. [NON-EXP,LOW] ...lives in La Jolla.
  b. [NON-EXP,HIGH] ...go to private school.
  c. [EXP,LOW] ...works the late shift.
  d. [EXP,HIGH] ...are left home on Friday nights.

(21) [IC PROMPT]: John detests the children of the musician who...
  a. [NON-EXP,LOW] ...lives in La Jolla.
  b. [NON-EXP,HIGH] ...go to private school.
  c. [EXP,LOW] ...permits their 3am drum solos.
  d. [EXP,HIGH] ...are arrogant and rude.

As (20) and (21) show, both verbtypes can be felicitously followed by an explanation or a non-explanation RC, and neither RC type enforces a particular attachment level. The hypothesis is that the combination of coherence biases and next-mention biases will render high-attaching explanation RCs more likely following IC verbs than non-IC verbs: Completions like (21d) will be more common than (20d). Low-attaching non-explanation RCs, on the other hand, are predicted to be more expected following non-IC verbs than IC verbs: Completions like (20a) will be more common than (21a).[7]

We conducted analyses of variance on the assessed RC completion types and on the assessed attachment sites to test for a main effect of verbtype. Because these measures involve examining proportions of binary categorical outcomes, we first applied an arcsine transformation (Sokal & Rohlf, 1995) to subject- and item-specific percentages in each condition. For clarity, we present grand means as back-transformed percentages. The observed RC types and RC attachment sites were also modeled using mixed-effects multinomial logistic regressions with random subject-specific and item-specific intercepts (Jaeger, 2008). We report the coefficient estimate and p-value (based on the Wald Z statistic; Agresti, 2002) for the factor verbtype in models fitted to the observed RC completion types and to the observed RC attachments.

3.2. Results

As predicted, IC verbs yielded significantly more high-attaching RCs (main effect of verbtype on attachment height: $F_1(1,51) = 27.158$, $p < 0.001$; $F_2(1,20) = 6.8475$, $p < 0.05$) and significantly more explanation-providing RCs than non-IC verbs (main effect of verbtype on RC type: $F_1(1,51) = 292.22$, $p < 0.001$; $F_2(1,20) = 87.665$, $p < 0.001$).[8] In the logistic regressions, verbtype was a significant factor for modeling the binary outcome of attachment height (whether the RC attached high: $\beta = 0.803$, $p < 0.005$) and the binary outcome of RC type (whether an RC provided an explanation: $\beta = 4.530$, $p < 0.001$). Fig. 1 shows how the pattern of RC attachment differs by verbtype: In the non-IC context, only 36.5% of the unambiguous elicited completions contained a high attachment, which matches the reported low-attachment preference for English; in the IC context, the low-attachment preference disappears with 50.6% of unambiguous completions containing a high attachment. All figures show subject means and standard errors.

As Fig. 2a shows, verbtype also affected the types of RCs participants produced: More than half (63.9%) of the RCs following IC verbs provided an explanation of the event in the matrix clause, whereas only a small proportion

[6] Appendix A.3 lists selected participant completions that exemplify each annotation.

[7] Note that the sample non-explanation RCs do not differ between the non-IC and IC conditions ((20a)–(20b), (21a)–(21b)) because such RCs need not reflect information about the event described in the matrix clause. Explanation RCs, on the other hand, provide an explanation of the matrix-clause event and therefore are shown varying with the matrix clause ((20c)–(20d), (21c)–(21d)).

[8] This is a conservative analysis in which an RC was excluded if at least one coder assessed it as ambiguous (22.5% of the total). The results remain significant if RCs are included if at least one coder assigned a non-ambiguous interpretation (attachment: $F_1(1,51) = 53.52$, $p < 0.001$; $F_2(1,20) = 8.1197$, $p < 0.01$; RC type: $F_1(1,51) = 356.07$, $p < 0.001$; $F_2(1,20) = 96.407$, $p < 0.001$). We restricted the analysis to subject-extracted RCs since object-extracted RCs made up fewer than 1% of the total completions, and their inclusion does not affect the overall results.

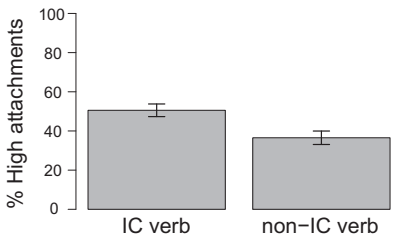

Fig. 1. Percentage of high attachments by verbtype.

(11.0%) of RCs following non-IC verbs provided an explanation. Fig. 2b shows the distribution of explanation RCs broken down by verbtype and attachment height.

Fig. 3 shows the pattern of attachment broken down by verbtype and RC type. Regardless of verbtype, explanation-providing RCs had a higher incidence of high attachment (66.3% for IC verbs, 47.0% for non-IC verbs) than RCs that did not provide explanations (26.0% for IC verbs, 35.9% for non-IC verbs). Pairwise comparisons of explanation vs. non-explanation RCs were significant in the IC condition ($F_1(1,49) = 35.351$, $p < 0.001$; $F_2(1,20) = 36.419$, $p < 0.001$; logistic regression: $\beta = 2.9391$, $p < 0.001$) but not significant in the non-IC condition ($F_1(1,32) = 0.4819$, $p = 0.49$; $F_2(1,8) = 0.6325$, $p = 0.45$; logistic regression: $\beta = 0.6246$, $p = 0.15$). Pairwise comparisons between the IC and non-IC conditions were significant for explanation RCs by subjects and in the mixed model ($F_1(1,32) = 4.394$, $p < 0.05$; $F_2(1,8) = 1.858$, $p = 0.21$; logistic regression: $\beta = 1.6354$, $p < 0.001$) and significant for non-explanation RCs ($F_1(1,49) = 6.454$, $p < 0.05$; $F_2(1,20) = 6.488$, $p < 0.05$; logistic regression: $\beta = -0.8355$, $p < 0.005$).

3.3. Discussion

The sentence-completion study was designed to test the hypothesis that an ensemble of pragmatic factors would conspire to yield more explanation-providing RCs—and as a result, a higher percentage of high-attaching RCs—in sentences with IC verbs than in sentences with non-IC verbs. Both of these predictions were confirmed. The pattern of high attachments in IC contexts therefore shows that models that predict a uniform low-attachment preference are inadequate. These results instead suggest that a variety of factors determine attachment biases; whereas in many contexts these factors conspire to yield a low attachment bias, in others they yield a high attachment bias. The fact that RC attachment biases proved to be dependent on the discourse relation between the RC and the matrix clause suggests that the relevant factors go beyond merely those derivable from properties of the NPs themselves.

The results also confirm Kehler et al. (2008)'s conclusion that IC verbs invoke two types of biases regarding upcoming material: a clause-level coherence bias toward upcoming explanations and an entity-level next-mention bias conditioned on the presence of an explanation relation. Whereas Kehler et al.'s work joined previous studies in demonstrating the effect of IC biases on intersentential pronoun interpretation, the current findings go further in demonstrating that explanations can be inferred to hold intrasententially so as to affect a syntactic attachment decision.

When we consider the two types of biases invoked by IC verbs, our results further suggest that the differences observed in RC attachment across verbtypes (Fig. 1) are more strongly driven by the clause-level biases towards an upcoming explanation (Fig. 2a) than by the biases toward

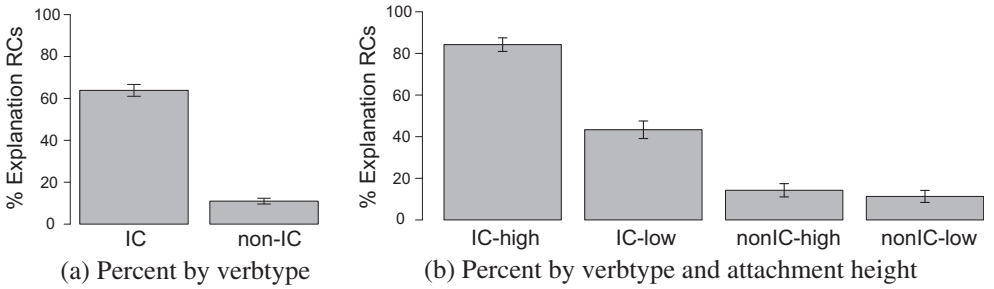

Fig. 2. Percentage of explanation RCs by verbtype and attachment height.

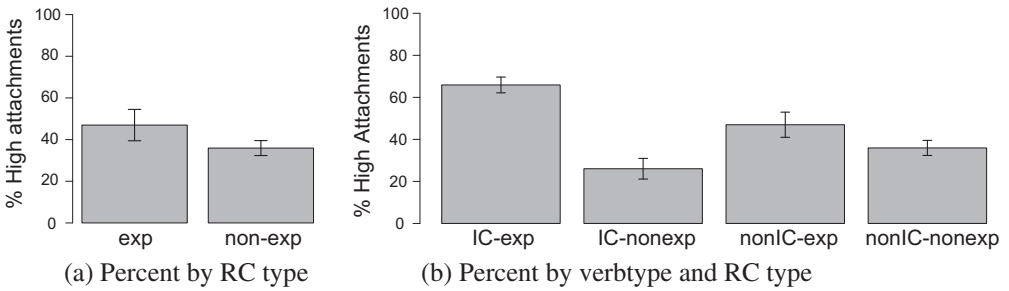

Fig. 3. Percentage of high attachments by verbtype and RC type.

focusing on the direct object specific to each coherence relation (Fig. 3a). While participants were somewhat more likely to favor the higher NP in explanation-providing RCs in the IC condition than in the non-IC condition (Fig. 3b), the overall pattern of attachment is driven by the strong bias to produce more explanations in the IC condition than in the non-IC condition.

Although the experiment confirmed our predictions regarding the IC biases, a closer analysis of the elicited completions suggests that several factors converged to reduce the strength of the effect from what might otherwise have been found. In particular, we identified two subpatterns of behavior that are not apparent in the aggregate effects. The first concerns the coherence bias, where we found that some verbs that have been classified in the literature as non-IC actually yielded a larger number of explanation-providing RCs than some IC verbs. For example, the verb *watch*, which McKoon et al. (1993) included in a non-IC condition, yielded 46.2% explanations – more than some IC verbs such as *like* (26.7% explanations) and *value* (22.7% explanations). Appendix A.3 lists the percentages of explanation RCs that each verb elicited. Caramazza, Grober, Garvey, and Yates (1977) previously commented that the next-mention biases of IC verbs lie along a continuum; here we find that the same is true for their biases towards ensuing explanations as well. We therefore would have expected a stronger effect if the IC verbs used had uniformly stronger biases towards explanations than their non-IC counterparts.

The second pattern concerns attachment bias: In a small number of our items, an IC verb systematically failed to induce a high-attachment preference, for reasons that turn out to involve properties of the complex object NP. Consider the following two prompts and sample completions:

(22) a. Alan punished the accountant of the businessmen who...
[HIGH] ...was cooking the books.
b. Bill congratulated the teacher of the second-graders who...
[LOW] ...had all passed the test.

The prompt in example (22a) upheld our predictions, yielding a large proportion of explanation-providing RCs (85.7%), and those RCs consistently attached high (100%). Example (22b) also yielded many explanation-providing RCs (81%), but in this case, the RCs tended to attach low (only 29% high attachment). To understand this discrepancy, notice that in both examples, the RC provides an explanation of the matrix-clause event: *punishing the accountant because the accountant cooked the books*, and *congratulating the teacher because the students passed the test*. However, whereas in (22a) the explanation directly describes the accountant, in (22b) the explanation describes the students, utilizing the implicit relationship between teachers and students to convey the relevant qualities of the teacher.[9] Although this circumstance undercuts the high-attachment effect we were looking for, it provides additional, unexpected evidence for our hypothesis that comprehenders use complex discourse-level inferencing to make a syntactic decision: In a case like (22b), the comprehender expects an explanation of the teacher-congratulation event in the matrix clause but knows that in situations with teachers and students, a teacher can receive credit for the students' accomplishments and so mentioning the students' accomplishments will implicitly praise the teacher. Thus, examples like (22b) demonstrate that in making a syntactic decision, comprehenders can use not only causal inferencing about the way that clauses relate but also knowledge about the real-world relationships that hold between specific NPs in a complex NP.

In summary, Experiment 1 confirmed our hypothesis. The results, however, are restricted to an off-line completion task. If, as we hypothesize, the coherence-driven biases that emerge are indeed deployed mid-sentence, then one would expect to see effects in comprehenders' incremental processing in a self-paced reading time experiment. The goal of Experiment 2 is to test this hypothesis.

4. Experiment 2: Self-Paced reading

Experiment 2 tests whether the attachment biases revealed by Experiment 1 generate expectations that are deployed rapidly in on-line comprehension. Specifically, we test the prediction that inferences about intraclausal coherence relations can affect local syntactic disambiguation before comprehenders have been exposed to complete clauses.

We adapted the stimuli from Experiment 1 to create a moving-window self-paced reading study with a 2×2 design that varied verbtype and RC attachment height as in (23)–(24). Underscores connect words presented together as a single region in the study.

(23) [NON-IC] John babysits the_children of the_musician who...
a. [LOW] ... is generally arrogant and rude.
b. [HIGH] ... are generally arrogant and rude.

(24) [IC] John detests the_children of the_musician who...
a. [LOW] ... is generally arrogant and rude.
b. [HIGH] ... are generally arrogant and rude.

The point of disambiguation for the RC attachment height in (23)–(24) is the finite embedded verb, which agrees in number with only one of the two preceding NPs (e.g., the verb *is* in (23a) agrees in number with *the musician*). Any biases comprehenders have regarding attachment of the RC should be evidenced in their processing of that verb: If the RC attachment height signaled by the finite verb violates the expected attachment height, reading time would increase. The finite embedded verb therefore constitutes the CRITICAL region of the experiment. Because differences in processing difficulty in self-paced reading often show up a region or two downstream of the critical region (see Mitchell, 1984), especially when the critical region is short as it is here, the immediately post-critical word was always

[9] Similarly behaving items included *scolded the landlady of the actors who...*, *detests the father of the students who...*, and *pities the bodyguards of the celebrity who...*

an adverb chosen to be non-indicative of attachment height (*generally* in (23)–(24)). This word and the subsequent word (*arrogant* in (23)–(24)) constitute the SPILLOVER regions for this experiment.

The default low-attachment bias predicts uniform results for (23)–(24): High-attaching RCs in (23b) and (24b) would yield longer reading times in the critical/spillover regions than the low-attaching RCs in (23a) and (24a). However, according to our hypothesis, a verbtype × attachment–height interaction is predicted. In the non-IC case, the default low-attachment bias is expected to be confirmed. However, for the IC case, we hypothesize that comprehenders will follow the same chain of reasoning outlined for Experiment 1 and, as such, will have a greater expectation that the upcoming RC will provide an explanation that re-mentions—and therefore attaches to—the direct object. Therefore, we expect the default low-attachment bias will be reduced, neutralized, or even reversed in the IC case. Importantly, reading time is being measured in the critical/spillover regions, that is, before comprehenders find out whether the relative clause actually provides an explanation. Therefore, differences in reading time would be due to comprehenders' expectations of an upcoming explanation, and not the actual presence of one.

4.1. Methodology

4.1.1. Participants

58 monolingual English speakers participated in the reading time experiment for credit in Linguistics and Psychology courses.

4.1.2. Materials

Each of the experimental items consisted of a matrix clause with a proper name, a verb, and a complex NP direct object, followed by a temporarily ambiguous RC, as in (23) and (24). The complex NP contained a singular NP and a plural NP. The embedded verb (from here on, the 'RC verb') was always a *be* or *have* verb form that was inflected for number agreement; depending on the item, it served either as an auxiliary or as the main verb of the relative clause. A semantically neutral adverb always appeared immediately after the embedded verb to provide a spillover region. Participants saw each item with either a non-IC or an IC matrix verb. We selected IC verbs from Experiment 1 that had strong biases towards explanation RCs and supplemented them with a few additional verbs taken from Kehler et al. (2008)'s study (which were in turn taken from McKoon et al. (1993)'s study, with some minor substitutions). The non-IC verbs consisted of a mix of verbs from Experiment 1, McKoon et al. (1993), and Levin (1993). We avoided non-IC verbs from Experiment 1 that induced a strong bias towards Explanations and avoided IC verbs that did not (see Section 3.3). The order of the singular NP and plural NP in the complex NP was balanced across stimuli so that high attachment was signaled with plural agreement for half the items and with singular agreement for the other half. We avoided constructing complex NPs for which explanations for the matrix-clause event could utilize an implicit, real-world relationship to implicate the low NP, since our hypothesis and the default low-attachment bias make the same prediction for low-attachment in such cases (see Section 3.3).

Verbtype and attachment height were manipulated within participants and within items. The experiment consisted of 10 practice items, followed by 20 experimental items mixed with 30 fillers, pseudorandomized for each subject. The filler items were similar to the stimuli in that some included proper names and RCs or other subordinate clauses. Filler RCs all attached unambiguously, either to the single available attachment site or to an attachment site enforced by a *who/that* relative pronoun. The 20 experimental items are listed in Appendix A.4.

4.1.3. Procedure

Items were presented in a moving-window self-paced reading paradigm, using DMDX experiment software (Forster & Forster, 2003). Sentences appeared in white letters on a dark background, left-justified on a 19″ CRT screen, and no sentence was longer than one line of text. Sentences initially appeared as a series of dashes (— — — —) obscuring the words, and participants pushed a button on a Logitech USB gamepad to reveal each region. The presentation was non-cumulative such that previous regions were replaced with dashes when the next region appeared. The critical region and the spillover regions were revealed one word at a time, but multi-word regions were used elsewhere to present short phrases such as a verb and a preposition (*stared at*, *stood near*) or a determiner and a noun (*the children*). Multi-word regions are indicated in the stimuli set in Appendix A.4. Participants pushed either a YES or NO button on the gamepad to answer a comprehension question after every sentence, and they received automatic feedback whenever they answered incorrectly. They were instructed to read as quickly and carefully as possible, making sure they understood the complete sentence and slowing down if they answered multiple questions incorrectly. We recorded reading times for each region as well as the participant's response to the comprehension question.

4.2. Results

After excluding three participants whose comprehension-question accuracy was not significantly better than chance, the percentage of correct responses was 93.03% for fillers and 85.07% for experimental items (percentages over subject means), indicating that participants paid attention to the task. Comprehension-question accuracy and reading times were analyzed with 2 × 2 ANOVAs, by subjects and by items. The results were also analyzed using linear mixed-effects models with random subject-specific and item-specific intercepts. For these models, we report the coefficient estimates and MCMC-derived p-values (Baayen, Davidson, & Bates, 2008). When mixed-effects analyses included tests for the presence of interactions, predictors were centered so that the main effects remain interpretable.

4.2.1. Comprehension-question accuracy

Table 1 shows the mean accuracy on comprehension questions for each condition. Question-accuracy ANOVAs were conducted on arcsine transformed proportions of correct answers. There was a marginal main effect of

Table 1
Raw RTs and question accuracy (subject means ± standard error).

	RC verb	Spillover1	Spillover2	Accuracy
IC.high	395.70 ± 16.83	430.43 ± 18.90	442.81 ± 18.84	0.873 ± .02
IC.low	398.83 ± 16.71	474.16 ± 23.26	477.19 ± 26.34	0.780 ± .02
non-IC.high	402.03 ± 16.55	501.48 ± 24.26	473.59 ± 20.22	0.862 ± .02
non-IC.low	403.96 ± 13.83	462.63 ± 20.03	437.50 ± 15.91	0.887 ± .02

attachment height favoring high-attaching RCs (marginal by subjects: $F_1(1,54) = 3.889$, $p = 0.054$; $F_2(1,19) = 2.778$, $p = 0.112$). There was also a main effect of verbtype favoring non-IC verbs (significant only by subjects: $F_1(1,54) = 4.59$, $p < 0.05$; $F_2(1,19) = 2.206$, $p = 0.154$). These main effects are driven by an interaction in which low-attaching RCs in the IC condition yielded lower accuracies than any other condition. The interaction that emerges is consistent with the predicted interaction for processing difficulty in cases in which the RC violates the expectations generated from the preceding context (verbtype × attachment–height interaction significant by subjects and marginal by items: $F_1(1,54) = 7.346$, $p < 0.01$; $F_2(1,19) = 3.89$, $p = 0.063$). In a mixed-effects logistic regression, attachment height was not a significant factor for modeling question accuracy (attachment: $\beta = -0.273$, $p = 0.13$), whereas verbtype and the verbtype × attachment interaction were significant (verbtype: $\beta = 0.445, p < 0.05$; verbtype × attachment interaction: $\beta = 0.972, p < 0.01$).

4.2.2. Reading time results

Table 1 shows the raw reading times by condition for the critical region and the spillover regions. Fig. 4 shows the residual reading times for each of the four conditions starting at the matrix verb.

We analyzed residual reading times at the critical region and two spillover regions. Residual reading times adjust for overall differences in participants' reading rates as well as differences in readers' sensitivity to word length. Residual RTs were calculated as the difference between the actual reading time on a word and the reading time predicted by a regression equation (computed separately for each participant, using all experimental and filler items) relating word length to reading time (Trueswell, Tanenhaus, & Garnsey, 1994). We removed residual RTs that were more than four standard deviations away from the mean, per region and per condition (0.36% of the data). The analysis we present below considers all non-outlier items, regardless of comprehension-question accuracy.

At the disambiguating RC verb (*is*/*are*), there were no significant effects for verbtype (Fs < 1), attachment height ($F_1(1,54) = 1.071$, $p = 0.31$; $F_2(1,19) = 1.124$, $p = 0.30$), or the verbtype × attachment interaction (Fs < 1). In a mixed-effects linear regression, the factors for verbtype, attachment height, and the verbtype × attachment interaction were not significant factors for modeling residual reading time (verbtype: $\beta = -0.1556$, $p = 0.99$; attachment: $\beta = 9.84$, $p = 0.31$; verbtype × attachment interaction: $\beta = -13.258$, $p = 0.51$).

At the first spillover region (*generally*), there were again no main effects of verbtype (Fs < 1) or attachment height ($F_1(1,54) = 1.295$, $p = 0.26$, $F_2 < 1$). However, a significant interaction was observed in the predicted direction: High attachments were read more slowly than low attachments in non-IC conditions but faster in IC conditions ($F_1(1,54) = 5.522$, $p < 0.05$; $F_2(1,19) = 6.167$, $p < 0.05$). In a mixed-effects linear regression, the factors for verbtype and attachment were not significant (verbtype: $\beta = 8.672$, $p = 0.47$; attachment: $\beta = 12.027$, $p = 0.31$), whereas the verbtype × attachment interaction was (verbtype × attachment interaction: $\beta = -63.60, p < 0.01$). To test for full cross-over interaction, we conducted pairwise tests of high vs. low attachment separately in IC vs. non-IC conditions. In the IC condition there was an effect of attachment level marginal by subjects, significant by items, and significant in a mixed-effects model ($F_1(1,54) = 3.45$, $p = 0.069$; $F_2(1,19) =$

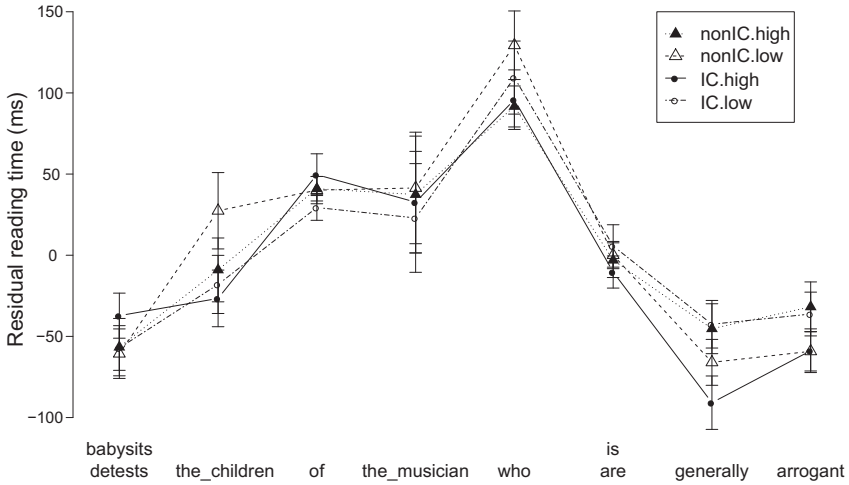

Fig. 4. Residual reading times.

7.91, $p < 0.05$; $p_{MCMC} < 0.05$). In the non-IC condition the effect was insignificant ($F_1(1,54) < 1$; $F_2(1,19) = 1.09$, $p = 0.31$; $p_{MCMC} = 0.12$).

At the second spillover region (*arrogant*), there were again no main effects (Fs < 1), but the same interaction was significant ($F_1(1,54) = 6.588$, $p < 0.05$; $F_2(1,19) = 4.967$, $p < 0.05$). In a mixed-effects linear regression, the main factors of verbtype and attachment height were not significant, but the interaction was (verbtype: $\beta = 3.106$, $p = 0.78$; attachment: $\beta = -3.279$, $p = 0.77$; verbtype × attachment interaction: $\beta = -47.10$, $p < 0.05$). To test for full crossover interaction, we conducted pairwise tests of high vs. low attachment separately in IC vs. non-IC conditions. In the IC condition the effect was not significant ($F_1(1,54) = 2.51$, $p = 0.12$; $F_2(1,19) = 1.97$, $p = 0.18$; $p_{MCMC} = 0.12$). In the non-IC condition the effect was significant by subjects and by items, and marginal in a mixed-effects model ($F_1(1,54) = 5.8$, $p < 0.05$; $F_2(1,19) = 4.37$, $p < 0.05$; $p_{MCMC} = 0.08$).

We also conducted an analysis of RTs summed across the two spillover regions, since a significant interaction pattern was observed in both regions. We found no main effects (Fs < 1) and an interaction significant by both subjects and items ($F_1(1,54) = 10.05$, $p < 0.01$; $F_2 = 9.56$, $p < 0.01$; $p_{MCMC} < 0.001$). To test for full crossover interaction, we conducted pairwise tests of high vs. low attachment separately in IC versus non-IC conditions. In the IC condition the effect was significant ($F_1(1,54) = 6.79$, $p < 0.05$; $F_2(1,19) = 9.08$, $p < 0.01$; $p_{MCMC} < 0.05$). In the non-IC condition the effect was marginal by subjects and significant in the mixed model analysis ($F_1(1,54) = 3.77$, $p = 0.058$; $F_2(1,19) = 2.33$, $p = 0.14$; $p_{MCMC} < 0.05$).

Analyses of the raw reading times were qualitatively the same, as were analyses of residual RTs with incorrectly answered items excluded.[10]

Earlier in the sentence, there was a marginal effect of verbtype at NP1 (*the_children*), with non-IC verbs yielding slower reading times (verbtype: $F_1(1,54) = 2.977$, $p = 0.09$; $F_2(1,19) = 3.945$, $p = 0.062$; attachment: $F_1(1, 54) = 1.616$, $p = 0.21$; $F_2(1,19) = 1.854$, $p = 0.19$; verbtype × attachment: Fs < 1; regression for NP1 with factors for verbtype: $\beta = 33.30$, $p = 0.06$; attachment: $\beta = 23.00$, $p = 0.19$; verbtype × attachment: $\beta = 29.613$, $p = 0.40$). No other pre-critical regions yielded significant effects.

4.3. An independent measure of verb bias

The foregoing results are supportive of our hypothesis that verbtype would affect initial RC attachment preferences and are consistent with the results of Experiment 1. In order to more thoroughly test the specific prediction that the same preferences that are implicated in cross-sentence implicit-causality biases (Garvey & Caramazza, 1974; McKoon et al., 1993; Kehler et al., 2008) are also the key factors modulating on-line RC attachment preferences, we conducted an additional norming study on the main clauses of our experimental materials. Rather than writing story completions to fragments containing RC contexts as in Experiment 1, we asked participants to write a new sentence following a full stop as in (25)–(26) in independent measure of the IC biases in these contexts:

(25) [NON-IC] John *babysits* the children of the musician. . . .

(26) [IC] John *detests* the children of the musician. . . .

By analyzing such data, we can calculate (i) the proportion of continuations that explain the first sentence (as opposed to employing other coherence relations), and (ii) the proportion of explanation continuations in which the direct object is the next mentioned referent. These proportions may allow us to characterize IC bias as a gradient, rather than a categorical, characteristic of verbs and the contexts in which they are used. Two key predictions regarding these proportions follow from our hypothesis: first, in comparing the main clauses of the IC and non-IC conditions of our study, the IC condition is predicted to yield both a larger proportion of explanation continuations and a larger proportion of direct object re-mentions in continuations in which an explanation coherence relation is operative; second, the resulting gradient measures of IC bias are expected to act as reliable predictors of attachment preferences (specifically, we should see a significant interaction between RC attachment and either of these independently observed measures of IC bias on reading times early in the RCs).[11]

It is important, however, to take into account one source of discrepancy between these cross-sentence next-mention biases and those in RC attachment as explored in Experiment 1: In contexts like (25)–(26), a greater-than-average bias toward re-mention of the direct object will come primarily at the expense of re-mentions of the subject referent, whereas in the case of the RC

[10] Considering the raw reading times, there were no effects at the disambiguating verb (Fs < 1; regression with factors for verbtype: $\beta = 4.112$, $p = 0.69$; attachment: $\beta = 5.577$, $p = 0.61$; verbtype × attachment: $\beta = -7.953$, $p = 0.72$). At the first spillover region, there was an effect of verbtype by subjects and a significant interaction (verbtype: $F_1(1,54) = 7.075$, $p < 0.05$; $F_2(1,19) = 3.548$, $p = 0.075$; attachment: Fs < 1; verbtype × attachment: $F_1(1,54)$=6.853, $p < 0.05$; $F_2(1,19) = 5.434$, $p < 0.05$; regression for Spillover1 with factors for verbtype: $\beta = 30.466$, $p < 0.05$; attachment: $\beta = 1.787$, $p = 0.88$; verbtype × attachment: $\beta = -81.31$, $p < 0.005$). At the second spillover region, there were no main effects (Fs < 1) and the same interaction was significant ($F_1(1,54) = 6.705$, $p < 0.05$; $F_2(1,19) = 6.078$, $p < 0.05$; regression for Spillover2 with factors for verbtype: $\beta = -2.968$, $p = 0.83$; attachment: $\beta = -2.738$, $p = 0.81$; verbtype × attachment: $\beta = -70.41$, $p < 0.005$).Considering the residual reading times with incorrectly answered items excluded, there were no effects at the disambiguating verb (verbtype: $F_1(1,54) = 1.442$, $p = 0.24$; $F_2(1,19) = 2.116$, $p = 0.16$; attachment: Fs < 1; verbtype × attachment: Fs < 1; regression with factors for verbtype: $\beta = 7.338$, $p = 0.43$; attachment: $\beta = 6.813$, $p = 0.51$; verbtype × attachment: $\beta = -12.77$, $p = 0.53$). At the first and second spillover regions there were no main effects but significant interactions (Spillover1: verbtype: $F_1(1,54) = 2.646$, $p = 0.11$; $F_2(1,19) = 1.701$, $p = 0.21$; attachment: Fs < 1; verbtype × attachment: $F_1(1,54) = 6.117$, $p < 0.05$; $F_2(1,19) = 5.216$, $p < 0.05$; regression for Spillover1 with factors for verbtype: $\beta = 22.064$, $p = 0.073$; attachment: $\beta = 7.779$, $p = 0.56$; verbtype × attachment: $\beta = -74.05$, $p < 0.005$; Spillover2: verbtype: Fs < 1; attachment: Fs < 1; verbtype × attachment: $F_1(1,54) = 7.598$, $p < 0.01$; $F_2(1,19) = 5.465$, $p < 0.05$; regression for Spillover2 with factors for verbtype: $\beta = 0.1607$, $p = 0.98$; attachment: $\beta = -2.4821$, $p = 0.84$; verbtype × attachment: $\beta = -64.89$, $p < 0.01$).

[11] We are grateful to an anonymous reviewer for the suggestion to both norm our verbs and use the results in a regression analysis of RTs.

contexts, attachments to the direct object will typically come at the expense of attachments to the referent in the object-of-PP position. Statistics for all three possible referents will therefore be used to test both of the predictions described above.

4.3.1. Methodology

Forty monolingual English speakers wrote story completions following prompts like those in (25)–(26). Two trained judges—the first author of this paper and a Linguistics graduate student—assessed the 630 elicited completions that re-mentioned a referent from the prompt. The judges annotated the responses for the completion type ('explanation' or 'non-explanation') and the choice of next mention (subject NP, direct object NP, or possessor NP). A completion was excluded from the analysis if at least one judge assessed the choice of next mention to be ambiguous (8% of completions).

4.3.2. Results: verbtype and gradient IC bias

Because these measures involve examining proportions of binary categorical outcomes, we conducted ANOVAs on arcsine-transformed subject- and item-specific means as we did for the completion study described in Section 3. We again present means as back-transformed percentages and report results from mixed-effect multinomial logistic regressions.

Column 1 of Table 2 shows the probability of an explanation given each verbtype (subject means) and the number of completions for each verbtype. The norming study confirmed that IC verbs yielded far more explanations (66.8%) than non-IC verbs (23.1%; main effect of verbtype on completion type: $F_1(1,39) = 65.83$, $p < 0.001$; $F_2(1,19) = 52.021$, $p < 0.001$; regression: $\beta = 2.081$, $p < 0.001$). Columns 2 and 3 show the probability of re-mentioning the direct object NP in explanations and non-explanations respectively. The study confirmed that explanation completions following IC verbs contained the largest number of re-mentions of the direct object NP (67.2%), compared to explanation completions following non-IC verbs (8.6%), non-explanation completions following IC verbs (20.9%), and non-explanation completions following non-IC verbs (29.3%). In order to establish that the rate of object re-mentions is significantly larger in explanations following IC verbs than in any other context, we conducted an ANOVA predicting the proportion of object next mentions given completion type (explanation vs. non-explanation) and verbtype (IC vs non-IC). The rate of object re-mention was larger in explanation completions than non-explanation completions (main effect of completion type, significant by subjects, marginal by items: $F_1(1,37) = 5.636$, $p < 0.05$; $F_2(1,18) = 4.130$, $p = 0.06$). The rate of object re-mentions was larger following IC verbs than non-IC verbs (main effect of verbtype: $F_1(1,37) = 42.187$, $p < 0.001$; $F_2(1,18) = 42.736$, $p < 0.001$). There was also a completion type $\times$ verbtype interaction, whereby object re-mentions were most frequent in explanation completions following IC verbs (interaction: $F_1(1,27) = 92.67$, $p < 0.001$; $F_2(1,15) = 42.947$, $p < 0.001$).

Table 2
Coherence and next-mention biases by verbtype. Support (n) in parentheses.

	Explanation bias	Object next-mention bias in explanations	Object next-mention bias in non-explanations
IC	0.668 (335)	0.672 (219)	0.209 (116)
non-IC	0.231 (295)	0.086 (70)	0.293 (225)

Because the data for the four conditions are not balanced (e.g., there were only 70 explanations following non-IC verbs but 219 explanations following IC verbs), a mixed-effect logistic regression is useful for evaluating main effects and the interaction between completion type and verbtype. In the regression, verbtype and completion type were significant factors for modeling the binary outcome of choice of next mention, and the completion type $\times$ verbtype interaction was also significant ($\beta_{verbType} = 1.239$, $p < 0.001$; $\beta_{completionType} = 0.782$, $p < 0.001$; $\beta_{interaction} = 3.518$, $p < 0.001$). Pairwise comparisons show that the rate of object re-mention in explanations following IC verbs (67.2%) is larger than that in explanations following non-IC verbs (8.6%; $t(69) = 10.327$, $p < 0.001$); it is larger than that in non-explanations following IC verbs (20.9%; $t(70) = 7.728$, $p < 0.001$), and it is larger than that in all other contexts collapsed together (20.2%; $t(82) = 6.878$, $p < 0.001$). Appendix A.5 lists the individual coherence and next-mention biases for each item, showing that the IC biases are not categorical but rather lie along a continuum (see Caramazza et al., 1977).

4.3.3. Results: modeling RTs with empirical item norms

Whereas the analyses reported in Section 4.2 used a dichotomous verbtype predictor (IC or non-IC) to model reading times, here we compare these analyses with new analyses using our norming study results as continuous predictors. We report analyses of our central results—RTs at the first and second spillover regions—using linear mixed-effects models with random subject- and item-specific intercepts. We consider models with the dichotomous verbtype predictor, models with a gradient norm (we investigated both the verb-specific bias toward an upcoming explanation and the bias toward object-NP re-mention given an explanation completion) as a predictor, and models with both as predictors. In all cases, RC attachment and its interactions were included as predictors, and all predictors were centered.

Our analysis using bias towards an upcoming explanation did indeed recover a significant interaction between item-specific bias and RC attachment on reading times in both spillover regions (first spillover region, explanation bias: $\beta = -2.41$, $p_{MCMC} = 0.72$; attachment: $\beta = 6.03$, $p_{MCMC} = 0.30$; verb-specific explanation bias $\times$ attachment: $\beta = 14.23$, $p_{MCMC} < 0.025$; second spillover region, explanation bias: $\beta = -1.13$, $p_{MCMC} = 0.81$; attachment: $\beta = -1.63$, $p_{MCMC} = 0.77$; verb-specific explanation bias $\times$ attachment: $\beta = 14.19$, $p_{MCMC} < 0.025$).

We investigated whether our gradient-bias measure gives us additional explanatory power above and beyond our categorical verbtype predictor—and vice-versa—by fitting a model with both predictors and using likelihood-ratio tests to compare it with models with only

the categorical verbtype predictor and only the gradient-bias predictor (in all cases, RC attachment and its appropriate interactions with the bias predictors were included). In neither case did the likelihood-ratio test indicate a significant improvement of the model with both predictor types over either model with only one predictor type (log-likelihood in the first spillover region: −7278.7 with both predictors, −7278.9 with only categorical verbtype; −7279.8 with only quantified bias; in the second spillover region, −7170.06 with both predictors, −7171.1 with only categorical verbtype, −7170.11 with only quantified bias). This result presumably reflects the fact that the two predictors are strongly correlated ($r = 0.773$, $t(1094) = 40.327$, $p < 0.001$). The fact that quantified bias toward upcoming explanation does not improve significantly on categorical verbtype as a predictor of reading times could easily be due to the measurement error inherent in estimating explanation bias from a continuation-study sample of limited size.

When using bias toward object-NP re-mention given an explanation, the results are nearly identical in the first spillover region, where we recover a significant interaction between quantified bias and RC attachment, but are less clear in the second spillover region, where the numerical direction of the interaction is correct, but fails to reach significance (first spillover region, next-mention bias: $\beta = -8.76$, $p_{MCMC} = 0.22$; attachment: $\beta = 4.93$, $p_{MCMC} = 0.47$; next-mention bias × attachment: $\beta = 17.81$, $p_{MCMC} < 0.05$; second spillover region, next-mention bias: $\beta = -8.11$, $p_{MCMC} = 0.18$; attachment: $\beta = -1.24$, $p_{MCMC} = 0.83$; next-mention bias × attachment: $\beta = 6.45$, $p_{MCMC} < 0.27$). Note that four non-IC verbs yielded no explanation continuations so the object-NP re-mention bias for explanations could not be calculated; data for those items were not included.

Likelihood-ratio tests indicate that in the first and second spillover regions, the combined model is statistically indistinguishable from either the quantified bias model or categorical verbtype model (log-likelihood in the first spillover region: −5811.7 with both predictors, −5812.9 with only categorical verbtype; −5811.9 with only quantified bias; in the second spillover region, −5703.7 with both predictors, −5704.3 with only categorical verbtype, −5704.3 with only quantified bias). As with explanation bias, re-mention bias is strongly correlated with verbtype ($r = 0.858$, $t(875) = 49.448$, $p < 0.001$); we attribute the poorer explanatory power of re-mention bias to the smaller sample size used to compute it (see Table 2), and the concomitantly larger measurement error.

4.4. Discussion

Experiment 2 was designed to test the hypothesis that expectations about discourse continuations have an impact on the immediate processing of RCs. This hypothesis was confirmed by the significant interaction between attachment level and verbtype on reading times at the first and second spillover regions immediately after the disambiguating finite verb in the relative clause. In fact, not only was the bias toward low-attaching RCs reduced in the IC condition as compared to the non-IC condition (as predicted), but analyses within the IC condition at the first spillover region and across the first two spillover regions showed a reversal of the default low-attachment bias, such that high-attaching RCs were actually read more quickly than low-attaching RCs.

Because the operative biases are tied only to comprehenders' *expectations* for an ensuing explanation rather than whether an explanation does in fact ensue—after all, at the spillover region the information needed to establish that an explanation relation indeed exists has yet to be encountered—these results stand in stark opposition to clausal integration accounts. Despite the fact that several different discourse-level sources of information contribute, and further that their integration requires a fairly complex chain of reasoning, the timecourse of the effect suggests that participants are invoking these biases mid-sentence and using them to generate expectations about syntactic attachment.

5. General discussion

Inference concerning the unspoken meaningful relationships between propositions—a process characterized here as the establishment of coherence relations—is a fundamental component of discourse interpretation. The studies reported in this paper establish that discourse coherence relations can have an impact on syntactic processing, specifically on the resolution of RC attachment ambiguity. Furthermore, these studies show that effects of discourse coherence relations are expectation-driven: Cues in a discourse influence comprehenders' expectations about upcoming coherence relations, and those expectations in turn influence comprehenders' syntactic processing. Our on-line experiment shows that these expectation-driven effects occur before comprehenders have been exposed to complete clauses, indicating that expectations about interclausal discourse coherence relations are updated incrementally, and can have moment-by-moment influence on syntactic disambiguation.[12] Specifically, the results indicate that comprehenders are aware that the IC verbs used in our experiments impute causality to their direct object, that they know that clauses with IC verbs are likely to be followed by an explanation of the eventuality the clause denotes, that they are aware that RCs can be used to implicate explanations, and, crucially, that they can bring all of these pieces of information together so as to influence an on-line syntactic attachment decision.

[12] "Incremental" has been defined in various ways to model word-by-word processing (Kamide, Altmann, & Haywood, 2003; Altmann & Mirković, 2009; Gennari & MacDonald, 2009). Our definition is closest to that of Kamide et al., who describe incremental word-by-word sentence processing as "requir[ing] the partial interpretation of what has been encountered thus far" (p. 152). In our case, the material that has been encountered prior to the point of disambiguation includes the coherence-biasing information provided by the matrix-clause verb and the structure-building information provided by the relative pronoun *who* which signals the beginning of an embedded clause. The partial interpretation includes the unresolved syntactic ambiguity of the RC attachment height, and so we take "incremental" to mean that discourse information can influence processing while syntactic decisions are still being resolved.

5.1. Implications for models of on-line syntactic comprehension

In keeping with the line of work started by Crain and Steedman (1985) and Altmann and Steedman (1988), and later pursued by Ni et al. (1996) and Sedivy (2002), our studies provide evidence that discourse-level interpretation processes can indeed impact on-line syntactic comprehension. That earlier work manipulated referential context in order to establish that a definite NP's requirement for referential uniqueness can influence attachment decisions. However, these earlier studies left open the question of whether the contextual effects were due specifically to a lexical requirement associated with definite determiners that enforces referential uniqueness, or whether the effects could be captured by a more general framework in which comprehenders' expectations about the pragmatic role of an upcoming clause can influence syntactic processing. Furthermore, that work demonstrated the influence of pragmatic expectations only in cases in which felicity or grammaticality was at stake. If we assume that comprehenders expect upcoming clauses not to appear arbitrarily, but rather to relate in meaningful ways to previous material, the effect observed in these earlier works (expectations for a clause that will restrict reference) represents a specific case of what we argue is part of comprehenders' more general cognitive reasoning concerning the way a discourse coheres. Our results thus reveal biases that are in effect whenever language processing requires comprehenders to infer pragmatic relationships between clauses, i.e., in most common discourses.

With respect to RC processing specifically, our experiments controlled for each of the factors that other models have proposed to account for variation in RC attachment ambiguity (Gilboy, Sopena, Clifton, & Frazier, 1995; Zagar et al., 1997; Desmet et al., 2002; Desmet & Gibson, 2003; Desmet, De Baecke, Drieghe, Brysbaert, & Vonk, 2006; Papadopoulou & Clahsen, 2006): The structure of the complex NP, the lexical properties of the individual nouns, and the referential context were all the same across conditions. What changed between conditions was the matrix-clause verb, which triggered expectations regarding the likelihood of an upcoming Explanation relation. The fact that comprehenders appear to be sensitive to coherence-level biases mid-sentence attests to the importance of constructing models of sentence processing that incorporate information about discourse coherence relations.

We believe that our results could be handled by a range of evidential models of on-line comprehension, so long as (a) they have a mechanism by which syntactic attachment preferences can be made incrementally, and (b) they would permit discourse-based biases to be taken into account and interact fully with any other biases that may be active. Such models include the competition-integration model (MacDonald, 1994; Spivey & Tanenhaus, 1998; McRae, Spivey-Knowlton, & Tanenhaus, 1998), probabilistic disambiguation/pruning and attention-shift models (Jurafsky, 1996; Narayanan & Jurafsky, 1998, 2002; Crocker & Brants, 2000), and surprisal (Hale, 2001; Levy, 2008). Although none of these models as presented to date have explicitly included discourse constraints, their probabilistic architectures allow for the incorporation of potentially arbitrary information sources, and thus there is no reason why discourse factors could not be smoothly incorporated into any of them. Note that in all of the models, so-called "default" attachment preferences are simply the consequence of the distribution of relevant information-source particulars. The results presented here add discourse coherence relations to the types of information sources that must be considered.

In light of the fact that the experimental effects show up in the spillover region, a reviewer for the paper suggests that our data could still be explained by a modular account, in which different sources of information are consulted in an ordered fashion (contra point (b) above), in particular with syntactic biases being primary and discourse biases contributing shortly thereafter but still before the end of the clause. We believe our results point away from such a possibility, suggesting instead that discourse information is available to influence processing while syntactic decisions are still being resolved. A modular account would predict the delay for high-attaching RCs in the non-IC sentences—where discourse information does not affect the default bias—to emerge earlier than the delay for low-attaching RCs in the IC sentences, where discourse information does affect the bias. This is not the case, as both effects show up in the spillover region. As we noted previously, spillover effects are common in stimuli with short critical regions such as those used here, to which we attribute the delay in both cases. We are therefore inclined to take our results as supporting a strong version of incrementality, in which both structural and non-structural information sources are utilized in concert on a moment-by-moment basis.

At the center of the modularity debate regarding the existence of non-structural effects during early syntactic processing are a set of studies that have investigated the effect of thematic fit on reduced-relative syntactic garden paths. In support of a modular account, Ferreira and Clifton (1986) reported that contexts that were hypothesized to reduce garden paths (inanimate nouns in contexts like *The evidence examined by…*) nonetheless yielded disruptions in eye movements during first-pass reading—disruptions that matched those observed in strong garden path contexts (animate nouns in contexts like *The defendant examined by…*). They reported that thematic fit only affected later measures of processing. Subsequent studies with improved materials (Trueswell et al., 1994) and high-span readers (Just & Carpenter, 1992) challenged those results, finding that manipulations of thematic fit could override the structural biases that lead to garden pathing. Clifton, Traxler, Mohamed, Williams, and Morris (2003) revisited these manipulations, and reported signs of disruption regardless of animacy condition in eye movements during and after first-pass reading of the disambiguating region. Whereas Clifton et al. admit that their "findings do not provide a basis for choosing between serial, depth-first parsing models and parallel, constraint satisfaction models" (p. 331), they nonetheless "suggest that

[their] findings are most straightforwardly understood in terms of serial, depth-first parsers" (*ibid*), and further suggest that new contradictory data may require new diagnostic experimental approaches or the identification of "manipulations where structural preferences apparently can be completely overcome" (p. 332). We submit that our results constitute such data, as we found a full reversal of the default low-attachment bias that has been the hallmark of modular "syntax-first" approaches.[13]

5.2. The immediate focusing vs. clausal integration debate

Our results also weigh in on the recent controversy concerning the time course during which IC information is used in sentence processing, a debate that has until now been centered on its use in pronoun interpretation. Proponents of the IMMEDIATE FOCUSING account (McKoon et al., 1993; McDonald & MacWhinney, 1995; Koornneef & Van Berkum, 2006, inter alia) argue that IC biases are utilized early enough so as to essentially constitute a focusing mechanism when interpreting pronominal expressions. Proponents of the CLAUSAL INTEGRATION account (Garnham et al., 1996; Stewart et al., 2000, inter alia), on the other hand, argue that IC information is used only as part of a sentence-final clause integration process. The clausal integration account predicts that IC effects will arise later during sentence interpretation than the immediate focusing account does, at least when a pronoun occurs early in the clause.

Our results strongly support the immediate focusing account. If IC information—not only IC biases toward a particular referent, but also the biases they contribute toward expecting an explanation to ensue—is not utilized until downstream linguistic material in the RC is processed, we are left with no explanation for why we find an effect in the spillover region immediately after the disambiguating auxiliary.

This view is supported by recent IC studies of pronoun interpretation. For instance, Koornneef and Van Berkum (2006) looked for mid-sentence reading delays caused by pronouns that are inconsistent with the bias of a preceding IC verb in two experiments with gender-unambiguous pronouns. In a word-by-word self-paced reading task, they found that readers slowed down at a bias-inconsistent pronoun, with a significant main effect emerging at the first two words thereafter. In an eye-tracking study that measured mean regression path durations, pronouns that were inconsistent with the IC bias reliably perturbed the reading process at or shortly after the pronoun. The results of both experiments therefore suggest that IC information becomes available rapidly enough to appear mid-sentence, even in passages in which the gender of the pronoun singles out a unique referent. Similarly, Pyykkönen and Järvikivi (2010) conducted an eye-tracking study in Finnish using a visual-world paradigm that asked whether IC effects would occur before the end of a clause containing an IC verb, that is, before either a connective or pronoun was encountered. They found a significant main effect of IC starting 900 ms after the verb onset, i.e., just after participants had encountered the verb/subject/object complex. These studies therefore support immediate focusing accounts. The current study does as well, and in fact extends the range of IC-sensitive phenomena to include relative-clause attachment in addition to pronoun interpretation.

We are not, however, suggesting that information occurring later in the RC will have no impact on syntactic attachment effects. In an account such as ours in which expectations are updated on an incremental, word-by-word basis, information encountered at any time can force a revision to the probabilities assigned to particular syntactic decisions. For instance, subsequent words in the RC might reduce the likelihood that the RC expresses an explanation, which would in turn reduce the likelihood of a high attachment. Alternatively, subsequent words might reinforce the expectation of an explanation, but one that mentions the low-position NP instead of the high one. In such situations, the model would predict processing difficulty at the time (or soon after) the bias-incongruent information is encountered. The crucial point is that comprehenders do not wait until downstream in the clause to start utilizing IC-driven probabilistic expectations; they instead use all relevant information (IC and otherwise) that is available at the time the RC is encountered in making syntactic attachment decisions.

5.3. Discourse continuations as a unit of prediction

Although our results can be incorporated into incremental models of probabilistic syntactic comprehension, they constrain these models in terms of the information sources that they must include. That is, models of sentence processing can no longer be built separately from models of discourse processing designed to capture the inferences comprehenders use in establishing discourse coherence. Whereas most researchers would not deny that complex inferencing affects language usage and comprehension, finding a quantifiable and ubiquitous unit over which to estimate predictions for processing effects has been hard to do. In this work, we have offered coherence relations as a concrete, quantifiable feature of all discourse contexts with which probabilistic expectations can be calculated. Note that coherence relations in such models must serve as both a unit of prediction—contextual cues influence the probability that a particular coherence relation is operative—and a feature implicated indirectly in a syntactic prediction—expectations about the operative coherence relation influence the probability of particular syntactic outcomes.

[13] It is worth noting that the more recent evolution of traditional modular garden-path theory into Construal Theory (Frazier & Clifton, 1996) treats relative-clause attachment as a "nonprimary relation" which is processed qualitatively differently from "primary relations" (i.e., complements), and under certain conditions can have its attachment decisions modulated by "non-structural as well as structural information" (Frazier and Clifton, Chapter 4; we thank Don Mitchell for this reference as well as the Clifton et al. reference). With this interpretation, Construal Theory could indeed accommodate our findings so long as expectations about upcoming discourse coherence relations and related next-mention preferences are part of the non-structural information that is taken into account.

6. Conclusions

The experiments presented here demonstrated that the resolution of local structural ambiguity is sensitive to comprehenders' expectations about upcoming discourse coherence relations, specifically explanation relations. To demonstrate this effect, we employed cases in which two clauses shared both a syntactic relationship and a discourse relationship, and hence in which syntactic and discourse processing might be expected to interact. An off-line sentence-completion study and an on-line self-paced reading study examined readers' expectations for high/low relative-clause attachments following implicit-causality and non-implicit causality verbs. In the off-line study, the widely reported low-attachment preference for English was observed in the non-implicit causality condition, but this preference gave way to more high attachments in the implicit-causality condition in cases in which (i) the verb's causally implicated referent occupies the high-attachment position and (ii) the relative clause provides an explanation for the event described by the matrix clause. In the on-line study, a similar preference for high attachment emerged in the implicit-causality context—crucially, before the occurrence of any linguistic evidence that the RC does in fact provide an explanation—whereas the low-attachment preference was consistent elsewhere. These findings constitute the first demonstration that expectations about ensuing discourse coherence relationships can elicit full reversals in syntactic attachment preferences, and that these discourse-level expectations can affect on-line disambiguation as rapidly as lexical and morphosyntactic cues.

By manipulating the IC status of the matrix-clause verb, we show that a concrete lexical factor can generate repercussions at the level of discourse coherence. As such, 'discourse-level factors' need not be relegated to the status of haphazard or fuzzy cues (see Kadmon, 2001 for a discussion of what constitutes a pragmatic explanation) nor do psycholinguists need to restrict their analyses to the constrained contexts in which referential effects emerge or to an approximation of a 'neutral' context in order to make claims about processing biases that are active *all else being equal*. In fact, all else is never equal, and our hope is that acknowledging this lack of neutrality in the discourse context will lead to more research quantifying the properties and structure of the surrounding discourse.

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Appendix A. Experimental materials

A.1. Story completion stimuli (Experiment 1)

The stimuli were all of the form *Name – IC/non-IC verb – complex NP - who*.

1. Carl admires/works with the agent of the rockstars who...
2. Greg adores/smiles at the secretaries of the lawyer who...
3. Jared blamed/noticed the friends of the athlete who...
4. Frank complimented/met the guests of the bride who...
5. Bill congratulated/visited the teacher of the second-graders who...
6. Candice criticized/talked to the leader of the activists who...
7. Beth despises/babysits the children of the jazz musician who...
8. Casey detests/looks like the father of the students who...
9. Melissa dislikes/watches the little girls of the neighbor who...
10. Sandra insulted/chatted with the gardeners of the millionaire who...
11. Ryan likes/resembles the captain of the old sailors who...
12. Joel pities/hires the bodyguards of the celebrity who...
13. Ken praised/videotaped the assistants of the CEO who...
14. Alan punished/saw the accountant of the businessmen who...
15. Tina resents/knows the doctors of the supermodel who...
16. Luis scolded/recognized the landlady of the actors who...
17. Craig rewarded/inspected the servants of the dictator who...
18. Scott ridiculed/counted the fans of the singer who...
19. George thanked/interviewed the representative of the employees who...
20. Alice values/lives next to the surgeon of the soldiers who...
21. Paul worships/listens to the coach of the cheerleaders who...

A.2. Sample story completions (taken from participants' completions from Experiment 1)

1. Beth babysits the children of the jazz musician who lives in La Jolla. [NON-IC, NON-EXP, LOW]
2. Frank met the guests of the bride who were her friends from high school. [NON-IC, NON-EXP, HIGH]
3. Melissa watches the little girls of the neighbor who works evening shifts. [NON-IC, EXP, LOW]

4. Craig inspected the servants of the dictator who were suspected of stealing. [NON-IC, EXP, HIGH]
5. Melissa dislikes the little girls of the neighbor who lives on her right. [IC, NON-EXP, LOW]
6. Frank complimented the guests of the bride who were sitting in the front row. [IC, NON-EXP, HIGH]
7. Bill congratulated the teacher of the second-graders who had all learned their times tables. [IC, EXP, LOW]
8. Alan punished the accountant of the businessmen who was notorious for IRS fraud. [IC, EXP, HIGH]

A.3. Verb biases observed in Experiment 1

Verbs differed in the proportion of explanation RCs produced.

Verb	Class	% Expl	Verb	Class	% Expl
chat-with	Non-IC	0	hire	Non-IC	34.8
count	Non-IC	0	adore	IC	36.0
interview	Non-IC	0	insult	IC	36.4
know	Non-IC	0	watch	Non-IC	46.2
live-next-to	Non-IC	0	compliment	IC	50.0
look-like	Non-IC	0	praise	IC	50.0
meet	Non-IC	0	admire	IC	52.6
recognize	Non-IC	0	reward	IC	54.5
resemble	Non-IC	0	scold	IC	60.0
see	Non-IC	0	videotape	Non-IC	61.1
talk-to	Non-IC	0	blame	IC	64.3
work-with	Non-IC	0	criticize	IC	66.7
visit	Non-IC	5.30	dislike	IC	76.2
babysit	Non-IC	8.00	worship	IC	80.0
smile-at	Non-IC	8.70	congratulate	IC	81.0
inspect	Non-IC	13.0	despise	IC	82.6
notice	Non-IC	14.3	pity	IC	82.6
listen-to	Non-IC	18.2	resent	IC	84.0
value	IC	22.7	punish	IC	85.7
like	IC	26.7	ridicule	IC	91.3
thank	IC	33.3	detest	IC	95.7

A.4. Reading time stimuli (Experiment 2)

The stimuli were all of the form *Name – IC/non-IC verb – complex NP – who – singular/plural RC verb - adverb - continuation*. The forward slash ('/') separates alternatives that differed between conditions (IC/non-IC; singular/plural). An underscore ('_') connects words that were revealed together in one region. Comprehension questions are listed in brackets.

1. Anna scolded/studied_with the_chef of the_aristocrats who was/were routinely letting food go to_waste. [Did food go to waste?]
2. John stared_at/lived_next_to the_teacher of the_second_graders who was/were definitely smartest in the school. [Was the teacher/were the second-graders smart?]
3. Jenny assisted/joked_with the_maid of the_executives who was/were regularly late to work. [Were the executives/was the maid late to work?]
4. Nick trusted/stood_near the_captain of the_sailors who has/have consistently weathered big storms. [Did the captain have Nick's confidence? Was Nick near the captain?]
5. Angela corrected/gossiped_with the_secretary of the_lawyers who has/have occasionally made small mistakes. [Have there been occasional errors?]
6. Bob comforted/greeted the_leader of the_activists who was/were deeply disappointed by the_court's decision. [Was Bob disappointed with the court's decision?]
7. Laura envies/knows the_manager of the_cashiers who has/have supposedly received a_huge raise. [Did the manager/cashiers get a huge raise?]
8. Zack valued/recognized the_daughter of the_shopkeepers who was/were usually willing to_spot him a_few_dollars. [Did Zack lend money to the daughter?]
9. Sarah fears/jogs_with the_uncle of the_toddlers who is/are often heard yelling and screaming. [Are toddlers known for being well behaved?]
10. Adam noticed/resembled the_representative of the_employees who was/were always wearing safety goggles. [Were the employees/Was the representative wearing safety goggles?]
11. Tina praised/met the_gardeners of the_millionaire who has/have recently installed a_solar powered sprinkler. [Has the millionaire/Have the gardeners put in a new sprinkler system?]
12. Justin hates/carpools_with the_cousins of the_accountant who is/are forever telling the_same tasteless jokes. [Is the accountant/Are the cousins likeable?]
13. Emily blamed/waited_with the_nieces of the_florist who has/have repeatedly ruined expensive orchids. [Did some flowers get damaged?]
14. Joe helped/ran_into the_brothers of the_athlete who is/are perpetually failing math class. [Are the brothers/Is the athlete failing math?]

15. Jessica reproached/worked_with the_doctors of the_supermodel who was/were adamantly in_favor of plastic surgery. [Did the supermodel/doctors advocate plastic surgery?]
16. Brian pacified/visited the_associates of the_businessman who was/were nearly bankrupted by the_new tax_policy. [Did the new tax policy benefit businesses?]
17. Melissa detests/babysits the_children of the_musician who is/are generally arrogant and rude. [Does Melissa get frustrated with the children?/Could Melissa be a teenager?]
18. Frank thanked/talked_to the_servants of the_dictator who has/have lately been helping the_poor. [Does Frank admire altruism?/Did Frank talk to the dictator's staff?]
19. Tracy congratulated/chatted_with the_bodyguards of the_celebrity who was/were constantly fighting off the_paparazzi. [Does the paparazzi ignore celebrities?]
20. Kevin mocked/counted the_fans of the_singer who was/were continually stagediving and getting hurt. [Were the fans diving off the stage? Is the singer someone who dives off the stage?] (See Section A.5.)

A.5. Item biases observed in norming study for Experiment 2 (by verb v)

Item	p(expl|v)	p(object|v, expl)	p(object|v, non-expl)
scold/chef/aristocrats	0.93	0.64	0.00
study-with/chef/aristocrats	0.50	0.22	0.11
stare/teacher/2nd-graders	0.70	0.21	0.33
live-next-door-to/teacher/2nd-graders	0.00	n.a.	0.14
assist/maid/executives	0.62	0.25	0.40
joke-with/maid/executives	0.14	0.00	0.50
trust/captain/sailors	0.68	0.85	0.17
stand-near/captain/sailors	0.27	0.25	0.00
correct/secretary/lawyers	0.53	0.63	0.43
gossip-with/secretary/lawyers	0.18	0.50	0.11
comfort/leader/activists	0.46	0.50	0.14
greet/leader/activists	0.20	0.00	0.08
envy/manager/cashiers	0.83	0.47	0.00
know/manager/cashiers	0.40	0.00	0.11
value/daughter/shopkeeper	0.25	1.00	0.07
recognize/daughter/shopkeeper	0.32	0.16	0.08
fear/uncle/toddlers	0.78	0.79	0.00
jog-with/uncle/toddlers	0.19	0.00	0.31
notice/representative/employees	0.44	1.00	0.40
resemble/representative/employees	0.00	n.a.	0.00
praise/gardeners/millionaire	0.75	0.56	0.33
meet/gardeners/millionaire	0.05	0.00	0.53
hate/cousins/accountant	0.70	1.00	0.00
carpool-with/cousins/accountant	0.40	0.25	0.33
blame/nieces/florist	0.79	0.91	0.00
wait-with/nieces/florist	0.33	0.00	0.38
help/brothers/athlete	0.50	0.75	0.50
run-into/brothers/athlete	0.00	n.a.	0.27
reproach/doctors/supermodel	0.83	0.60	0.50
work-with/doctors/supermodel	0.05	0.00	0.47
pacify/associates/businessman	0.42	0.50	0.27
visit/associates/businessman	0.54	0.00	0.33
detest/children/musician	0.89	0.88	0.50
babysit/children/musician	0.10	0.00	0.39

(*continued on next page*)

Item	p(expl|v)	p(object|v, expl)	p(object|v, non-expl)
thank/servants/ dictator	0.58	0.73	0.25
talk-to/servants/ dictator	0.37	0.00	0.17
congratulate/ bodyguards/ celebrity	0.82	1.00	0.00
chat-with/ bodyguards/ celebrity	0.56	0.00	0.50
mock/fans/singer	0.68	0.23	0.33
count/fans/singer	0.00	n.a.	0.46

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