

# The activation of inappropriate analyses in garden-path sentences: Evidence from structural priming <sup>☆</sup>

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## Abstract

In three structural priming experiments, we investigated temporarily ambiguous sentences such as *While the man was visiting the children who were surprisingly pleasant and funny played outside*. Participants produced more transitive sentences following such temporarily ambiguous sentences than following unambiguous sentences that were disambiguated by the use of a comma, indicating that the initial transitive analysis remained activated even though it was inconsistent with the disambiguation. We argue that this provides evidence against full deactivation of the inappropriate analysis. Our results support models that claim that the initial, inappropriate analysis remains activated, either because it leaves a memory trace [Kaschak, M. P., & Glenberg, A. M. (2004) This construction needs learned. *Journal of Experimental Psychology: General*, 133, 450–467] or because readers do not fully reanalyze the sentence when they encounter the disambiguation [Christianson, K., Hollingworth, A., Halliwell, J.F., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology*, 42, 368–407].

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## Introduction

An essential part of understanding a sentence is to construct and activate the appropriate syntactic structure. For most sentences, this is straightforward and does not result in noticeable processing difficulty. However, sentence processing research has shown that language comprehenders often face difficulty with sentences that contain a temporary syntactic ambiguity (e.g., Mitchell, 1994; Pickering & Van Gompel, in press; Tanenhaus & Trueswell, 1995).

Several studies have provided evidence that readers experience difficulty when they read so-called

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“garden-path” sentences such as (1) (e.g., Ferreira & Henderson, 1991; Frazier & Rayner, 1982; Pickering & Traxler, 1998; Pickering, Traxler, & Crocker, 2000).

1. While the man was visiting the children who were surprisingly pleasant and funny played outside.

This sentence is temporarily ambiguous: Before *played outside*, the verb *visiting* could be transitive, with the phrase *the children who were surprisingly pleasant and funny* as its direct object, or intransitive, with this phrase serving as the subject of the main clause. Experimental work suggests that readers initially adopt the transitive analysis and analyze *the children who were surprisingly pleasant and funny* as the direct object of *was visiting*. When they encounter *played outside*, the transitive analysis turns out to be ungrammatical, and this results in processing difficulty. Hence, (1) is harder to process than (2), where the transitive analysis is immediately ruled out by the comma following the subordinate verb (Clifton, 1993; Pickering & Traxler, 1998; Sturt, Pickering, & Crocker, 1999), and (3), where the transitive analysis is the correct interpretation (Ferreira & Henderson, 1991, 1993; Frazier & Rayner, 1982).

2. While the man was visiting, the children who were surprisingly pleasant and funny played outside.
3. While the man was visiting the neighbors the children who were surprisingly pleasant and funny played outside.

It is often assumed that upon encountering the disambiguation, readers activate the appropriate analysis while the initial, inappropriate analysis is deactivated. This assumption is implicit in many sentence processing models, but is perhaps best illustrated by constraint-based theories, because they make the clearest assumptions about the activation of syntactic analyses. They claim that readers activate the possible analyses of a syntactically ambiguous sentence in parallel and these analyses compete for activation (e.g., MacDonald, Pearlmutter, & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998; Spivey & Tanenhaus, 1998; Tabor, Juliano, & Tanenhaus, 1997; Tabor & Tanenhaus, 1999). Multiple linguistic and probabilistic sources of information determine the activation levels of the analyses. Analyses that are strongly supported become highly activated, whereas analyses that receive little support are deactivated. One possibility is that this deactivation is due to direct inhibitory connections between the alternative syntactic analyses (e.g., MacDonald et al., 1994). Alternatively, there may be no such direct connections, and deactivation may occur because the total amount of activation of the alternative syntactic analyses is constant, so if the activation of the appropriate analysis

increases by some amount, the activation of the alternative, inappropriate analysis must decrease by the same amount (e.g., McRae et al., 1998; Tabor & Tanenhaus, 1999). In the latter case, no direct inhibitory connections between the analyses are necessary for deactivation of the inappropriate analysis to occur.

The current paper addresses the issue of whether the inappropriate analysis is *fully deactivated*, that is, whether its activation following the disambiguation is the same as following a completely unambiguous sentence. Such a *full deactivation account* predicts that the activation of the transitive analysis following: (1) should be equal to that following (2). Note that this account does not make any assumptions about the activation of the intransitive analysis after processing (1) and (2) relative to resting activation of the intransitive analysis before processing these sentences. The inappropriate analysis may be deactivated relative to initial resting activation levels or return to resting activation.

Some theories assume that full deactivation does not occur. In particular, many constraint-based theories are consistent with the idea that the inappropriate analysis is partly deactivated following the disambiguation, but retains some residual activation (e.g., McRae et al., 1998; Spivey & Tanenhaus, 1998). However, the full deactivation account is compatible with some versions of constraint-based theories. For example, MacDonald et al. (1994) claimed that “disambiguation involves activating one alternative of a given type and inhibiting all others of this type” and they “see this as a winner-take-all process” (p. 686). They argue that “processing involves activation of different alternatives and settling into a stable pattern in which only one alternative is active at each level of representation” (p. 697), suggesting that following disambiguation, the inappropriate analysis receives no activation. These statements suggest that the activation of the intransitive analysis following the temporarily ambiguous sentence (1) should be the same as following the unambiguous sentence (2). Similarly, in Tabor and Tanenhaus’s (1999) attractor-based model, the processor cannot continue to the next word in the sentence until syntactic ambiguity is fully resolved (i.e., until it reaches an attractor), so at each word, the preferred analysis receives maximal activation, whereas inappropriate and non-preferred analyses lose all activation. Therefore, the activation of the inappropriate analysis should be the same following temporarily ambiguous and unambiguous sentences.

However, two recent studies suggest that the initial, inappropriate analysis is not fully deactivated after the disambiguation (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Kaschak & Glenberg, 2004). Kaschak and Glenberg had participants read sentences such as (4).

- 4a. The wood floor needs cleaned before our parents get here.  
 4b. The wood floor needs to be cleaned before our parents get here.

Sentence (4a) employs a construction that was novel for their participants. In four experiments, they showed that when participants repeatedly encountered this construction, it gradually became easier to process, while the facilitation was less pronounced in control sentences like (4b). Furthermore, explicit instruction also made the novel construction easier.

Apart from this novel construction, sentences like (4) have an analysis where *cleaned* serves as a modifier, as in *The wood floor needs cleaned corners*. In one experiment, one group of participants was exposed to a series of novel constructions like (4a) during an initial training phase, while another group was exposed to unambiguous control sentences like (4b). Both groups of participants then read sentences like (5), which contained a modifier (e.g., *cooked*).

5. The meal needs cooked vegetables so the guests will be happy.

Participants in the novel construction group read *vegetables* in (5) more quickly than participants from the control group, with no comparable difference occurring when the sentence did not involve this modifier construction. These results suggest that participants construct the (inappropriate) modifier analysis when reading sentences like (4a) during the training phrase, but not when reading sentences like (4b), and that this inappropriate analysis facilitates subsequent processing of modifier sentences. Most importantly, this indicates that the inappropriate analysis retains activation.

A further experiment showed comparable results. It compared one group of participants who received explicit instructions about the meaning of the novel construction with another group who did not. Both groups were exposed to sentences with the novel construction during the training phase. Not surprisingly, explicit instructions reduced difficulty with such sentences, specifically around *before* in (4), suggesting that participants were more likely to adopt the modifier analysis without explicit instruction. Next, they read modifier sentences such as (5). Participants who had not received instruction were faster reading *vegetables* than participants who had. This indicated that participants in the no-instruction group constructed the (inappropriate) modifier analysis for the novel construction during the training phase and therefore subsequently found this analysis easier to read than participants in the instruction group, who did not normally construct the modifier analysis. As in the previous experiment,

this suggested that the activation of the modifier analysis persisted even though it was incorrect. Together, the experiments therefore provide evidence that initial but inappropriate analyses retain activation, at least in cases where the appropriate analysis is a newly learned construction.

Kaschak and Glenberg (2004) argued that the construction of the inappropriate syntactic analysis in novel constructions facilitates the processes that are involved in constructing this analysis. These processes leave a memory trace, which facilitates subsequent processing of structures that are the same or similar to the inappropriate analysis. Their results support the view that the initial (but inappropriate) analysis is not fully deactivated. However, Kaschak and Glenberg did not investigate standard syntactic ambiguities. In their experiment, an ambiguity arose because participants had just learnt a new construction, so it is unclear whether similar effects would occur for garden-path sentences. As they note, it is possible that people use special strategies for dealing with new constructions.

However, Christianson et al. (2001) found evidence that is consistent with the view that even in standard syntactic ambiguities, inappropriate analyses remain activated. They presented participants with transitive/intransitive ambiguities such as (6), followed by questions such as (7).

6. While Bill hunted the deer that was brown and graceful ran into the woods.  
 7. Did Bill hunt the deer?

Participants often answered the question incorrectly, responding “yes.” They argued that participants adopted the transitive analysis in the temporarily ambiguous sentences, and then often did not abandon this analysis. This explanation is somewhat different from the account favored by Kaschak and Glenberg (2004): Christianson et al.’s explanation assumes that the remaining activation is due to a failure to reanalyze, whereas Kaschak and Glenberg’s account assumes that even when reanalysis is successful, the initial analysis remains activated. However, both accounts claim that inappropriate analyses remain activated, in contrast to the full deactivation account.

Christianson et al. (2001) also found that participants usually correctly answered “yes” to questions about the appropriate subject analysis (e.g., *Did the deer run into the woods?*), with the total percentage of “yes” responses to the two questions combined being well over 100%. This implies that participants failed to abandon the inappropriate transitive analysis even though they correctly adopted the subject analysis.

In a series of experiments, Christianson et al. (2001) attempted to rule out alternative explanations for their

data. An obvious possibility is that participants were drawing an inference based on the assumption that the man was likely to have been hunting the deer. In accord with this possibility, participants were more likely to respond “yes” after (6) than after a condition that ended *paced in the zoo* (in which case it is unlikely that Bill hunted the deer). But a number of other results from Christianson et al.’s experiments make this account unlikely to be the full explanation of their findings. First, participants were more likely to give the incorrect answer after (6) than when the clauses were reversed (e.g., *The deer that was brown and graceful ran into the woods while Bill hunted.*), even though both sentences allow the same inference to be drawn. Second, incorrect answers were more common with the difficult garden-path in (6) than the easier garden-path employing the semantically equivalent phrase *the brown and graceful deer* (cf. Ferreira & Henderson, 1991). Perhaps most importantly, Christianson et al. contrasted the conditions in (8).

- 8a. While Anna dressed the baby that was small and cute spit up on the bed.  
 8b. While Anna dressed, the baby that was small and cute spit up on the bed.  
 9. Did Anna dress the baby?

Here, the control sentence (8b) differs from (8a) only in the presence of the comma after *dressed*. Additionally, intransitive interpretations of *dressed* and other “reflexive absolute transitive” verbs are inconsistent with transitive interpretations: *Anna dressed* must mean that Anna dressed herself. Hence participants could not be adopting the intransitive analysis of (8a) and inferring that Anna must be dressing the baby. Still, participants answered “yes” to (9) more often after (8a) than (8b).

However, Christianson et al.’s (2001) study employed a measure of comprehension that is potentially subject to strategic effects or biases, because the questions encouraged participants to reevaluate the sentences. Perhaps the most obvious possibility is that participants retained a surface-level representation of the target sentence, and then checked this against the question. When participants encountered the question, they may have recalled the sentence from the beginning until they had found what they regarded as a reasonable answer to the question. For example, after reading *Did Anna dress the baby?* they could recall the first words of the target sentence *While Anna dressed the baby* in (8a), and answer “yes.” In (8b), they would not answer “yes” because the analysis would be ruled out by the comma. More generally, Christianson et al.’s account assumes that participants produced a “final” representation of the target sentence before they answered the question, but it may be that the question

affects the processing of the target sentence. It is therefore necessary to rule out such strategic explanations before it is possible to conclude that inappropriate analyses remain activated.

#### *Structural priming of inappropriate analyses*

One way of investigating language processing with a measure that does not require people to reevaluate the critical sentences is to use *structural priming*. Following observations of a tendency for people to produce syntactic structures across utterances (e.g., Weiner & Labov, 1983), Bock (1986) demonstrated that participants tend to describe pictures using the same syntactic form that they have just employed when repeating a sentence. Specifically, they tended to use passives after passives but actives after actives, and *prepositional object* forms (e.g., *The rock star sold some cocaine to an undercover agent*) after prepositional object forms but *double object* forms (e.g., *The rock star sold an undercover agent some cocaine*) after double object forms. Comparable priming effects occur in different languages (Hartsuiker & Westenberg, 2000; Scheepers, 2003), using a range of constructions (Cleland & Pickering, 2003; Ferreira, 2003; Griffin & Weinstein-Tull, 2003; Hartsuiker & Westenberg, 2000) and methods, including spoken sentence completion (Branigan, Pickering, Stewart, & McLean, 2000a, 2000b), written sentence completion (Pickering & Branigan, 1998), and sentence recall (Potter & Lombardi, 1998). The effect is not due to lexical repetition (Bock, 1989), though can be enhanced by such repetition (Pickering & Branigan, 1998). There is good evidence that some structural priming effects are specifically due to syntactic repetition (Bock & Loebell, 1990), though some structural priming effects have a non-syntactic origin (Bock, Loebell, & Morey, 1992). Most important for the purposes of our current experiments, participants do not tend to be aware of the manipulations and the effects appear to be largely implicit (e.g., Bock & Griffin, 2000).

Structural priming studies show priming from one act of production to another, and there is also evidence for priming from one act of comprehension to another (Arai, Van Gompel, & Scheepers, 2006; Branigan, Pickering, & McLean, 2005; Scheepers & Crocker, 2004; cf. Mehler & Carey, 1967). Most relevantly, studies have also shown that an act of comprehension can prime a subsequent act of production. Levelt and Kelter (1982) found that participants tended to repeat the syntactic form of the question in their answer, though their effects could have been lexical in origin. Potter and Lombardi (1998) found that the structure of sentences in recall was affected by priming from a sentence that was comprehended as well as by one that was produced. Branigan et al. (2000a, 2000b) had a participant and a confederate play a dialogue game in which they took

turns to describe pictures to each other, and found that the participant tended to mirror the syntactic form used by the confederate (see also Cleland & Pickering, 2003; Hartsuiker, Pickering, & Veltkamp, 2004; Haywood, Pickering, & Branigan, 2005).

Findings that structural priming occurs from comprehension to production are consistent with recent psycholinguistic theories that stress the commonalities between language production and comprehension. For example, Pickering and Garrod (2004) argued that during dialog, interlocutors achieve understanding by aligning their representations, and that this alignment is largely a result of priming from production to comprehension and vice versa at different levels of linguistic representation. They are also consistent with a recent computational model proposed by Chang, Dell, and Bock (2006), who claimed that structural priming is a form of implicit learning that has long-lasting effects, similar to language learning during acquisition. In their model, structural priming is always due to the comprehension of a prime sentence, rather than due to production. During comprehension, the processor predicts the next word in the sentence. Learning (and therefore priming) occurs when the prediction of the next word turns out to be incorrect and the model has to adjust the weights in its representations accordingly. Hence, the assumption that priming occurs from comprehension to production is fundamental to their model. Indeed, Bock, Dell, Chang, and Onishi (in press) found long-term priming from comprehension to production, just as Bock and Griffin (2000) found long-term priming from production to production.

Studies investigating priming between comprehension and production have usually focused on sentence production processes, but they also potentially provide a method for studying comprehension. Specifically, if an inappropriate analysis of a syntactically ambiguous sentence retains its activation, then that analysis may prime the production of a subsequent utterance. Thus structural priming might provide evidence about whether the processor initially considered an analysis, and whether that analysis remains activated. The structural priming method has the advantage that it does not involve a metalinguistic task that requires participants to reevaluate the syntactically ambiguous sentences or may highlight potential ambiguities. Of course, participants may become aware of the ambiguity when they discover that their initial analysis was incorrect. However, this would also occur during normal reading in the absence of a priming task; there is no reason to believe that the structural priming method makes people more aware of the ambiguity. By contrast, in the question-answering method employed by Christianson et al. (2001), participants may have adopted specific strategies when they had to answer the question about the sentence and may have reprocessed the sentence. Furthermore,

the question may have highlighted the potential ambiguity in the sentences, and this might have affected the responses to the questions as well. In the structural priming method that we used, participants read a prime sentence that was either temporarily ambiguous or unambiguous, and subsequently provided a spoken completion to a target fragment. The task did not involve explicit recall of the prime sentences, nor did it involve a secondary task that might encourage participants to reprocess the sentences.

#### Overview of the experiments

In three structural priming experiments, participants silently read prime sentences such as (1) and (2), repeated here as (10a) and (10b), and subsequently read target fragments such as (11) aloud and completed them.

- 10a. While the man was visiting the children who were surprisingly pleasant and funny played outside.
- 10b. While the man was visiting, the children who were surprisingly pleasant and funny played outside.
- 11. When the doctor was visiti. . .

As noted above, (10a) is temporarily ambiguous, whereas (10b) is disambiguated by the comma. Following prior research (e.g., Frazier & Rayner, 1982), we predict that participants will initially adopt the transitive analysis in (10a), treating *the children who were surprisingly pleasant and funny* as the direct object of *was visiting*, and then experience difficulty when the disambiguation (*played outside*) is inconsistent with this analysis. In contrast, the use of the comma in (10b) should prevent readers from adopting the transitive analysis, and hence this sentence should be easier to read than (10a).

But what is the ultimate fate of the inappropriate transitive analysis in (10a)? If it remains activated, it might affect completions of the target fragment (11). Such fragments can be completed using the subordinate verb (e.g., *visiting*) as a transitive verb, as in (12a), or as an intransitive verb, as in (12b).

- 12a. When the doctor was visiting the patient, he prescribed a medicine.
- 12b. When the doctor was visiting the patient had a heart attack.

If the initial analysis remains activated in (10a), then it may prime participants to complete (11) using a transitive continuation such as (12a) rather than an intransitive continuation such as (12b). Such a finding would provide evidence against full deactivation of the inappropriate analysis, in accord with both Kaschak and Glenberg (2004) and Christianson et al. (2001). It would therefore support accounts according to which the

initially adopted analysis remains activated. If we observe such a priming effect, this would also be the first evidence for transitivity priming. Transitive and intransitive primes have been compared in experiments investigating the production of target structures that could be either active or passive (Bock, 1986; Bock & Griffin, 2000), but to our knowledge, there has been no published research investigating the effect of transitive and intransitive primes on the production of targets that could be either transitive or intransitive.

One possibility is that any priming in (10–11) would be syntactic, because the transitive analysis has an additional syntactic role (the direct object) relative to the intransitive analysis. However, priming might also be non-syntactic in nature. First, the transitive and intransitive analysis differ in the number of thematic roles that are overtly expressed: The transitive analysis contains an overt theme (or patient) role, whereas the intransitive analysis does not, so the priming effect may be thematic in nature. Second, the priming effect might also have a prosodic component, because the prosody of the subordinate verb (e.g., *was visiting*) and the noun phrase following it is different when the verb is used as a transitive or intransitive. The current experiments did not investigate whether any priming effects were syntactic. Rather, the question they addressed was whether some aspect of the initial analysis remains activated, be it syntactic or non-syntactic.

We now report three priming experiments that investigated whether inappropriate analyses remain activated, using prime sentences like (10) and target fragments like (11). Experiment 1 additionally investigated whether the length of the temporarily ambiguous phrase affected the activation of the inappropriate analysis (cf. Ferreira & Henderson, 1991) and Experiment 2 investigated the effect of early semantic disambiguation (cf. Pickering & Traxler, 1998). In Experiments 1 and 2, we repeated the subordinate verb (e.g., *visiting*) in prime and target, because previous structural priming studies (Branigan et al., 2000b; Cleland & Pickering, 2006; Pickering & Branigan, 1998) suggest that verb repetition may enhance priming effects. This raises the possibility that any such priming effects would be lexical in origin. Hence, Experiment 3 compared conditions where the verb in prime and target was repeated with conditions where the verb was not repeated.

### Experiment 1

The aim of Experiment 1 was twofold. First and foremost, we attempted to distinguish between a full deactivation account and remaining activation accounts such as proposed by Kaschak and Glenberg (2004) and Christianson et al. (2001). According to remaining activation accounts, the production of the transitive structure

should be facilitated following temporarily ambiguous primes such as (13a) relative to unambiguous primes such as (13b).

- 13a. While the man was visiting the children who were surprisingly pleasant and funny played outside. (ambiguous, long noun phrase)
- 13b. While the man was visiting, the children who were surprisingly pleasant and funny played outside. (unambiguous, long noun phrase)
- 13c. While the man was visiting the children played outside. (ambiguous, short noun phrase)
- 13d. While the man was visiting, the children played outside. (unambiguous, short noun phrase)
- 14. When the doctor was visiti. . .

Hence, participants should produce more transitive completions to the target fragment (14) following (13a) than following (13b). In contrast, the full deactivation account predicts that the inappropriate analysis should not retain any activation. Only the appropriate analysis should remain activated, regardless of whether the prime sentence is temporarily ambiguous, so the number of transitive completions should be the same after (13a) and (13b). Note that we had the same verb in the prime and target in order to increase the chances of observing a priming effect (cf. Pickering & Branigan, 1998).

The second aim was to investigate whether possible priming effects are modulated by the length (or syntactic complexity) of the temporarily ambiguous phrase. Frazier and Rayner (1982) showed that difficulty with transitive/intransitive ambiguities was larger when the temporarily ambiguous phrase was long, as in (13a) than when it was short, as in (13c). Subsequent studies have confirmed this (e.g., Ferreira & Henderson, 1991; Warner & Glass, 1987). Furthermore, Christianson et al. (2001) showed that participants answered questions about the transitive analysis in long temporarily ambiguous phrases incorrectly more often than questions about short phrases, suggesting that they more often failed to abandon the transitive analysis when the phrase was long.

There is some debate about why the length effect occurs (see Ferreira & Henderson, 1991; Frazier & Rayner, 1982; Tabor & Hutchins, 2004; Warner & Glass, 1987). In the current study, we did not attempt to test these different explanations of the length effect, but investigated whether the length of the temporarily ambiguous phrase affects the activation of the inappropriate analysis. Christianson et al. (2001) argued that readers more often fail to abandon the transitive analysis when the phrase is long. Hence, the remaining activation should be higher after long than short temporarily ambiguous phrases, so we might expect that the difference in number of transitive completions to the target

in (14) should be larger for the long conditions (13a) and (13b) than for the short conditions (13c) and (13d).

Finally, although our main interest was in the fragment completions, we also measured reading times for the prime sentences. This enabled us to explore whether there was a relationship between prime reading times and target completions.

### Method

#### Participants

In the studies reported here, all participants were students from the University of Dundee who were paid for their participation. They were native speakers of British English and none of them was dyslexic. None of them took part in more than one experiment or pre-test. Experiment 1 employed 40 participants.

#### Items

We constructed 36 experimental items like (13–14); see Appendix A. Prime sentences consisted of a subordinate clause followed by a main clause. The subordinate clause consisted of a subordinate conjunction (*as*, *when*, or *while*), followed by a noun phrase that was the subject of the subordinate clause, and a verb. The main clause consisted of a noun phrase that was (on the correct interpretation) the subject of the main clause, and a verb phrase.

The experiment contained four prime conditions. In the unambiguous conditions, the subordinate verb (e.g., *was visiting*) was followed by a comma, so that the noun phrase following it (e.g., *the children who were surprisingly pleasant and funny*) could not be interpreted as its direct object. As a result, the verb should be treated as intransitive. In the temporarily ambiguous conditions, there was no comma, so the noun phrase following it was temporarily ambiguous: It could be interpreted as the subject of the following, main clause verb, in which case the subordinate verb should be treated as intransitive, or as a direct object of the subordinate verb, in which case this verb should be treated as transitive. The disambiguation occurred at the main clause verb. In the long noun phrase conditions, the noun phrase following the subordinate verb consisted of an article plus noun followed by a relative clause. The relative clause consisted of a copula verb and an adverbial phrase. In the short noun phrase conditions, the relative clause was omitted.

The target fragments, which had to be completed by the participants, were identical in all conditions. They consisted of a subordinate conjunction, a noun phrase, and a subordinate verb. The conjunction and noun phrase were different from those used in the prime, but the verb was the same in prime and target. The verb was chosen such that, according to our intuitions, there was no strong bias for using it as either a transitive or

intransitive in combination with the conjunction and noun phrase.

The final one or two characters of the target verbs were missing in order to avoid a possible confound due to the fact that the comma was present in the unambiguous primes but absent in the temporarily ambiguous primes. After seeing a comma in the unambiguous primes, participants might assume that a comma should normally be used whenever the verb is at the end of the clause and is therefore intransitive. Hence, if there is no comma following the target verb, participants might assume that this verb should be interpreted as transitive. In contrast, after seeing no comma in the temporarily ambiguous primes, participants may assume that no comma needs to be used when the verb is intransitive. If there is no comma following the verb in the target, this may suggest to participants that it should be interpreted as intransitive. The incomplete verbs avoided this confound, because they did not indicate whether they were followed by a comma or not.

We also constructed filler items, all of which consisted of a complete sentence followed by a fragment. Both the complete sentences and fragments had a variety of different structures. In order to encourage comprehension, some of the complete filler sentences were followed by a comprehension question. In addition, we constructed complete filler sentences that had a similar structure to the experimental primes, but were (in contrast to the experimental items) followed by a comprehension question.

#### Design

Both filler and experimental items consisted of a complete sentence followed by a sentence fragment. There were 36 experimental items, each having four conditions. We constructed four lists comprising nine items from each condition, with exactly one version of each item appearing in each list, together with 108 fillers. For 48 fillers, a comprehension question about the complete sentence intervened between the complete sentence and the fragment. For half, the correct response was “yes,” for the other half, it was “no.” Eight of these questions followed a filler with a structure that was very similar to the experimental items. The experimental items and fillers were placed in a single random order, with six fillers preceding the first experimental sentence and four fillers following a break half way through the experiment. Ten participants were randomly assigned to each list.

#### Procedure

The items were presented on a 17 in. monitor using the DMDX experiment software (Forster & Forster, 2003). A button box connected to a PC recorded participants' reading times for the prime sentences. A microphone connected to a minidisk recorder was

used to record participants' completions to the target fragments.

Each trial in the experiment consisted of a complete sentence followed by a sentence fragment. On some trials, a comprehension question about the complete sentence intervened between the complete sentence and the fragment. The complete sentences were presented in a black font, the questions in green, and the fragments in a red font. Participants read the complete sentences silently, and their reading times were recorded. They read the sentence fragments aloud and provided a spoken completion to them. After each complete sentence or fragment, they pressed a button to proceed. Comprehension questions were answered by either pressing a YES or NO button.

Participants were instructed to make sure they understood the complete sentences, but to read at their normal rate. They were also asked to complete the sentences in a grammatical and meaningful way and to do this as quickly as possible. Participants were tested individually and completed a practice session before the experiment.

#### Scoring and analyses

Target completions were transcribed before scoring. In this and the following experiments, we first excluded all continuations in which words in the fragment had been changed, the prime was read aloud, or the reading time for the prime sentences was longer than 15 s or shorter than 500 ms. We refer to these exclusions as *erroneous responses*.

We scored the remaining continuations as to whether they were transitive or intransitive continuations of the target verb. They were scored as transitive when the target verb was followed by a direct object and as intransitive when the verb had no direct object. All other non-erroneous responses were considered to be *other category responses* and were excluded from the main analyses. Other category responses included completions where the verb was immediately followed by a prepositional object. Although such completions are strictly speaking intransitive, they were sometimes very similar to transitive completions (e.g., *When the acrobat was juggling with some tennis balls ...* is very similar to *When the acrobat was juggling some tennis balls ...*), so it is possible that they are in fact primed by transitive uses of the verb. For similar reasons, completions where the subordinate verb was immediately followed by an adverbial phrase were treated as other category responses. Other category responses also included completions where the phrase following the verb was an indirect object, the head of an infinitival phrase (e.g., *While the man was helping the woman to clean the house ...*), a clausal object (e.g., *When the manager was dictating what he wanted ...*), or the object of a verb with a particle (e.g., *When the chef was chopping up the onions ...*), because the objects in these completions are very differ-

ent from the direct object in the transitive interpretation of the temporarily ambiguous primes. All incomplete continuations were also treated as other category responses. Finally, reading times for the prime sentences were excluded when they were longer than 15 s or shorter than 500 ms.

#### Results

In this and the following experiments, we present the analyses of the excluded responses followed by the analyses of the percentage of transitive target completions. We then present analyses of the prime reading times, of the prime reading times relative to the type of completion, and of the completions with reading times as a covariate. The means for the percentages of transitive completions are presented in Fig. 1, whereas the percentages of other category responses and the reading times are presented in Table 1. The results from all analyses are presented in Table 2.

#### Exclusions

We excluded 1.8% of completions because they were erroneous responses and .3% of reading times because they were shorter than the minimum cut-off or longer than the maximum cut-off. Other category responses, which were also excluded from the analyses of the percentage of transitive responses, constituted 3.9% of all non-erroneous responses. The other category responses were analyzed using one ANOVA with participants as the random variable ( $F1$ ) and one with items as the random variable ( $F2$ ), which provide an indication of whether effects generalize across participants and items, respectively. We also calculated the  $\text{min}F'$  statistic, which provides an indication of whether effects simultaneously generalize over both participants and items. This latter statistic is considered to be relatively conservative (e.g., Clark, 1973; Wike & Church, 1976). Ambiguity (temporarily ambiguous vs. unambiguous) and noun phrase length (long vs. short) were treated as within-participants and -items variables. We also included participant/item group (I–IV) as a between-participants and -items variable in order to eliminate the variance caused by random differences between groups (Pollatsek & Well, 1995), but did not analyze this variable. The ANOVAs showed no effect of ambiguity or length on the percentage of other category responses, nor an interaction between ambiguity and length, with a 95% confidence interval (CI) of 1.7% (calculated using the MSE for the interaction of ambiguity and length from the by-participants analysis, Masson & Loftus, 2003).

#### Completions

Fig. 1 presents the percentage of transitive completions out of the total number of transitive and intransitive completions. We conducted ANOVAs with the

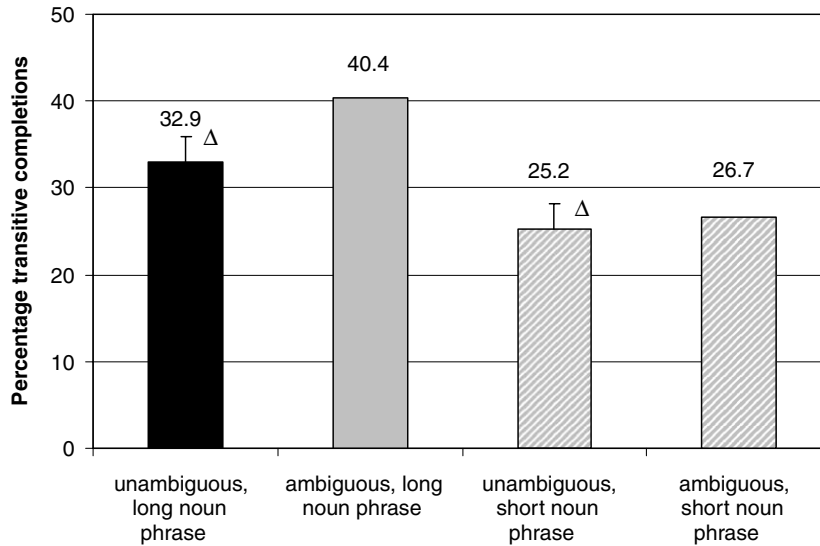


Fig. 1. Percentage transitive completions by condition for Experiment 1. The error bars represent the 95% CIs for the pairwise comparisons ( $\Delta$ ) based on the MSe of the interaction of ambiguity and length (3.0%).

Table 1

Experiment 1: Means for the percentages of other category responses and prime reading times

	Long noun phrase		Short noun phrase	
	Unambiguous	Ambiguous	Unambiguous	Ambiguous
Other category responses (as a percentage of all non-erroneous responses)	3.7	5.7	3.1	3.1
Reading times (in ms) preceding a transitive completion	4961	5634	3092	3440
Reading times (in ms) preceding an intransitive completion	4543	5134	3129	3056
Overall reading times (in ms)	4739	5339	3121	3148

Note: The number of transitive and intransitive completions was different within conditions, so the overall reading time means are different from the average of the transitive and intransitive means.

same variables as in the analyses of other category responses. The completions showed main effects of ambiguity and noun phrase length, with participants producing more transitive completions after temporarily ambiguous primes (33.6%) than after unambiguous primes (29.1%) and more transitive completions after primes with long noun phrases (36.7%) than after primes with short noun phrases (25.9%). The interaction between ambiguity and noun phrase length was only significant by participants. For sentences with long noun phrases, participants produced more transitives after temporarily ambiguous (40.4%) than after unambiguous primes (32.9%) as indicated by the 95% CI of 3.0% (again calculated using the MSe for the interaction from the by-participants analysis). For the sentences with short noun phrases, there was no such difference (26.7% after ambiguous primes vs. 25.2% after unambiguous primes, with the same 95% CI of 3.0%).

#### Reading times

We conducted ANOVAs on the overall reading times by condition using the same variables as before. The analyses showed main effects of ambiguity and noun phrase length. The ambiguity effect indicated a standard garden-path effect: Reading times were longer for temporarily ambiguous sentences (4244 ms) than for unambiguous sentences (3930 ms). The length effect indicated that sentences with long noun phrases (5039 ms) took longer to read than those with short noun phrases (3135 ms). However, the main effects were qualified by an interaction between the variables. For sentences with long noun phrases, the ambiguous condition (5339 ms) took longer to read than the unambiguous condition (4739 ms) as indicated by the 95% CI of 150 ms (calculated using the MSe for the by-participant interaction). In contrast, for sentences with short noun phrases there was no clear difference between the ambiguous and

Table 2  
Experiment 1: Results of the statistical analyses

	By participants			By items			min $F'$		
	<i>df</i>	<i>F</i> 1	<i>p</i>	<i>df</i>	<i>F</i> 2	<i>p</i>	<i>df</i>	min $F'$	<i>p</i>
<i>ANOVA results of the percentages of other category responses</i>									
Ambiguity	1, 36	1.09	.30	1, 32	1.28	.27	1, 68	<1	
Length	1, 36	1.95	.17	1, 32	2.44	.13	1, 68	1.08	.30
Ambiguity × length	1, 36	1.38	.25	1, 32	2.45	.13	1, 65	<1	
<i>ANOVA results of the percentages of transitive completions</i>									
Ambiguity	1, 36	5.42	.03*	1, 32	6.39	.02*	1, 68	2.93	.09
Length	1, 36	28.56	<.01*	1, 32	16.28	<.01*	1, 61	10.37	<.01*
Ambiguity × length	1, 36	5.05	.03*	1, 32	1.923	.18	1, 54	1.39	.24
<i>ANOVA results of the reading times</i>									
Ambiguity	1, 36	26.19	<.01*	1, 32	21.14	<.01*	1, 66	11.70	<.01*
Length	1, 36	215.74	<.01*	1, 32	300.64	<.01*	1, 67	125.60	<.01*
Ambiguity × length	1, 36	14.97	<.01*	1, 32	16.50	<.01*	1, 68	7.85	<.01*
<i>ANCOVA results of the completions with reading time as a covariate</i>									
Ambiguity	1, 51	4.47	.04*	1, 57	4.69	.04*	1, 108	2.29	.13
Length	1, 77	2.28	.14	1, 60	2.35	.13	1, 136	1.16	.28
Ambiguity × length	1, 38	3.10	.09	1, 34	1.70	.20	1, 64	1.10	.30
<i>Linear mixed effect results of the reading times by type of completion</i>									
	<i>df</i>	<i>F</i>	<i>p</i>						
Ambiguity	1, 1351	24.82	<.01*						
Length	1, 1351	760.94	<.01*						
Completion	1, 1351	5.64	.02*						
Ambiguity × length	1, 1351	19.24	<.01*						
Ambiguity × completion	1, 1351	<1							
Length × completion	1, 1351	2.53	.11						
Ambiguity × length × completion	1, 1351	<1							

\*  $p < .05$ .

unambiguous condition (3148 vs. 3121 ms, with the same 95% CI of 150 ms).

#### Reading times relative to type of completion

It is possible that reading times reflect how successfully participants managed to deactivate the inappropriate transitive analysis in the ambiguous sentences. For example, the inappropriate transitive analysis may be more likely to remain activated on those trials where reading times are long. Therefore, we conducted analyses on the reading times for the primes that included type of target completion (transitive or intransitive) as a variable. We excluded all erroneous and other category target completions, so in Table 1 the averages across the transitive and intransitive means by condition are slightly different from the overall reading times by condition (which included erroneous and other category responses). Because type of completion was not experimentally controlled, a large number of participants and items had one or more missing condition means. This essentially made traditional by-participant and -item analyses impossible. We therefore analyzed the data using a linear mixed effect model (Pinheiro & Bates, 2000) with the variables ambiguity, noun phrase length,

and type of completion as fixed variables and both participants and items as random variables in a single analysis. This analysis included all observations without averaging over either participants or items, which enabled us to generalize simultaneously over participants and items. The test statistics based on linear mixed effect models are generally less conservative than min  $F'$ , and Baayen, Tweedie, and Schreuder (2002) and Baayen (2004) have argued that they are more appropriate than traditional analyses based on participant and item means.

As in the earlier reading time analyses, there were effects of ambiguity, length, and an interaction between ambiguity and length. More interestingly, we also observed a main effect of completion, but no interaction between completion and ambiguity, nor between completion and length, nor among all three variables (95% CI = 587 ms, calculated using the standard error for the three-way interaction in the linear mixed effect model).

Reading times for the primes were longer when participants produced transitive target completions (4460 ms) than when they produced intransitive completions (3876 ms); note that these overall transitive and

intransitive means differ, respectively, from the mean of the four transitive means and the mean of the four intransitive means in Table 1, because the number of transitive and intransitive completions was different between conditions. The absence of an interaction between ambiguity and completion indicates that this pattern occurred regardless of whether the prime sentence was ambiguous. This suggests that reading times for the ambiguous conditions are not affected by how hard or easy participants find it to deactivate the inappropriate transitive analysis. Instead, the results indicate that transitive completions are generally preceded by longer reading times on the prime trials than intransitive completions, even when the prime is unambiguous.

#### *Completion analyses with reading times as a covariate*

The reading time by completion analyses suggest that on trials with longer reading times, participants tended to produce more transitive completions. Hence, in theory it is possible that the completion results shown in Fig. 1 are entirely caused by reading time differences between the conditions: The longer the reading times for a particular condition, the more transitive completions. In order to remove reading time as a predictor of type of completion, we conducted analyses of covariance with reading time as a covariate. Satterthwaite's (1946) method was used to compute the appropriate error terms.

The results of the analyses of covariance showed that the effect of ambiguity remained significant by participants and items. This suggests that the effect of ambiguity is not due to differences in reading times for the primes. By contrast, the effect of length disappeared, suggesting that the earlier observed effect of length on type of completion may have been due to reading time differences between the long and short conditions: Longer prime sentences may have resulted in more transitive completions because they took longer to read. The interaction between noun phrase length and ambiguity was also not significant (95% CI = 3.0%, based on the  $MSe_{\text{interaction}}$  by participants), which suggests that the earlier observed interaction in the analyses without reading times as a covariate may have been caused by reading time differences among the conditions.

#### *Discussion*

The results from the completions showed that participants produced more transitive completions following temporarily ambiguous sentences than following unambiguous sentences. This is inconsistent with full deactivation accounts, which claim that the inappropriate analysis should be entirely deactivated following the disambiguation. In contrast, the results support accounts such as proposed by Kaschak and Glenberg (2004) and Christianson et al. (2001), which claim that the

initial but inappropriate analysis remains activated. Importantly, the ambiguity effect on completions was not caused by reading time differences between the ambiguous and unambiguous conditions. Our analyses of the completions with reading times as a covariate showed that after removing reading time as a predictor, the effect of ambiguity on target completions remained.

We also observed a main effect of noun phrase length on the target completions: Participants produced more transitive completions following sentences with long noun phrases than short noun phrases. However, this effect disappeared when reading times were included as a covariate in the completion analyses. This suggests that it may have been due to differences in reading times: Sentences with longer reading times result in more transitive completions, and therefore, sentences with long noun phrases may have resulted in more transitive completions.

There was no clear evidence for an interaction between ambiguity and length in the completion analyses: The interaction reached significance by participants in the main analyses, but not by items, and completely disappeared when reading times were included as a covariate. Thus, there is no clear evidence that the inappropriate analysis remains more activated following long temporarily ambiguous noun phrases than following short ones. The analyses using reading time of the prime as a covariate suggest that the difference in transitive completions may have been slightly larger for the long noun phrase than for the short noun phrase conditions because the difference in reading times is also larger for the long noun phrase conditions. Thus, the weak interaction in the main analyses does not appear to be due to differences in activation of the inappropriate analysis. This contrasts with the findings from Christianson et al. (2001), who observed that participants were more likely to answer questions about the initial, inappropriate analysis incorrectly when the temporarily ambiguous phrase was long than when it was short. In our experiment, which did not involve explicit judgments about the sentences, there was no clear evidence that the length of the temporarily ambiguous phrase had an effect on the extent to which it remained activated.

Reading times were longer for temporarily ambiguous than for unambiguous sentences. However, the ambiguity effect was mainly carried by the sentences with long noun phrases. When the noun phrase was long, temporarily ambiguous sentences took longer to read than unambiguous sentences, indicating that readers initially adopted the transitive analysis in the temporarily ambiguous sentences, and experienced difficulty when the disambiguation was inconsistent with it. In contrast, when the noun phrase was short, there was no significant difference. This suggests that readers found it much harder to reanalyze the long temporarily

ambiguous sentences than the short ones. It confirms previous findings by Frazier and Rayner (1982), Ferreira and Henderson (1991), and Warner and Glass (1987). Not surprisingly, we also observed a main effect of length on reading times, indicating that long sentences took longer to read than short sentences.

Reading times were also longer preceding transitive than intransitive target completions. One possible explanation for this finding is that transitive sentences may be more complex to produce than intransitive sentences (they require an additional syntactic and thematic role), so harder-to-read prime sentences may have resulted in more complex, and therefore transitive, target completions. More interestingly, there was no interaction between ambiguity and type of completion on reading times. In both the temporarily ambiguous and unambiguous conditions, reading times for the primes were longer preceding transitive than intransitive target completions, which suggests that reading times were longer when the transitive analysis (rather than the intransitive analysis) was highly activated following the processing of the prime sentences. However, given that this effect occurred regardless of ambiguity, it was unrelated to the reading difficulty participants experienced when trying to deactivate the inappropriate analysis in the temporarily ambiguous prime sentences.

## Experiment 2

Experiment 1 provided no clear evidence that an early syntactic disambiguation due to the length of the temporarily ambiguous noun phrase resulted in a smaller activation of the inappropriate analysis. Experiment 2 investigated the effect of an early semantic disambiguation. In an eye-movement reading study, Pickering and Traxler (1998) investigated transitive/intransitive ambiguities and observed that reading times for the temporarily ambiguous noun phrase were longer when it was implausible as a direct object of the preceding subordinate verb than when it was plausible. However, at the point of syntactic disambiguation (the main clause verb), the pattern of results was reversed. These results indicate that readers rapidly take into account the plausibility of the initial transitive analysis, and experience difficulty at the temporarily ambiguous noun phrase when it is implausible as a direct object. Pickering and Traxler argued that the reversal of the effect following syntactic disambiguation can be explained in two ways. One possibility is that the implausibility of the transitive analysis triggers a reanalysis process. When readers subsequently reach syntactic disambiguation, they have already reanalyzed, so processing should be easy relative to sentences where the initial analysis was plausible. Alternatively, readers may experience difficulty when

they discover that the initial analysis is implausible, but this may not result in reanalysis. On this account, the reversal of the effect at syntactic disambiguation can be explained by assuming that readers commit less strongly to an implausible analysis than to a plausible analysis. Therefore, reanalysis at the syntactic disambiguation should be easier when the initial analysis is implausible than when it is plausible.

In Experiment 2, we investigated whether the plausibility of the transitive analysis affects the activation of this analysis following syntactic disambiguation. We employed prime sentences such as (15), followed by target fragments such as (16).

- 15a. While the businessman was interviewing the worker that was from the rival company had vanished. (ambiguous, plausible object)
- 15b. While the businessman was interviewing, the worker that was from the rival company had vanished. (unambiguous, plausible object)
- 15c. While the businessman was interviewing the letter that was from the rival company had vanished. (ambiguous, implausible object)
- 15d. While the businessman was interviewing, the letter that was from the rival company had vanished. (unambiguous, implausible object)
- 16. While the cop was interviewi...

In (15a) and (15b), the noun phrase following the subordinate verb (*the worker that was from the rival company*) is plausible as the direct object of the subordinate verb *interviewing*, but in (15c) and (15d) it is not. The two plausible object conditions are essentially the same as the long conditions in Experiment 1, so we expect more transitive completions following the temporarily ambiguous condition (15a) than the unambiguous condition (15b). This would provide further evidence against full deactivation accounts. However, in the temporarily ambiguous condition (15c), plausibility information provides early semantic disambiguation, and this may affect the activation of the inappropriate transitive analysis. Reanalysis may be easier when plausibility provides early disambiguation, so the initial transitive analysis may be easier to deactivate. Alternatively, semantic information may not affect whether the inappropriate analysis remains activated, because it may not be effective as a cue for deactivating this analysis.

We expect that reading times for the temporarily ambiguous sentences should be longer than for the unambiguous sentences. If semantic implausibility facilitates reanalysis, the difficulty in the ambiguous implausible object condition should be less than in the ambiguous implausible object condition. But if semantic plausibility does not affect reanalysis difficulty, the two temporarily ambiguous conditions should not differ.

Note that we measured reading times for the whole prime sentence, so our method does not inform us *where* in the sentence readers experienced processing difficulty, in contrast to Pickering and Traxler's (1998) eye-movement study. Finally, as in Experiment 1, we examined whether there is a relationship between the reading times for the primes and the target completions.

### Method

#### Participants

Forty further participants took part in the priming experiment.

#### Items

We constructed 50 prime sentences such as (15), from which we selected 36 sentences using the plausibility norms from the pretests (see below). Each was paired with a target sentence such as (16). See Appendix A for a list of all selected items. The items were very similar to those used in Experiment 1, except that the noun phrase following the subordinate verb was always long, and we manipulated the plausibility of this phrase as the direct object of the verb. In the plausible object conditions, the noun phrase following the subordinate verb was a plausible direct object of the subordinate verb. In the implausible object conditions, this noun phrase was an implausible direct object of the subordinate verb, so in essence, the disambiguation in the temporarily ambiguous condition occurred at this noun phrase. We also included 108 fillers in the experiment, which were the same as in Experiment 1.

#### Plausibility pretests

To check the plausibility of the prime sentences, we conducted two pretests on all 50 items. Pretest 1 examined whether the plausibility manipulation at the noun following the subordinate verb was working as expected. Twelve participants indicated whether the noun was a plausible direct object of the subordinate verb by rating the plausibility of sentences such as *The businessman was interviewing the worker* or *The businessman was interviewing the letter* on a 7-point scale, with 1 indicating very implausible and 7 indicating very plausible. Participants rated all 50 items in both the plausible and implausible object conditions. For the 36 items that we selected for the priming experiment, there was a clear plausibility difference between the plausible object condition (mean 6.75, SE .04) and the implausible object condition (mean 1.71, SE .06).

Pretest 2 tested whether the noun phrase following the subordinate verb was equally plausible as a subject of the following, main clause verb by rating sentences such as *The worker/letter that was from the rival company had vanished* on a 7-point scale. Twelve further participants rated all 50 items in both conditions. For the

selected items, there was no difference in plausibility between the plausible and implausible object conditions (both conditions: mean 5.35, SE .09), indicating that both noun phrases were equally plausible subjects.

#### Design, apparatus, procedure, and scoring

They were the same as in Experiment 1.

### Results

As in Experiment 1, we present analyses of the excluded responses, the percentage of transitive target completions, the prime reading times, the prime reading times relative to the type of completion, and the completions with reading times as a covariate. The means for the percentages of transitive completions are presented in Fig. 2, whereas the percentages of other category responses and the reading times are presented in Table 3. The results of all analyses are presented in Table 4.

#### Exclusions

We excluded 4.3% of completions because they were erroneous responses and 1.4% of reading times because they were shorter than 500 ms or longer than 15 s. Other category responses (2.7% of non-erroneous responses) were also excluded from the target completions. We analyzed the other category responses using ANOVAs with ambiguity (temporarily ambiguous vs. unambiguous) and object plausibility (object plausible vs. implausible) as within-participants and -items variables and participant/item group (I–IV) as a between-participants and -items variable. These analyses showed no effects of ambiguity, plausibility, or interaction between ambiguity and plausibility (CI = 1.6%, calculated using the MSe for the interaction ambiguity × plausibility from the by-participants analysis).

#### Completions

Fig. 2 presents the percentages of transitive completions to the target fragments (as a percentage of the total number of transitive and intransitive completions). We conducted ANOVAs with the same variables as in the analyses of the other category responses. The completion data showed an effect of ambiguity, with more transitive completions after temporarily ambiguous (34.8%) than after unambiguous prime sentences (29.0%). There was no effect of object plausibility: The percentage of transitive completions was similar following primes with a plausible (33.1%) and an implausible object (30.7%). Finally, there was no interaction between ambiguity and object plausibility (95% CI = 4.4%).

#### Reading times

We conducted ANOVAs on the prime reading times using the same variables as in the analyses of the other category responses. We observed a main effect of

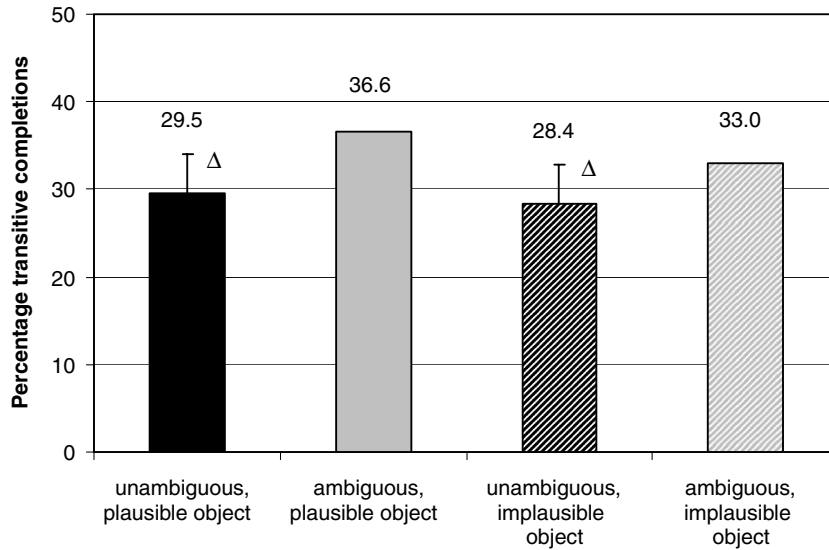


Fig. 2. Percentage transitive completions by condition for Experiment 2. The error bars represent the 95% CIs for the pairwise comparisons ( $\Delta$ ) based on the MSe of the interaction of ambiguity and plausibility (4.4%).

Table 3

Experiment 2: Means for the percentages of other category responses and prime reading times

	Plausible direct object		Implausible direct object	
	Unambiguous	Ambiguous	Unambiguous	Ambiguous
Other category responses (as a percentage of all non-erroneous responses)	2.3	2.4	3.4	2.6
Reading times (in ms) preceding a transitive completion	5136	5791	5060	5927
Reading times (in ms) preceding an intransitive completion	5034	5562	5114	5627
Overall reading times (in ms)	5048	5710	5146	5727

Note: The number of transitive and intransitive completions was different within conditions, so the overall reading time means are different from the average of the transitive and intransitive means.

ambiguity: Reading times were longer for temporarily ambiguous (5719 ms) than for unambiguous sentences (5097 ms). However, there was no effect of object plausibility or interaction between ambiguity and object plausibility (95% CI = 174 ms).

#### Reading times relative to type of completion

In order to examine whether reading times for the temporarily ambiguous primes were longer or shorter on trials where the inappropriate transitive analysis was activated than on trials where it was not, we included type of target completion in the reading time analyses. As in Experiment 1, we excluded all erroneous and other category completions. We analyzed the data using a linear mixed effect model with the variables ambiguity, plausibility, and type of completion as fixed variables and both participants and items as random variables. As in the earlier reading time analyses, we observed an effect of ambiguity, but no effect of plausibility or inter-

action between ambiguity and plausibility. More relevant, although prime reading times were somewhat longer when the target completion was transitive (5507 ms) than when it was intransitive (5320 ms), the effect of completion was not significant (95% CI = 727 ms, calculated using the standard error for the three-way interaction in the model). Furthermore, there was no interaction between completion and ambiguity or three-way interaction. However, there was a marginal interaction between type of completion and plausibility. The means suggested that type of completion had a slightly larger effect in the plausible conditions (transitive 5492 ms vs. intransitive 5279 ms) than in the implausible conditions (transitive 5523 ms vs. intransitive 5360 ms). (The number of transitive and intransitive observations was unequal, so these means are different from those that can be calculated from Table 3). However, it should be noted that this marginally significant difference of 50 ms was small compared

Table 4  
Experiment 2: Results of the statistical analyses

	By participants			By items			min $F'$		
	<i>df</i>	<i>F</i> 1	<i>p</i>	<i>df</i>	<i>F</i> 2	<i>p</i>	<i>df</i>	min $F'$	<i>p</i>
<i>ANOVA results of the percentages of other category responses</i>									
Ambiguity	1, 36	<1		1, 32	<1		1, 56	<1	
Plausibility	1, 36	<1		1, 32	<1		1, 66	<1	
Ambiguity × plausibility	1, 36	<1		1, 32	<1		1, 68	<1	
<i>ANOVA results of the percentages of transitive completions</i>									
Ambiguity	1, 36	6.77	.01*	1, 32	11.64	<.01*	1, 65	4.24	.04*
Plausibility	1, 36	1.31	.26	1, 32	2.43	.13	1, 64	<1	
Ambiguity × plausibility	1, 36	<1		1, 32	<1		1, 52	<1	
<i>ANOVA results of the reading times</i>									
Ambiguity	1, 36	33.77	<.01*	1, 32	27.98	<.01*	1, 66	15.30	<.01*
Plausibility	1, 36	<1		1, 32	<1		1, 65	<1	
Ambiguity × plausibility	1, 36	<1		1, 32	<1		1, 68	<1	
<i>ANCOVA results of the completions with reading time as a covariate</i>									
Ambiguity	1, 73	5.24	.03*	1, 46	3.53	.07	1, 100	2.11	.15
Plausibility	1, 38	<1		1, 34	2.71	.11	1, 52	<1	
Ambiguity × plausibility	1, 38	<1		1, 34	<1		1, 63	<1	
<i>Linear mixed effect results of the reading times by type of completion</i>									
	<i>df</i>	<i>F</i>	<i>p</i>						
Ambiguity	1, 1351	58.44	<.01*						
Plausibility	1, 1351	<1							
Completion	1, 1351	2.12	.15						
Ambiguity × plausibility	1, 1351	<1							
Ambiguity × completion	1, 1351	1.09	.30						
Plausibility × completion	1, 1351	3.07	.08						
Ambiguity × plausibility × completion	1, 1351	<1							

\*  $p < .05$ .

to the non-significant 187 ms main effect of type of completion.

#### Completion analyses with reading times as a covariate

As in Experiment 1, in order to remove reading time as a predictor of completion type, we conducted analyses of covariance on the completions with reading times as a covariate. The effect of ambiguity remained significant by participants and was marginal by items, suggesting that the effect of ambiguity on the completions was probably not due to differences in reading times between the conditions. There was no effect of plausibility nor interaction between ambiguity and plausibility (95% CI = 6.0%, based on the MSe for the by-participant interaction ambiguity × plausibility).

#### Discussion

As in Experiment 1, participants produced more transitive completions after temporarily ambiguous sentences than after unambiguous sentences. This provides further evidence against accounts which claim that the inappropriate analysis is completely deactivated following disambiguation. In contrast, the results support

accounts which claim that the initial, inappropriate analysis remains activated. The completions showed no interaction between ambiguity and plausibility. Hence, there was no evidence that an early semantic disambiguation influenced the activation of the inappropriate analysis in the temporarily ambiguous sentences. Including reading time as a covariate in the target completion analyses showed the same pattern as the main completion analyses, indicating that the pattern of results was not due to differences in reading times between conditions.

Reading times were longer for temporarily ambiguous than for unambiguous sentences, indicating that readers initially adopted the transitive analysis in the temporarily ambiguous sentences, and experienced difficulty when the disambiguation was inconsistent with it. There was no interaction between ambiguity and plausibility, suggesting that readers initially adopted the inappropriate analysis in both temporarily ambiguous conditions and that overall, processing was about equally difficult in both conditions. Our self-paced reading method does not enable us to pinpoint where readers experienced processing difficulty. However, given Pickering and Traxler's (1998; Pickering et al. 2000)

eye-movement results, it seems likely that difficulty occurred at or shortly following the noun phrase in the implausible conditions, whereas it occurred at the syntactic disambiguation in the plausible conditions.

In contrast to Experiment 1, there was no clear evidence that reading times for the prime sentences were longer preceding transitive than intransitive completions, though the means were in the same direction. Furthermore, the reading time analyses that included type of target completion as a variable showed no interaction between ambiguity and type of completion, confirming the pattern observed in Experiment 1. Hence, the activation of the inappropriate analysis is unaffected by the degree of difficulty in the temporarily ambiguous sentences.

### Experiment 3

In Experiments 1 and 2, we used the same subordinate verb in the prime and the target in order to maximize our chances of observing a priming effect. Pickering and Branigan (1998; Branigan et al. 2000b; Cleland and Pickering 2006) showed that for unambiguous sentences, structural priming was larger when the verb in the prime and target was repeated than when they were different. Therefore, the use of repeated verbs in our experiments raises the possibility that the observed effects are purely lexical in origin. In Kaschak and Glenberg's (2004) account, one possibility is that the memory trace of the inappropriate transitive analysis may only occur for the particular verb that was used in the temporarily ambiguous sentence. Procedures associated with the transitive use of this particular verb may be facilitated, but there may not be a more general, lexically independent facilitation of the transitive structure. Similarly, in Christianson et al.'s (2001) account, it is possible that the failure to abandon the transitive analysis for a particular verb may result in remaining activation of the transitive analysis for that verb only. Hence, facilitation of the transitive analysis would not occur for verbs other than the particular verb in the prime. This *lexically specific priming account* predicts that participants should produce more transitive completions in the ambiguous condition (17a) than in the unambiguous condition (17b), because the verb is the same in prime and target. But there should be no difference between (17c) and (17d), because the verbs are different.

- 17a. When the teenager was eating the pizza that had been ordered well over an hour ago arrived.  
While the grandmother was eati. . .
- 17b. When the teenager was eating, the pizza that had been ordered well over an hour ago arrived.  
While the grandmother was eati. . .

- 17c. When the teenager was cooking the pizza that had been ordered well over an hour ago arrived.  
While the grandmother was eati. . .
- 17d. When the teenager was cooking, the pizza that had been ordered well over an hour ago arrived.  
While the grandmother was eati. . .

Alternatively, the remaining activation of the inappropriate analysis may be lexically independent. In Kaschak and Glenberg's (2004) account, the memory trace may occur for the transitive structure in general, independent of particular words such as verbs. Similarly, in Christianson et al.'s (2001) account, the failure to abandon the transitive analysis may result in a general facilitation of the transitive structure. This *lexically independent priming account* predicts that the remaining activation of the transitive analysis should be the same, regardless of the particular verb that is used in the temporarily ambiguous sentence. Hence, participants should produce more transitive completions in (17a) than in (17b), where the verb is repeated, and this difference should be the same in (17c) and (17d), where the verb is different.

Of course, the remaining activation of the inappropriate analysis may be partly lexically specific and partly lexically independent. This account predicts more transitive completions in the ambiguous than in the unambiguous conditions, but the priming effect should be larger when the verb is repeated than when it is not. Such a finding would be similar to that found in priming studies investigating unambiguous structures (Branigan et al., 2000b; Cleland & Pickering, 2003, 2006; Pickering & Branigan, 1998). For example, Pickering and Branigan (1998) investigated ditransitive sentences that could have either a prepositional object or double object structure. They found that priming occurred both when the verb was repeated and when it was different, but the effect was larger when the verb was repeated. However, these results may not generalize to priming of inappropriate analyses and they may not generalize to transitive/intransitive priming investigated in the current experiments.

The results from this experiment may also shed light on a different issue. A number of constraint-based theories (e.g., McRae et al., 1998; Spivey & Tanenhaus, 1998; Tabor & Tanenhaus, 1999) claim that the total amount of activation of all possible structures in an ambiguity is constant. Hence, if the activation of the transitive analysis increases by a particular amount for the sentences in our experiments, the activation of the alternative, subject analysis (according to which the noun phrase following the verb is the subject of the main clause) must decrease by exactly the same amount: The activations of the two analyses are completely dependent. From this, it follows that if the activation of the transitive analysis is affected by ambiguity, the activation of the

subject analysis should also be activated by ambiguity. According to this type of account, it is not possible that the activation of one of the analyses is affected by ambiguity, whereas the other is not, because this would imply that the activations of the two analyses are independent.

For the ambiguities in our experiments, these accounts claim that the activation of the transitive analysis and the subject analysis are dependent. Let us consider one pattern of results that would be inconsistent with this claim. If we observe that participants produce more intransitives following repeated verbs than following different verbs, this would indicate that the activation of the subject analysis is larger following repeated than different verbs. If this verb repetition effect is equally large for ambiguous and unambiguous primes, this would further indicate that the subject analysis is equally activated following ambiguous and unambiguous primes. However, if at the same time we observe that participants produce more transitives following ambiguous than unambiguous primes, this would indicate that the transitive analysis is more activated following ambiguous primes than unambiguous primes. In other words, the activation of the subject analysis would not be affected by ambiguity, whereas the activation of the transitive analysis would. The activation of the analyses would therefore be independent.

### Method

#### Participants

Forty further participants took part in the experiment.

#### Items

An example of the items is shown in (17). See [Appendix A](#) for all items. The prime sentences were the same as in Experiment 1, except that in all conditions the noun phrase following the subordinate verb was long. The structure of the target sentence fragments was also the same. In the repeated verb conditions, the verb in the prime and target was the same (as in Experiments 1 and 2) but in the different verb conditions, the verb in prime and target was different. Because the items had to be similar in plausibility for the two verbs, the verbs were somewhat related in meaning for some items. We counterbalanced the verb in the target, so that in four of the conditions (exemplified in [17]) one particular verb (e.g., *was eating*) appeared in the target, whereas in the other four conditions, the alternative verb (e.g., *was cooking*) occurred in the target.

#### Design, apparatus, procedure, and scoring

They were the same as in Experiments 1 and 2, except for the following. We used 40 experimental items, each having eight conditions (including the verb counterbalancing conditions). We constructed eight lists compris-

ing five items from each condition, with exactly one version of each material appearing in each list, together with 114 fillers. Five participants were randomly assigned to each of the lists.

### Results

As in the previous Experiments, we analyzed the excluded responses, the percentages of transitive completions, the reading times, the reading times relative to the type of completion, and the completions with reading times as a covariate. The means for the percentages of transitive completions out of all transitive and intransitive responses are shown in [Fig. 3](#). We also analyzed the percentages of transitive completions out of all non-erroneous responses, which are shown in [Table 5](#) together with the percentages of other category responses and the reading times. The results of all analyses are presented in [Table 6](#).

#### Exclusions

We excluded 4.4% of completions because they were erroneous responses and .9% of reading times because they were shorter than 500 ms or longer than 1500 ms. Of the remaining completions, we excluded 8.4% because they were other category responses. We conducted ANOVAs on the other category responses with ambiguity (temporarily ambiguous vs. unambiguous) verb repetition (repeated vs. different verb), and verb counterbalancing condition as within-participants and -items variables, and participant/item group (I–VIII) as a between-participants and -items variable. We do not report any analyses of the verb counterbalancing variable because they are not of theoretical interest.

There was a main effect of verb repetition on the percentage of other category responses, indicating that participants produced more other category responses when the verb was different (10.2%) than when it was repeated (6.6%). We observed no effect of ambiguity, but there was an interaction between ambiguity and verb repetition. For unambiguous primes, participants produced significantly more other category responses when the verb was different (11.7%) than when it was repeated (5.0%), as indicated by the 95% CI of 4.0% (calculated using the MSe for the interaction between ambiguity and verb repetition by participants). This suggests that participants were less likely to produce a transitive or intransitive completion when the verb was different than when it was repeated. In contrast, there was no verb repetition effect for ambiguous primes (8.2% when the verb was repeated, 8.6% when it was different, with the same 95% CI of 4.0%). Note that the effects in the other category responses do not affect the conclusions we draw from the main completion analyses: As shown below in the completion analyses, the effects were the same, regardless of whether transitive completions were ana-

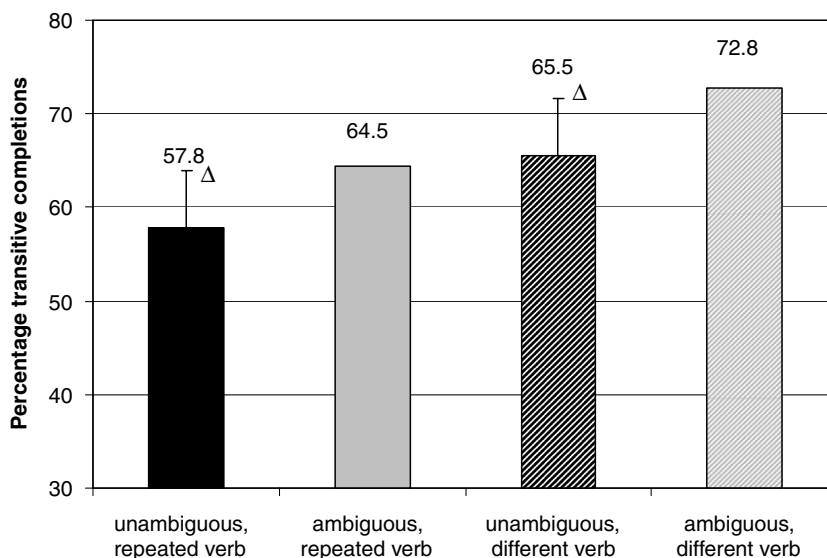


Fig. 3. Percentage transitive completions by condition for Experiment 3. The error bars represent the 95% CIs for the pairwise comparisons ( $\Delta$ ) based on the MSE of the interaction of ambiguity and verb repetition (6.1%).

Table 5

Experiment 3: Means for the percentages of other category responses, transitive completions (as a percentage of all non-erroneous responses), and prime reading times

	Repeated verb		Different verb	
	Unambiguous	Ambiguous	Unambiguous	Ambiguous
Other category responses (as a percentage of all non-erroneous responses)	5.0	8.2	11.7	8.6
Transitive completions (as a percentage of all non-erroneous responses)	54.9	59.2	57.8	66.6
Reading times (in ms) preceding a transitive completion	4963	5529	5296	5614
Reading times (in ms) preceding an intransitive completion	4870	5572	4830	5314
Overall reading times (in ms)	5000	5592	5182	5522

Note: The number of transitive and intransitive completions was different within conditions, so the overall reading time means are different from the average of the transitive and intransitive means.

lyzed as a percentage of all transitives plus intransitives or as a percentage of all non-erroneous responses.

### Completions

Fig. 3 shows the percentage of transitive completions as a percentage of all transitive and intransitive completions. ANOVAs on the completions were conducted using the same variables as in the analyses of other category responses. They revealed main effects of ambiguity and verb repetition. Participants produced more transitive completions after temporarily ambiguous primes (68.6%) than after unambiguous primes (61.6%), and they produced fewer transitives when the prime verb was repeated in the target (61.1%) than when it was different (69.1%). However, there was no interaction between the two variables (95% CI = 6.1%). Because

the percentage of other category completions differed between conditions, we also conducted analyses on the transitive completions as a percentage of the total number of non-erroneous completions (rather than as a percentage of the total number of transitive and intransitive completions, as in the main analyses). The means are presented in Table 5 and the analyses in Table 6. The effects were similar to those in the main analyses: There were effects of ambiguity and verb repetition, but no interaction (95% CI = 6.0%).

### Reading times

We conducted ANOVAs on the reading times using the same variables as before. There was a significant effect of ambiguity on reading times, with temporarily ambiguous sentences (5557 ms) taking longer to read

Table 6  
Experiment 3: Results of the statistical analyses

	By participants			By items			min $F'$		
	<i>df</i>	<i>F</i> 1	<i>p</i>	<i>df</i>	<i>F</i> 2	<i>p</i>	<i>df</i>	min $F'$	<i>p</i>
<i>ANOVA results of the percentages of other category responses:</i>									
Ambiguity	1, 32	<1		1, 32	<1		1, 58	<1	
Repetition	1, 32	18.37	<.01*	1, 32	6.71	.01*	1, 53	4.91	.03*
Ambiguity × repetition	1, 32	4.94	.03*	1, 32	7.17	.01*	1, 62	2.92	.09
<i>ANOVA results of the percentages of transitive completions (out of all transitive and intransitive responses):</i>									
Ambiguity	1, 32	6.03	.02*	1, 32	12.44	<.01*	1, 57	4.06	.05*
Repetition	1, 32	10.07	<.01*	1, 32	19.32	<.01*	1, 58	6.62	.01*
Ambiguity × repetition	1, 32	<1		1, 32	<1		1, 46	<1	
<i>ANOVA results of the percentages of transitive completions (out of all non-erroneous responses):</i>									
Ambiguity	1, 32	5.75	.02*	1, 32	10.39	<.01*	1, 59	3.70	.06
Repetition	1, 32	5.08	.03*	1, 32	8.64	<.01*	1, 60	3.20	.08
Ambiguity × repetition	1, 32	2.13	.15	1, 32	<1		1, 53	<1	
<i>ANOVA results of the reading times:</i>									
Ambiguity	1, 32	24.73	<.01*	1, 32	25.77	<.01*	1, 64	12.62	<.01*
Repetition	1, 32	1.14	.29	1, 32	<1		1, 56	<1	
Ambiguity × repetition	1, 32	2.79	.10	1, 32	2.40	.13	1, 64	1.29	.26
<i>ANCOVA results of the completions with reading time as a covariate:</i>									
Ambiguity	1, 67	<1		1, 57	6.11	.02*	1, 87	<1	
Repetition	1, 40	6.98	.01*	1, 40	14.36	<.01*	1, 71	4.69	.03*
Ambiguity × repetition	1, 38	<1		1, 38	<1		1, 48	<1	
<i>Linear mixed effect results of the reading times by type of completion:</i>									
	<i>df</i>	<i>F</i>	<i>p</i>						
Ambiguity	1, 1393	37.71	<.01*						
Repetition	1, 1393	1.46	.23						
Completion	1, 1393	1.54	.21						
Ambiguity × repetition	1, 1393	1.78	.18						
Ambiguity × completion	1, 1393	<1							
Repetition × completion	1, 1393	<1							
Ambiguity × repetition × completion	1, 1393	<1							

\* $p < .05$ .

than unambiguous sentences (5091 ms). The sentences in the repeated and different verb conditions were identical (as we counterbalanced for the use of the two different verbs), so unsurprisingly, there was no effect of repetition or interaction between ambiguity and repetition (95% CI = 208 ms).

#### Reading times relative to type of completion

In order to determine whether reading times of the prime sentences were different on trials where the target was completed as a transitive from trials where it was completed as an intransitive, we included type of completion as a variable in the reading time analyses. As in Experiments 1 and 2, all erroneous and other category responses were excluded. We used a linear mixed effect model with ambiguity, repetition, and completion as fixed variables, and both participants and items as random variables. As the earlier analyses, this analysis showed an effect of ambiguity and no effect of repetition or interaction between these two variables. More interestingly, although reading

times for the primes were slightly longer when the target completion was transitive (5367 ms) than when it was intransitive (5126 ms), the effect of type of completion was not significant and there were no interactions with completion (95% CI = 707 ms, calculated using the standard error for the three-way interaction in the model).

#### Completion analyses with reading times as a covariate

In order to remove reading time as a predictor of target completion, we conducted an analysis of covariance with reading time as a covariate. We observed an effect of ambiguity in the by-items analysis. There was an effect of verb repetition, but no interaction between ambiguity and verb repetition (95% CI = 5.1%, based on the  $MSE_{\text{interaction}}$  by participants).

#### Discussion

Consistent with Experiments 1 and 2, participants produced more transitive completions following

temporarily ambiguous than following unambiguous primes. This provides further evidence against full deactivation accounts and supports accounts that claim that the initial, inappropriate analysis retains activation. The ambiguity effect in the completions did not interact with verb repetition: The difference between the ambiguous and unambiguous condition was the same when the verb was repeated as when it was different. This provides evidence for the lexically independent account, which claims that the facilitation caused by the remaining activation of the inappropriate transitive analysis occurs for the transitive structure in general, and is not confined to the particular verb that is used in the prime sentence. It is inconsistent with the lexically specific account, because it predicts that facilitation of the remaining activation should be specific to the particular verb used in the prime. As in Experiments 1 and 2, the analyses including reading times as a covariate showed similar results to the main analyses, suggesting that the results from the completions were not caused by reading time differences between conditions.

One possible concern is that the semantic similarity of verbs in the different verb conditions was sufficiently high that it prevented a verb repetition effect. Semantic similarity can affect priming: Cleland and Pickering (2003) found stronger priming between noun phrases when the head nouns were semantically related (e.g., *the goat that's red* – *the sheep that's red*) than when they were semantically unrelated (*the knife that's red* – *the sheep that's red*). However, Cleland and Pickering also found that lexical repetition (*the sheep that's red* – *the sheep that's red*) enhanced priming more than semantic similarity (*the goat that's red* – *the sheep that's red*). Likewise, Schoonbaert, Hartsuiker, and Pickering (2006) found more within-language priming when the verbs were repeated than cross-language priming when the verbs were translation-equivalents, even though they found similar within- and between-language priming when the verbs had different meanings. Hence the effects of lexical repetition appear to be due to word repetition rather than semantic similarity or equivalence. Additionally, all studies that have shown verb-repetition effects have used dative verbs (*give*, *hand*, *send*, etc.) which tend to have quite similar meanings, relating to acts of transfer (e.g., Branigan et al., 2000b; Pickering & Branigan, 1998). Moreover, our experiment demonstrates that a verb repetition effect can be obtained with the verbs that we used. Participants produced fewer transitive completions following repeated verbs than different verbs. To see what this means, it is easier to consider the percentage of *intransitive* completions. The percentages of transitive and intransitive completions were completely dependent (the percentage of other completions was very low and they were excluded from the analyses), so this result indicates

that participants produced *more* intransitive completions in the repeated verb conditions than in the different verb conditions. In other words, priming from the subject analysis was lexically dependent.

Another interesting aspect of the completion data is that they suggest that the activations of the transitive and intransitive analysis are not fully dependent. That is, the total activation of the two analyses is not constant. As we have just explained, participants produced more intransitive completions in the repeated verb conditions than in the different verb conditions. Hence, the activation of the appropriate subject analysis, according to which the temporarily ambiguous phrase was the subject of the main clause, was larger when the verb was repeated than when it was not. Interestingly, the subject-priming effect was not affected by the ambiguity of the prime sentences: There was no interaction between verb repetition and ambiguity, indicating that priming from the appropriate subject analysis was equally strong in the temporarily ambiguous conditions as in the unambiguous conditions. This is an important finding, because it suggests that participants adopted the subject analysis roughly equally often in the ambiguous and unambiguous conditions and that the activation of the subject analysis was the same following ambiguous and unambiguous primes. This contrasts with the activation of the transitive analysis, which was larger following ambiguous than following unambiguous primes. Thus, the activations of the two analyses were independent and their total activation was not constant. This is difficult to reconcile with a number of constraint-based theories (e.g., McRae et al., 1998; Tabor & Tanenhaus, 1999) that claim that the total activation of the analyses should remain constant.

Our results suggest that participants correctly adopted the appropriate subject analysis in the temporarily ambiguous sentences even though the transitive analysis also remained activated. This is consistent with Christianson et al.'s (2001) Experiment 2. In this experiment, the percentage of incorrect (“no”) answers to questions about the subject analysis was only marginally higher in the temporarily ambiguous than in an unambiguous condition where the order of the clauses was reversed, whereas there was a much more pronounced difference in the questions about the transitive analysis. In the temporarily ambiguous sentences, the total percentage of correct (“yes”) responses to the subject analysis plus that of incorrect responses to the transitive analysis was well over 100%, so Christianson et al. argued that readers often adopted the subject analysis without abandoning the inappropriate transitive analysis. Thus, participants essentially activated two inconsistent analyses in parallel. However, in Christianson et al.'s experiment, participants may have had a general tendency to respond “yes” to the questions. This may have caused the total per-

centage of “yes”-responses to be over 100%. The results from our priming experiment rule out this explanation and show similar findings with a task that does not encourage participants to reevaluate the sentences.

Finally, reading times for the primes were longer for the temporarily ambiguous than for the unambiguous sentences, again suggesting that readers initially adopted the transitive analysis in the temporarily ambiguous sentences, and then had to reanalyze. As in Experiment 2 (but unlike Experiment 1), reading times preceding transitive completions were not significantly different from reading times preceding intransitive completions. Furthermore, there was no interaction between ambiguity and target completion for the prime reading times, again suggesting that the activation of the inappropriate analysis in the ambiguous conditions is unrelated to reading difficulty in the prime sentences.

### General discussion

In three structural priming experiments, participants produced more transitive sentences following temporarily ambiguous prime sentences where the initial transitive analysis later turned out to be incorrect than following unambiguous prime sentences. This provides evidence that the initial but inappropriate analysis retains activation even after the sentence has been disambiguated towards the alternative analysis. Experiment 1 provided no clear evidence that the activation of the inappropriate analysis is affected by the length of the temporarily ambiguous phrase, because the length effect in the target completions appeared to be mainly caused by the differences in reading times of the prime sentences. Similarly, Experiment 2 suggested that its activation is unaffected by early semantic disambiguation. Experiment 3 showed that priming from the inappropriate analysis was equally large, regardless of whether the verb in the prime and target were the same or different. This suggests that priming from the inappropriate analysis in our experiments was lexically independent. In contrast, priming from the appropriate subject analysis was lexically specific, because it was larger when the verb was repeated than when it was different. Furthermore, this verb repetition effect was equally large in the temporarily ambiguous as in the unambiguous conditions, suggesting that participants in our experiments activated the appropriate subject analysis in the ambiguous sentences even though the inappropriate transitive analysis also remained activated. Finally, none of the experiments provided any evidence that the activation of the inappropriate, transitive analysis is related to the reading difficulty that participants experience when they try to deactivate the inappropriate transitive analysis. This suggests that

reading times do not reflect whether people were successful in deactivating the inappropriate analysis.

Our results are largely consistent with Christianson et al. (2001), who showed that participants more often answered questions about the inappropriate analysis incorrectly when the sentence was temporarily ambiguous than when it was unambiguous. However, participants in their experiments may have engaged in task-specific strategies when they answered the question and this may have caused them to activate the inappropriate analysis. Our experiments show evidence for activation of the initial, inappropriate analysis using a method that does not involve a metalinguistic task that requires explicit evaluation of the critical sentences. Kaschak and Glenberg (2004) used a reading method, which provides an implicit measure of sentence comprehension, and showed that the inappropriate analysis of temporarily ambiguous sentences facilitated subsequent processing of similar structures. However, in their experiments, the appropriate analysis was a newly learned structure. As they noted, people may use special strategies when they process novel structures. Our experiments show that very similar effects occur for temporarily ambiguous sentences that do not involve a new construction. Furthermore, the results show that structural priming, which has usually been employed to investigate sentence production processes, is also a very fruitful and useful method for investigating language comprehension.

There are two possible reasons why the initial, inappropriate analysis remains activated. First, Christianson et al. (2001; Ferreira, Christianson, & Hollingworth, 2001) argued that readers often do not reanalyze fully and fail to abandon the initially adopted analysis. Across all trials, this would result in a higher activation of the inappropriate analysis after temporarily ambiguous than after unambiguous sentences. This would explain the findings of our experiments. Christianson et al. also claimed that even though the initial analysis is not abandoned, the alternative analysis (the subject analysis in their and our experiments) is usually adopted. Thus, readers perform a partial reanalysis of the sentence. They argued that there are two plausible ways of explaining this. One possibility is that the temporarily ambiguous phrase is simultaneously attached as a direct object to the preceding verb phrase and as a subject to the following verb phrase. Such “double attachment” would result in a syntactic structure that violates standard assumptions in most linguistic theories, so it is unclear whether such an aberrant structure would prime transitive structures. However, it would explain why both the transitive and the subject analysis are activated, as suggested by our Experiment 3. Alternatively, Christianson et al. proposed that upon encountering the disambiguation in transitive/intransitive ambiguities, the processor may “steal” the temporarily ambiguous noun

phrase from the subordinate verb and attach it as the subject of the main clause (cf. Fodor & Inoue, 1998). However, the processor fails to delete the thematic role assigned by the subordinate verb, so in temporarily ambiguous sentences, the subordinate verb ends up with an empty argument node. Assuming that a transitive prime can have an empty object argument node and that this node primes transitives, this would explain our results.

A different reason for why the initial, inappropriate analysis remains activated is suggested by Kaschak and Glenberg (2004). They proposed that when readers construct and adopt a structure, the processes that are involved in constructing and adopting that analysis are facilitated, leaving a memory trace. Thus, one might argue that certain procedures are activated, rather than the structure itself. The main difference between Kaschak and Glenberg's account and that of Christianson et al. (2001) is that the former account assumes that the initial analysis remains activated even if reanalysis is completely successful. This explains in a straightforward way why the initial analysis is facilitated even if later disambiguation is inconsistent with it. It also explains why both the transitive and subject analysis are facilitated, as observed in Experiment 3. Readers construct both the transitive and the subject analysis (even though the transitive analysis may later be abandoned), so both analyses should be facilitated following the temporarily ambiguous sentences in our experiments. In Kaschak and Glenberg's account, the activations of the alternative analyses are independent, and there is no deactivation of the inappropriate analysis (apart from gradual decay), so both analyses can be highly activated. Furthermore, there is no need to assume that the processor constructs a different syntactic structure for temporarily ambiguous than for unambiguous sentences.

It is worth mentioning that Kaschak and Glenberg (2004) argued for a specific type of memory trace. They claimed that the memory trace is episodic, so the memory trace should be different depending on the particular task participants were engaged in when they processed the stimulus (e.g., Kolers, 1973, 1979; Morris, Bransford, & Franks, 1977; Whittlesea & Wright, 1997). It therefore seems plausible to assume that the memory trace should be different for comprehension and production tasks. However, our results showed that comprehension of a prime sentence resulted in priming in a subsequent production task. This suggests that the memory trace is not episodic, but is at least partially independent of task and modality (just as it appears to be independent of written vs. spoken modality; see Cleland & Pickering, 2006).

At present, the evidence is consistent with both a (non-episodic) memory trace account and Christianson et al.'s (2001) account. The learning paradigm employed by Kaschak and Glenberg (2004) does not

indicate whether the facilitation due to the remaining activation of an initial analysis is caused by a memory trace, as they suggested, or by to a failure to reanalyze fully. Given that the intended analysis in their experiments was a novel construction that participants did not normally consider grammatical, it is possible that participants failed to abandon the initial analysis on a considerable proportion of trials. In our experiments, the intended analysis was always grammatical, so it is likely that participants were more successful in abandoning their initial analysis. Still, the results are consistent with the idea that participants failed to do this on some trials, and that these trials caused the observed effects. Similarly, they are consistent with accounts that assume that reanalysis is successful, but the initial analysis leaves an episodic trace. Although Christianson et al.'s (2001) results may seem to provide evidence that the remaining activation is at least partly due to a failure to reanalyze fully, this finding may be due to the method, as mentioned in the Introduction. Future research should provide further tests of the two accounts. For example, if for a particular set of items, participants correctly answer questions about the initial, inappropriate analysis, this would indicate that they have reanalyzed. If the inappropriate analysis still primes for such items, this finding would indicate that the initial analysis remains activated even if reanalysis is successful.

Current evidence also does not indicate whether the remaining activation is truly syntactic. In Kaschak and Glenberg's (2004) study, the appropriate interpretation of *The wood floor needs cleaned* requires *cleaned* to be a verb, but under the initial, inappropriate analysis it is an adjective (as in *cleaned corners*). Verbs and adjectives differ both syntactically and semantically, so this study is consistent with remaining syntactic or semantic activation of the initial analysis. In Christianson et al.'s (2001) experiments, the inappropriate transitive analysis in *While Bill hunted the deer that was brown and graceful ran into the woods* also differs both syntactically and thematically from the appropriate transitive analysis.

Similarly, in our experiments, the inappropriate, transitive analysis contained an overtly specified theme (or patient) role, whereas the intransitive analysis did not. Thus, the temporarily ambiguous sentences may have primed an overt theme. Note, however, that the appropriate, intransitive analysis in virtually all our items contained an implied theme. For example, in the appropriate analysis of *While the man was visiting the children who were surprisingly pleasant and funny played outside*, the man was visiting one or more persons who remain unspecified in the sentence. Hence, in most items, the number of event roles was the same in the transitive and intransitive analysis, so it is unlikely that the priming effects were due to the number of event roles that the verbs took. If the priming effects were thematic, they are

related to whether the theme role was overtly specified or not.

Experiment 3 provides evidence that the remaining activation is not principally lexical-semantic. The priming of the transitive analysis occurred even when no content words were repeated in the prime and target, and the effect was the same regardless of whether the verb was repeated. Thus, from the perspective of a memory trace account (Kaschak & Glenberg, 2004), the trace is not specific to particular words in the sentence or their meaning. From the perspective of an account which claims that readers fail to abandon the initial analysis (Christianson et al., 2001), the activation of this analysis is independent of the meaning of the particular words in the sentence.

Finally, the remaining activation may have been prosodic. The prosody of the subordinate verb and the noun phrase following it are different in the transitive and intransitive analysis, so it is possible that the prosody assigned during the (silent) reading of the primes resulted in target completions with a similar prosody. Future experiments will have to pin down to what extent the remaining activation is syntactic. The important finding of the current experiments is that at least some aspects of the initial but inappropriate analysis of garden-path sentences remain activated.

Our findings also have important implications for constraint-based theories of sentence processing. In most current constraint-based theories (e.g., MacDonald et al., 1994; McRae et al., 1998; Spivey & Tanenhaus, 1998; Tabor & Tanenhaus, 1999), reanalysis involves deactivating an initially adopted analysis and simultaneously boosting the activation of an alternative analysis. The current results show that following a syntactic disambiguation, the initial analysis is not fully deactivated. This is inconsistent with some constraint-based theories (e.g., MacDonald et al., 1994; Tabor & Tanenhaus, 1999), which suggest that the inappropriate analysis should not retain any activation. However, other constraint-based theories (e.g., McRae et al., 1998; Spivey & Tanenhaus, 1998) claim that the initial analysis retains some activation following syntactic disambiguation.

Constraint-based models have more difficulty accounting for the results from Experiment 3 and Christianson et al. (2001), which suggest that readers correctly activate the temporarily ambiguous phrase as the subject of the main clause, while at the same time, they fail to deactivate the inappropriate transitive analysis. Most constraint-based theories claim that the sum of the activation of all analyses remains constant (e.g., McRae et al., 1998; Tabor & Tanenhaus, 1999) and are therefore completely dependent. Hence, the higher the activation of the subject analysis, the lower the activation of the transitive analysis should be. For constraint-based models it is difficult to

explain how both analyses can be retained and have a high activation. Future implementations of constraint-based models may have to be refined in order to account for our results.

Recently, it has been suggested that structural priming is a form of implicit learning. Support for this comes from a study by Bock and Griffin (2000), who showed that structural priming effects can last over at least ten intervening trials, suggesting that the effects are due to long term learning mechanisms. Furthermore, Chang et al. (2006) have demonstrated that the same computational learning mechanisms can be used to model many findings from both the language acquisition literature and from structural priming. Our results therefore have important implications for exposure-based sentence processing theories (e.g., Mitchell, Cuetos, Corley, & Brysbaert, 1995; Trueswell, Tanenhaus, & Kello, 1993). These theories assume that processing difficulty during syntactic ambiguity resolution is affected by the frequency with which people have encountered the alternative syntactic analyses: The more often a particular structure has been encountered, the easier it should be to process. Our results suggest that it may not be quite so simple. If a sentence is temporarily ambiguous, then the initial analysis also retains some activation even though it is not the ultimately correct analysis. Hence, for future exposure-based theories, it will be important to take into account whether people were exposed to temporarily ambiguous structures or to unambiguous structures. Exposure to unambiguous structures results in subsequent facilitation of the correct analysis only, but exposure to temporarily ambiguous structures results in facilitation of the initially adopted but incorrect analysis as well.

In conclusion, our experiments showed that the initial, inappropriate analysis of garden-path sentences remains activated, using a method that does not require metalinguistic judgments about the sentences. Our findings have important implications for theories of syntactic ambiguity resolution, because they indicate that the initial, inappropriate analysis is not completely deactivated. They support proposals put forward by Kaschak and Glenberg (2004) and Christianson et al. (2001), who argued that initial but inappropriate syntactic analyses retain activation.

## Appendix A

### *Items for Experiment 1*

As the child was painting, a lorry (that was unusually large and heavy) passed.

When the art teacher was painti...

As the man was cleaning, the bucket (that was old and almost completely broken) tipped over.

When my mother was cleani...

While the chairman dictated, the report (that was extremely worrying and distressing) arrived.  
 When the manager dictat. . .  
 As the man was filming, the children (who were noticeably happy and excited) smiled.  
 When the cameraman was filmi. . .  
 As the woman ordered, the fish (which was delicious and unusually tender) was prepared.  
 When the customer was orderi. . .  
 As the student was typing, the essay (which was awfully difficult and tedious) got creased.  
 When the secretary was typi. . .  
 While the old man smoked, the cigars (that were quite strong and smelly) were thrown away.  
 When the teenage girl smok. . .  
 As the mare was feeding, the colt (that was black and very graceful) jumped.  
 When the young mother was feedi. . .  
 While the man was visiting, the children (who were surprisingly pleasant and funny) played outside.  
 When the doctor was visiti. . .  
 While the researcher was reading, the paper (which was long and terribly dull) was blown away.  
 When the schoolboy was readi. . .  
 While the young girl was sketching, the flowers (which were bright red and yellow) were arranged.  
 When the art student was sketchi. . .  
 While the landlord was decorating, the bedroom (which was dirty and badly maintained) was done up.  
 When the handyman was decorati. . .  
 While the actors were performing, the scene (which was extremely hard and demanding) was interrupted.  
 When the singer was performi. . .  
 While the child was watching, the clown (who was very funny and rather clumsy) tripped.  
 When the guard was watchi. . .  
 While the driver was parking, a van (which was extremely old and rather rusty) started hooting.  
 When the motorist was parki. . .  
 While the lecturer was supervising, the students (who were lazy and badly behaved) started chatting.  
 When the manager was supervisi. . .  
 While the actor was writing, the biography (which was shocking and controversial) fell down.  
 When the author was writi. . .  
 While the undertaker was digging, the pit (that was remarkably wide and deep) collapsed.  
 When the workman was diggi. . .  
 While the toddler was drawing, the cat (that was really aggressive and vicious) ran away.  
 When the artist was drawi. . .  
 While the woman was chopping, the tomatoes (that were overripe and very red) rolled away.  
 When the chef was choppi. . .  
 While the scholar edited, the letters (that were very old and valuable) were put away.  
 When the publisher editi. . .  
 While the stuntman was juggling, the skittles (which were shiny and fairly valuable) were stolen.  
 When the acrobat was juggli. . .

While the lead singer practised, the song (that was very powerful and moving) was recorded.  
 When the footballer practis. . .  
 As the lion attacked, the baboon (that was short and rather hairy) sat nearby.  
 When the soldier attacke. . .  
 While the salesman was phoning, the assistant (who was diligent and hard-working) sat down.  
 When the receptionist was phoni. . .  
 While the farmer drove, the tractor (that was very powerful and expensive) broke down.  
 When the old lady drov. . .  
 While the chef was cooking, the carrots (that were extremely fresh and tasty) were delivered.  
 When the housewife was cooki. . .  
 While the woman was baking, the flan (that was very rich and fruity) burnt.  
 When the cook was baki. . .  
 While the football coach trained, the striker (who was very agile and quick) tripped up.  
 When the army officer traine. . .  
 While the pupil was interrupting, the headmaster (who was bad-tempered and impatient) got angry.  
 When the interviewer was interruptin. . .  
 While the warrior was fighting, the enemy (who were badly injured and exhausted) retreated.  
 When the swordsman was fighti. . .  
 While the lady was knitting, the hat (that was very bright and colourful) fell.  
 When grandmother was knitti. . .  
 As the cadets saluted, the captain (who was strict and authoritarian) started shouting.  
 When the soldier salut. . .  
 While the gentleman was eating, the steak (that was tough and overcooked) became cold.  
 When the customer was eati. . .  
 While the girl was vacuuming, the bedroom (which was rather shabby and neglected) was dusted.  
 When the cleaning lady was vacuumi. . .  
 As the policeman was approaching, the pickpocket (who was rather tricky and cunning) fled.  
 When the man was approachi. . .

#### *Items for Experiment 2*

While the woman was eating, the cheese/brandy that was expensive and very tasty was brought out.  
 When the tiger was eati. . .  
 While the dancer was practising, the routine/actress that was very stunning and impressive was on next.  
 When the musician was practisi. . .  
 While the lieutenant was interrogating, the captive/warship that had broken down suddenly appeared.  
 When the mafia boss was interrogati. . .  
 While the lady was baking, the cake/wine that was fruity and thought to be extremely tasty fell over.  
 When the friend was baki. . .  
 While the druid was performing, the ritual/priest that was very important and serious was interrupted.  
 When the guitarist was performi. . .

As the mother was cooking, the pizza/video that the teenager had kept on asking for was delivered.  
 When the nanny was cooki. . .  
 While the hostess was chopping, the melon/cider that was really delicious and very popular was served.  
 When the butcher was choppi. . .  
 While the soldier was digging, the trench/patrol that was looking out over the battlefield was attacked.  
 When the gardener was diggi. . .  
 As the owner was interviewing, the chairman/computer that was from the accounting department broke down.  
 When the constable was interviewi. . .  
 While the housemaid was sewing, the jumper/teapot that was fairly old and quite badly stained was washed.  
 When the child was sewi. . .  
 While the teenager was heckling, the actor/chair that was stood at the front of the stage fell over.  
 When the activist was heckli. . .  
 While the enemy was pursuing, the platoon/chateau that was to the north of the town centre was attacked.  
 When the police officer was pursui. . .  
 While the therapist was counselling, the parent/letter that had come from the hospital in town arrived.  
 When the advisor was counsell. . .  
 While the foreman was supervising, the plumber/bathtub that should be in the upstairs bathroom was outside.  
 When the administrator was supervisi. . .  
 When the employer was recruiting, the deputy/gossip that had surprised everyone a great deal was mentioned.  
 While the company was recruiti. . .  
 While the secretary was typing, the document/engineer that was awfully long and tedious had disappeared.  
 When the student was typi. . .  
 While the captain was sailing, the boat/rope that was usually kept at the harbour was moved.  
 When the skipper was saili. . .  
 While the landlord was redecorating, the corridor/mattress that was covered with dust and dirt was cleaned.  
 When the painter was redecorati. . .  
 While the boy was swimming, the river/horse that was very fast and quite impressive was pointed out.  
 When the contestant was swimmi. . .  
 While the old lady was knitting, the scarf/jelly that was very bright and colourful was made.  
 When the governess was knitti. . .  
 While the man was flying, the airplane/motorcar that was dirty and a little rusty was moved.  
 When the fighter pilot was flyi. . .  
 While the girl was pestering, the youth/music that was extremely loud and irritating annoyed everyone.  
 When the bully was pesteri. . .  
 When the councillor was phoning, the mayor/photo that appeared in the newspaper last week was pointed out.  
 While the salesman was phoni. . .  
 While the jogger was running, the race/hero that everyone nearby had been carefully watching was filmed.  
 When the athlete was runni. . .  
 While the cleaner was vacuuming, the hallway/workman that was dirty and covered in dust was cleaned up.  
 When grandmother was vacuumi. . .

While the driver was parking, the vehicle/rubbish that had been left on the street for a while was removed.  
 When the motorist was parki. . .  
 While the comedian was performing, the comedy/porter that was really popular and well-liked was stopped.  
 When the singer was performi. . .  
 While the officer was interrogating, the suspect/shotgun that was found at the crime scene was locked away.  
 When the FBI agent was interrogati. . .  
 While the maid was sewing, the outfit/sherry that had been saved for a special occasion was brought out.  
 When the seamstress was sewi. . .  
 While the man was eating, the dinner/coffee that had been made over half an hour ago got cold.  
 When the dog was eati. . .  
 As the assistant was cooking, the veal/chef that had recently won a prestigious award was complimented.  
 When the housekeeper was cooki. . .  
 While the performer was practising, the dance/owner that was found to be opening the show tonight was ignored.  
 When the footballer was practisi. . .  
 While the cook was chopping, the cabbage/martini that was to go with the main course was prepared.  
 When the landlady was choppi. . .  
 As the explorer was digging, the ditch/canoe that was fairly long and narrow became waterlogged.  
 When the undertaker was diggi. . .  
 While the housewife was baking, the cake/cook that was pictured at the front of the recipe book arrived.  
 When the boy scout was baki. . .  
 While the businessman was interviewing, the worker/letter that was from the rival company had vanished.  
 When the cop was interviewi. . .

### *Items for Experiment 3*

When the landlord was decorating/vacuuming, the hallway that was fairly dirty and covered in dust was tidied.  
 While the flatmate was decorati/vacuumi. . .  
 While the woman was eating/cooking, the lamb that had been marinated with some garlic and thyme was carved.  
 When the assistant was eati/cooki. . .  
 When the detective was phoning/assisting, the lawyer who was involved in a high-profile case was mentioned.  
 While the receptionist was phoni/assisti. . .  
 While the mercenaries were surrounding/hunting, the escapee who had been on the run for weeks surrendered.  
 When the poachers were surroundi/hunti. . .  
 When the runner was pursuing/overtaking, the competitor who seemed to be getting extremely tired slipped.  
 While the cop was pursui/overtaki. . .  
 While the professor was lecturing/observing, the postgraduate who had agreed to take the classes talked.  
 When the instructor was lecturi/observi. . .  
 When the journalist was lobbying/investigating, the firm that conducted controversial animal studies closed.  
 While the bureaucrat was lobbyi/investigati. . .  
 While the football trainer was coaching/evaluating, the player who was trying out for the team practised.  
 When the volunteer was coachi/evaluati. . .

When the physio was instructing/monitoring, the footballer who was recovering from a recent injury tripped.  
 While the foreman was instructi/monitori. . .  
 While the scoutmaster was saluting/inspecting, the scouts who had finished putting up the tents were waiting.  
 When the ambassador was saluti/inspecti. . .  
 When the dancer was practising/performing, the routine that would be opening the show tonight was ignored.  
 While the actress was practisi/performi. . .  
 While the deliveryman was parking/approaching, the lorry that contained some heavy crates was unloaded.  
 When the man was parki/approachi. . .  
 When the photographer was filming/heckling, the defendant who was trying to leave the courthouse tripped.  
 While the onlooker was filmi/heckli. . .  
 While the nanny was supervising/visiting, the children who were all outside in the back garden played.  
 When the contractor was supervisi/visiti. . .  
 When the gunman was shooting/chasing, the soldier who was caught in the heavy cross-fire retreated.  
 While the gangster was shooti/chasi. . .  
 While the policewoman was helping/following, the paramedic who was experienced and well-trained interrupted.  
 When the skipper was helpi/followi. . .  
 While the spectator was nearing/cheering, the entrants who lined up for the charity run in the park started.  
 When the youngster was neari/cheeri. . .  
 While the student was writing/studying, the essay that was on 18th century English literature got created.  
 When the author was writi/studyi. . .  
 When the decorator was cleaning/painting, the doors that were to go on the new kitchen units were delivered.  
 While the gardener was cleani/painti. . .  
 When the troops were attacking/guarding, the marksmen who were hid at the fourth floor window fired.  
 While the fugitive was attacki/guardi. . .  
 While the salesman was phoning/assisting, the secretary who was working on the monthly accounts yawned.  
 When the organiser was phoni/assisti. . .  
 While the policeman was pursuing/overtaking, the woman who had been speeding in the outside lane slowed.  
 When the motorist was pursui/overtaki. . .  
 While the handyman was decorating/vacuuuming, the box-room that was very shabby and full of junk was emptied.  
 When the hotelier was decorati/vacuumi. . .  
 When the teenager was eating/cooking, the pizza that had been ordered well over an hour ago arrived.  
 While the grandmother was eati/cooki. . .  
 While the campaigner was lobbying/investigating, the politician who was responsible for the new policies listened.  
 When the solicitor was lobbyi/investigati. . .  
 When the tribesmen were surrounding/hunting, the tiger that was well-hidden in dense undergrowth attacked.  
 While the leopards were surroundi/hunti. . .  
 While the actor was practising/performing, the scene that required a great deal of concentration ended.  
 When the pianist was practisi/performi. . .  
 When the captain was saluting/inspecting, the cadets who stood to attention on the parade ground sniggered.  
 While the duke was saluti/inspecti. . .

When the biologist was lecturing/observing, the researchers who worked in the community health unit chatted.  
 While the headmaster was lecturi/observi. . .  
 When the gymnast was coaching/evaluating, the athlete who was training for the New York marathon stretched.  
 While the expert was coachi/evaluati. . .  
 When the driver was parking/approaching, the bus that was taking the American tourists to the coast set off.  
 While the workman was parki/approachi. . .  
 While the supervisor was instructing/monitoring, the technician who was working on the latest project helped.  
 When the administrator was instructi/monitori. . .  
 While the man was filming/heckling, the comedian who was drunk and becoming rather bad-tempered swore.  
 When the reporter was filmi/heckli. . .  
 When the boss was writing/studying, the report that would be discussed in tomorrow's meeting arrived.  
 While the physicist was writi/studyi. . .  
 While the platoon was shooting/chasing, the militia who had now been on the run for weeks surrendered.  
 When the cowboy was shooti/chasi. . .  
 When the professor was supervising/visiting, the scientist who had done pioneering work was discussed.  
 While the stepfather was supervisi/visiti. . .  
 While the housewife was cleaning/painting, the bookcase that stood in the corner of the room toppled over.  
 When the carpenter was cleani/painti. . .  
 While the rebels were attacking/guarding, the dictator who had recently been overthrown from government fled.  
 When the squadron was attacki/guardi. . .  
 When the team-mate was nearing/cheering, the batsman who had been batting for almost two hours was caught.  
 While the tourists were neari/cheeri. . .  
 When the vet was helping/following, the farmer who was herding the sheep into the meadow slipped.  
 While the explorer was helpi/followi. . .

## References

- Arai, M., Van Gompel, R.P.G., & Scheepers, C. (2006). Priming ditransitive structures in comprehension (manuscript submitted for publication.)
- Baayen, R. H., Tweedie, F. J., & Schreuder, R. (2002). The subjects as a simple random effect fallacy: Subject variability and morphological family size in the mental lexicon. *Brain and Language*, 81, 55–65.
- Baayen, R. H. (2004). Statistics in psycholinguistics: a critique of some current gold standards. In G. Libben & K. Nault (Eds.), *Mental lexical working papers I* (pp. 1–45). Edmonton.
- Bock, J. K. (1986). Syntactic persistence in language production. *Cognitive Psychology*, 18, 355–387.
- Bock, K. (1989). Closed-class immanence in sentence production. *Cognition*, 31, 163–186.
- Bock, J.K., Dell, G. S., Chang, F., & Onishi, K. H. (in press). Persistent structural priming from language comprehension to language production. *Cognition*.
- Bock, K., & Loebell, H. (1990). Framing sentences. *Cognition*, 35, 1–39.

- Bock, K., Loebell, H., & Morey, R. (1992). From conceptual roles to structural relations: Bridging the syntactic cleft. *Psychological Review*, 99, 150–171.
- Bock, K., & Griffin, Z. M. (2000). The persistence of structural priming: transient activation or implicit learning? *Journal of Experimental Psychology: General*, 129, 177–192.
- Branigan, H. P., Pickering, M. J., Stewart, A. J., & McLean, J. F. (2000a). Syntactic priming in spoken production: linguistic and temporal interference. *Memory & Cognition*, 28, 1297–1302.
- Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000b). Syntactic co-ordination in dialogue. *Cognition*, 75, B13–B25.
- Branigan, H. P., Pickering, M. J., & McLean, J. F. (2005). Priming prepositional-phrase attachment during comprehension. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31, 468–481.
- Chang, F., Dell, G. S., & Bock, K. (2006). Becoming syntactic. *Psychological Review*, 113, 234–272.
- Christianson, K., Hollingworth, A., Halliwell, J. F., & Ferreira, F. (2001). Thematic roles assigned along the garden path linger. *Cognitive Psychology*, 42, 368–407.
- Clark, H. H. (1973). The language-as-fixed-effect fallacy: a critique of language statistics in psychological research. *Journal of Verbal Learning and Verbal Behavior*, 12, 335–359.
- Cleland, A. A., & Pickering, M. J. (2003). The use of lexical and syntactic information in language production: evidence from the priming of noun-phrase structure. *Journal of Memory and Language*, 49, 214–230.
- Cleland, A. A., & Pickering, M. J. (2006). Do writing and speaking employ the same syntactic representations? *Journal of Memory and Language*, 54, 185–198.
- Clifton, C. Jr., (1993). Thematic roles in sentence parsing. *Canadian Journal of Experimental Psychology*, 47, 222–246.
- Ferreira, F., & Henderson, J. M. (1991). Recovery from misanalyses of garden-path sentences. *Journal of Memory and Language*, 30, 725–745.
- Ferreira, F., & Henderson, J. M. (1993). Reading processes during syntactic analysis and reanalysis. *Canadian Journal of Experimental Psychology*, 47, 247–275.
- Ferreira, F., Christianson, K., & Hollingworth, A. (2001). Misinterpretations of garden-path sentences: implications for models of sentence processing and reanalysis. *Journal of Psycholinguistic Research*, 30, 3–20.
- Ferreira, V. S. (2003). The persistence of optional complementizer production: why saying “that” is not saying “that” at all. *Journal of Memory and Language*, 48, 379–398.
- Fodor, J. D., & Inoue, A. (1998). Attach anyway. In J. D. Fodor & F. Ferreira (Eds.), *Reanalysis in sentence processing* (pp. 101–141). Dordrecht, The Netherlands: Kluwer.
- Forster, K. I., & Forster, J. C. (2003). DMDX: a windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, and Computers*, 35, 116–124.
- Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: eye movements in the analysis of structurally ambiguous sentences. *Cognitive Psychology*, 14, 178–210.
- Griffin, Z. M., & Weinstein-Tull, J. (2003). Conceptual structure modulates structural priming in the production of complex sentences. *Journal of Memory and Language*, 49, 537–555.
- Hartsuiker, R. J., & Westenberg, C. (2000). Word order priming in written and spoken sentence production. *Cognition*, 75, B27–B39.
- Hartsuiker, R. J., Pickering, M. J., & Veltkamp, E. (2004). Is syntax separate or shared between languages? Cross-linguistic syntactic priming in Spanish-English bilinguals. *Psychological Science*, 15, 409–414.
- Haywood, S., Pickering, M. J., & Branigan, H. P. (2005). Do speakers avoid ambiguities during dialogue? *Psychological Science*, 16, 362–366.
- Kaschak, M. P., & Glenberg, A. M. (2004). This construction needs learned. *Journal of Experimental Psychology: General*, 133, 450–467.
- Kolers, P. A. (1973). Remembering operations. *Memory & Cognition*, 1, 347–355.
- Kolers, P. A. (1979). A pattern-analyzing basis of recognition. In L. S. Cermak & F. I. M. Craik (Eds.), *Levels of processing in human memory* (pp. 363–384). Hillsdale, NJ: Erlbaum.
- Levelt, W. J. M., & Kelter, S. (1982). Surface form and memory in question answering. *Cognitive Psychology*, 14, 78–106.
- MacDonald, M. C., Pearlmutter, N. J., & Seidenberg, M. S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review*, 101, 676–703.
- Masson, M. E. J., & Loftus, G. R. (2003). Using confidence intervals for graphically based data interpretation. *Canadian Journal of Experimental Psychology*, 57, 203–220.
- McRae, K., Spivey-Knowlton, M. J., & Tanenhaus, M. K. (1998). Modeling the influence of thematic fit (and other constraints) in on-line sentence comprehension. *Journal of Memory and Language*, 38, 283–312.
- Mehler, J., & Carey, P. (1967). Role of surface and base structure in the perception of sentences. *Journal of Verbal Learning and Verbal Behavior*, 6, 335–338.
- Mitchell, D. C. (1994). Sentence parsing. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 375–409). San Diego, CA: Academic Press.
- Mitchell, D. C., Cuetos, F., Corley, M. M. B., & Brysbaert, M. (1995). Exposure-based models of human parsing: Evidence for the use of coarse-grained (nonlexical) statistical records. *Journal of Psycholinguistic Research*, 24, 469–488.
- Morris, C. D., Bransford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior*, 16, 519–533.
- Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language*, 39, 633–651.
- Pickering, M. J., & Garrod, S. (2004). Toward a mechanistic psychology of dialogue. *Behavioral and Brain Sciences*, 27, 169–225.
- Pickering, M. J., & Traxler, M. J. (1998). Plausibility and recovery from garden paths: an eye-tracking study. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24, 940–961.
- Pickering, M. J., Traxler, M. J., & Crocker, M. W. (2000). Ambiguity resolution in sentence processing: Evidence against frequency-based accounts. *Journal of Memory and Language*, 43, 447–475.

- Pickering, M. J., & Van Gompel, R. P. G. (in press). Syntactic parsing. In M. J. Traxler & M. A. Gernsbacher (Eds.), *The handbook of psycholinguistics*. San Diego, CA: Elsevier.
- Pinheiro, J. C., & Bates, D. M. (2000). *Mixed effects models in S and S-plus*. New York: Springer-Verlag.
- Pollatsek, A., & Well, A. D. (1995). On the use of counterbalanced designs in cognitive research: a suggestion for a better and more powerful analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 785–794.
- Potter, M. C., & Lombardi, L. (1998). Syntactic priming in immediate recall of sentences. *Journal of Memory and Language*, 38, 265–282.
- Satterthwaite, F. W. (1946). An approximate distribution of estimates of variance components. *Biometrics Bulletin*, 2, 110–114.
- Scheepers, C. (2003). Syntactic priming of relative clause attachments: persistence of structural configuration in sentence production. *Cognition*, 89, 179–205.
- Scheepers, C., & Crocker, M. W. (2004). Constituent order priming from listening to comprehension: a visual-world study. In M. Carreiras & C. Clifton, Jr. (Eds.), *The on-line study of sentence comprehension: Eyetracking, ERPs, and beyond* (pp. 167–185). New York: Psychology Press.
- Schoonbaert, S., Hartsuiker, R. J., & Pickering, M. J. (2006). *The representation of lexical and syntactic information in bilinguals: evidence from syntactic priming*. Unpublished manuscript.
- Spivey, M. J., & Tanenhaus, M. K. (1998). Syntactic ambiguity resolution in discourse: modeling the effects of referential context and lexical frequency. *Journal of Experimental Psychology: Learning Memory and Cognition*, 24, 1521–1543.
- Sturt, P., Pickering, M. J., & Crocker, M. W. (1999). Structural change and reanalysis difficulty in language comprehension. *Journal of Memory and Language*, 40, 136–150.
- Tabor, W., Juliano, C., & Tanenhaus, M. K. (1997). Parsing in a dynamical system: an attractor-based account of the interaction of lexical and structural constraints in sentence processing. *Language and Cognitive Processes*, 12, 211–271.
- Tabor, W., & Tanenhaus, M. K. (1999). Dynamical models of sentence processing. *Cognitive Science*, 23, 491–515.
- Tabor, W., & Hutchins, S. (2004). Evidence for self-organized sentence processing: digging-in effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30, 431–450.
- Tanenhaus, M. K., & Trueswell, J. C. (1995). Sentence comprehension. In J. Miller & P. Eimas (Eds.), *Handbook of perception and cognition* (pp. 217–262). San Diego, CA: Academic Press.
- Trueswell, J. C., Tanenhaus, M. K., & Kello, C. (1993). Verb-specific constraints in sentence processing: separating effects of lexical preference from garden-paths. *Journal of Experimental Psychology Learning, Memory, and Cognition*, 19, 528–553.
- Warner, J., & Glass, A. L. (1987). Context and distance-to-disambiguation effects in ambiguity resolution: evidence from grammaticality judgments of garden path sentences. *Journal of Memory and Language*, 26, 714–738.
- Weiner, E. J., & Labov, W. (1983). Constraints on the agentless passive. *Journal of Linguistics*, 19, 29–58.
- Wike, E. L., & Church, J. D. (1976). Comments on Clark's "The language-as-fixed-effect fallacy". *Journal of Verbal Learning and Verbal Behavior*, 15, 249–255.
- Whittlesea, B. W. A., & Wright, R. L. (1997). Implicit (and explicit) learning: acting adaptively without knowing the consequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23, 181–200.