

Unrestricted race: A new model of syntactic ambiguity resolution

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In: A. Kennedy, R. Radach, D. Heller, & J. Pynte (Eds.) (2000), *Reading as a perceptual process* (pp. 621-648). Oxford: Elsevier.

This is the pre-publication manuscript.
The published version may slightly differ.

Short title: Unrestricted race model

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Abstract

In this chapter, we focus on a previously ignored aspect of sentence processing theories: is processing difficulty caused by reanalysis or competition? According to two-stage theories (e.g., Frazier, 1979; Rayner, Frazier, & Carlson, 1983), reanalysis should occur when an initially adopted reading is inappropriate. In contrast, current constraint-based theories (e.g., MacDonald, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998) claim that processing difficulty is due to a competition between two or more syntactic analyses that are about equally activated. We review a number of eye-tracking experiments investigating this issue. No competition was observed in any of the experiments, thus ruling out current constraint-based theories. In fact, the opposite pattern emerged: sentences that should have produced processing difficulty according to constraint-based theories were actually easier to process than sentences that should not have produced difficulty. The data also turn out to be problematic for two-stage theories, as non-syntactic information appears to be employed before the point of reanalysis. The data provide evidence for a new model of syntactic ambiguity resolution (cf. Traxler, Pickering, & Clifton, 1998; Van Gompel, Pickering, & Traxler, 1999), the unrestricted race model. In this model, processing difficulty is due to reanalysis, but multiple sources of information can determine which analysis is initially adopted.

Introduction: two-stage versus constraint-based theories

Current sentence processing theories can roughly be divided into two fundamentally different classes which make very different claims about the architecture of the language processor. One class of theories are what we will call the two-stage theories. The garden-path theory, initially proposed by Frazier (1979; see also Ferreira & Clifton, 1986; Frazier, 1987; Rayner, Carlson, & Frazier, 1983), has been the most influential of these theories, but there are other theories which are very similar in their basic assumptions, although they differ in many details (e.g., Abney, 1989; Crocker, 1995; Inoue & Fodor, 1995; Pickering, 1994; Pritchett, 1992). Many of the basic ideas of these theories date back from Bever (1970) and Kimball (1973), and they are strongly influenced by the modularity hypothesis (Fodor, 1983; Forster, 1979). One of the basic assumptions that two-stage theories make is that some potentially useful sources of information are initially ignored in sentence processing, because the sentence processor is informationally encapsulated. In the garden-path theory, for example, only information about syntactic tree structures can be used initially, and all other sources of information, such as thematic roles, discourse context, semantic plausibility and lexical frequency, are ignored during this initial stage. Other theories assume that information such as thematic roles (e.g., Pritchett, 1992; Abney, 1989) is used initially. By virtue of the fact that some sources of information are used later than others, all these models share the assumption that the processor works in two stages. In the first stage, the processor adopts one analysis on the basis of a restricted range of information. In the second stage, other sources of information are employed. If the initial analysis of an ambiguous syntactic structure is incorrect, another analysis is pursued. This reanalysis process causes processing disruption (a garden-path effect).

The second class of theories are the constraint-based theories which are descended from older interactive theories (e.g., Marslen-Wilson, 1975; Taraban & McClelland, 1988; Tyler & Marslen-Wilson, 1977). Since the early 1990s, constraint-based theories have become the dominant type of account of sentence processing. Recently, these models have been worked out in more detail, so that it is possible to derive some predictions from them (e.g., MacDonald, Pearlmutter & Seidenberg, 1994; McRae, Spivey-Knowlton, & Tanenhaus, 1998; Tabor, Juliano, & Tanenhaus, 1997). All constraint-based theories stipulate that the processor works in a single stage and that it can employ all sources of information immediately. Because all relevant

information can be employed immediately, there should be no reason to predict differences between on-line preferences while people are reading a sentence, and off-line preferences such as measured by sentence fragment completion studies. Constraint-based theories assume a parallel processor: different possible analyses of an ambiguous syntactic structure are activated simultaneously by the various sources of information and compete with each other until a certain threshold level is reached (e.g., McRae et al., 1998). When one analysis receives more support than the others, little competition occurs between the analyses, resulting in little processing difficulty. But when one or more alternative analyses are about equally activated, there is a strong competition between the analyses, which should lead to processing difficulty.

Constraint-based theories usually claim that this process of competition is exactly the same as in lexical processing (e.g., MacDonald et al., 1994). A number of studies on lexical ambiguity resolution observed that ambiguous words for which both meanings were equally high in frequency (balanced words) were read more slowly than their unambiguous controls, whereas ambiguous words that had a frequency bias toward one meaning (biased words) were read as fast as unambiguous control words (e.g., Duffy, Morris & Rayner, 1988; Rayner & Duffy, 1986; Rayner & Frazier, 1989; Sereno, Pacht & Rayner, 1992). This can be interpreted as evidence for a process of competition between two meanings of a balanced ambiguous word. Similarly, when biased words were put in preceding contexts favouring the low frequency meaning, reading times were slower than when they were put in a context favouring the high frequent meaning (e.g., Dopkins, Morris & Rayner, 1992; Duffy et al., 1988; Rayner & Frazier, 1989; Rayner, Pacht & Duffy, 1994). This is also consistent with a competition process between two alternative meanings. Therefore, if syntactic ambiguity resolution is indeed similar to lexical ambiguity resolution, competition effects should obtain in syntactic ambiguities as well.

On the other hand, some proponents of two-stage sentence processing theories claim that syntactic and lexical ambiguity resolution are fundamentally different (e.g., Frazier, 1989; Rayner & Morris, 1991; Traxler, Pickering & Clifton, 1998; Van Gompel, Pickering & Traxler, 1999). Competition may arise in lexical ambiguity resolution, but by virtue of its serial architecture, it cannot arise in syntactic ambiguity resolution.

The unrestricted race model

In Van Gompel et al. (1999; cf. Traxler et al. 1998) we proposed an alternative to current sentence processing models, the unrestricted race model, which we will describe in more detail here. This model combines properties of both constraint-based and two-stage models, but is different from both. As in constraint-based theories, there is no restriction on the sources of information that can provide support for the different analyses of an ambiguous structure; hence it is unrestricted. In the model, the alternative structures of a syntactic ambiguity are engaged in a race, with the structure that is constructed fastest being adopted. The more sources of information support a syntactic analysis and the stronger this support is, the more likely this analysis will be constructed first. The model claims that when the various sources of information strongly favour one analysis over its alternative (a biased ambiguity), this analysis will nearly always be adopted. In contrast, when two analyses are about equally preferred (a balanced ambiguity), each analysis will be adopted about half the time. A weak bias, however, might lead to one analysis being adopted most, but not all of the time. This is one way the unrestricted race model can account for gradations in garden-path effects (e.g., Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Trueswell, Tanenhaus, & Kello, 1993; Trueswell, Tanenhaus, & Garnsey, 1994; but see conclusions for further discussion of how graded garden-path effects may arise). In contrast to constraint-based theories, only one analysis is constructed at a time. Because only a single analysis is available at any time, reanalysis may sometimes be necessary if information following the initial analysis is inconsistent with it. Thus, the unrestricted race model is a two-stage reanalysis model.

The model assumes that the parser is strictly incremental. As it encounters each word, it checks whether the syntactic structure built so far is consistent with the new information provided by the word. If it is inconsistent with this information, reanalysis takes place, resulting in processing difficulty. There are logical restrictions on what information can be used first. Consider (1):

1. While the guests were eating plates were brought in.

The verb to eat permits (at least) two analyses, corresponding to the transitive and intransitive uses of the verb. On the correct analysis in (1), eating is intransitive. However, the transitive analysis is initially preferred, at least for verbs which have a more frequent transitive

than intransitive use (e.g., Clifton, 1993; Ferreira & Henderson, 1990; 1991; Frazier & Rayner, 1982; Holmes, Stowe, & Cupples, 1989; Pickering & Traxler, 1998; Trueswell et al., 1993). The semantic implausibility of eating plates in fact rules out this analysis in (1). However, because syntactic analysis is a prerequisite for semantic analysis, the processor cannot employ plausibility information immediately. The processor first needs to construct the direct object analysis before it can determine that it results in an implausible analysis. Thus, if the implausibility of the transitive analysis is sufficiently strong, reanalysis is predicted at plates, which is consistent with experimental evidence (Pickering & Traxler, 1998). Although semantic plausibility information can be used extremely rapidly, it cannot prevent a garden-path occurring. Thus, the prediction that syntactic processing precedes semantic processing naturally falls out of the architecture of the model. It is not a property that has to be stipulated independently in the way informational encapsulation is in Fodor (1983).

Research suggests that there are similar restrictions on the use of other sources of information. For example, Traxler and Pickering (1996) investigated sentences such as (2):

- 2a. I recognised she and her family would be unhappy here. (incongruent case marking)
- 2b. I recognised you and your family would be unhappy here. (congruent case marking)

The verb recognised can occur with a sentence complement, as in the ultimately correct analysis in (2), or with a direct object (as in I recognised her). The case marking of she in (2a) makes the direct object analysis impossible, whereas the case of you is ambiguous between a direct object and a subject analysis. Traxler et al. observed that readers experienced more difficulty in the region she and her family in (2a) than in you and your family in (2b). This suggests that this case is analogous to (1). As in (1), there is an initial preference to analyse the following noun phrase of the verb (recognised) as its direct object rather than as the subject of the following clause, at least for transitive biased verbs. Analogous to the use of semantic plausibility information, we assume that the processor first needs to construct the direct object analysis before it can assess that the case marking of she is inconsistent with it. Hence, reanalysis has to take place in (2a), resulting in processing difficulty compared to (2b).

The unrestricted race model claims that the use of non-syntactic information depends on where this information becomes available. If it occurs in the sentence at or after the point where

the ambiguity arises, as in (1) and (2), it cannot be employed during the initial parse. But conversely, it predicts that non-syntactic information that precedes the point of ambiguity can be employed immediately. In the latter case, our claim is similar to that of current constraint-based theories. As an example of such a case, we will now consider (3):

3. The hunter saw two poachers hiding behind the bushes.

He killed the poacher with the rifle.

In the second sentence in (3), the prepositional phrase with the rifle is ambiguous between VP attachment (as in killed with the rifle) and NP attachment (as in the poacher with the rifle). In the absence of a context, such sentences normally demonstrate a preference for VP attachment (Britt, 1994; Britt, Perfetti, Garrod & Rayner, 1992; Clifton, Speer & Abney, 1991; Ni, Crain & Shankweiler., 1996; Rayner et al., 1983; Spivey-Knowlton & Sedivy, 1995; though cf. Taraban & McClelland, 1988). In (3), the preceding context sentence supports the NP attachment analysis. Because there are two poachers in the context, the second sentence is more felicitous if the prepositional phrase selects one of the two poachers - in other words, if the NP attachment analysis is adopted (cf. Crain & Steedman, 1985; Altmann & Steedman, 1988). Crucially, this discourse information can be used at the poacher, before the point where the ambiguity arises (at with), and therefore the unrestricted race model predicts that it will be used initially.

The claims that the unrestricted race model makes differ from both the garden-path theory (e.g., Frazier, 1979; 1987) and referential theory (e.g., Altmann & Steedman, 1988; Crain & Steedman, 1985). The garden-path theory claims that discourse information is completely ignored during initial processing and that readers always adopt VP attachment first, regardless of context. According to referential theory, the processor's initial decision is merely based on discourse information and therefore, it should override any structural preferences. The unrestricted race model predicts that the initial analysis is based on both discourse information and a preference for VP attachment. Which analysis is adopted depends on the strength of both sources of information.

We think that current research supports the position of the unrestricted race model. For example, Britt (1994) showed that discourse information neutralised the VP attachment preference in verbs with an optional prepositional phrase, but did not override it. When the

prepositional phrase was obligatory, there was no effect of context. This suggests that contextual neutralisation depends on the strength of the VP attachment preference. Furthermore, Britt et al. (1992) showed that contextual neutralisation occurred for VP/NP attachment ambiguities such as (3), but that context did not have a neutralising effect for reduced relative clause ambiguities (see e.g., Bever, 1970; Rayner, et al., 1983), which are more strongly biased towards one analysis. Both results are somewhat difficult to reconcile with referential and garden path theory. According to referential theory, contextual information should always override (rather than neutralise) a bias that occurs when a sentence is presented in the absence of a context. This override should occur independently of whether a phrase is obligatory or not, and independently of the particular structure used. The garden path theory claims that context should never neutralise or override a structural bias (but see Clifton & Ferreira, 1989). Because the unrestricted race model predicts that the strength of both syntactic and non-syntactic information determines whether neutralisation, override or neither takes place, the results are more consistent with this model. However, they are also consistent with current constraint-based theories (e.g., MacDonald et al., 1994; Spivey-Knowlton & Sedivy, 1995; Spivey-Knowlton, Trueswell & Tanenhaus, 1993), which make the same predictions.

As we shall see, the unrestricted race model makes different predictions from both two-stage and constraint-based theories with respect to when processing difficulty occurs. In order to test these new predictions and to contrast them with predictions from current two-stage and constraint-based theories, we conducted a number of experiments, which we will describe below. These experiments investigated a previously neglected issue: the question of whether processing difficulty is caused by competition or reanalysis.

Reanalysis or competition? Shedding new light on sentence processing theories

To date, a great deal of research on syntactic ambiguity resolution has attempted to distinguish between two-stage and constraint-based theories by investigating whether non-syntactic information can be employed immediately or not. Unfortunately it hasn't reached a very clear conclusion, as proponents of both types of models usually claim that the data are compatible with their model. A number of studies have suggested that non-syntactic information

such as lexical frequency information (Trueswell et al., 1993; Trueswell, 1996), discourse information (Altmann & Steedman, 1988; Altmann, Garnham, & Dennis, 1992) and semantic information (Trueswell et al., 1994) can be employed extremely rapidly, which appears inconsistent with two-stage theories. However, proponents of two-stage theories have claimed that reanalysis can occur extremely rapidly when non-syntactic information is very strong, and that current methodologies such as self-paced reading or even eye-tracking may not be sensitive enough to detect garden-path effects in such cases (e.g., Clifton & Ferreira, 1989). Similarly, proponents of constraint-based theories respond to findings that non-syntactic information does not guide initial processing (e.g., Ferreira & Henderson, 1990; Ferreira & Clifton, 1986; Mitchell, 1987; Mitchell, Corley, & Garnham, 1992; Rayner, Garrod, & Perfetti, 1992) by claiming that the manipulation of non-syntactic information was not strong enough.

For this reason, we decided to focus on a currently neglected aspect of sentence processing theories: whether reanalysis or competition causes processing difficulty in syntactic ambiguity resolution. This question is a very important one, because, as we have described in the introduction, it discriminates between two fundamentally different architectures and distinguishes between the two main approaches in syntactic processing. Furthermore, it addresses the question of whether syntactic and lexical ambiguity resolution show the same characteristics, or whether they are completely different. Therefore, it is perhaps surprising that there has been very little research to investigate competition versus reanalysis and that the few studies which did claim to provide evidence for one or the other are in fact equivocal on a closer inspection.

Some of the first researchers who claimed to have found evidence for reanalysis were Rayner et al. (1983). They tested sentences such as (4), which are syntactically ambiguous between VP and NP attachment:

- 4a. The spy saw the cop with a revolver but the cop didn't see him. (NP attachment)
- 4b. The spy saw the cop with the binoculars but the cop didn't see him. (VP attachment)

Sentences like (4a) were semantically disambiguated towards NP attachment, whereas sentences like (4b) involved VP attachment (although many items were in fact semantically ambiguous). Rayner et al. observed that (4a) took longer to read than (4b) and took this as evidence for a

reanalysis process in (4a). They claimed that the processor initially pursued the structurally simpler VP attachment analysis (as in see with the binoculars) in both sentences. Because this analysis resulted in an implausible analysis in (4a), reanalysis had to take place, which caused the longer reading times compared to (4b), where no such reanalysis was necessary.

However, these results can easily be accounted for in a constraint-based framework assuming competition (cf. Spivey-Knowlton & Sedivy, 1995). Because the VP attachment analysis is preferred (presumably due to frequency information) but plausibility supports the alternative NP attachment analysis (as in the cop with a revolver), a process of competition arises in (4b) but not in (4a) where both sources of information are consistent.

More recently, proponents of constraint-based theories have claimed to have found evidence for competition. For example, MacDonald (1994) tested sentences such as (5) which are temporally ambiguous between a main clause analysis (as in The ruthless dictator fought in the coup ten years ago.) and a reduced relative clause (as in the ultimately correct analysis in [5]).

5a. The ruthless dictator captured in the coup was hated throughout the country. (good reduced relative constraint)

5b. The ruthless dictator fought in the coup was hated throughout the country. (bad reduced relative constraint)

She compared them with unambiguous base-line conditions that included that was after dictator and observed that the reading time difference between the ambiguous condition and the unambiguous control was greater for (5a) than (5b) in the region consisting of captured/fought in the coup. She attributed this difference to a competition process in (5a). In (5) the main clause analysis is activated because it occurs most frequently or is least complex. In (5a), however, captured in the coup is barely consistent with the main clause analysis and supports the reduced relative alternative. Hence, MacDonald claimed that this led to competition between the two analyses. No such competition occurred in (5b), because fought in the coup is compatible with the main clause analysis.

Although MacDonald's data were consistent with a competition mechanism and thus with constraint-based theories, they can also be explained in a two-stage framework. This

approach predicts that readers initially adopt the main clause analysis because this is the preferred analysis, but subsequently have to revise this analysis in (5a), because in the coup makes this analysis highly unlikely. In (5b), reanalysis does not occur until was hated.

The same argument applies for an experiment by McRae et al. (1998), in which sentences such as (6) and their unambiguous controls (disambiguated by that was) were tested.

6a. The crook arrested by the detective was guilty of taking bribes. (implausible main clause)

6b. The cop arrested by the detective was guilty of taking bribes. (plausible main clause)

In (6a) the reduced relative is plausible and the main clause analysis is not, whereas it is the other way around in (6b). McRae et al. observed an interaction between sentence type (6a) and (6b) and ambiguity (ambiguous vs. unambiguous sentences) in the ambiguous region arrested by. In (6a) this region was much more difficult to read than in its unambiguous control, whereas this difference was less pronounced in (6b). This is consistent with competition: in (6a), the main clause, which is activated because it is structurally simple or highly frequent, competes with the plausibility of the reduced relative and the information provided by by, which support the reduced relative clause analysis; whereas in (6b) both the preference for a main clause and plausibility support the main clause analysis and only by supports the alternative. Thus, competition should be less here, and their reading-time data was consistent with this prediction.

Indeed, the reading times mirrored findings from a sentence completion task. Sentence fragments up to and including by were nearly always completed as a main clause in (6b), but in (6a) completions as a main and reduced relative were about equally frequent. McRae et al. took the reading time results in combination with the completion data as evidence for competition and as support for their constraint-based simulation. They went on to claim that the results are inconsistent with the garden-path model and with two-stage models in general. They supported this claim by building simulations of the garden-path model using the same competition model but with the modification that all constraints except the main clause bias were delayed. These garden-path simulations made less accurate predictions than the constraint-based simulation in which all constraints were used simultaneously.

However, the assumption that two-stage theories incorporate competition is incorrect; instead, they employ reanalysis. Hence, the simulations do not show that constraint-based

models predict processing performance better than two-stage models. They merely show that in a competition architecture, immediate use of all information gives a more accurate prediction of processing than when some information is delayed. In fact, a two-stage processor can straightforwardly account for the data. On such an account, the main clause analysis is preferred and initially adopted in both (6a) and (6b). In (6a), the analysis becomes implausible when the region arrested by is encountered, because the main clause analysis is implausible and because the by-phrase usually indicates a reduced relative analysis. Hence, reanalysis ensues and processing difficulty arises. In (6b), arrested is consistent with a main clause analysis and therefore no reanalysis should take place at this point. By can trigger reanalysis in the region arrested by, but McRae et al.'s completion data indicated that this constraint alone is not very strong, as about half of their participants completed (6b) as a main clause after arrested by ... This suggests that reanalysis did not always occur in this region in (6b), whereas reanalysis was much more frequent in (6a), in which main clause completions were much less frequent. Thus, both reanalysis and competition theory predict that processing difficulty in the region arrested by should be less in (6b) than in (6a), and McRae et al.'s results can be accounted for by either theory.

Relative clause attachment experiments: evidence against constraint-based theories and the garden-path model

Thus, the aforementioned studies do not allow us to distinguish between reanalysis and competition. In order to resolve this debate, we need a case where reanalysis and competition frameworks make different predictions. Such a case occurs in globally ambiguous structures in which two analyses are roughly equally preferred. Competition frameworks predict that such globally ambiguous sentences should be more difficult to process than sentences that are disambiguated. In a globally ambiguous sentence, more than one syntactic structure remains activated throughout the sentence and therefore competition should occur between the analyses, which ought to produce difficulty. But when a sentence is disambiguated, only one analysis remains activated and therefore no such competition should arise. In contrast, according to reanalysis frameworks, globally ambiguous sentences should never be more difficult than

disambiguated sentences, because reanalysis should never occur for globally ambiguous sentences. Because the unrestricted race model is also a reanalysis model, it also predicts that ambiguous structures can never be more difficult than disambiguated structures. But in contrast to other two-stage models, it claims that non-syntactic information can be employed initially. This leads, as we shall see, to different predictions in a number of cases.

Traxler et al. (1998) (Experiments 1 and 3) tested the predictions of the various theories in two eye-tracking experiments that used relative clause attachment ambiguities such as (7-8). (Three other conditions, which we will not discuss here, were included in the experiment that tested sentences like [7].)

7a. The son of the driver that had the moustache was pretty cool. (ambiguous)

7b. The car of the driver that had the moustache was pretty cool. (NP2 attachment)

7c. The driver of the car that had the moustache was pretty cool. (NP1 attachment)

8a. The steak with the sauce that was tasty didn't win a prize. (ambiguous)

8b. The steak with the sauce that was runny didn't win a prize. (NP2 attachment)

8c. The steak with the sauce that was tough didn't win a prize. (NP1 attachment)

All these sentences are syntactically ambiguous, in that the relative clause can be attached to the first noun phrase (NP1) or the second noun phrase (NP2) of the sentence. Each item had three conditions: a globally ambiguous condition (version a), a condition that was semantically disambiguated toward NP2 attachment (version b) and a condition semantically disambiguated toward NP1 attachment (version c). This plausibility manipulation was checked by off-line pretests.

Further offline pretests were conducted to determine whether there was a preference for either NP1 or NP2 attachment. As we shall see, this is important to derive predictions from some of the models. Participants had to indicate which noun phrase they thought that the relative clause modified. This is a commonly used methodology to assess the bias in syntactically ambiguous sentences (e.g., Cuetos & Mitchell, 1988; Frazier & Clifton, 1996; Gilboy, Sopena, Clifton & Frazier, 1995; Hemforth, Konieczny & Scheepers, in press). There was a clear bias toward NP2 attachment in sentences such as (8), with the preposition with. Participants

indicated that the relative clause attached to NP2 81% of the time. The bias was much less pronounced in sentences such as (7), with the preposition of. Attachment to NP2 was chosen only 68% of the time. Because the plausibility norms indicated that the plausibility of the attachment sites did not differ, these percentages reflected the bias in the materials before the point where plausibility was manipulated (at moustache in [7] and tasty/runny/tough in [8]).

Constraint-based theories predict that the globally ambiguous condition (7a) should be more difficult to read than the disambiguated conditions (7b) and (7c). In (7a), the semantic plausibility constraint does not favour one analysis over the other, and neither is there a strong non-semantic preference that biases one analysis over the other. Therefore, competition should emerge in (7a). They predict fairly similar difficulty for (7b) and (7c), as the difference in preference (68% vs. 32%) was relatively small. If there is a difference, NP2 attachment should be easier than NP1 attachment, because the offline pretest indicated that NP2 attachment is somewhat preferred.

In constraint-based theories, the degree of processing difficulty depends on the bias of the materials, as measured by the off-line pre-tests. These pre-tests indicated that the bias for NP2 was much stronger in (8) than in (7). Thus, the predictions for (8) are different. Little competition is predicted in the ambiguous condition (8a), because the non-semantic NP2 preference information activates one analysis much more than the other. If the bias is strong enough, the ambiguous condition should be no more difficult than the NP2 attachment condition (8b), in which both plausibility information and the bias for NP2 attachment favour the same analysis. Condition (8c) should be most difficult: there should be a competition between the preference for NP2 and plausibility information which disambiguates toward NP1.

The predictions of two-stage models are different. According to the garden-path model (Frazier, 1979; 1987; Rayner et al., 1983) the principle of late closure causes the processor to make an initial attachment to NP2 in both (7) and (8). It should not matter whether there is an off-line preference for NP2 attachment or not. When NP2 attachment is implausible, reanalysis should occur. This predicts reanalysis in (7c) and (8c), but no reanalysis should occur in the other conditions, because the initially adopted NP2 attachment is plausible.

Recently, Frazier and Clifton (1996) have presented a new theory of syntactic ambiguity resolution: construal. According to construal theory, syntactic relationships can be divided into two different types: primary and non-primary relations. Primary relations include the subject

and predicate of a finite clause, and complements and obligatory constituents of primary relations. Other relations are non-primary. For primary relations, the processor behaves as in the garden-path model, with only one analysis being pursued at a time. In contrast, construal applies to non-primary relations: they are associated in the currently active theta domain (the entire extended maximal projection of the most recent theta assigner), which can contain more than one possible attachment site. The processor then decides which site in the active theta domain to attach the non-primary relation to, on the basis of both syntactic and non-syntactic information.

Relative clauses constitute non-primary relations. In (8), the active theta domain for the relative clause attachment is with + NP2 (i.e., with the sauce), because with assigns a theta role to NP2. Hence, only NP2 is available as attachment site and therefore NP2 attachment should always be initially adopted in (8), just as in garden-path theory. The predictions are different for (7). Here, the active theta domain is the NP1 + of + NP2 complex (i.e., the son of the driver), because the preposition of does not assign a theta role to NP2. Construal stipulates that the relative clause is associated to this complex. At this point, both syntactic and non-syntactic information can be used to attach the relative clause to one of the NPs. Because plausibility information can be employed at this stage, the processor should somehow select the most plausible analysis. Construal does not make clear what mechanism is used. One possibility is that plausibility information guides attachment to the most plausible NP without resulting in processing cost in any of the three conditions. Another possibility is that the most plausible analysis is selected after a process of competition, as in constraint-based theories. This would make the ambiguous condition more difficult to read than the disambiguated conditions. And finally, the processor may slow down whenever one analysis is implausible before it adopts the alternative. Thus, construal does not make any predictions about how the ambiguous condition is processed.

Finally, the unrestricted race model predicts that the degree of processing difficulty depends on how often the initial analysis has to be revised. The more often reanalysis is required, the greater processing difficulty for a particular structure should be. When a structure is strongly biased, the processor will adopt the preferred analysis in nearly all cases. For example, NP2 attachment will nearly always be adopted in (8). When subsequent information is inconsistent with the preferred analysis, as in (8c), reanalysis will nearly always have to occur

and the average processing difficulty should be great. In contrast, when subsequent information is inconsistent with the dispreferred analysis, as in (8b), little or no processing difficulty is predicted, because the dispreferred analysis is hardly ever adopted initially and therefore reanalysis should seldom occur. Reanalysis should never occur in a globally ambiguous sentence (where both analyses are plausible), because the initial analysis is appropriate regardless of which analysis was adopted.

The model makes different predictions for balanced ambiguities. In such ambiguities, each analysis will be adopted half the time. Given that there is only a slight preference in (7) (68% in the off-line test), the model predicts that reanalysis will occur in both (7b) and (7c). In (7b) reanalysis will occur on some trials because the implausible NP1 attachment was adopted initially, whereas in (7c) reanalysis will occur on some trials because NP2 attachment was adopted. Both conditions should produce more difficulty than the ambiguous condition (7a), in which the initial analysis is plausible regardless of which analysis was initially adopted. If the slight NP2 attachment preference is sufficiently strong, condition (7c) may also be more difficult than (7b), because reanalysis may occur somewhat more often in (7c) than in (7b).

Traxler et al. (1998) conducted two eye-tracking studies to test the predictions of the theories for (7) and (8). For the biased structure in (8), readers experienced more difficulty in the NP1 attachment condition than in the ambiguous and NP2 attachment condition, which did not differ from each other. The earliest point at which this pattern occurred was in first-pass regressions out of a short region immediately following the disambiguating noun (in this case, didn't win). (Throughout this chapter, first-pass regressions is defined as the percentage of times leaving a region to the left before going past it.) This is consistent with other studies employing semantic disambiguation in our laboratory (Pickering & Traxler, 1998). (Unlike many studies, our critical regions contain a single word.) The same pattern also obtained in total time on the critical noun (e.g., tasty, runny, tough). (Total time is defined as the sum of all fixations in a region.)

The results from the experiment testing sentences such as (7) were very different. Total times on the critical word (moustache) were shorter in the ambiguous conditions than both disambiguated conditions, which did not differ from each other. This result provides strong evidence against competition-based frameworks. A competition mechanism predicts that the ambiguous condition should be more difficult to read than the disambiguated conditions, but the

opposite was the case. In order to provide a more rigorous test of the competition mechanism, the items that were most balanced (ranging between 35% and 60% NP2 preference) were analysed separately. Competition frameworks predict that the competition between the two analyses in the ambiguous condition should be strongest for these items. However, the pattern of results for these items was exactly the same as for the entire set of items.

The results also provide evidence against the garden path model, because late closure predicts that the NP1 attachment conditions should be more difficult to read than the ambiguous and NP2 attachment condition in both (7) and (8). Although this occurred in (8), it did not occur in (7). Reading times for the NP2 attachment condition in (7b) were longer than for the ambiguous condition, indicating that readers sometimes reanalysed an initially adopted NP1 attachment in condition (7b). Thus, we can conclude that late closure did not always apply.

The different pattern of results for (7) and (8) might be consistent with construal theory. As NP2 is the only NP in the active theta domain in (8), NP2 attachment should always apply. This is consistent with the results: NP2 attachment is easier than NP1 attachment and as easy as the globally ambiguous sentence. In (7), both NP1 and NP2 are in the active theta domain, which is consistent with the finding that the disambiguated conditions did not differ in the eye-tracking study. Furthermore, if one assumes that processing difficulty occurs whenever one attachment site is implausible, one can account for the finding that the disambiguated conditions were harder to read than the ambiguous condition.

The unrestricted race theory's proposals regarding the mechanisms that are employed in syntactic ambiguity resolution are also consistent with the results. In particular, it predicts different patterns of results for biased and balanced syntactic ambiguities. In a biased ambiguity such as (8), readers should nearly always adopt NP2 attachment initially, which should result in reanalysis in (8c), but not in (8a) and (8b). This was borne out by the data. In balanced ambiguities, the unrestricted race model predicts that readers should initially adopt each analysis half the time. This pattern of results obtained for sentences such as (7). Both (7b) and (7c) were more difficult to read than the ambiguous condition (7a). This indicates that reanalysis took place on a considerable number of occasions in both disambiguated conditions, whereas reanalysis was never required in the ambiguous condition. This pattern of results provides strong support for the unrestricted race model.

The data from sentences (7) are crucial for the reanalysis/competition issue. However, the results from these sentences obtained in total times, a relatively late measure of processing difficulty. Therefore, we conducted two further experiments on this kind of relative clause attachment ambiguity in order to determine whether the results can be obtained in earlier measures.

In the first experiment, we used sentences such as (9) (Traxler et al., 1998; Experiment 2). They are very similar to (7), but the relative pronoun is who rather than that and the sentences are disambiguated by the gender of a reflexive pronoun (himself/herself). In the second experiment (Van Gompel, Pickering, Liversedge & Traxler 1999) we used sentences such as (10), which are disambiguated by the plausibility of a verb rather than a noun. As in the previous experiments, plausibility norms were obtained which confirmed this plausibility manipulation.

9a. The brother of the colonel who shot himself on the balcony had been very depressed.
(ambiguous)

9b. The daughter of the colonel who shot himself on the balcony had been very depressed. (NP2 attachment)

9c. The daughter of the colonel who shot herself on the balcony had been very depressed. (NP1 attachment)

10a. The advisor of the mayor that had been driven to the meeting had a lot of problems.
(ambiguous)

10b. The village of the mayor that had been driven to the meeting had a lot of problems.
(NP2 attachment)

10c. The mayor of the village that had been driven to the meeting had a lot of problems.
(NP1 attachment)

We conducted offline preference pretests to determine whether the materials were biased. The ambiguous condition (9a) produced 70% NP2 attachment in the offline test. The ambiguity in (10) was more balanced, with participants choosing NP2 attachment on 49% of the trials. The reliability of the latter result was confirmed by a completion task (e.g., Garnsey et al. 1997;

McRae et al., 1998; Trueswell et al., 1993) in which participants had to complete sentence fragments after that had been... Of all relative clause completions, 57% were attached to NP1, which is very similar to the results from the offline preference pretest. The reason for the difference in preference between (9) and (10) is not entirely clear. It may reflect random differences between the materials (there was also some variability within each set of materials), differences in off-line attachment preferences due to the relative pronoun (who vs. that), or subtle differences in the likelihood of particular NPs taking a relative clause modifier. Currently, no theory provides a satisfactory account of why there should be a difference in preference. Note, however, that the difference in results for (9) and (10) does not disprove either constraint-based theories, construal or the unrestricted race model, as all these theories are underspecified with respect to what preferences should obtain in relative clause ambiguities such as (9) and (10).

The earliest effects for the sentences (9) and (10) obtained in first-pass regressions out of the region following the critical word (on the balcony and to the meeting), indicating that processing difficulty occurred soon after reading the disambiguating word. In (9), more regressions from this region occurred when the relative clause had to be NP1 attached (9c) than when the sentence was globally ambiguous (9a). The number of regressions in the NP2 attachment condition (9c) was also greater than in the ambiguous condition, but this result was only significant by items. A similar pattern occurred in total times on the critical region (himself/herself). These results are again consistent with the unrestricted race model, which predicts that the ambiguous condition should be easiest to read. The absence of a significant difference between the NP1 attachment condition and the ambiguous condition is compatible with the model. The 70% NP2 attachment preference suggests that the ambiguity in (9) was not perfectly balanced. Therefore, when the relative clause was disambiguated towards NP2 attachment, readers may have had to reanalyse in only a few instances, so that the difference between the NP2 attachment and ambiguous condition became impossible to detect. The direction of the means suggests that this was indeed the case.

Because the ambiguity in (10) is more balanced, the unrestricted race model predicts that the difference between the NP2 attachment and the ambiguous condition should be clearer. This was indeed the case. The percentage of regressions out of the post-critical region (i.e., to the meeting) in the ambiguous condition was less than in the disambiguated conditions. The

disambiguated conditions did not differ. The same pattern was obtained in regression path times for this region. (Regression path time is defined as the sum of all fixations in and outside the region from first entering the region until first going past it; cf. Brysbaert & Mitchell, 1996; Duffy et al., 1988; Konieczny, Hemforth, Sheepers, & Strube, 1997). This replicates the pattern found for sentences like (7) in early measures of processing difficulty. Total reading times on the critical word (driven) showed the same result. Clearly, this pattern provides very strong support for the unrestricted race theory.

On the other hand, the results from (9) and (10) cannot be reconciled with competition-based frameworks such as current constraint-based theories. Such theories claim that globally ambiguous sentences should be slower than disambiguated sentences, because competition should arise when two syntactic analyses are about equally favoured by the various sources of information, but not when plausibility supports only one analysis.

Experiments on VP/NP attachment ambiguities: problems for construal theory and referential theory

The results from the relative clause attachment ambiguities are consistent with the unrestricted race model, but they are also consistent with construal theory, as this theory does not specify what mechanism is used to resolve syntactic ambiguities involving non-primary relations such as relative clauses. Hence, the finding of a reanalysis effect can be reconciled with the model. Construal theory stipulates that primary relations are processed in a fundamentally different way from non-primary relations.

One case where construal does not apply is in sentences such as (11):

11a. The hunter killed the dangerous poacher with the rifle not long after sunset. (ambiguous)

11b. The hunter killed the dangerous leopard with the rifle not long after sunset. (VP attachment)

11c. The hunter killed the dangerous leopard with the scars not long after sunset. (NP attachment)

Van Gompel et al. (1999) tested the processing of sentences like these. Such VP/NP attachment ambiguities have been investigated by other researchers (Britt, 1994; Britt et al., 1992; Clifton et al., 1991; Ni et al., 1996; Rayner et al., 1983; Spivey-Knowlton & Sedivy, 1995; Taraban & McClelland, 1988), but the comparison of all three conditions has not been conducted before. In these sentences, the prepositional phrase with the rifle/scars can be syntactically attached to either the verb (killed) or the object NP (the dangerous poacher/leopard). Construal theory predicts that the phrase will be initially attached to the verb, because this instantiates a primary relation, whereas attachment to the NP does not (Frazier & Clifton, 1996: p. 45). Thus, it predicts that VP attachment will always be adopted initially, and therefore that reanalysis should never occur when this analysis is plausible, as in (11b). The VP attachment condition should be no more difficult than the ambiguous condition (11a). Only the NP attachment condition (11c) should be difficult, because the initially adopted verb attachment has to be revised.

In fact, for this kind of ambiguities, construal theory makes exactly the same predictions as garden path theory, although for different reasons. In garden path theory, VP attachment is initially adopted because minimal attachment applies, rather than because primary relations are preferred to non-primary relations. Importantly, both construal theory and garden-path theory claim that non-syntactic constraints cannot be used initially to resolve ambiguities involving primary relations. In their second experiment, Van Gompel et al. (1999) tested this claim using sentences such as (12):

- 12a. The hunter killed only the poacher with the rifle not long after sunset. (ambiguous)
- 12b. The hunter killed only the leopard with the rifle not long after sunset. (VP attachment)
- 12c. The hunter killed only the leopard with the scars not long after sunset. (NP attachment)

According to Ni et al. (1996), only functions as a form of discourse information (see also Paterson, Liversedge, & Underwood, in press). Ni et al. explained the discourse effects of only in the context of referential theory (Crain & Steedman, 1985; Altmann & Steedman, 1988). According to referential theory, readers initially adopt the analysis that has fewest unsupported presuppositions. In (11), the VP attachment analysis involves a simple noun-phrase (e.g., the dangerous leopard), which requires the processor to postulate the existence of a single dangerous leopard, whereas the NP attachment analysis involves a complex noun phrase (e.g., the

dangerous leopard with the scars) which requires the postulation of a set of dangerous leopards. Because only a single leopard is mentioned in (11), postulating one leopard requires fewest unsupported presuppositions, and therefore the VP attachment analysis will be adopted.

Ni et al. argued that the situation is different in (12). In these sentences, only precedes the object NP. They claim that in such a case, readers assume more than one poacher or leopard. As a result, the processor analyses the prepositional phrase as a modifier, resulting in NP attachment. This should result in the VP attachment condition (12b) being more difficult than the ambiguous condition (12a) and NP attachment condition (12c), because reanalysis of the initially adopted NP attachment should only take place in (12b). Clearly, these predictions contrast with those from construal and garden-path theory, which stipulate that discourse information cannot be employed initially and that (11) and (12) are processed similarly.

The predictions of the unrestricted race theory depend on the bias in (11) and (12). In order to establish the preference in these sentences we conducted an offline preference pretest on the ambiguous conditions (11a) and (12a) and a completion study on all conditions. In the offline preference study, readers indicated that they took the prepositional phrase as VP attached 78% of the time in sentences like (11), and 55% of the time in sentences like (12). The completions showed similar results: 93% VP attachment in (11) and 40% VP attachment in (12). Although there was a numerical difference between the offline data and the completions, both indicated that the items in (11) were VP attachment biased, and that the items in (12) were roughly balanced. On the basis of these results, the unrestricted race model predicts that the NP attachment condition in (11c) should be difficult and that the ambiguous and VP attachment conditions should produce little or no difficulty. Because (12) is a balanced ambiguity, both disambiguated conditions should be difficult to read as compared with the ambiguous condition. Thus, the predictions of the unrestricted race model contrast with construal, garden-path theory and referential theory. They also contrast with constraint-based theories, which claim that processing difficulty arises due to a competition process. According to these theories, the ambiguous condition in a balanced ambiguity such as (12) should be more difficult than its disambiguated counterparts.

Two eye-tracking experiments using sets of materials like (11) and (12) were conducted (Van Gompel et al., 1999). For both sets of materials, the earliest effects arose in first-pass regressions and regression path times for the post-critical region (i.e., not long after). This

showed that the basic eye-movement patterns are similar for biased and balanced ambiguities and indicated that the processing of balanced ambiguities such as (12) is no more delayed than that of frequently investigated biased ambiguities such as (11).

The results from (11) showed that VP attachment was easier than NP attachment, as reflected in first-pass regressions and regression path times for the post-critical region (e.g., not long after), and total times on the critical noun (e.g., rifle/scars) and the region preceding it (with the). This pattern is consistent with the pattern observed in previous research on this type of ambiguity. Additionally, the experiment provided data about the processing of an ambiguous condition, which had not been investigated before. Both first-pass regressions and regression path times for the post-critical region, and total times on the critical noun and the region preceding it indicated that the ambiguous condition was easier than the NP attachment condition, and did not differ from the VP attachment condition. This result is consistent with the predictions of the unrestricted race model for biased ambiguities, but it is also consistent with other models.

The results from (12) are crucial in distinguishing between the theories. First-pass regressions and regression path times for the post-critical region, and total times in the region with the revealed that both the VP and NP attachment condition were more difficult to read than the ambiguous condition. The disambiguated conditions did not differ. This result is evidence against construal theory and the garden path theory, which claim that VP attachment is always initially adopted, so reanalysis should never be required in the VP attachment condition. However, the VP attachment condition was more difficult to read than the ambiguous condition. This finding is incompatible with Frazier (1995), who claimed that there is no evidence for processing difficulty when a structure is disambiguated toward an analysis that is favoured by minimal attachment or late closure. The NP attachment condition was also more difficult than the ambiguous condition. This provides evidence against Ni et al.'s version of referential theory, which claims that NP attachment should always be initially adopted when the direct object noun-phrase is preceded by only. As a result, reanalysis should never be necessary in the NP attachment condition. Finally, the predictions of competition frameworks such as current constraint-based theories were once more disconfirmed. Contrary to their predictions, the ambiguous condition was easiest to read. This conclusion was corroborated by a correlation analysis. According to competition models, the more balanced an ambiguity is, the stronger the

competition process. However, there was no correlation between the strength of the preference for an analysis (as assessed by both the offline preference and completion study) and the number of regressions from the post-critical region of the ambiguous condition.

The results from (12) can be naturally explained by the unrestricted race model. Because (12) is a closely balanced ambiguity, VP and NP attachment should be adopted initially about equally often. This was borne out by the fact that the disambiguated conditions did not differ: in both conditions reanalysis should take place about half the time. The model explains why both were more difficult to read than the ambiguous condition, in which the initial analysis was always appropriate.

Conclusions

The results from the experiments reported above are clear. Using different structures and disambiguations, we have consistently found that sentences containing global, balanced syntactic ambiguities are easier to read than balanced syntactic ambiguities which are subsequently disambiguated. These results cannot be explained by frameworks that incorporate a competition mechanism for syntactic ambiguity resolution. A competition mechanism predicts that balanced globally ambiguous conditions should be more difficult because the constraints do not favour one analysis over the other. An ambiguous condition can never be faster than a disambiguated condition. Thus, these results provide evidence against current constraint-based theories (e.g., MacDonald, 1994; MacDonald et al., 1994; McRae et al., 1998; Spivey-Knowlton & Sedivy, 1995; Trueswell et al., 1993; 1994), which do assume such a mechanism.

As mentioned before, studies on lexical ambiguity resolution suggest that lexical ambiguity resolution proceeds through a process of competition. A number of studies (e.g., Duffy et al., 1988; Rayner & Duffy, 1986; Rayner & Frazier, 1989; Sereno et al., 1992) have shown that balanced (in terms of frequency of the meanings) ambiguous words in a neutral context are more difficult to read than unambiguous controls. Our findings of reanalysis in syntactic ambiguity resolution suggest that the mechanisms in syntactic ambiguity resolution are fundamentally different from those in lexical ambiguity resolution. This distinction between lexical and syntactic processing is inconsistent with lexically oriented parsing theories, such as

most current constraint-based theories (e.g., MacDonald et al., 1994; Trueswell, 1996, Trueswell et al., 1993). It supports the alternative claim (e.g., Frazier, 1989; Rayner & Morris, 1991; Traxler et al, 1998; Van Gompel et al., 1999) that lexical and syntactic ambiguity resolution are different.

However, the results from our experiments did not support the predictions of the garden path theory. Both (7) and (12) showed that readers are sometimes garden-pathed on the structurally simplest analysis. The late closure principle was disconfirmed by the finding that relative clause attachment to NP2 in (7b) was more difficult than the globally ambiguous condition, and the minimal attachment principle was disconfirmed because the VP attachment condition in (12b) was also more difficult than its globally ambiguous counterpart. In both cases, the garden path theory predicts that the structurally simplest analysis is always chosen initially, so reanalysis should never occur.

The results from the relative clause attachment ambiguities were consistent with construal theory. However, the results from the VP/NP attachment ambiguity were not. Construal theory predicts that in sentences such as (11) and (12) VP attachment should always be adopted because it constitutes a primary relation, and NP attachment does not. The VP attachment condition in (12b) should be no more difficult than the ambiguous condition, but it was.

This leaves us with only one surviving account, the unrestricted race model. This model combines properties of constraint-based theories and traditional two-stage theories. As in constraint-based theories, non-structural information can be used initially. Although it is difficult to make comparisons between experiments using different materials, some of the experiments reported in this chapter suggest that non-structural information such as thematic information associated with different prepositions (with and of) can be employed in the initial stage of processing. When a relative clause had to be attached to a NP1 + with + NP2 complex, a NP2 attachment preference occurred, but the NP2 preference was much less pronounced when a relative clause had to be attached to a NP1 + of + NP2 complex. The experiments on VP/NP attachment ambiguities suggested that discourse information associated with only can be used initially. When the direct object NP is not preceded by only, a VP attachment preference occurred, but when it was, there was no clear preference for either VP or NP attachment.

In line with two-stage theories, the unrestricted race model stipulates that processing difficulty is caused by reanalysis, not by a competition process between two or more analyses. When subsequent information is inconsistent with a previously adopted analysis, reanalysis occurs. This prediction was supported by the finding that sentences containing global, balanced syntactic ambiguities are easier to read than balanced syntactic ambiguities which are subsequently disambiguated.

We think that the unrestricted race model can account for many findings in the literature that have been taken as support for constraint-based theories. We have mentioned in the introduction that reanalysis models can readily account for data that seemed to support a competition mechanism (MacDonald, 1994; McRae et al., 1998). The unrestricted race model can also account for recent findings that garden-path effects range on a continuum (e.g., Garnsey et al., 1997; Trueswell et al., 1993; 1994). For example, in a recent study, Garnsey et al. (1997) investigated structures such as (13).

13a. The art critic wrote the interview had been a complete disaster. (direct object biasing verb)

13b. The bank guard confessed the robbery had been his own idea. (subject biasing verb)

In these sentences the noun phrases the interview and the robbery are temporarily ambiguous between a direct object of the preceding verb (wrote/confessed) and the subject of the following clause. In (13a), the verb wrote is biased toward the direct object analysis, whereas in (13b) the verb confessed is biased towards the subject analysis. Garnsey et al. showed that first-pass reading times in the disambiguating region had been differed from an unambiguous control sentence in (13a), but not in (13b). Furthermore, the degree of difficulty in the disambiguating region was correlated with the strength of the preference for the direct object or subject analysis. For example, they observed that difficulty in the disambiguating region increased in sentences with subject biased verbs as the verb's likelihood of being used with direct objects increased, indicating that garden-path effects ranged on a continuum. Garnsey et al. took this as support for constraint-based theories and claimed that the results were incompatible with serial lexical guidance models (e.g., Ford, Bresnan, & Kaplan, 1982). They argued that in such models, readers should always initially adopt the subject analysis in subject-biased verbs. They claimed that the strength of this bias should not matter in these models, because the processor always

adopts the preferred verb frame. However, these are not the claims that the unrestricted race model makes. The unrestricted race model can readily account for the findings. Because lexical preference information is used initially, it determines the number of times that each analysis was initially adopted (contrary to the kind of serial lexical guidance model Garnsey et al. describe). The more often reanalysis is required, the more difficult, on average, a sentence will be. Hence, in sentences with very strong subject biasing verbs the subject analysis will be adopted more frequently than in sentences with a somewhat weaker subject bias. Consequently, reanalysis in the disambiguating region should occur less often when the subject bias is strong than when it is weak. Similarly, it predicts the subject analysis should be adopted more often in (13b) than (13a), explaining the pattern Garnsey et al. obtained for these sentences.

In a very similar study which investigated sentences such as (14), Pickering, Traxler, and Crocker (1998) obtained seemingly different results.

14a. The athlete realised his goals somehow would be out of reach. (plausible direct object)

14b. The athlete realised his shoes somehow would be out of reach. (implausible direct object)

They contrasted sentences with a plausible direct object such as (14a) with sentences that had an implausible direct object such as (14b). The verb in these sentences always biased the following NP towards a subject of the following clause. Nevertheless, they observed that reading the noun shoes in (14b) was more difficult than goals in (14a). This can be taken as evidence that the lexical frequency bias of the verb does not determine initial preferences. Considered in this way, the results are in conflict with the results from the Garnsey et al. experiment, as was indeed argued by Pickering et al. (1998).

Clearly, the idea that lexical preferences are not initially employed by the processor is incompatible with the unrestricted race model. We would like to suggest two possible explanations here to account for the Pickering et al. results in the unrestricted race model. In the first explanation, there is no structural preference for the direct object analysis (as in constraint-based theories). However, even though only the verb bias is initially used, readers may still adopt the dispreferred direct object reading in a minority of cases. Indeed, a completion study using sentence fragments up to and including the determiner (his in [14]) produced 70% subject completions. Hence, even though the direct object reading was dispreferred, readers may still

initially have adopted this analysis in 30% of the cases, resulting in reanalysis on a minority of trials. Because both the direct object and the subject analysis were plausible in (14a), reanalysis never occurred and it was therefore easier to read than (14b). Thus, the unrestricted race model suggests an interesting explanation for these findings.

An alternative explanation is that lexical preferences are used immediately, but that other information is also brought to bear. Pickering et al. (1998) proposed an informativity account to explain their data (see also Chater, Crocker, & Pickering, 1998). According to this model, readers' choice of initial analysis pays attention to lexical preferences and other sources of information that suggest which analysis is most likely to be correct. However, they are not driven exclusively by these preferences. The argument is that it is not necessarily most efficient to initially adopt the analysis most likely to be correct. It may also be useful to pay attention to how testable an analysis is. The critical question is whether subsequent information is likely to provide good evidence about whether the analysis was correct or not. After realised, the processor can adopt the object or the subject analysis. If the processor adopts the object analysis, it will then encounter one of two types of noun. If it encounters a word like goals, ambitions or dreams (or very few others), there is a good chance this analysis will be correct. If it encounters shoes, house, friend (or almost anything else), it will know this analysis cannot be correct. Hence this analysis is highly testable. But if it adopts the subject analysis, any noun is possible as the subject of the new clause, but none is particularly likely. Hence, the analysis is much less testable. The argument is that it makes more sense to adopt the testable object analysis, and see whether the following noun confirms or disconfirms this analysis, than to adopt the less testable subject analysis. However, Pickering et al. argue that it would not be efficient to ignore frequency information entirely, and therefore propose the informativity model, whereby the processor pays attention to both frequency and testability in determining which analysis to pursue.

According to this explanation, the testability of the object analysis is much greater than the testability of the subject analysis, and this difference in testability is much greater than the frequency difference in favour of the subject analysis. Consequently, the processor adopts the object analysis initially, hence explaining the difficulty of (14b) compared with (14a). This implies that lexical preferences still have some influence, but that they can be outweighed by structural preferences.

The focus of this chapter has been to explain gradations in processing difficulty by the proportion of times readers have to revise their initially adopted analysis. However it is important to stress that this is almost certainly not the only factor involved in explaining such gradations. There is some, although somewhat limited, evidence that the processing cost of adopting an initial analysis may affect degree of difficulty (e.g., Gibson, 1998; Holmes, Kennedy & Murray, 1987). Even when a structure is unambiguous, structures may differ in the processing cost associated with accessing them or with integrating them into the previously built structure.

Another factor that may affect degree of difficulty in reanalysis is that some reanalyses are harder than others. For example, Sturt, Pickering, and Crocker (1999) found that reanalysing the direct object as part of a sentence complement of a verb, as in (15a) is easier than reanalysing it as a subordinate clause as in (15b):

15a. The Australian woman saw the famous doctor had been drinking quite a lot. (sentence complement)

15b. Before the woman visited the famous doctor had been drinking quite a lot. (subordinate clause)

A corpus analysis showed that the preference to take a following noun-phrase as a direct object rather than the subject of a following clause was equally strong for both saw and visited. Nevertheless, sentences such as (15b) were more difficult to read than sentences such as (15a). This supports the idea that structures can differ in their degree of reanalysis difficulty (see also Ferreira & Henderson, 1991; Gorrell, 1995; Pritchett, 1988, 1992; Sturt & Crocker, 1996).

Clearly, it is important to develop theories as to how reanalysis proceeds (see e.g., Fodor & Ferreira, 1998; Inoue & Fodor, 1995; Ferreira & Henderson, 1991; Fodor & Inoue, 1994; Sturt & Crocker, 1996). Similarly, we think it is crucial to our understanding of sentence processing to devise theories that provide principled accounts of how initial preferences arise, rather than deriving predictions from completions or offline preference studies. Once we have coherent theories of such processes, we believe that they can be incorporated into the unrestricted race model. We hope that future research will take us closer to this goal.

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AUTHOR NOTES

Roger van Gompel acknowledges an ESRC Postgraduate Studentship and a University of Glasgow Postgraduate Studentship. Martin Pickering acknowledges support of ESRC Research Grant no. R000234542. We would like to thank Chuck Clifton for helpful discussions, and Wayne Murray for comments on an earlier draft of this chapter.