

Interaction with context during human sentence processing*

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Abstract

Psychological theories of natural language processing have usually assumed that the sentence processor resolves local syntactic ambiguities by selecting a single analysis on the basis of structural criteria such as Frazier's (1978) "minimal attachment." According to such theories, alternative analyses will only be attempted if the initial analysis subsequently proves inconsistent with the context. (See also Ferreira & Clifton, 1986; Ford, Bresnan, & Kaplan, 1982; Rayner, Carlson, & Frazier, 1983). An alternative hypothesis exists, however: If sentences are understood incrementally, more or less word-by-word (Marslen-Wilson, 1973, 1975), then syntactic processing can in principle exploit the fact that interpretations are available, using them "interactively" to select among alternative syntactic analyses on the basis of their plausibility with respect to the context. The present paper considers possible architectures for such incremental and interactive sentence processors, and argues for an architecture

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in which alternative analyses are initially offered in parallel, and are then discriminated among by immediate appeal to the comprehension process under a selective or "weak" interaction, as opposed to directive or "strong" interaction. We note that such an architecture does not compromise the modularity hypothesis of Fodor (1983) in any way. We review experimental evidence which has been claimed to show that human sentence processing is non-interactive and mediated by purely structural criteria. New results are presented which appear incompatible with the structuralist proposal, and which support the interactive hypothesis. We suggest reasons why the earlier contrary results may be discounted, and conclude that the human sentence processing mechanism resolves modifier-attachment ambiguities by recourse to higher-level contextual and referential information under the weak interaction.

All speakers of all human languages share the intuition that comprehension of spoken and written sentences proceeds in a piecemeal, "incremental" fashion, each word seemingly contributing to a gradual accretion of meaning in the mind of the recipient, more or less as soon as that word is encountered. Our intuitions cannot be expected to reveal much of what actually constitutes "meaning," but they do suggest that not only "sense" or language-internal meaning, but also the individuals and entities referred to in the domain of discourse, become available immediately. That is, they suggest that it is not merely semantic interpretation that is incremental, but the process of reference, or integration of the utterance meaning with the discourse model itself.

If interpretations and even referents are available at every turn in sentence processing, then it is clearly possible that they might play some part in resolving the local syntactic ambiguities that are so surprisingly abundant in natural language sentences, by selecting among analyses according to their appropriateness to the context of utterance. The present paper will present evidence that human syntactic processing is indeed "interactive" in this strictly limited sense. In the first part, we discuss some possible architectures for incrementally interactive language processors, and argue for the psychological reality of one in particular. In Part 2 we present experimental evidence for the claim that incremental semantic interpretation and reference evaluation under such a regime is the major influence in resolving modifier-attachment ambiguities, a class whose resolution (and occasional *mis*-resolution, in "garden paths") has hitherto been ascribed to Frazier's (1978) purely structural "minimal attachment" strategy.

Part 1: Architecture

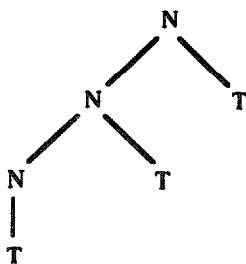
1. Introduction

The "strong competence hypothesis" of Bresnan and Kaplan (Bresnan, 1982) embodies the attractive assumption that rules of natural grammar may be expected to correspond directly to the steps that a processor goes through in assembling a given analysis. Under this hypothesis, the only additional components of a processor besides the grammar itself are: (a) a mechanism for building interpretable structures according to the rules of the grammar; and (b) a mechanism for coping with local ambiguities as to *which* rule of the grammar to apply – that is, a mechanism for deciding which analysis or analyses to pursue at any given point in a sentence.

The property that the strong competence hypothesis postulates is, of course, not a *necessary* property for a language processor, as Berwick and Weinberg (1983) have pointed out, but its psychological appeal is obvious. Nevertheless, when taken in conjunction with our overwhelming intuition that comprehension is incremental, it immediately leads to a paradox. Almost nothing else that we know about natural language grammar seems to be as we would expect if the hypothesis held.

Take surface structure, for example. There is no particular problem about constructing artificial grammars which correspond in a direct fashion with an incremental processor. Any left-branching grammar, generating trees of the following form, provides an example (N stands for non-terminal symbols or phrases, and T stands for terminal symbols or words):

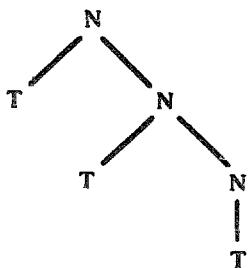
(1)



If in addition we assume a rule-to-rule compositional semantics, then for each terminal in a left-to-right pass through the sentence, as soon as it is syntactically incorporated into a phrase, the interpretation of that phrase can be provided. And since the interpretation is complete, it may also be evaluated – for example, if the constituent is a noun or a noun phrase, then its extension

or referent may be established. In contrast, a right-branching grammar, giving rise to trees such as the following, does not have this property for a left-to-right processor:

(2)



In the absence of some further apparatus going beyond rule-to-rule processing and rule-to-rule semantics, all comprehension (as opposed to purely syntactic structure building) must wait until the end of the string, when the first complete constituent is built and can be interpreted.

If human grammars are indeed incrementally interpreted as our intuitions suggest, and if the strong competence hypothesis does indeed hold, then we might expect left-branching structures to be the rule among the languages of the world. But English itself provides an obvious example of an extravagantly right-branching language, apparently ill-matched under the strong competence hypothesis and the rule-to-rule assumption to the manifest intuition that incremental interpretation is available to its users.

There are a number of ways out of this apparent paradox. Perhaps the easiest is to assume that the strong competence hypothesis is simply wrong, and that steps in processing are not in fact related rule-to-rule with the grammar. This tactic has been popular among linguists. They argue quite rightly that the competence hypothesis is really no more than a heuristic device, since the questions of the psychological reality of incremental interpretation and of the nature of grammar are logically independent. Demonstrating the reality of incremental interpretation could not disprove orthodox generative grammar: There is no *necessity* for such a relation. Processors, including incrementally interpreting ones, can be quite independent of what we think of (say, on semantic grounds) as "the" syntax of a language. However, in the case of human language, there is a price to pay in theoretical terms, for to abandon the strong competence hypothesis is to complicate greatly the problem of "plastic" or incremental development. The explanatory burden is merely shifted onto the theory of acquisition, and hence (by arguments familiar from Chomsky, 1968) onto the theory of evolution. In the absence of any

good argument showing why the apparently extremely rapid evolution of language should have eschewed the obvious advantages of plasticity, such a move fails by Occam's razor.

A second way of escaping the paradox is to deny the validity of our intuition that interpretation is truly incremental, and to claim that the sensation of incremental interpretation is an artifact, brought about either by the extreme rapidity and predictive nature of syntactic processing itself, or by the way in which the context makes the message itself redundant, or by processes of semantic interpretation that are supposed to proceed entirely autonomously, without benefit of syntactic analysis. Probably as a result of this tendency to play down the role of incremental comprehension, the majority of experiments investigating the mechanism which resolves attachment ambiguities during syntactic processing have neglected to control adequately for the possibility that it is an important factor. However, in the face of evidence concerning the real-time incremental nature of interpretation in sentence processing (e.g., Marslen-Wilson, 1975, 1987; Marslen-Wilson & Tyler, 1980; Tanenhaus, Carlson, & Seidenberg, 1985; Tyler & Marslen-Wilson, 1977), the immediacy of noun phrase evaluation (Garrod & Sanford, 1985; Shillcock, 1982), and the early context-dependent disambiguation of ambiguous nouns (Swinney, 1979), we conclude that human sentence processors *do* build interpretations and access referents incrementally. The only question is whether these interpretations are actually *used* in the resolution of attachment ambiguity. The purpose of the present paper is to consider just this question, and we return to the experimental evidence below.

It is not often remarked that there is a third and potentially less disadvantageous way out of the paradox, namely, to retain the strong competence hypothesis, and continue to respect our intuitions concerning incremental comprehension, but to reject the standard theories of grammar. One group who have advocated a move of this kind are the lexical-functional grammarians (Bresnan 1982; cf. Steedman 1985a) who claim that their theory is compatible with an incremental semantics. Ades and Steedman (1982) and Steedman (1985b, 1987b) propose an alternative theory of grammar which is also claimed to be very directly compatible with incremental semantics. The theory consists in an augmentation or extension of the categorial grammar of Ajdukiewicz (1935), which they call "combinatory grammar." Combinatory grammar fragments have been developed for a number of problematic constructions involving single and multiple unbounded dependencies and coordinate constructions. One interesting consequence of the theory lies in its radical implications for the concept of surface structure. The theory implies that the surface structure of many apparently *right*-branching constructions in English is in fact *left*-branching. Importantly, it also allows an appropriate

semantic interpretation to be compositionally assigned to each of the non-standard constituents that result. The theory thus has the desirable property of being directly compatible with incremental comprehension under the strong competence hypothesis.

The incremental semantics that we have in mind for such a syntax is of a kind developed by Mellish (1981, 1985), who represents reference as a process of constraint satisfaction: As the reader progresses through a text, he or she accumulates an ever increasing number of constraints which the referents of the referring expressions must satisfy. This process of incremental evaluation involves having available representations of "partially evaluated" referents. These are simply the members of the set of referents which all satisfy the available constraints. This set gradually becomes more and more refined as the analysis proceeds, until just one candidate referent remains. Haddock (1987, 1988) refines Mellish's account in a number of respects, and applies it to the incremental interpretation of sentences using a combinatory grammar of the kind alluded to above (cf. also Hinrichs & Polanyi, 1985).

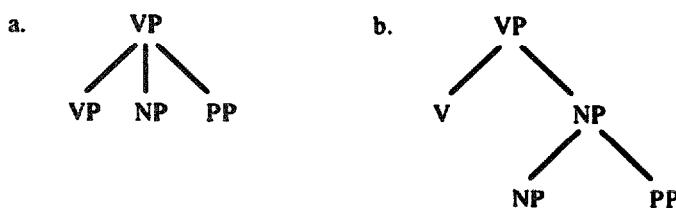
In the following section of this paper, in order to make the succeeding discussion more concrete, we briefly review an experimental paradigm due to Crain (1980) which has been claimed to support the view that human sentence processing draws on the results of incremental comprehension in order to resolve attachment ambiguities during parsing. This is contrasted with structural techniques for resolving such ambiguities, such as minimal attachment. In the third section we use this paradigm as the basis for considering in some detail the various possible architectures for incremental and interactive sentence processors. We extend arguments by Crain and Steedman (1985) – hereafter referred to as C&S – and Fodor (1983) to conclude that, independently of any particular grammatical theory, there is really only one such architecture that is theoretically, empirically, and computationally reasonable. This architecture is of a kind we call "parallel weakly interactive." In Part 2 we shall consider some new experimental results which contrast the incremental/interactive view of local syntactic ambiguity resolution with the non-interactive structural accounts which currently predominate.

2. Psycholinguistic motivation

There is a well-established psycholinguistic tradition of accounting for the resolution of local syntactic ambiguities by purely structural criteria, rather than by any appeal to semantics (e.g., Bever, 1970; Ferreira & Clifton, 1986; Ford et al., 1982; Frazier & Fodor, 1978; Kimball, 1973; Rayner et al., 1983). Much of this work can be summarised as proposing two main families of structural criteria. The first is a criterion which amounts to choosing the

analysis which produces fewest phrase structure nodes. So, for example, the verb phrase (VP) *tickle the man with a gladiolus* has (given some assumptions about constituent structure) the following two analyses, because of the ambiguity of the prepositional phrase (PP) *with a gladiolus* between a VP argument and a Chomsky-adjoined noun phrase (NP) modifier:

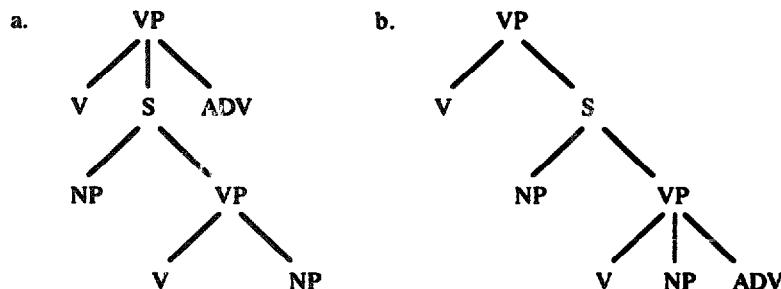
(3)



Under a criterion that has been most succinctly defined by Frazier (1978) and given the name "minimal attachment,"¹ analysis (a) is supposedly preferred to (b) by the human sentence processing mechanism, because it has fewer nodes.

The second strategy applies to the case where a category such as a VP modifier could attach to more than one VP in the sentence structure, as in the ambiguous sentence *she said it tickled her yesterday*, where the unambiguous adverbial modifier *yesterday* could modify the saying or the tickling, thus:

(4)



The two analyses do not differ in complexity, but there is general agreement that the preferred reading is for the modification of the tickling – that is, for attachment as low down and far to the right of the structure as possible, an observation variously enshrined in strategies of "right association" (Kimball,

¹Kimball (1975) proposes a forerunner of Frazier's minimal attachment principle, though in a slightly less general form.

1973), "late closure" (Frazier, 1978) or "final arguments" (Ford et al., 1982).

The unacceptable effect of sentences such as

- (5) The horse raced past the barn fell.

is commonly attributed to one of the minimal attachment family of strategies, which entails a preference for the garden-path inducing VP reading of the substring "*raced past the barn*" over the non garden-pathing participial phrase reading. However, it has always been known that semantics can on occasion override such effects. Bever (1970) himself noted that the garden-path effect in examples like (6a) below could be overridden by sense-semantic effects arising from the involvement of different kinds of arguments, as in (6b):

- (6) a. The authors read in the garden stank.
 b. The articles read in the garden stank.

It is important to be clear from the start that this purely sense-semantic effect is only one of the non-syntactic effects at work, and turns out to be comparatively hard to manipulate by comparison with the referential effects that we discuss below. Crain (1980), reported by C&S, found a rather slight effect of contrasts such as the following:

- (7) a. The teachers taught by the Berlitz method passed the test.
 b. The children taught by the Berlitz method passed the test.

Rayner et al. (1983) and Ferreira and Clifton (1986) found no effect at all (we return to this below). In addition, Rayner et al. claimed that measurements of reading time derived from eye movement data revealed a preference for the minimally attached reading of syntactically ambiguous VPs such as *saw the cop with a revolver*, regardless of the apparent implausibility of seeing with a revolver. Thus sentences such as (8b) which require a non-minimal attachment of the prepositional phrase to make sense took longer to read than minimally attached ones such as (8a):

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

They therefore concluded that the initial choice of analysis was not determined by semantic information.

However, this conclusion is too hasty. There is an even stronger semantic/pragmatic biasing factor present, for which Rayner et al. (1983) neglected to control. Crain (1980) and C&S pointed out that complex NPs differ from simple ones not only in structural complexity, but in *presuppositional* complexity – that is, in the assumptions that they embody concerning the entities which are established in the context of utterance, and by virtue of which the

NPs actually refer.² In particular, postmodifiers such as participial phrases, prepositional phrases and restrictive relative clauses all presuppose that there is a set of entities of the type denoted by the head noun, which the modifier restricts over.

An experiment by Crain (1980, reported in C&S) will help to make the point. Consider the following pair of sentences:

- (9) a. The psychologist told the woman that he was having trouble with *her husband*.
- b. The psychologist told the woman that he was having trouble with *to visit him again*.

Both sentences contain a local ambiguity at the word "that" between an analysis of the following string as a complement clause, as in (a), or as a relative clause, as in (b). In the "null" context, in which sentences are presented in isolation, minimal attachment predicts that the ambiguity will be resolved in favour of the complement analysis, so that version (b), which demands the relative-clause analysis, engenders a garden-path effect.

However, the use of a restrictive relative clause modifier in (9b) presupposes that there is more than one woman in the context of discourse, and that one of these women is distinguished by being troublesome to the psychologist.³ By contrast, the absence of a modifier in (9a) presupposes that just one woman is established in the context of discourse. Crain argued that, if incremental comprehension were indeed characteristic of human processors, then a context which supported the presuppositions of either the simple or the complex NP analyses of the locally ambiguous substrings in the earlier examples could make the processor favour that analysis, overriding the classic garden-path effect, or creating novel garden paths where there were none before. Moreover, he argued, the fact that the so-called null context supports the presuppositions of *neither* analysis did not mean that it would be *neutral* with respect to the two analyses.

To demonstrate the first point – that garden-path effects could be controlled by referential context – Crain preceded the presentation of "complement" and "relative" target sentences like (9) above by contexts that supported the presuppositions of the respective analyses. For the "psychologist" sentences, such contexts would be the following:

²The question of what exactly is meant by an "entity" here, and of what is meant by its being "established in the context," is one to which we return below. For the moment we shall just assume that these notions are well founded.

³We assume that the possibility of interpreting this relative as *non-restrictive* is excluded by: (a) the absence of punctuation, and (b) the fact that in most dialects, *that*, unlike *who(m)*, cannot introduce non-restrictives.

(10) a. *Complement-supporting context*

A psychologist was counselling a man and a woman. He was worried about one of them but not about the other.

b. *Relative-supporting context*

A psychologist was counselling two women. He was worried about one of them but not about the other.

These contexts constitute a minimal pair, differing only in the number of women that were involved.⁴ The first context supports the presupposition of sentence (9a) that there is one wife in the context, and therefore demands the complement-clause analysis. It fails to support the presuppositions of the relative sentence (9b) that there are several wives under discussion. If the classic garden-path effect is under the control of context, then that effect should be unaffected or even exacerbated here. By contrast, the second context supports the presuppositions of the relative-clause sentence (9b), and denies those of the complement-clause target (9a). On the same assumption, this second context should therefore reduce or even eliminate the classic garden-path effect. The two types of contexts illustrated in (10) can be crossed with the corresponding pairs of target sentences illustrated in (9), to yield four conditions: complement-supporting context, complement target (CC); complement-supporting context, modifier target (CM); modifier-supporting context, modifier target (MM); and modifier-supporting, complement target (MC). The prediction is that the "crossed" conditions CM and MC should engender garden paths, while the "uncrossed" conditions CC and MM should not.

In order to assess whether or not a garden path was either created or eliminated, Crain used an incremental grammaticality judgement task, in which subjects were instructed to press a response key as soon as they judged the target sequence to be ungrammatical. While some details of Crain's actual

⁴The actual context/target pairs used by Crain (1980) were slightly different, and were as follows:

Complement-supporting context

A psychologist was counselling a married couple. One member of the pair was fighting with him but the other one was nice to him.

Relative-supporting context

A psychologist was counselling two married couples. One of the couples was fighting with him but the other one was nice to him.

Targets

The psychologist told the wife that he was having trouble with her husband (to leave her husband).

The crucial difference between the two contexts is that they differ in the number of wives that could be *inferred* to be involved. In the main text, we follow Altmann (1988) and adopt contexts which minimise the amount of information that must be inferred (see below). Altmann reports reading time data for these new materials which suggest that Crain's results were not simply artifacts of this inferencing requirement.

experiment are criticised in Altmann (1986) and below, he was able to show exactly this effect of context on just those local syntactic attachment ambiguities whose processing characteristics have elsewhere been claimed to support minimal attachment and related structural strategies. Crain's experiments used a wide variety of presuppositionally loaded grammatical parameters and constructions, including definiteness, participial modifiers, and restrictive relatives. Although it cannot be claimed that the grammaticality judgement task he used tells us where in the sentence the fateful decision is taken, it will be important later to recall that it does nonetheless provide a clear index of when subjects experience a true garden path – that is, of when they are unable to find *any* grammatical analysis, as opposed to experiencing a processing difficulty which they can overcome.

C&S proposed a mechanism for such context-based decisions of local syntactic ambiguities which invoked a "principle of referential success." Altmann (1986, 1987) refined it as a "principle of referential failure," which defines the decision as occurring as soon as it is discovered that the crucial definite NP fails to refer. We reformulate this criterion here as follows: First, let us say that (the interpretation of) a definite noun-phrase is "referentially supported" when all its referential presuppositions are satisfied by the context. Thus, a simple definite NP "*the woman*" is referentially supported if there is a unique woman in the reader/hearer's internal model of the discourse, and a complex NP "*the woman that he was having trouble with*" is so if there are several women in the model exactly one of whom is distinguished by that property. Crucially, we shall also assume that an incremental semantics of the kind sketched in the introduction will provide an interpretation for *incomplete* complex NPs such as "*the woman that ...*" and "*the man who found ...*," which is referentially supported if the model respectively includes a set of women who can be distinguished between on the basis of some yet to be specified properties, and a set of men at least one of whom is distinguished by having found something.

The principle that we require can then be defined simply as follows:

(11) *The principle of referential support*

An NP analysis which is referentially supported will be favoured over one that is not.

In the case of a text such as the following, in which the context establishes two women in the model, an analysis of the string *the woman that* as a simplex NP followed by complementiser will be rejected in favour of an analysis as an incomplete complex NP under this criterion:

(12) A psychologist was counselling two women. He was worried about one

of the pair but not about the other. The psychologist told *the woman that*

Under the incremental semantics we assume here, the simplex analysis of "*the woman*" can be discarded as soon as it is found that it is not referentially supported, by virtue of its failing to refer. If the final sentence continues "... he was having trouble with *her husband*," then misanalysis will result. Conversely, in a context such as the following, the same principle will favour the simplex analysis:

- (13) A psychologist was counselling a man and a woman. He was worried about one of the pair but not about the other. The psychologist told *the woman that*

The analysis of "*the woman*" as an incomplete complex NP can be discarded once it is established that there is no set of women over which the still to be encountered NP modifier can restrict. In this case, the continuation "... he was having trouble with *to visit him again*" will precipitate misanalysis.⁵

Within the constraint satisfaction model of reference which we sketched in the introduction to this paper, the principle of referential support can be interpreted as favouring analyses of definite NPs which accumulate additional constraints until such time as they prove effective in limiting the set of potential referents to containing just one member.⁶ This implies that constraints can be applied and evaluated incrementally. We return below to the important question of how such processors might actually be organised, and what architectures are possible or sensible for such processors. It is more important for the moment to note that our proposal also has implications for the processing of sentences in the so-called "null" context, typical of many psycholinguistic sentence-processing experiments, in which *no* analysis is referentially supported, because there are *no* previously introduced discourse entities.

⁵While they make the same broad predictions about Crain's (1980) experimental results, the principle of referential support and its predecessor the principle of referential success (C&S, p. 331) make divergent predictions about the locus of the effect. Referential success predicts that a decision is made only once the complex NP analysis is complete and found to refer, while referential support predicts that a decision is made once the simple NP analysis fails to refer, given the incremental architecture we advocate here. Because of this divergence, the two principles could be distinguished empirically by considering the following text:

A psychologist was counselling two women. He was worried about one of the pair but not about the other. The psychologist told *the woman that he had been at school with* to keep in touch.

Referential support predicts that there should be no garden path, despite the failure of the string "*the woman that he had been at school with*" to refer successfully, and its consequent pragmatic anomaly.

⁶We follow Haddock (1987, 1988) in assuming that the uniqueness requirement of definites is a "closure constraint," which only applies at the point where the NP is complete.

The process of reference – even definite reference – is not confined to the mere identification of entities that are already established in the discourse model. We often encounter definite referring expressions whose referents are *not* previously established – for example, in fictions such as novels, or in explicitly intensional contexts, as in:

- (14) Did you see *the man who just walked past the window*?

Such definites refer to entities which the *speaker* regards as established. But for the hearer they may or may not be so. If they are not, then the hearer must, in the terms of Heim (1982), "accommodate" the reference, by introducing appropriate representations in his or her discourse model. Importantly, if a referring expression not only denotes a novel entity, but carries additional presuppositions which are also not yet satisfied, then they must also be accommodated.

In the traditional psycholinguistic experiment, in which sentences are presented out of context, definite expressions still carry their presuppositions, which must be supported or accommodated by the hearer. In a case of local ambiguity it is reasonable to assume that the reading carrying fewest unsupported presuppositions, and therefore requiring fewest modifications to the database, will be favoured, under what C&S called a "principle of parsimony" (cf. Hobbs, Stickel, Martin, & Edwards, 1988, who limit abductive inference by a similar principle):

- (15) *The principle of parsimony*

A reading which carries fewer unsupported presuppositions will be favoured over one that carries more.

It should be clear at this point that, under the present theory, there is simply no such thing as context which is referentially neutral with respect to the attachment ambiguities of noun-phrases that are typically considered in minimal attachment experiments. If the NP is definite, then a context including exactly one entity of the type identified by the head noun will bias the processor towards the simplex or minimally attached analysis. But if the context includes *no* entities of the type identified by the head noun, then it will *also* bias the processor to the simplex analysis, as this carries fewer presuppositions which must be accommodated by the hearer than does the complex analysis. Only a context containing more than one entity of the relevant type will bias it towards the complex analysis.⁷ It is by definition impossible to construct a context which biases to neither analysis, or one

⁷See C&S for discussion of related effects in indefinites.

which biases equally to both.⁸ It follows that any experiment that attempts to falsify the interactive model cannot depend upon the supposed neutrality of any contexts: Contexts must be actively manipulated to explicitly support or deny the relevant presuppositions. Since it is often hard to be sure what the contents of a subject's discourse model actually are, such experiments must control for this uncertainty by using *minimal pairs* of contexts, which differ only in the cardinality of the relevant sets. This requirement implies that such experiments simply have to cross the context types and the target sentence types, as Crain did: Anything less fails to adequately address the predictions of the theory.

It should also be clear at this point that the earlier principle of referential support is simply a special case of the principle of parsimony: An interpretation which is referentially supported by definition carries *no* unsupported referential presuppositions, and so is favoured under this principle over an interpretation which is not referentially supported. The present theory therefore accounts for the behaviour of the processor both when contexts are controlled and when sentences are presented in isolation under a single pragmatic principle.

3. Architectures for incrementally interpreting interactive processors

We can identify a number of parameters that determine possible architectures for interactive processors of the kind that are implied by the preceding discussion. As we shall see, the purely structural account of Frazier (1978) and the interactive account just described make different demands on the architectures which will support them. At issue is not just the type of information (e.g., structural versus referential) which is used by the processor when faced with a choice, but also the time at which such information becomes available and the time at which the processor can use that information during the resolution of local syntactic ambiguities.

⁸We note that C&S report an experiment by Crain (1980) which did in fact attempt to construct neutral contexts. The following text illustrates Crain's approach to constructing such contexts:

Several buyers were in town for the sale. One buyer was sent a special invitation by the store owners. The other buyers were outraged, and called a lawyer. The lawyer notified the buyer that the store owners had requested to make themselves/himself available only at the sale.

The problem here is that the reader must determine whether the referring expression "*the buyer*" in the last sentence refers to the buyer introduced in the second sentence of the text, or to one of the *set* of buyers introduced in the penultimate sentence. It is the outcome of this decision which determines whether the target referring expression can successfully refer. However, there is no suggestion in the experiment that both alternatives must be simultaneously equally salient to a given experimental subject. Presumably any individual subject focusses on the salient buyer, or the set of buyers, but not both, as C&S admit.

The first distinction we shall discuss concerns the nature of the interaction itself. C&S distinguish two versions of the interactive hypothesis, which they call the "strong" and "weak" versions. The strong version allows semantics to instruct syntax actively on a course of action, such as to pursue one analysis rather than another, while the weak version allows semantics merely to select between the alternatives offered to it by syntax. A second parameter concerns the "fineness of grain" of the interaction, that is, the question of whether the comprehension process can adjudicate only over large units, such as clauses, or whether appeal can be made more frequently, perhaps at each successive word. Finally, weakly interactive processors, at least, may be further divided according to a third parameter into "parallel" and "serial" versions, which differ according to the way in which alternative analyses are offered to semantics for selection.⁹

In the sections that follow, we first review these parameters, arguing that the human sentence processor has a *parallel, fine-grained, weakly interactive* architecture. We then contrast this architecture and its empirical predictions with the serial non-interactive alternative proposed by Frazier and others.

3.1. Strong and weak interaction

According to the strong interaction hypothesis, semantics and context can "prescribe" specific courses of action to syntactic processing, actively restricting the search space within which it operates, by affecting, for example, the order in which rules of grammar are to be tried, or even by entirely ruling some of them out.

The weak version of the interaction hypothesis is much more limited. According to this version, syntax autonomously proposes analyses, while semantics and context merely dispose among the alternatives offered.¹⁰ The only permitted interaction is one whereby the interpretative processes may deliver judgement on the contextual appropriateness of the alternatives that are proposed by syntax, causing it to abandon some, while continuing with others. The results of evaluation can thus suspend a line of analysis on the grounds that its interpretation is contextually inappropriate, but cannot pre-dispose syntactic processing towards any particular construction, a proposal

⁹A further parameter governing the architecture of any language processor concerns the direction of application of the rules of the grammar, whether top-down and predictively through the rules of the grammar, or bottom-up, starting from the words in the string. For the purposes of this paper, this parameter is less critical than the others insofar as little depends on it with respect to the timing of the human sentence processor's decisions during the resolution of local syntactic ambiguities.

¹⁰Some authors (e.g., Fodor, 1983) have since preferred to talk of "instructive" versus "selective" interaction, rather than strong versus weak, but we will continue to use the latter terms.

which is tentatively endorsed by Fodor (1983, p. 78n). This is the mechanism that we were tacitly assuming earlier, when arguing that the representation of several potential referents in the listener's internal account of the discourse (the two wives in Crain's example) will cause a simple NP analysis ("*the woman*") to be rejected in favour of a complex NP analysis ("*the woman that he was having trouble with*"). Contexts which do not support the presuppositions of restrictive adjuncts, including the so-called "null context," will support the simple NP analysis.

C&S argue on meta-theoretical grounds against the alternative "strong" interaction hypothesis, according to which the referential context might *predispose* the processor towards certain constructions. They note that, while some versions of the strong interaction hypothesis are empirically distinguishable from the weak variety, others are not. A version which predicts that the presence in a hearer's discourse representation of several wives predisposes the processor towards complex NP analyses *in general* – that is, not just *the woman that he was having trouble with* but also *the horse (that was) raced past the barn* – certainly makes a strong prediction, although it is too absurd to be worthy of experimental investigation. But a version which says that the presence of several women in the context, together with the fact that the word "*woman*" is the head of the construction serves to temporarily reorder the rules of the grammar such that the material following "*the woman*" is incorporated into a complex NP analysis (e.g., by attempting the relative pronoun analysis of "*that*" before the complementiser analysis) could probably not be distinguished experimentally from the alternative weak hypothesis, according to which the analyses would be developed first, then adjudicated by appeal to the context. However, the only reasonable way of implementing such a proposal seems to amount to implementing the weak interaction, for *how* could the context exert this very specific effect, except by making use of an interpretation? And how can such interpretations be obtained other than via syntax? It is noticeable that the strong interaction has rarely if ever been implemented as a program.

3.2 Fineness of grain in interactive processing

A second parameter of incremental semantics and the architecture of a weakly interactive processor is the "fineness of grain" or intimacy of the interaction – that is, the size of units proposed by syntax that are adjudicated by processes of comprehension. At one extreme, one might believe that such interactions only apply to complete clauses or even sentences (cf. theories of clausal processing, e.g., Fodor, Bever, & Garrett, 1974). Or one might believe that smaller units such as noun-phrases can be evaluated as soon as they are complete, without waiting for the rest of the matrix clause. (Such more

intimate incremental semantics and interactive processing was a feature of Winograd's [1972] program.) At the other extreme, one might believe that even more intimacy was possible. If, as our intuitions suggest, the most incomplete fragments of phrases can be interpreted, then an interactive parser could appeal very frequently indeed, perhaps as each new word is encountered.

However, there is an important restriction on this aspect of the processor. If a rule-to-rule grammar and processor are to conform to the strong competence hypothesis, then only *constituents*, as defined by the grammar, can receive an interpretation, or be evaluated, or be used to guide interactive processing. If one adheres to that hypothesis, then the lower bound on the intimacy of incrementation and interaction is simply a question of grammar. We have already noted that theories of grammar exist which have much freer notions of surface constituency than traditional alternatives.

We also note that, under the constraint satisfaction-based account of reference that we assume, there is very little difference between the interpretation of a simplex NP and that of the head of a complex NP. In both cases, the interpretation consists of a set of constraints which must be satisfied by the candidate referent(s). The difference is that the completion of the simplex analysis imposes certain further "closure" constraints, such as the uniqueness condition of definites. It follows that alternative interpretations can be entertained simultaneously, and that the processing of the common substring permits *both* interpretations. We regard this "representation sharing" across analyses as providing a plausible basis for implementing parallel fine-grained weakly interactive processors, of the kind discussed in the next section.

In the light of these observations, we propose to reserve the epithet "interactive" for processors which exploit the *maximum* fineness of grain permitted by the grammar, that is, where all constituents are offered up for semantic or pragmatic adjudication as soon as they are constructed. Any processor which, like the clausal processor of Fodor et al. (1974) and the strategy-based processors of Frazier (1987), defers all semantic or pragmatic evaluation of certain constituents past the point at which they are built, is in the present terms *non-interactive*.

3.3. Serial versus parallel evaluation

Once one is committed to the weak interaction, at whatever fineness of grain, it is clear that there is a third parameter that must be fixed in specifying an interactive architecture, namely whether the proposal of alternative analyses by the syntactic component for adjudication by the comprehension process occurs serially or in parallel. Inspection of the principle of parsimony

(and of its special case, the principle of referential support) will show that they refer to a *comparison* of alternatives. Plausibility is not an all-or-none property, like syntactic well-formedness. We cannot reject a *single* interpretation on grounds of implausibility. We can only reject it in comparison with some more plausible alternative, simply because it may be the *only* analysis. We therefore claim that weakly interactive processors must by definition propose syntactic alternatives for semantic and pragmatic adjudication *in parallel*.¹¹

Nevertheless, it might be argued that the specific pragmatic property that is most central to the present paper, namely referential support, could in principle be redefined as an all-or-none criterion of success or failure to refer. If so, it could then be deployed in a *serial* weakly interactive parser. For example, we can imagine a parser which initially proposed the minimally attached, simplex NP reading for "*the woman*" in "*the woman that he was having trouble with*," then immediately evaluated it with respect to the context, rejecting it when it failed to refer and immediately switching to the alternative, complex NP analysis.

Such a "serial fine-grain weakly interactive" processor would be strikingly less elegant than the parallel alternative using constraint satisfaction and structure sharing discussed earlier. For example, it would have to distinguish failure to refer in the context of several women from failure to refer in the context of no women at all, if it were to capture the effect of the null context. And it still would not explain how mere non-referential pragmatic plausibility can affect the resolution of syntactic ambiguity, as appears to be the case for Bever's *articles/authors read in the garden* sentences (6).

Because it is so much more complex than the parallel version, we regard such an architecture as at best inherently implausible, if indeed it is feasible at all. However, if precipitation of syntactic reanalysis by appeal to the context could proceed with the fineness of grain that our hypothetical example assumes, then such an architecture would in the limit be empirically indistinguishable from the parallel one that we argue for, as Steedman (1987a) points out.

Even so, such serial fine-grain weak interaction is to be distinguished from the kind of process that is argued for in accounts based on the minimal attachment strategy. We return to this distinction in the next section, in

¹¹It is uncontroversial that, at least at the level of lexical access, the human sentence processor is capable of pursuing multiple analyses in parallel, and that they are selected according to the weak interaction. The essential finding is that multiple lexical hypotheses are entertained prior to disambiguation by context (Swinney, 1979) or additional acoustic-phonetic input (Marslen-Wilson, Brown, & Zwitserlood, unpublished manuscript; Zwitserlood, 1985). It seems reasonable to suppose that context serves in these cases to select the most plausible candidate. That is, it selects on the basis of a comparison amongst the alternatives (cf. Marslen-Wilson's, 1987, principle of the contingency of perceptual choice).

which the empirical consequences which follow from the above theory, and which distinguish it from the alternatives, are discussed.

4. Non-interactive architectures based on the minimal attachment strategy

We have argued on grounds of principle that if human sentence processing is interactive, then the only architecture that makes sense is the one which we call the (fine-grain) "parallel weak" interaction. We have done so at some length because we feel that there is a degree of confusion in the literature as to what is meant by interaction, and even as to whether it is possible to permit it at all without transgressing Fodor's (1983) modularity criterion. We claim to have shown that such processors are not only coherent and modular, but also remarkably simple.

They also make very strong empirical predictions concerning the locus and effect of context on processing. These predictions diverge from those of the minimal attachment model, and allow us to distinguish the two experimentally.

The accounts of Rayner et al. (1983), Frazier (1987), and Ferreira and Clifton (1986), all admit that semantics and pragmatics may eventually precipitate reanalysis. This must be so, for otherwise the parser could never find *any* analysis for sentences such as

- (16) I saw the girl with red hair.

However, while there appear to be uncertainties and differences of opinion as to exactly *how* this happens (see below), all of them agree on *where* in the sentence the initial minimally attached analysis can be evaluated, and *when* this precipitates the production of an alternative analysis. All agree that this can only happen *when the initial minimally attached analysis is complete, or when that analysis is syntactically blocked*.¹² It follows that, in present terms, these processors are entirely non-interactive.

Non-interactive processors of this kind make two very strong predictions concerning the effect of context on processing load. These predictions distinguish them from the interactive processors defined above. The first prediction of the non-interactive model is to do with the potential effect of context upon garden-path phenomena, by which we emphasise again that we mean what Bever (1970) originally meant, namely the phenomenon of being unable to arrive at *any* grammatical analysis for a perfectly grammatical and otherwise

¹²See for example, the discussion in Ferreira and Clifton (1986, pp. 365-6), who claim that "nonsyntactic information is not used during the initial syntactic analysis of a sentence," and that "it is at the stage of reanalysis, not initial analysis, that nonsyntactic information sources are consulted."

acceptable sentence. The prediction of the non-interactive model is simply that *there cannot exist sentences which do not cause a garden path in one context, but which do cause a garden path in another*. To see why this claim follows, consider the familiar “psychologist” example again, and in particular the case where the context includes two women – that is, where the complex NP “*the woman that he was having trouble with*” is referentially supported:

- (17) A psychologist was counselling two women. He was worried about one of them but not about the other. The psychologist told the woman that he was having trouble with to visit him again.

In processing the final sentence, the minimal attachment-based processor will as always persist with its initial analysis of “*the woman*” as a simplex NP, and of the remainder as a *that*-complement, until the syntactic anomaly is encountered at the beginning of the phrase “*to visit him again*,” or until the pragmatic anomaly with the referential context is discovered, whichever occurs soonest. At this point, reanalysis must be possible (since subjects do not actually fail to find a grammatical analysis). One reasonable way of implementing a minimal attachment processor would be to assume that the processor backtracks to the earlier choice point, explores the alternative complex NP analysis, completes the sentence, and then evaluates the result, which happens to successfully refer. However, this entire process, just like the initial analysis, would be entirely blind to context up until the very last step. It follows that we must predict that if the processor can avoid blocking grammatically in this case, then there can be *no* context which will ever lead to an irrecoverable garden path on this sentence. In particular, contexts which directly contradict the referential presuppositions of the grammatical analysis, such as the following “one woman” example, should not fail to produce a grammatical analysis, though of course they will be pragmatically anomalous.

- (18) A psychologist was counselling a man and a woman. He was worried about one of them but not about the other. The psychologist told the woman that he was worried about to visit him again.

The interactive model makes the contrary prediction: *All* NP attachment garden paths are the result of mismatches between contextual support and the referential presuppositions of the target sentences. Of course, such examples are precisely the cases investigated by C&S. They found that garden pathing could be controlled by context in analogous examples: Subjects reported that the final sentence in (18) was *ungrammatical* more often than the final sentence in (17).

It is worth noting what a serious challenge such data offer to the serial non-interactive model. If such a processor can recover from an initial mis-

analysis in the earlier example (17), without having access to any specific facts about the context, why can it not succeed in exactly the same purely syntactic process in the later context (18)? Why does it only succeed in those contexts where the alternative analysis is in fact supported? It would be a strange serial non-interactive processor indeed that had foresight about the compatibility with the context of an analysis which it had not yet built because it was serial, and that allowed the success of such purely syntactic processes as backtracking to be determined by referential facts to which it could have no access because it was non-interactive.

Rayner et al. (1983), Ferreira and Clifton (1986), and Frazier (1987) in fact propose a rather different basis for initiating reanalysis than the blind backtracking described above. They hypothesise a "thematic processor" which proceeds entirely without benefit of syntax, comparing the plausibility of all possible combinations of the various NPs (or rather, their head nouns) with the various subcategorisations or thematic frames of the main verb. If the most plausible thematic frame conflicts with an initial syntactic analysis, then reanalysis is initiated. Whatever the plausibility or implausibility of this proposal, a mere thematic processor does not appear to help with the examples of Crain (1980) and Altmann (1987), in which the thematic roles are invariant, and only referential properties of the contexts are varied. Ferreira and Clifton acknowledge this difficulty, and suggest (1986, p. 365) that "it is possible that a discourse processor that represents discourse and sentence topics communicates with the thematic processor and recommends plausible verb arguments based on these topics," perhaps using "a mental model [which] ... holds in non-verbal form a structural analogue of the entities and relationships among them described in the discourse." The details of this proposal are not specified, but it appears to resemble a process of "analysis by synthesis," according to which the discourse processor anticipates all the likely things that *might be* said. One suspects it must be easier to just wait and see what *is* said, as the interactive processor does.

The serial non-interactive processor, with or without an attendant discourse processor, gives rise to a second, similarly strong, prediction. In those cases where reanalysis is required, there will always be an increase in processing load, regardless of the state of the context, and it will occur either at the point of syntactic disambiguation or at the point, usually at the end of a clause, at which the initial analysis can be evaluated against the context – whichever is sooner. In those cases where syntactic reanalysis is *not* required there will be *no* increase in processing load at the point of syntactic disambiguation. Any processing load due to semantic or pragmatic anomaly will show up later, again, usually at the point of syntactic closure. The interactive model predicts that if the context fails to support the presuppositions of the

target, there will be an increase in processing load, again, at the point of disambiguation, or at the point of closure. If the context *does* support the presuppositions of the target, then there will be no such increase in processing load. It is this second set of predictions that are addressed in the second part of the paper.

Part 2: Evidence for interaction

5. Introduction

It will be obvious from the previous discussion that any experiment which attempts to distinguish interactive and non-interactive processing of NP attachment ambiguities must have two characteristics. First, it must control referential properties of the context, particularly the number of entities of the relevant types, and their distinguishing properties. Second, to adequately test *either* the predictions concerning contextual control of classical garden paths *or* the predictions concerning the locus of processing difficulties, any experiment must not only examine minimally and non-minimally attached sentences in appropriate referential contexts. It must also examine the effect of *crossing* contexts with targets – that is, the effect of referentially non-supportive contexts. Anything less weakens the experiment by ignoring a central prediction of the interactive theory, namely that misanalyses can be avoided *or induced*, given the right kind of context.

A number of studies have claimed to investigate the role of contextual information with respect to the resolution of the family of ambiguities traditionally associated with minimal attachment – that is, PP attachment, reduced relative/active main verb ambiguities, and relative-complement ambiguities. However, most of these studies have failed to satisfy even the first of the above requirements. For instance, Holmes (1984) claimed that the contextual plausibility of one attachment or another in (19) below did not influence the processor's initial choice of which analysis to pursue.

- (19) The parents talked about the problem with the mathematician.

However, this study used the contextual manipulations in (20) below, and made no claim to investigate referential influences on attachment preferences.

- (20) a. The parents discussed with the math teacher what could be done about the difficult exam, but no solution was reached.

- b. The parents discussed among themselves what could be done about the math teacher, but no general agreement was reached.

(From Holmes, 1984a.)

Both of the above contexts support the minimally attached analysis of the target according to the present account, because both included exactly one teacher. This failure to control the referential properties of the context also characterises the study by Rayner et al. (1983) which was discussed earlier, and which merely manipulated *a priori* plausibility. It also applies to Experiment 1 of Ferreira and Clifton (1986). The latter, using an eye-movement measure of phrasal reading times, found evidence of an immediate increase in processing load for implausible agents over plausible ones in pairs such as the following, but found that there was also evidence for an increase in processing load at the point of syntactic disambiguation.

- (21) a. The man brought to the high priest could hardly be described as appealing.
 b. The meal brought to the high priest could hardly be described as appealing.

They, too, claimed that their result contradicted the interactive hypothesis. However, the result is in fact exactly what that hypothesis predicts. If a simplex NP analysis that is pragmatically favoured by the null context is also comparatively implausible, as in example (21b), then the effect of the anomaly will show up immediately. However, unless the simplex reading is a complete semantic impossibility (as seems to be the case with Bever's *articles read ... Example 6*), it will not override the pragmatic preference, and the analysis will be pursued until the syntactic anomaly is encountered.¹³

Ferreira and Clifton (1986) present two further experiments, in which they do manipulate referential factors. They report no effects of context on phrasal reading time (as measured via eye-movement data and subject-paced reading times). Moreover, they did find effects of attachment: The minimally attached (MA) sentences led to shorter reading times than the non-minimally attached (NMA) sentences.

Ferreira and Clifton (1986) used two sets of target sentences in their study:

- (22) a. The editor played the tape agreed the story was big.
 b. The editor played the tape and agreed the story was big.

¹³We note that most of the materials given in Appendix 1 to Ferreira and Clifton (1986) still allow some fairly plausible interpretation up until the disambiguation point. For example, in the above example, the string "the meal brought" could continue as in "the meal brought back memories of Minasota."

- (23) a. Sam loaded the boxes on the cart onto the van.
 b. Sam loaded the boxes on the cart before his coffee break.

In each case, the (a) sentence is nonminimally attached. Each target was preceded by either a biasing context (NMA-supporting for the (a) sentences, and MA-supporting for the (b) sentences) or a neutral context.

Ferreira and Clifton (1986) chose not to cross context with target, claiming that the longer reading times which would be due to the pragmatic anomaly of the resulting passages would be uninformative. However, we have seen that this claim is specific to the minimal attachment hypothesis. Their omission of the crossed conditions clearly prevented them from testing the interactive hypothesis to the full, since one of its crucial predictions is that increased processing loads, due to misanalysis, can be *induced* in minimally attached materials. The omission also deprives them of an important opportunity to control for any intrinsic effects in the materials extraneous to those of context and attachment.

Ferreira and Clifton's (1986) prediction was that the NMA sentences should take longer to process, irrespective of context, than the MA sentences (because of the structurally induced garden path in the NMA materials), and that any increased processing load due to reanalysis would show up at the point of disambiguation. Their results appear to support these predictions.¹⁴

Ferreira and Clifton's (1986) interpretation of their results is based on two assumptions. The first is that in felicitous contexts the MA and NMA sentences should induce the *same* reading times if context does guide the processor's choice of initial analysis. The second is that their contexts were indeed felicitous with respect to the presuppositions accompanying each target sentence, with the neutral contexts being neutral with respect to the accompanying presuppositions. We shall consider each of these assumptions in turn.

The fact that the NMA sentences took longer than the MA sentences can be explained in a variety of ways, none of which compromises the interactive hypothesis. One possible explanation relies on the fact that MA and NMA sentences are actually quite *unlikely* to require the same processing times, even when in felicitous contexts. This is because of the extra work required for the NMA sentence in order to infer that "*the editor played the tape*" has as its antecedent the editor mentioned in "*he ran a tape for one of his editors*." Altmann (1987, 1988) demonstrates the effects of such inferencing on reading time, and shows that reading time differences in studies of local syntactic ambiguity may be artifacts caused by such inferences. Ferreira and Clifton

¹⁴This said, it should be noted that in their eye-movement study, the effect of attachment on the reduced-relative examples failed to reach significance on the by-subjects analysis.

(1986) reject this as a possible objection because, they claim, any such differences should show up on the ambiguous noun-phrase, and not, as they find, on the following (disambiguating) material. They thus interpret increases in reading time in this area as reflecting syntactic reanalysis. However, according to Ehrlich and Rayner (1983, p. 84):

... more complex processes [than lexical retrieval and some syntactic parsing] such as those involving integration are not necessarily completed during the fixation on which the process was initiated (see also Just & Carpenter, 1980; Carpenter & Just, 1983).

So the observed increases in reading time in the disambiguating regions *could* (and most likely *do*) reflect integrative processes concerned with the evaluation of the preceding noun-phrase, rather than syntactic reanalysis.

In the case of the PP-attachment examples in (23), it is less likely that inferencing of the kind just described could be responsible for the difference between the NMA and MA sentences when preceded by their respectively felicitous contexts.¹⁵ The wording which made up the restrictive modifier in (23a) ("*on the cart*") was the same (apart from the changed article) as the wording introduced in the context when the two sets of boxes were introduced ("*He had a pile of boxes on a cart and another pile on the floor*"). Altmann (1988) reports that reading time differences due to inferencing disappear, at least with relative/complement sentences such as those used by Crain (1980), when the same wording is used in context and target. However, there is another difference between the NMA and MA sentences, concerning the amount of information that must be derived from the target sentence and subsequently added to the subjects' discourse model. In the MA-supporting context, some boxes are introduced, but it is not specified just where they are. The MA target (23b) then mentions that the boxes (wherever they are) are moved onto the cart. In the NMA-supporting context, there are two sets of boxes, and the subject must modify his or her discourse model, on reading the final phrase "*onto the van*" in (23a), to reflect not just the fact that the boxes are now on the van, but also that the boxes in question are those that had been on the cart. The final phrase "*before his coffee break*" in (23b) does

¹⁵In the case of the NMA target preceded by the so-called "neutral" context, inferencing very probably was responsible for the observed effects. It is evident from the following "neutral" context used by Ferreira and Clifton (1986), that there was in fact *no* referent to be found in the context for the italicised expression in the final target sentence – it has to be inferred:

Sam worked at a factory warehouse. His job was to make sure that boxes of merchandise were ready to be delivered. Sam wanted to go for his coffee break, but his boss said he had a little more work to do. He wanted Sam to free up a cart for some guys in another department. Sam loaded *the boxes on the cart* onto the van.

not require this complexity of processing. Stenning, Patel, and Levy (1987) demonstrate that the time to process a phrase increases with the amount of information that must be added to the discourse model as a result of that processing. Consequently, it is to be expected that in these cases, the NMA target will take longer to process than the MA target.

In addition to the masking effects of the factors just described, the lack of any effect of context in the Ferreira and Clifton (1986) study may simply be due to inadequate contextual manipulations. In the "neutral" context below, which Ferreira and Clifton used in conjunction with (23) above, a number of potential referents are introduced ("*his editors*"). Ferreira and Clifton claim that this satisfies Crain and Steedman's (1985) requirement that more than one editor is mentioned (which is felicitous with the reduced relative interpretation). But in order to ensure felicity with the minimal attachment interpretation, one of these potential referents for the ambiguous noun-phrase is then "foregrounded" (Chafe, 1972) – see the italicised phrases.

- (24) John worked as a reporter for a big city newspaper. He sensed that a major story was brewing over the city hall scandal, and he obtained some evidence that he believed pretty much established the mayor's guilt. He went to his editors with a tape and some photos because he needed their approval before he could go ahead with the story. He brought out a tape for *one of his editors* and told *him* to listen carefully to it. The editor played the tape (and) agreed the story was big.

However, in making the minimal attachment felicitous, this also has the effect of making the restrictive modification *infelicitous*. The context thus biases towards the minimal attachment, and is far from neutral. This passage exemplifies the problems associated with trying to construct neutral contexts.¹⁶ We also note in passing that the presuppositions associated with specifically past-participial reduced relatives are extremely complex and ill-understood. These presuppositions are particularly difficult to control experimentally (Crain, personal communication, 1988; Forster, personal communica-

¹⁶It could be suggested that the experimental paradigm that we are discussing is therefore in danger of circularity. A context is supposed to bias either to minimal attachments, nonminimal attachments, or (in Ferreira and Clifton's [1986] account) to neither. Whether or not the bias is successful, however, appears to be assessable only on the outcome of experiments such as our own and theirs. If contextual biases are not observed, then this may either be because context has no role in selecting the initial syntactic analysis (as Ferreira and Clifton would claim) or because the bias has been unsuccessful. However, this apparent circularity is broken in our own experiment by the use of crossed contexts as controls. Recall that the principles of referential support, and more generally of parsimony, predict that it will be actually *impossible* to construct a "neutral" context which biases to neither the simple nor complex NP analyses. Depending on the cardinality of the relevant set, a context either selects one or the other. Once again, it is for this reason that the experimenter must cross contexts with targets, rather than attempt to construct neutral contexts.

tion, 1988), and are not among the constructions actually used by either C&S or the present authors in experiments manipulating context.

We have argued that neither of the two assumptions on which Ferreira and Clifton (1986) base their interpretation of the results (uniformity of processing time and efficacy of their contextual manipulation) are necessarily valid. In the following section we describe two experiments which yielded results exactly *opposite* to Ferreira and Clifton's, and consider the implications of such results for minimal attachment.

6. Reference and PP-attachment ambiguities

Crain (1980) used an incremental grammaticality judgement task in order to determine whether or not subjects garden pathed to a particular sentence given one or other of the possible contexts. The words of the sentence were presented on a screen one at a time in RSVP fashion, and subjects were instructed to depress a response key as soon as they thought the sentence was ungrammatical. Crain used only a small number of materials in his study, too few, in fact, to determine the relative contributions of target construction and context type to the observed effects, and too few to determine the statistical generality of the effect to different subjects and different materials (Clark, 1973).

It is important that we are able to factor out the respective contributions of target and context if we are to distinguish the present parallel interactive proposal from a serial non-interactive model in which minimal attachment does determine the initial analysis, but in which the contextual anomaly (in the case of referential failure) precipitates reanalysis before the syntactically disambiguating part of the utterance is reached (at a cost in processing that we might hope would show up on some appropriate measure). Within such a model, one might expect an effect of target construction to reflect the processor's initial (context-independent) choice of analysis, and an effect of context to reflect the processor's eventual choice of analysis (although we have already discussed the theoretical problems associated with such a model). In the experiments that follow, we use global reading times (Experiment 1)¹⁷ and phrasal reading times (Experiment 2) as the appropriate measure.¹⁸ The latter task is included in order to counter a possible objection to

¹⁷Experiment 1 is from Altmann (1986), and aspects of this experiment are reported in reduced form in Altmann (1985, 1987).

¹⁸Although eye-movement data have been argued to provide a finer-grain analysis of where reading time differences are located, we feel that reading times alone are only marginally less informative. It is often unclear what differences in eye movements reflect. They could reflect purely syntactic processes, such as the occurrence

global reading times, which could be argued to confound early processing effects with later post-interpretive ones.

The experiments investigated the effects of referential context on ambiguous prepositional phrase materials similar to those used in the Rayner et al. (1983) study – that is, examples that are locally ambiguous between the attachment of a prepositional phrase to the immediately preceding noun-phrase (the NP attachment) or to the preceding verb (the VP attachment) as in (25) below.

- (25) a. The burglar blew open the safe *with the diamonds*.
 b. The burglar blew open the safe *with the dynamite*.

The experiments were designed to test the hypothesis that the NP attachment is facilitated (in terms of the reading time measure) when the preceding context introduces more than one candidate referent to the NP. The VP attachment should be facilitated if there is no need to modify the NP restrictively: that is, if just one candidate referent to the NP is introduced in the context.

Under the minimal attachment hypothesis, one would expect no effect of context on the VP-attached materials, since these are minimally attached and hence the first analysis to be chosen will be the correct one. Moreover, there should be no effect of referential context on the NP-attached targets because the VP attachment will always be attempted first, and then be rejected on the basis of Rayner et al.'s (1983) thematic selection process, in which real world knowledge, such as the fact that one can't blow things open with diamonds, coupled with knowledge about the alternative thematic structures of a verb (e.g., <experiencer, theme> versus <experiencer, theme, instrument>), is used to suggest an alternative attachment. Thematic selection should be insensitive to referential context because it is information about the *verb* that is used to suggest alternative analyses in the event of an inappropriate initial analysis (see also Ferreira & Clifton, 1986). Of course, these predictions rest in part on the questionable assumption that these reading times reflect only syntactic reanalysis, a question to which we return below. However, even if the assumption is incorrect, the minimal attachment hypothesis predicts that the nonminimally attached targets, which will always require reanalysis, should still induce longer reading times than their mini-

of local ungrammaticality (i.e., at the point of syntactic disambiguation), syntactic reanalysis, and so on. They could also reflect higher-level processes, such as the integration of the lexical item into an internal model of the discourse or text (see Carpenter & Just, 1983; Ehrlich & Rayner, 1983; Just & Carpenter, 1980). In the absence of data on the localisation of integrative effects such as whether referential failure is marked by increased fixations on the noun-phrase, on the following items, both of these, or none of these, we believe the advantages of eye-movement data in studies such as these to be minimal.

mally attached counterparts when both targets are presented in referentially felicitous contexts.

6.1. Experiment 1 – Method

Thirty-two target sentence pairs were constructed. For each target pair, a pair of contexts was constructed: In one context only one candidate referent for the post-verbal noun-phrase was introduced (to support VP attachment in the target sentence) and in the other, two candidates were introduced (to support NP attachment). We will refer to such contexts as “VP-supporting” and “NP-supporting,” respectively.

The following are examples of the contexts and targets used in the experiment:

- (26) *NP-supporting context:* Asks: Which safe is referred?

A burglar broke into a bank carrying some dynamite.

He planned to blow open a safe.

Once inside he saw that there was a safe with a new lock and a safe with an old lock.

VP-supporting context:

A burglar broke into a bank carrying some dynamite.

He planned to blow open a safe.

Once inside he saw that there was a safe with a new lock and a strongbox with an old lock.

Target sentences such as the following were constructed:

- (27) *NP-attached target* Safe-new lock

The burglar blew open the safe with the new lock and made off with the loot.

VP-attached target. blew open-dynamite

The burglar blew open the safe with the dynamite and made off with the loot.

The contexts are “minimally different” to the extent that the *only* change is from “*a safe with ... and a strongbox with ...*” (one candidate referent and therefore VP-suggesting) to “*a safe with ... and a safe with ...*” (two candidate referents and therefore NP-supporting). Thus any differences in reading time for the same target sentence can only be due to this one modification, the effect of which is to change the cardinality of the set of safes introduced into the story from one to more than one.

In addition to the two contexts shown above, a further version of each context was constructed by replacing the first sentence of each context by the following:

(28) A burglar broke into a bank carrying some dynamite *and some gelignite.*

The purpose of this manipulation was to explore its effect on reading times to the VP-attached targets. The rationale here was that in the simple case in which only dynamite is mentioned, the VP target contains redundant information – it is already known that the burglar had some dynamite, and it is therefore no surprise that he blew the safe open using the dynamite. VP modification may be more felicitous, on the other hand, if there is a choice of instrument with which the blowing open may have been done – that is, a choice between the burglar having used either the dynamite or the gelignite. We shall refer to this independent variable as the instrument variable.

Target sentences were presented on just one line of the screen, and were not split between two lines as shown here. Target sentence pairs were matched as closely as possible for length (in characters). There were eight versions of each example (2 Context \times 2 Instrument \times 2 Target). The design was a factorial repeated measures design incorporating a Latin square. Eight sets of stimuli were constructed, with only one version of each of the 32 examples appearing in any one given set. Each stimulus set was presented to a different group of subjects. No subject saw more than one version of the same example, each subject was exposed to all eight conditions, and each example was represented in each one of its eight versions. The 32 test items were embedded in 48 fillers which bore varying degrees of resemblance to the test items.

All materials were presented by computer, one sentence at a time. In those cases where the length of a context sentence exceeded 80 characters (the maximum permitted on one line of the screen) the sentence was presented on two lines. None of the target sentences exceeded 80 characters.

Subjects were instructed to press a button as soon as they had read and understood the sentence presented on the screen. This caused the next sentence in the sequence to appear. At the end of each sequence, subjects were presented with a simple yes/no question in order to test, and hence encourage, comprehension of the referential context. The following is a typical example:

(29) Did the burglar find a strongbox?

Sixty-four members of the University of Edinburgh student community were paid to participate in the experiment. All were native speakers of English and naive as to the purpose of the experiment.

6.2. Experiment 1 – Results

Reaction times falling more than 1.96 standard deviations away from the mean were replaced by the critical cut-off value. Fewer than 4.6% of the data

points were affected by this procedure. The overall results are summarised in Table 1. A three-way ANOVA (Context \times Instrument \times Target) showed that there was *no* effect of instrument on the obtained reading times ($F_1(1,56) = 0.98, p = .325; F_2(1,31) = 0.90, p = .349$), and nor were there any interactions between the instrument variable and any other. Consequently the data were collapsed across the instrument dimension, and new analyses performed. The new results are summarised in Table 2 and Figure 1.

Two-way ANOVAs (Context \times Target), by subjects and by materials, were performed on the collapsed data. A strong main effect of context was found: $F_1(1,56) = 85.74, p < .0001; F_2(1,31) = 41.51, p < .0001$; Min $F'(1,60) = 27.97, p < .005$. A strong main effect of target was also found: $F_1(1,56) = 56.05, p < .0001; F_2(1,31) = 27.00, p < .0001$; Min $F'(1,60) = 18.22, p < .005$. There was also a strong Context \times Target interaction: $F_1(1,56) = 22.53, p < .0001; F_2(1,31) = 10.77, p = .0026$; Min $F'(1,60) = 7.29, p < .005$.

Multiple Scheffé tests showed the following results (numbers in parentheses refer to the numbered points in Figure 1):

- (i) (4) NP-supporting/VP-attached was significantly greater than all other points ($p < .005$).
- (ii) (3) VP-supporting/VP-attached and (2) VP-supporting/NP-attached were not significantly different from one another ($p > .1$).
- (iii) (2) VP-supporting/NP-attached was significantly greater than (1) NP-supporting/NP-attached ($p < .005$).

6.3. Discussion of Experiment 1

Contrary to the predictions of the minimal attachment hypothesis, there were effects of referential context on both the VP- and NP-attached materials, and the minimally attached VP materials evoked *longer* response times than their nonminimally NP-attached counterparts. If minimal attachment

Table 1. *Experiment 1: Reading times per sentence (in centiseconds)*

Target	Context (No. of referents)			
	1	2	1	2
1 Instrument	2 Instrument	1 Instrument	2 Instrument	
VP-attachment	275.2	275.5	310.9	313.4
NP-attachment	272.7	276.8	262.0	265.0

Figure 1. *Experiment 1: Mean reading times in centiseconds, under two conditions of referential context: NP-supporting (2 referents) versus VP-supporting (1 referent).*

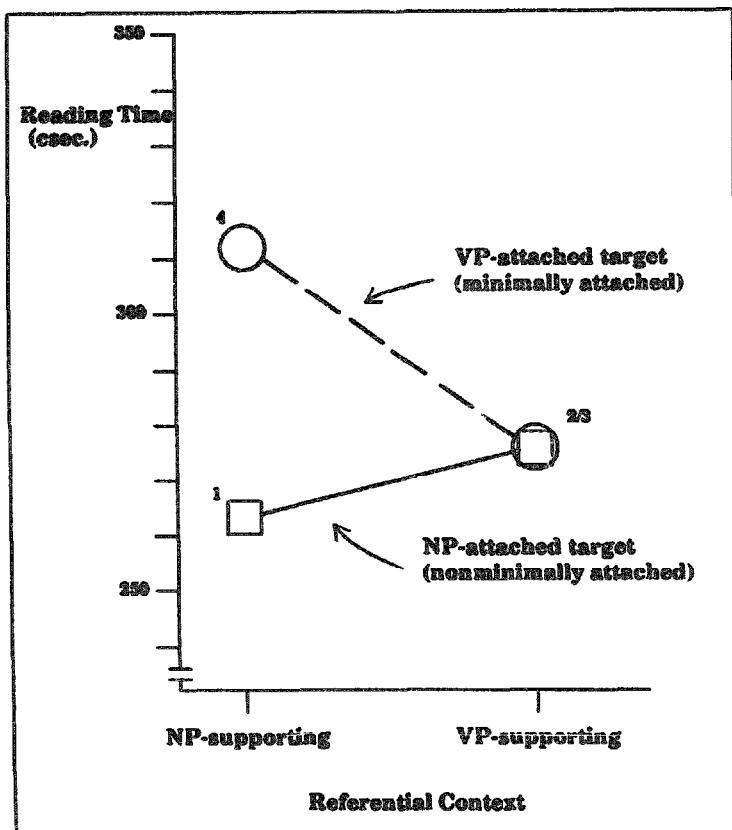


Table 2. *Experiment 1: Reading times per sentence (in centiseconds)*

Target	Context (No. of referents)	
	1	2
VP-attachment	275.3	312.1
NP-attachment	274.8	263.5

governed the operations of the processor, we would expect exactly the opposite result.

One possible objection to these results might be that they may not reflect reading time differences located at the crucially disambiguating prepositional phrase. Minimal attachment effects may have been located at these phrases, but may have been masked out by much later, post-interpretative, processing effects. In order to counter this objection, we performed a second experiment using phrasal reading times to provide an on-line measure of the processing difficulty associated with the disambiguating prepositional phrases. It has been demonstrated that phrasal reading times, using a subject-paced cumulative display, closely mirror gaze durations as measured by eye-movement studies (Ferreira & Clifton, 1986; Kennedy & Murray, 1984). The purpose of this second experiment is to show that the pattern of reading time differences found in Experiment 1 is indeed located at the disambiguating prepositional phrase, and is not an artifact of the off-line nature of the global reading time task. We defer further discussion of Experiment 1 until the General Discussion below.

6.4. Experiment 2 – Method

The same 32 context and target sentence pairs from Experiment 1 (omitting the instrument variable) were used with one minor modification: In Experiment 1, the contexts contained two prepositional phrases which modified NPs ("Once inside he saw that there was *a safe with a new lock* and *a safe with an old lock*") but none which modified VPs. The processing of the prepositional phrase "*with the new lock*" in the NP-attached target could have been facilitated by the fact that such modifications had already been encountered in the prior context. This would not have been the case for the phrase "*with the dynamite*" in the VP-attached target – there were no such modifications in either context. In this experiment, the two prepositional phrases in the contexts were replaced as follows:

(30) *NP-supporting context:*

A burglar broke into a bank carrying some dynamite.

He planned to blow open a safe.

Once inside he saw that there was a safe, *which had a new lock* and a safe *which had an old lock*.

VP-supporting context:

A burglar broke into a bank carrying some dynamite.

He planned to blow open a safe.

Once inside he saw that there was a safe *which had a new lock* and a strongbox *which has an old lock*.

The experimental items are listed in the Appendix. There were 48 filler items, and the design was the same as that reported for Experiment 1, with four versions of each example (2 Context \times 2 Target).

The experiment was a subject-paced reading task, with the first two sentences of each experimental item being presented sentence-by-sentence, and the second two phrase-by-phrase. (The reason for presenting the first two sententially was simply that it was felt that subjects would soon tire if the entire experiment were conducted phrasally.) Each new phrase appeared one character to the right of the preceding phrase, which remained on the screen. The target sentences were segmented as follows:

- (31) The burglar/blew open/the safe/with the dynamite (new lock)/and made off/with the loot.

As in Experiment 1, the two versions of the disambiguating prepositional phrase were matched for number of characters.

At the end of each sequence, subjects were presented with two yes/no questions in order to encourage comprehension. The following are typical examples:

- (32) Did the burglar find a strong box?
Did the burglar steal anything?

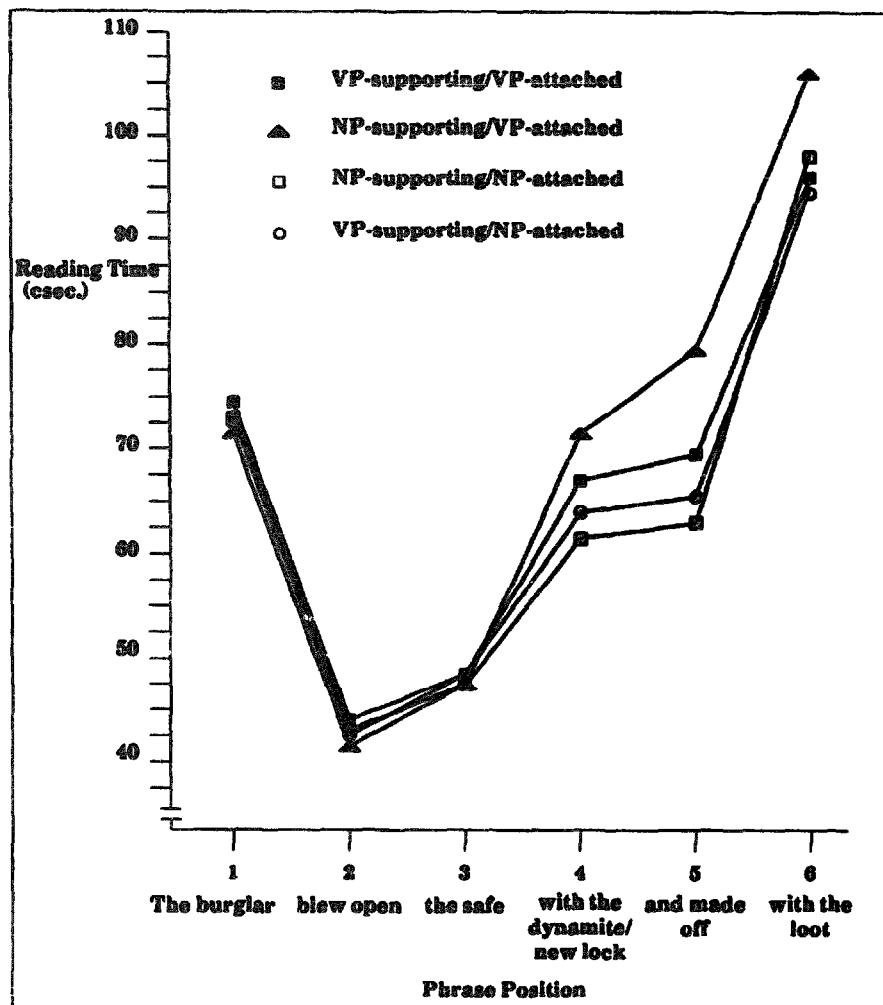
Thirty-two members of the University of Edinburgh student community were paid to participate in the experiment. All were native speakers of English and naive as to the purpose of the experiment.

6.5. Experiment 2 – Results

Reaction times falling more than 2.5 standard deviations away from the mean were replaced by the critical cut-off value. Fewer than 3% of the data points were affected by this procedure. The results are summarised in Figure 2.

Three-way ANOVAs (Context \times Target \times Phrase), by subjects and by materials, were performed on the data. In the following analyses, the context dimension is treated as follows: The context is felicitous if it supports the presuppositions of the target (NP-supporting for NP-attached targets, VP-supporting for VP-attached targets), and infelicitous if not. A main effect of context was found – targets in felicitous contexts were read faster than in infelicitous contexts: $F_1(1,28) = 7.39, p = .0111; F_2(1,31) = 8.75, p = .0059$. A main effect of target was also found – NP-attached targets were read faster than VP-attached targets: $F_1(1,28) = 33.23, p < .0001; F_2(1,31) = 19.01, p = .0001$.

Figure 2. Experiment 2: Mean reading times in centiseconds, by phrase.



There was also a Context \times Target interaction: $F_1(1,28) = 8.5, p = .0069$; $F_2(1,31) = 10.2, p = .0032$. There was also a strong main effect of phrasal position $F_1(5,140) = 95.91, p < .0001$; $F_2(5,155) = 164.57, p < .0001$, Min $F'(140,10) = 60.60, p < .005$. In addition, all interactions involving phrase were significant on both subjects and items analyses.

Following Ferreira and Clifton's (1986) findings, that the crucial differences in reading time occurred in the disambiguating region of the prepositional phrase, separate two-way ANOVAs (Context \times Target) were performed on just the data from these phrases (Phrase 4) – see Table 3 and Figure 3. There was a main effect of context (felicity): $F_1(1,28) = 6.44, p = .0170$; $F_2(1,31) = 4.35, p = .0454$. A main effect of target $F_1(1,28) = 14.28, p = .0008$; $F_2(1,31) = 10.19, p = .0032$. There was no Context \times Target interaction: $F_1(1,28) = 0.41$; $F_2(1,31) = 0.40$ – that is, the magnitude of the context effect is the same for both target conditions.

Multiple Scheffé tests showed the following results (numbers in parentheses refer to the numbered points in Figure 3):

- (i) (4) NP-supporting/VP-attached was significantly greater than all other points ($p < .005$).
- (ii) (3) VP-supporting/VP-attached was significantly greater than (2) VP-supporting/NP-attached ($p < .005$).
- (iii) (2) VP-supporting/NP-attached was significantly greater than (1) NP-supporting/NP-attached ($p < .05$).

6.6. Discussion of Experiment 2

Figure 2 clearly illustrates that the pattern of results obtained with global reading times is reflected by differences located on the critical disambiguating phrase (Phrase 4), and is not merely an artefact of differences occurring elsewhere in the target sequence. In fact, the global reading times from Experiment 1 are reflected almost perfectly in the phrasal reading times found using one of the on-line measures favoured by Ferreira and Clifton (1986) themselves. Given that the results so closely mirror those of Experiment 1, this experiment provides evidence against the suggestion that the pattern of results in the earlier experiment may have been artifactual on the fact that the contexts had contained prepositional phrases which, like the NP-attached target sentences, modified NPs, but had not contained any prepositional phrases which, like the VP-attached target sentences, modified VPs.

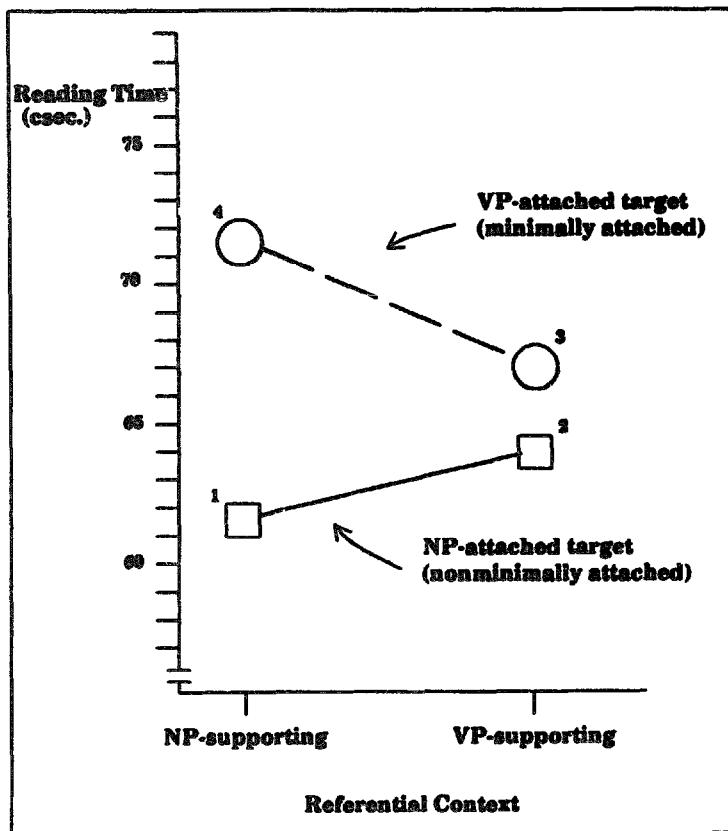
6.7. General discussion

Experiment 1 showed that nonminimally attached targets do not evoke the consistently longer reading times which would be expected on the noninteractive account. Nonminimally attached targets actually evoked consistently *faster* reading times.

Experiment 2 addressed a possible objection to the results of Experiment 1, namely that they did not represent differences in processing load *at the crucial disambiguation point*, but that they were due to post-interpretative processing effects located elsewhere, either post-phasally, or even post-sen-

Table 3. *Experiment 2: Reading times to Phrase 4 (in centiseconds)*

Target	Context (No. of referents)	
	1	2
VP-attachment	66.9	71.5
NP-attachment	63.9	61.4

Figure 3. *Experiment 2: Mean reading times for phrase 4 (the prepositional phrase) in centiseconds, under two conditions of referential context: NP-supporting (2 referents) versus VP-supporting (1 referent).*

tentially. The phrasal reading times from Experiment 2 exactly mirrored the results from Experiment 1 – all the reading time differences found in the earlier experiment were replicated on the critical disambiguating prepositional phrase (with the exception of one pair-wise comparison which just achieved significance in Experiment 2 – see below). The fact that the NP-attached targets produced faster reading times than their VP-attached counterparts must thus be due to differences in processing load at the disambiguating prepositional phrase.

In fact, we note that in Ferreira and Clifton's (1986) study, for a sentence such as "*Sam loaded the boxes on the cart (onto the van)/(before his coffee break)*," the first pass reading times to the phrase "*the boxes on the cart*" in the NMA-NMA condition also appear to have been faster than reading times in this same region for the MA-MA condition. This observation, coupled with the earlier observation that the differences they observe at the final "disambiguating" phrase may have been due to factors other than syntactic anomaly, suggests that their results and our own are not as different as might at first appear.

The question is whether these findings can be reconciled with a theory of minimal attachment. We could start by proposing that minimal attachment does select the initial analysis, and that the observed effects of context are due only to the referential anomaly of the VP-attached target in the NP-supporting context, and the anomaly of the NP-attached targets in the VP-supporting context. But such a proposal fails to explain the effect of target construction, which is in the opposite direction to that predicted by minimal attachment.

Alternatively, it might be argued that the effect of context on target construction only reflects the processor's eventual choice of analysis – its initial choice having been determined by minimal attachment, and its final choice having been arrived at once the minimally attached analysis was found to be incompatible with the context (Ferreira & Clifton, 1986; Frazier, 1987). We have already indicated the theoretical problems which we believe are implicit in any such proposal. But in any case, such a view is again incapable of explaining the empirical observation that the minimally attached sentences, which require no syntactic reanalysis, take *longer* to process than the nonminimally attached sentences which do require reanalysis. This same effect was found in an earlier experiment which also included a "null" context condition (Altmann 1985, 1987). The minimal attachment predictions were borne out in the null context, but not elsewhere. Furthermore, all reading times in this experiment were significantly reduced once a context was provided ($p < .005$ on multiple Scheffé tests). Holmes (1979) reports a similar effect of context on reading times to subject/object relatives.

Our argument that the present results are incompatible with the minimal attachment strategy rests on the observation that the NP-attached sentences were processed faster than the VP-attached sentences. However, it might seem surprising that the processing time in felicitous contexts for NP- and VP-attached targets are not equal. This might appear to suggest that there is some contextual infelicity associated with the VP attachment. Experiment 1 examined this possibility, by investigating the effect on VP attachment of introducing two instruments with which to modify the action denoted by the verb, so that the eventual VP modification would not provide redundant information. However, whether there was just one instrument (leading to redundancy in the VP-attached target), or whether there were two, made absolutely no difference to the obtained reading times. This does not preclude the possibility of there having been some residual infelicity in the materials, but it is hard to see how the VP modification could be made more felicitous if not by this manipulation.

We believe that the explanation for the difference between the two targets lies instead in the different processes that must be initiated to assess the plausibility of each attachment. In the case of the VP-attached targets, the plausibility of the modification is assessed relative to the subject's *general world knowledge*. In the case of the NP-attached targets, however, it is the subject's *discourse model* which must be accessed and searched. Given the open-ended nature of the former, and the circumscribed nature of the latter, one might reasonably expect the discourse model to contain less information, in absolute terms, than the knowledge base containing world knowledge. Consequently, one would expect the decision process to be relatively faster for the circumscribed discourse model than for open-ended world knowledge.

This conjecture is supported by the following observation. It is a corollary of such an account that the difference between the alternative analyses should be decreased if the alternative analysis to the restrictive NP attachment did *not* require accessing general world knowledge. Just such a case occurs with the relative/complement materials used by Crain (1980). Altmann (1988) reports a reading time study using similar materials in which there were *no* residual differences in reading times to relative clause and complement clause target sentences once the inferencing required to process the target sentences – see above – was controlled. The corollary would thus appear to be confirmed.

The difference between NP- and VP-attached targets in the infelicitous conditions is presumably due to the continuing influence of the fact that under the only possible grammatical analysis, the VP-attached target fails to refer at all, whereas the NP-attached target does refer, albeit redundantly. Evidence for this point of view is provided by the fact that the increased

reading times in the infelicitous VP-attached condition continue through Phrases 5 and 6 (see Figure 2), whereas the increased reading time at Phrase 4 to the infelicitous NP-attached condition continues through to Phrase 5, but disappears by the final phrase.

Finally, we must consider why the infelicitous NP target takes less time to process (at least in Experiment 2) than the felicitous VP target. In both cases, the NP attachment analysis is initially ruled out and the VP attachment is attempted first, and it might seem that the NP-attached target would necessarily take longer. However, we should not assume that ruling out an implausible analysis takes as long as establishing all the implications of a plausible one. The former requires no modifications to the discourse model, whereas the latter requires the addition of new information.

The preceding discussion is no more than a post hoc analysis of certain details of the data, and is merely intended to show that these details are not inconsistent with the general model we propose. Subsequent research is required to investigate the further assumptions we make here. In the absence of any truly on-line measure, it is in the end impossible to factor out processing effects due to syntactic (re)analysis and processing effects which reflect interpretation and integration. Crain's (1980) use of the incremental grammaticality judgement task is one way of distinguishing purely syntactic effects leading to syntactic misanalysis from mere semantic anomaly. In the light of his results, and those reported here, it would nevertheless appear that the interactive hypothesis and the principle of referential support is a more adequate account of the resolution of local attachment ambiguities than are minimal attachment and other equivalent structurally based strategies (e.g., Ford et al., 1983; Wanner, 1980).¹⁹

7. Conclusions

There are two ways out of the paradox that the serial non-interactive model runs into when faced with the present results. One is to assume that the

¹⁹Janet Fodor has pointed out that our results may be confounded by a recency effect: The lexical items "new lock" which appear in the NP-attached target appeared more recently in the prior context than did the item "dynamite," which appears in the VP-attached target. The result of some such priming effect would be to favour (and hence reduce reading times to) NP-attached targets. If the difference between the two targets in their respectively felicitous contexts is indeed due to this factor, then it is surprising that the effect should persist into the following phrase ("and made off"), and that it is not masked out by the increased reading times found in the global reading task used in Experiment 1. Further research is required in order to assess the magnitude, if any, of such effects, and the apparently rather remote possibility that the results we report are entirely due to these effects.

context can somehow be accessed without the benefit of syntax at all, and an alternative syntactic analysis thereby be proposed. The advocates of serial autonomy presumably do not intend to claim that the state of the context can predictively affect the future operations of some kind of backtracking processor, ensuring that it succeeds only when the context warrants it. Such a proposal would amount to incorporating not only interaction, but the strong interaction. However, the only alternative seems to be to assume that the "thematic" processor invoked by Rayner et al. (1983) is not only capable of accessing the discourse model, without using alternative syntactic analyses, but is also capable of constructing those alternative syntactic analyses in its own right. We take it that this is what Ferreira and Clifton have in mind when they refer to a thematic processor which "operates on the output of the syntactic processor (verbs and their arguments) and, if necessary, proposes alternative analyses that are more semantically or contextually appropriate" (1986, p. 365). Such syntax-free semantic processors have on occasion been proposed – for example, by Schank (1975). However, such proposals are the central target of Fodor's (1983) critique, and sit uneasily with the claim that the non-interactive theory is modular (Clifton & Ferreira, 1987; Frazier, 1984).

A far simpler way to resolve the paradox appears to be to abandon serial autonomy altogether and to adopt the parallel weakly interactive model advocated here, embodying the principle of parsimony and its corollary the principle of referential support. Nothing in this proposal conflicts in any way with the modularity hypothesis. While an unusually high degree of parallel structure is claimed to hold between syntax, processing, semantics and even the inference system, with a consequent reduction of the theoretical burden upon innate specification, these components are all formally and computationally autonomous and domain-specific. While the modules can communicate, their communication is restricted to a channel of the narrowest possible bandwidth. The interpretive component under the weak interactive hypothesis may need no more than one bit, the capacity to say yes or no, in order to direct the syntactic processor to continue or abandon a particular analysis. Nobody has ever seriously proposed that any *less* communication than this was implicated between syntax and semantics in human language processing. The controversy has rather centred upon *when* in the course of an analysis this channel could be used. The present claim that interpretation can deliver a verdict to the syntactic processor with great fineness of grain – say, after every word – does not compromise the informational encapsulation and consequent theoretical wholesomeness of that processor, any more than a theory which says that the same information can only be delivered at the closure of a clause.

Appendix

The following are the VP-supporting contexts and target sentences from Experiment 2. The NP-supporting context is given for the first material only:

A burglar broke into a bank carrying some dynamite. He planned to blow open a safe. Once inside he saw that there was a safe which had a new lock and a strongbox which had an old lock.

A burglar broke into a bank carrying some dynamite. He planned to blow open a safe. Once inside he saw that there was a safe which had a new lock and a safe which had an old lock. The burglar / blew open / the safe / with the dynamite (new lock) / and made off / with the loot.

A mechanic walked up to a car carrying a monkey wrench. He thought he'd have to change a tyre. On examining the car he found that there was a tyre which had a faulty valve and a fuel line which had a small hole in it. The mechanic / changed / the tyre / with the monkey wrench (faulty valve) / but it took / a long time.

A convict escaped from his cell clutching a knife. He was prepared to attack a warder if necessary. Once outside he saw a warder holding a bunch of keys and a policeman holding a long truncheon. The convict / suddenly lunged at / the warder / with the knife (keys) / before / running off.

A schoolteacher walked into class carrying a bamboo cane. He sadistically hoped that he would have to beat a boy. On entering he saw that a boy who had a broken leg and a girl who wore glasses didn't stand up for him. The schoolteacher / beat / the boy / with the bamboo cane (broken leg) / but the boy / didn't cry out.

John had bought a diamond stylus for his stereo. He planned to play a record. He'd been given a record which had a lot of noisy crackle and a cassette which had a lot of hiss. John / decided to play / the record / with the diamond stylus (noisy crackle) / but it sounded / terrible.

A historian was working in the British Museum holding a magnifying glass. He'd sat down to study a map. On his desk there was a map which had an appalling tear and a manuscript which seemed in perfect condition. The historian / had to study / the map / with the magnifying glass (appalling tear) / so as / to value it.

An artist was working at a table holding a long brush. He had a sudden premonition that he was going to knock over a bottle. On the table there was a bottle containing some paint and a small jug filled with water. The artist /

accidently knocked over / the bottle / with the brush (paint) / and swore / loudly.

A window cleaner was climbing his ladder clutching a cloth. He'd been asked to wipe a window. Once up the ladder he saw that there was a window which had a lot of dirt on it and a skylight which was relatively clean. The window cleaner / wiped / the window / with the cloth (dirt) / while singing / to himself.

A workman climbed down a manhole carrying a saw. He expected to have to cut through a valve. Down the manhole he found a valve which had a lot of rust on it and a section of pipe which had been leaking gas. The workman / cut through / the valve / with the saw (rust) / before fitting / a new one.

A man was walking up and down a dark street carrying an iron crowbar. He hoped to break into a shop. He noticed that there was a shop which had a broken window and a post office which was fitted with a burglar alarm. The man / broke into / the shop / with the iron crowbar (broken window) / but nobody / saw him.

A monkey had been trained to eat using a fork. It was supposed to eat a banana. It was given a banana which had a bruise on it and an apple that was perfect. The monkey / ate / the banana / with the fork (bruise) / much to everyone's / surprise.

A caretaker was walking along a corridor carrying some nails. He'd been told to repair a door. He saw a door which had a large crack in it and a locker which wouldn't shut properly. The caretaker / repaired / the door / with the nails (crack) / and then took / a tea break.

A skinhead was walking along a street carrying a large knife. He was planning to attack a policeman. He eventually saw a policeman who had a large scar on his face and a policewoman wearing spectacles. The skinhead / suddenly attacked / the policeman / with the knife (scar) / and then / ran off.

A dressmaker was working on a dress using a pair of scissors. She had to cut some material for the pockets. She had a piece of material which had a pattern on it and a piece of leather which was plain. The dressmaker / cut / the material / with the scissors (pattern) / and then went / to have lunch.

A fireman was running to the scene of a fire carrying a heavy axe. He had to smash down a door. When he got to the scene of the fire he found a door which had a very rusty lock and a window which was nailed shut. The fireman / smashed down / the door / with the heavy axe (rusty lock) / but smoke / overcame him.

A little girl borrowed from the kitchen a bread knife. She wanted to cut an orange into pieces. She found in the fruit bowl an orange which had a very thick rind and a tangerine which had a thin rind. The little girl / tried to cut / the orange / with the bread knife (thick rind) / but to no / success.

A chemist was adjusting a bunsen burner. He was about to heat up a solution. On his bench there was a solution which had blue crystals in it and a powder containing red dye. The chemist / heated / the solution / with the bunsen burner (blue crystals) / but the gas / went out.

A drunk was walking along a street wielding an empty bottle. He felt like smashing a window. In front of him he saw a window made of stained glass and a glass door which had bars covering it. The drunk / smashed / the window / with the empty bottle (stained glass) / and staggered off / laughing.

A vet went into an animal cage carrying a dart gun. He had to tranquillise a lion. Inside the cage there was a lion that had a big mane and a puma that didn't have any mane at all. The vet / tranquillised / the lion / with the dart gun (big mane) / and then / examined it.

A tribesman was running through the forest carrying a long spear. He intended to kill a lion. On arriving at a clearing he found a lion which had very sharp teeth and a tiger which had strange coloured paws. The tribesman / killed / the lion / with the long spear (sharp teeth) / and carried it / back home.

A demolition man was on his way to work in his bulldozer. He'd been told to go to a particular address to demolish a house. Once at the address he found a house which had an ornate fountain in its garden and a church covered in fine carvings. The man / demolished / the house / with the bulldozer (fountain) / but it wasn't / the right one.

A furniture restorer was getting out some paint stripper. He'd been asked to strip a cabinet. In his workshop there was a cabinet which had brass hinges and a chest which had aluminium hinges. The restorer / stripped / the cabinet / with the paint stripper (brass hinges) / and then / waxed it.

A doctor walked into a waiting room carrying a stethoscope. He'd arranged to examine a woman patient. In the waiting room there was a woman who had a temperature and a man who seemed to have stomach pains. The doctor / examined / the woman / with the stethoscope (temperature) / but couldn't / help her.

A secretary was sitting at her desk on which was a manual typewriter. She was told to type up a report. She was handed a report covered in diagrams and a letter written in different colours. The secretary / typed up / the report / with the typewriter (diagrams) / and then went / to lunch.

A burglar was trying to break into a house and had a credit card in his hand. He wanted to open a door. He found a door which had a faulty lock and a window which had a cracked frame. The burglar / opened / the door / with the credit card (faulty lock) / and quickly / slipped inside.

A cleaning lady started on her morning rounds carrying a brush. She would have to clean a corridor that morning. In the building there was a corridor which had lots of plants along it and a lounge which had lots of pictures on the walls. The cleaning lady / cleaned / the corridor / with the brush (plants) / and then / lit a cigarette.

A woman was looking through some clothes while holding some darning wool. She needed to repair a sock. She found in the pile of clothes a sock which had a hole in it and a jumper which was getting a bit thin. The woman / repaired / the sock / with the wool (hole) / but hurt her finger / in the process.

A little boy was playing in a garden kicking a ball about. He was warned that he'd probably break a window. Close to him was a window which had a crack in it and a statue that looked very old. The boy / did accidentally break / the window / with the ball (crack) / and ran home / crying.

A chef was working in his kitchen by a food mixer. He was preparing to make a cake. Somebody came into the kitchen and asked him to bake a cake containing dried fruit and a pie topped with jam. The chef / started to make / the cake / with the food mixer (dried fruit) / but ran out / of eggs.

A gardener was working in a garden adjusting a chainsaw. He needed to cut down a tree. He was standing by a tree covered in greenfly and a tall shrub which had been dead a long time. The gardener / cut down / the tree / with the chainsaw (greenfly) / but was v 'y sad / about it.

A detective was sitting at a window holding a set of binoculars. He'd been asked to watch a woman. In the room he was looking into there was a woman holding a revolver and a man holding a grenade. The detective / watched / the woman / with the binoculars (revolver) / and then made / a phone call.

A man was decorating a room and had with him a large brush. He'd decided to paint a door. In the room there was a door which had a large crack in it and a window which wouldn't close. The man / decided to paint / the door / with the large brush (crack) / and do the window / later.

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Résumé

Les théories psychologiques de traitement des langues naturelles ont habituellement supposé que le processeur de phrases résolvait les ambiguïtés syntaxiques locales en sélectionnant une seule analyse sur la base de critères structurels comme le principe de l'"attachement minimal" de Frazier (1978). D'après ces théories, les analyses alternatives seront seulement envisagées si l'analyse initiale se révèle être inconsistante avec le contexte. (voir aussi ...). Cependant, une autre hypothèse est possible: si les phrases sont comprises de façon progressive, plus ou moins mot à mot (Marslen-Wilson 1973, 1975), alors le traitement syntaxique peut en principe exploiter le fait que les interprétations sont disponibles, et les utiliser de façon "interactive" pour sélectionner parmi les différentes analyses syntaxiques en fonction de leur plausibilité par rapport au contexte. Cet article considère les architectures possibles pour de tels processeurs de phrases interactifs et progressifs, et argumente en faveur d'une architecture telle que les différentes analyses sont offertes en parallèle, et sont distinguées par un appel immédiat au processus de compréhension, selon une interaction sélective ou "faible", par opposition à l'interaction directive ou "forte". Nous notons qu'une telle architecture ne compromet en aucune façon l'hypothèse de modularité de Fodor (1983). Nous faisons la revue les données expérimentales présentées comme suggérant que le système de traitement des phrases humain était non-interactif et reposait sur des critères purement structurels. Nous présentons de nouveaux résultats qui semblent incompatibles avec la proposition structurelle, et qui soutiennent l'hypothèse interactive. Nous suggérons des raisons qui permettent d'écartier les résultats contraires obtenus auparavant, et concluons que le mécanisme de traitement des phrases humain résoud les ambiguïtés de type modifieur-attachement en ayant recours à des informations contextuelles et référentielles de plus haut niveau sous l'interaction faible.