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## COMPREHENDING SENTENCES WITH MULTIPLE FILLER-GAP DEPENDENCIES

Lyn Frazier and Charles Clifton

1. Introduction

In this paper, we will discuss the processing of sentences with multiple "filler-gap" dependencies. Processing of any sentence requires that the language user be able to assign meaning in a way that is consistent with the rules of his language. In "filler-gap" sentences such as (1),

1. This is the girl<sub>i</sub> the teacher<sub>j</sub> wanted \_\_\_<sub>j</sub> to talk to \_\_\_<sub>i</sub>.

this includes recovering the dependency between the noun phrase the girl and the position following the preposition to, and the dependency between the noun phrase the teacher and the position preceding the infinitival verb phrase. Most versions of the "revised extended standard theory" (e.g., Chomsky, 1980) hypothesize that lexically null categories, or "gaps," occur in sentences like (1). We will assume this approach (although alternative linguistic analyses of such constructions will be considered later) and, for convenience, will refer to dependencies between a lexically specified phrase and a lexically null category (e.g., in (1), between the teacher<sub>j</sub> and \_\_\_<sub>j</sub>) as "filler-gap" dependencies.

Such dependencies pose several interesting problems for the sentence parsing mechanism. The parser must identify fillers and gaps but has no clear overt markers in the lexical string<sup>1</sup> to help it do so. Further, gaps may be arbitrarily far removed from their fillers, subject to special constraints on the type of material intervening between filler and gap (cf. Ross, 1967). The parser must also have some mechanism for resolving temporary ambiguities with respect to the identification and assignment of fillers and gaps. Note, for example, the ambiguity that persists up to the last word in (1), which should be compared with (2):

2. This is the girl<sub>i</sub> the teacher wanted \_\_\_<sub>i</sub> to talk.

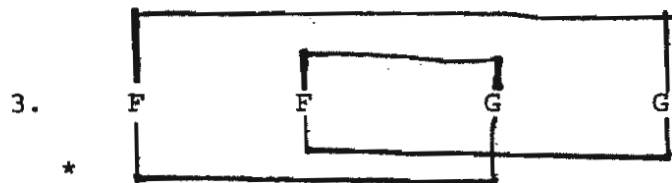
Finally, the parser must be able to discriminate among apparent violations

of well-formedness constraints, e.g., the constraint that a prepositional phrase must contain a noun phrase object might appear to be violated if the noun phrase position is occupied by a gap, or if the parser has misanalyzed some earlier portion of the sentence, or if the apparent violation is real and the sentence ungrammatical.

Our primary purpose here is to investigate some issues concerning how fillers are assigned to gaps. We will provide evidence for a particular strategy which readers seem to follow in initially assigning fillers to gaps. We will also provide evidence concerning when in the course of comprehending a sentence a reader uses such different kinds of information as phrase structure information, subcategorization information, and semantic control information.

### 1.1 Assignment strategies

We propose that an analysis of the parser's operation can provide an explanation of a fact common to many languages. Intersecting assignments of dependencies between fillers and gaps seem to be prohibited in cases where the rules of the language permit either a nested or a disjoint assignment. In the schematic example (3), the upper (nested) bracketing is permitted, while the lower (intersecting) bracketing is prohibited.



Fodor (1978) provides the most extensive analysis of this observation, and proposes a no-ambiguity constraint, the "Nested Dependency Constraint," for English sentences with multiple fillers and gaps. The ungrammaticality of (4b) and the availability of only the silly reading of (4c), demonstrate the constraint.

4. a. Which pot<sub>i</sub> is this soup<sub>j</sub> easy to cook \_\_\_<sub>j</sub> in \_\_\_<sub>i</sub>?
- b. \*Which pot<sub>i</sub> is this soup<sub>j</sub> easy to cook \_\_\_<sub>i</sub> in \_\_\_<sub>j</sub>?
- c. Which soup<sub>i</sub> is this pot<sub>j</sub> easy to cook \_\_\_<sub>j</sub> in \_\_\_<sub>i</sub>?

Some other languages do permit intersecting dependencies as well as nested dependencies, perhaps as an unpreferred or specially marked case (cf. Engdahl 1979, 1980a, 1980b, for a discussion of Swedish and Norwegian; Hankamer 1980, and Kuno ms. for a discussion of Turkish; and Reinhart 1979, for a discussion of Hebrew). We are aware of no language that freely permits intersecting dependencies but imposes restrictions on nested dependencies.

It is very tempting to explain the Nested Dependency Constraint in terms of processing strategies or constraints. In the common case where

all fillers precede all gaps (cf. 3), a nested assignment obtains if the parser fills each gap it encounters with the most recent potential filler. Superficially, the parser may be said to follow a Most Recent Filler strategy. Various theorists have proposed mechanisms that might underly the Most Recent Filler strategy. Fodor (1978) suggested that the preference for nested dependencies comes about because the parser always tries to construct uninterrupted stretches of well-formed deep structure. If the parser makes an intersecting assignment of dependencies, the filler (e.g., the second filler in illustration 2) not yet assigned after the first gap will interrupt the otherwise potentially well-formed stretch of deep structure. Fodor later abandoned her earlier account (1980), and suggested (personal communication) that the parser follows a strategy of assigning the most recent filler to a gap as a way of meeting the grammatical constraint that fillers must c-command (Reinhart, 1976) their gaps. In a right-branching language such as English, the first of two fillers will typically c-command a larger portion of a sentence than will the second, and thus the parser will maximize its chances of finding legitimate gaps for both fillers if it attempts to assign the lower (second) of two fillers to the first gap it encounters.

~~Wanner and Maratsos (1978) provided a contrasting account, within~~ an ATN model of relative clause processing. They suggested that relative clauses can be processed just as non-embedded sentences are, if it is assumed that noun phrases whose grammatical function cannot yet be determined are placed in a special push-down memory store, the "HOLD" buffer. The head of a relative clause, such as "the witch" in (5a) and (5b), will be placed in the HOLD buffer when the relative pronoun is encountered.

5. a. The witch<sub>i</sub> who \_\_\_<sub>i</sub> despised sorcerers frightened little children.
- b. The witch<sub>i</sub> whom sorcerers despised \_\_\_<sub>i</sub> frightened little children.

At some point, the parser will not receive an obligatory constituent in the lexical string. It will then check the HOLD buffer, and if it contains a constituent of the correct syntactic category, the constituent will be retrieved from HOLD and assigned to this position in the sentence. Since the HOLD buffer is a push-down store, the most recent filler will always be on top, and will therefore be retrieved to fill a gap.

Solan (1980) suggested that structural factors, not simple recency, govern the choice of a filler for a gap. He claimed that the parser attempts to fill a gap from the nearest S-domain to its left. The parser abides by the strategy of moving right-to-left past the first S boundary: ...NP<sub>i</sub>...[S...gap<sub>i</sub>... in finding a gap.<sup>2</sup> Solan also noted that pronoun interpretation, like filler-gap assignment, may abide by something like his proposed "Local Parsing Strategy." This is clearly an area that warrants further investigation especially given the finding that children initially treat pronouns and gaps in a similar manner; Chomsky, 1969; Solan, 1980;

Lust, 1978. However, the issue is beyond the scope of the present investigation.

We propose yet another account of the preference for nested dependencies, a cautious extension of the Most Recent Filler hypothesis, which we term the "Saliency" hypothesis. The Saliency hypothesis claims that readers and listeners initially assign an identified gap to the momentarily most salient filler. The saliency of a filler reflects primarily the amount of attention it attracts, and presumably is determined by a number of factors. Recency is one such factor. The most recent filler is, other things being equal, the most salient one. In spoken language, stress may be another such factor. Stressing a more distant filler may make it more salient, facilitating comprehension of sentences such as (2) which require the more distant filler to be assigned to the left-most gap. Stressing the more recent filler may increase its saliency and increase the ease of comprehending sentences such as (1) in which this filler should be assigned to the first gap. (Engdahl, 1980b, tentatively suggests that contrastive stress on the first filler may be a necessary condition of acceptability of intersecting filler-gap dependencies in Norwegian.) The presence of a relative pronoun may affect saliency. Intuitively, the presence of the relative pronoun in (6) makes this sentence easier to understand than the otherwise identical (2).

6. This is the girl who the teacher wanted to talk.

The relative pronoun may highlight "the girl" as a potential filler. Presumably, pragmatic factors may affect the saliency of fillers, and discourse factors may, also (cf. Cutler & Fodor, 1979).

We find the Saliency Hypothesis attractive, because it would explain why a wide variety of factors influence filler-gap assignments, and because it may prove to be a special case of an even more general parsing principle. Frazier & Fodor (1979) argue that there is a general tendency for the human sentence parsing mechanism to adopt the first analysis available to it, and provide some compelling arguments for the generality of this tendency in their discussion of such parsing preferences as minimal attachment and local attachment. We can hypothesize that salient potential fillers are preferentially assigned to gaps because highly salient fillers are retrieved from memory, and assigned to gaps, most rapidly. The Saliency Hypothesis may, at its roots, amount to the hypothesis that the most quickly retrieved filler is the filler which the parser prefers to assign to an identified gap. This statement of the hypothesis skirts some critical questions. Consider, for instance, the case where a noun phrase can be retrieved from memory very rapidly, but had occurred in a sentence in a position which would not enable it to serve as a filler. We consider it an unresolved question as to whether the parser would ever tend to assign that noun phrase to a NP gap it encountered.<sup>3</sup> More generally, we consider it an open question whether factors other than availability in memory contribute to the saliency of a phrase as a potential filler.

While we attempt to provide some evidence for the Saliency hypothesis in the research we report here, our primary goal is to obtain evidence about the existence of a general tendency to assign a gap to the most recent filler. We hypothesize that readers initially assign the

most recent potential filler to an identified gap in an on-line fashion, but must reanalyze a sentence and correct the filler-gap assignment if later information proves the initial assignment to be incorrect. In (2), repeated for convenience, we hypothesize that readers initially assign "the teacher" to the potential gap before

2. This is the girl<sub>i</sub> the teacher<sub>j</sub> wanted \_\_\_<sub>i</sub> to talk.

"to talk", but then must change this assignment when they reach the end of the sentence without having assigned the obligatory filler, "the girl", to a gap. We report the results of an experiment in which we measured the time taken to comprehend sentences whose proper comprehension either followed, or violated, the strategy of assigning a gap to the most recent filler. Before describing the experiment, however, we must consider the topic of what information the parser might use to correct initial filler-gap assignments, and when it uses that information.

### 1.2 The Use of Semantic Control Information

Sentences such as (1) and (2) are temporarily ambiguous up to the last word of each sentence; verbs such as "wanted," "asked," and "chose" are ambiguous in their control properties, in that they permit either subject control of a gap in embedded subject position (as in (7a)), or the presence of a lexically specified noun phrase in this position (as in (7b)).

7. a. The teacher wanted to talk.  
b. The teacher wanted the girl to talk.

Consider now the use of such a verb as the matrix verb of a relative clause, such as (1) and (2) (repeated here).

1. This is the girl the teacher wanted to talk to.  
2. This is the girl the teacher wanted to talk.

When the relative clause contains an obligatory gap to which the head noun phrase of the relative clause must be assigned (as in (1)), such verbs require their subject to control the interpretation of the gap before the complement verb. However, if the remainder of the relative clause does not contain a gap (as in (2)), then the head of the relative clause must be assigned to the gap before the complement verb. The Most Recent Filler strategy suggests that the subject of the ambiguous verb will initially be assigned to the gap before the complement verb, and that this assignment is revised only when it becomes clear that the relative clause contains no other gap.

Other verbs are unambiguous in their control properties. Examples (8a) and (8b) contain a verb of obligatory subject control, while (9a) and (9b) contain a verb that obligatorily takes a lexically specified noun phrase in object position.

8. a. The teacher decided to talk.  
b. \*The teacher decided the girl to talk.

9. a. \*The teacher forced to talk.  
b. The teacher forced the girl to talk.

When used in relative clauses (10a and b) such verbs provide information that blocks the temporary ambiguity seen in (1) and (2).

10. a. This is the girl<sub>i</sub> the teacher<sub>j</sub> decided \_\_\_<sub>j</sub> to talk to \_\_\_<sub>i</sub>.  
b. This is the girl<sub>i</sub> the teacher<sub>j</sub> forced \_\_\_<sub>i</sub> to talk.

Listeners and readers evidently use such semantic control information in understanding sentences. They realize that such sentences as (11),

11. a. \*This is the girl the teacher decided to talk.  
b. \*This is the girl the teacher forced to talk to.

which violate semantic control properties of their verbs, are ungrammatical. However, the real question is, when in the course of understanding a sentence do they use the semantic control information? In particular can it block the application of the Most Recent Filler strategy, or can it be used only after the application of that strategy, to correct misassignments made? Intuitively, the former seems to be the case. Sentence (10b) seems easier to understand than sentence (2), even though both violate the Most Recent Filler strategy.

However, it is possible that people use semantic control information only after they use lexical category information in applying the Most Recent Filler strategy. They may first temporarily assign "the teacher" to the gap after "forced" in (10b), and only later, when semantic control information becomes available, reassign "the girl" to that gap. No adequate experimental evidence bears on the question of when semantic control information is used. Wanner and Maratsos (1978) report one experiment whose interpretation demands that a filler be assigned on the basis of the semantic control information of a verb, but they interrupted sentence presentation for a five second period (during which a secondary task was presented), so that their measure (a measure of memory capacity) cannot be taken to reflect normal on-line processes.

The experiment reported here was designed to show the effects of the Most Recent Filler strategy by using a measure of processing time at the end of a sentence, when any corrections of inappropriate filler-gap assignments had to be made. It used sentences whose semantic control properties were ambiguous (such as (1) and (2)), which clearly should reflect the operation of the Most Recent Filler strategy, as well as sentences with verbs of unambiguous control (e.g., 10a and 10b), where the operation of the Most Recent Filler strategy should be seen only if it is used prior to the use of semantic control information.

### 1.3 The Experiment

We measured the ease of understanding relative clause sentences that obeyed or did not obey the Most Recent Filler strategy (e.g., (1) versus



(2)), to determine whether sentences that obey the strategy would be understood more quickly, with more confidence, and greater accuracy. We refer to sentences such as (1), which obey the strategy, as "Recent Filler" sentences, and sentences such as (2), which do not, as "Distant Filler" sentences, and thus predict that Distant Filler sentences will be harder to understand than Recent Filler sentences. We also compared sentences with and without an overt relative pronoun, as a test of the Saliency hypothesis. If presence of the relative pronoun makes the first filler more salient, it should aid comprehension of Distant Filler sentences while hurting comprehension of Recent Filler sentences. Finally, we tested Distant Filler and Recent Filler sentences using unambiguous verbs as the matrix verb of the relative clause, such as (10a) and (10b), as well as sentences with ambiguous verbs in an effort to determine when semantic control information is used. If readers initially follow the Most Recent Filler strategy in assigning fillers to gaps even when the unambiguous verb of a Distant Filler sentence clearly prohibits such an assignment, then Recent Filler sentences with unambiguous verbs should still be comprehended more easily than Distant Filler sentences with unambiguous verbs. If readers use information about semantic control properties at the same time they use information about lexical categories and permissible phrase structure configurations, in a fully interactive parallel fashion (cf. Mraslen-Wilson, 1975; Mraslen-Wilson and Tyler, 1980), the difference between Recent Filler and Distant Filler sentences should disappear when unambiguous verbs are used. Readers should always make the right initial assignment of fillers to gaps in these sentences.

One additional experimental manipulation was employed, as a control against an experimental artifact. Note that the Recent Filler sentences end in a preposition, while the Distant Filler sentences do not. In our experiments, we presented the words of a sentence one at a time, approximately three per second, and measured comprehension time from the time the last word in a sentence is presented. (We used this procedure because pilot studies convinced us it provided a sensitive and effective measure of comprehension difficulty, at least near the end of a sentence.) Perhaps a preposition is read more rapidly than other words, especially content words (Bradley, 1978), or perhaps a preposition more clearly signals the end of a sentence than other words (even though all sentence-final word displays included a period). Such effects would artifactually speed comprehension of Recent Filler sentences. To check this possibility, we included Distant and Recent Filler sentences which ended with a temporal adverbial phrase (e.g., "yesterday," "next week," or "after the ball"). Such phrases must follow the preposition in our Recent Filler sentences, and including them makes Distant and Recent Filler sentences end identically. Including a final adverbial phrase also allowed us to test the possibility that subjects could do some reanalysis of incorrect filler-gap assignments during the presentation of the phrase. Since the phrase unambiguously signals that no preposition is forthcoming if one has not already appeared, and thus the sentence must be a Distant Filler sentence, subjects could begin to correct the effects of the Most Recent Filler strategy and assign the head of the relative clause to the gap before the complement verb. If they were to do so, then the difference between Distant Filler and Recent Filler sentences could be reduced when a final adverbial phrase was present.



## 2. Experimental findings

### 2.1 Method

Fifty-nine college students were tested in a sentence comprehension time task. Ten subjects were rejected because of equipment failure or experimenter error, and one for not being a native speaker of English. A subject saw a total of 96 sentences (after eight practice sentences) presented on a computer-controlled video display. Each word of each sentence was presented for 300 msec at the same position of the display, with a 50 msec blank interval between words. A period was displayed with the last word of a sentence. Subjects were instructed to pull one trigger of a response console with the right index finger if they intuitively felt they understood a sentence, and a different trigger, with the left index finger, if they failed to understand a sentence. They were instructed to make their comprehension decision as soon as possible after the end of a sentence, and were asked to make their decision on a quick, intuitive basis, without reviewing the sentence in their mind. They were instructed to indicate "missed it" (failure to understand) if they would normally be inclined to go back and re-read a sentence, and "got it" (understand) otherwise. The time from the onset of the sentence-final word to the trigger response was recorded.

On a randomly selected one-third of the trials on which a subject indicated understanding a sentence, a question about the sentence was presented. Subjects answered the question orally, and the experimenter recorded the answer.

Forty-eight sentences were constructed as experimental material, in addition to forty-eight non-experimental sentences of varied forms and eight practice sentences. Each experimental sentence consisted of a single main clause which ended with a noun phrase containing a relative clause, which in turn contained a complement construction within the verb phrase. Examples are "The mayor is the crook who the police chief expected to leave town with," "Those women are the board members the company president promised to deliver the committee presentation to," and "We were worried about the little girl who the other children forced to take the blame." Each experimental sentence could appear in sixteen different forms, illustrated in Table 1.

The forms are defined by the factorial combination of (1) presence or absence of a relative pronoun, (2) presence or absence of a sentence-final adverbial phrase, (3) consistency or inconsistency with the Most Recent Filler Strategy; or, equivalently, presence or absence of a preposition in the relative clause's complement's verb phrase; and (4) ambiguity or nonambiguity of the semantic control properties of the matrix verb of the relative clause. We will refer to these variables as (1) Relative pronoun versus No Relative pronoun; (2) Final phrase versus No-Final phrase; (3) Recent Filler versus Distant Filler; and (4) Ambiguity versus No-ambiguity. We tried to maintain semantic plausibility for all sixteen forms of each experimental sentence.

TABLE 1

## Illustration of the Sixteen Sentence Forms

1. No final phrase, Rel, Recent Filler, Ambig;	Everyone liked the woman who the little child begged to sing those stupid French songs for.
2. No final phrase, Rel, Recent Filler, Unamb.	Everyone liked the woman who the little child started to sing those stupid French songs for.
3. No final phrase, Rel. Distant Filler, Amb.	Everyone liked the woman who the little child begged to sing those stupid French songs.
4. No final phrase, Rel, Dis. Filler, Unamb.	Everyone liked the woman who the little child forced to sing those stupid French songs.
5. No final phrase, No-Rel, Rec. Filler, Amb.	Everyone liked the woman the little child begged to sing those stupid French songs for.
6. No final phrase, No-Rel, Rec Fil, Unamb.	Everyone liked the woman the little child started to sing those stupid French songs for.
7. No final phrase, No-Rel, Dis Filler, Amb.	Everyone liked the woman the little child begged to sing those stupid French songs.
8. No final phrase, No-Rel, Dis Fil, Unambig.	Everyone liked the woman the little child forced to sing those stupid French songs.
9. Final phrase, Rel, Recent Fil, Ambig.	Everyone liked the woman who the little child begged to sing those stupid French songs for last Christmas.
10. Final phrase, Rel, Recent Filler, Unambig.	Everyone liked the woman who the little child started to sing those stupid French songs for last Christmas.
11. Final phrase, Rel, Distant Filler, Ambig.	Everyone liked the woman who the little child begged to sing those stupid French songs last Christmas.
12. Final phrase, Rel, Distant Filler, Unambig.	Everyone liked the woman who the little child forced to sing those stupid French songs last Christmas.
13. Final phrase No-Rel, Recent Filler, Ambig.	Everyone liked the woman the little child begged to sing those stupid French songs for last Christmas.
14. Final phrase No-Rel. Recent Filler, Unamb.	Everyone liked the woman the little child started to sing those stupid French songs for last Christmas.

TABLE 1 (Cont.)

15. Final phrase No-Rel, Distant Filler, Ambig.	Everyone liked the woman the little child begged to sing those stupid French songs last Christmas
16. Final phrase, No-Rel, Distant Filler, Unambig.	Everyone liked the woman the little child forced to sing those stupid French songs last Christmas.

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A sentence-final adverbial phrase was constructed for each sentence, mostly temporal phrases ("next Spring;" "during the filming;" "after the scandal") but in a few cases, of various forms ("for MGM;" "if they were wise"). The phrases were chosen so that they would have to follow any gapped preposition within the complement verb phrase, and thus effectively rule out the possibility of a Recent Filler reading for a sentence in which a preposition did not precede the final phrase.

A single question was made up for each sentence used in the experiment. Half of the questions for experimental sentences queried the subject of the complement verb (e.g., "Who expected to leave town," "Who delivered the presentation," and "Who took the blame?"), while the remaining questions queried haphazardly selected aspects of the sentences.

Sentences were presented in blocks of eight sentences each, with brief rest periods between blocks. On each block, four experimental and four dummy sentences were presented, in individually-randomized orders. A counter-balancing scheme met the following design features: (1) Each subject received three experimental sentences in each of the 16 sentence forms; (2) Each sentence form was presented once in each group of four blocks of eight sentences; (3) Each sentence was tested in each form for three different subjects; and (4) No subject saw more than one version of any sentence.

## 2.2 Results

The data are presented in Tables 2 through 7. The mean reaction times were computed for all "got it" responses (responses indicating a feeling of successful comprehension), after eliminating the 2% of all responses that were longer than 3500 msec or more than four standard deviations greater than the mean reaction time for a subject. The percentage "got it" responses considered all responses, regardless of their reaction times.

Two analyses were performed on the reaction time data, one treating subjects as the random variable, and the other treating sentences as the random variable. Similar analyses of variance were performed on the percentage "got it" responses. The fixed effects factors in these analyses were the four factors that defined the sixteen sentence forms. Missing comprehension time data occurred when a subject failed to report under-

standing all three sentences of a given form (or, in the analysis allowing generalization to other sentences, when all three subjects who received a particular experimental sentence in a particular form failed to indicate understanding of it.) They were replaced using an iterative technique described by Myers (1972), in which they are estimated as a combination of the mean reaction times for other sentences of that form and the mean reaction time to other sentences by the subject (or, in the sentences analysis, the mean reaction time to the other forms of the sentence) for which data were missing.

The main finding was very simple: Subjects more quickly indicated successful understanding of Recent Filler sequences than of Distant Filler sentences, 1071 ms. 1165 msec,  $\min F'(1, 74) = 4.07$ ,  $p < 0.5$ . Subjects also indicated successful understanding of more Recent Filler than Distant Filler sentences, 78% vs. 66%,  $\min F'(1, 94) = 14.21$ ,  $p < .01$ . These results are consistent with the prediction of the Most Recent Filler hypothesis.

The theoretically critical interaction between Recent vs. Distant Filler and Ambiguous vs. Non-Ambiguous verb was thoroughly nonsignificant in both reaction time analyses ( $F_1(1, 47) = 0.72$  and  $F_2(1, 47) = 0.17$ , for the subjects and sentences analyses, respectively). The mean reaction times appear in Table 2. The difference in comprehension time between Recent

TABLE 2

## Mean Reaction Times, "Got it" Responses

Syntax	Relative Pronoun		Mean
	Present	Absent	
	Ambiguous Verb		
Recent Filler	1069	1077	1073
Distant Filler	1120	1228	1174
Mean	1095	1153	1124
	Unambiguous Verb		
Recent Filler	1094	1042	1068
Distant Filler	1141	1170	1155
Mean	1118	1106	1112
	Pooled Over Verbs		
Recent Filler	1081	1059	1071
Distant Filler	1130	1199	1165
Mean	1106	1129	1118

and Distant Filler sentences was 101 msec for sentences whose complement verb could countenance either form, while it was 87 msec for sentences

whose complement verb forced one reading or the other. This finding invited the conclusion that readers use semantic control information only after they have applied the Most Recent Filler strategy.

TABLE 3

Mean Reaction Times, "Got it" Responses

Syntax	Final Adverbial Phrase		
	Present	Absent	Mean
Recent Filler	1055	1085	1070
Distant Filler	1129	1200	1165
Mean	1092	1142	1117

The effect of presence versus absence of a sentence-final adverbial phrase is shown in Table 3. There was a nonsignificant tendency for comprehension times to be faster when the final phrase was present than when it was absent,  $F_1(1, 47) = 3.84$ ,  $p = .06$ , and  $F_2(1, 47) < 1$ . This tendency seemed to be larger for the Distant Filler than for the Recent Filler sentences, but the interaction  $F$  was less than 1.0 in both analyses. To the extent that the effect of presence versus absence of a sentence-final adverbial phrase can be trusted, it does indicate that readers may begin correcting an initial misanalysis during the presentation of the phrase. However, the clearest conclusion to draw from Table 3 is that the effect of Recent versus Distant Filler was clearly, and significantly, present, regardless of presence or absence of the final phrase, indicating that the effect was not trivially due to the easier reading of sentence-final prepositions than other sentence-final words.

The one significant interaction involved Recent versus Distant Filler Relative Pronoun versus No Relative Pronoun  $F(1, 47) = 6.05$ ,  $p < .02$  (but  $F_2(1, 47) = 1.36$ ,  $p > .10$ ). The interaction may be seen in the bottom panel of Table 2. The effect of Recent versus Distant Filler was 49 msec (still significant at the .05 level) when the sentence contained a relative pronoun, but 140 msec when it did not. The apparent interaction held true regardless of whether the verb was ambiguous or unambiguous (top two panels of Table 2). Presence of the relative pronoun seemed to facilitate comprehension of Distant Filler sentences, but possibly to impair comprehension of Recent Filler sentences, consistent with the predictions of the Salience Hypothesis.

The analysis of numbers of sentences which subjects indicated understanding was generally consistent with the analysis of comprehension times. As indicated earlier, subjects indicated understanding more Recent Filler than Distant Filler sentences. Table 4 shows that subjects did not more frequently indicate understanding of sentences with unambiguous verbs than

TABLE 4  
Percentage of "Got it" Responses

Syntax	Relative Pronoun		Mean
	Present	Absent	
	Ambiguous Verb		
Recent Filler	75	79	77
Distant Filler	68	58	63
Mean	72	69	70
	Unambiguous Verb		
Recent Filler	80	76	78
Distant Filler	75	63	69
Mean	78	70	74
	Pooled Over Verbs		
Recent Filler	78	77	78
Distant Filler	72	61	66
Mean	75	69	72

sentences with ambiguous verbs, 74 versus 70%,  $F_1(1, 47) = 2.73$ ,  $p > .10$ ,  $F_2(1, 47) = 2.61$ ,  $p > .10$ . Of special interest is the fact that any difference in the effect of verb ambiguity between the presumably preferred Recent Filler reading and the non-preferred Distant Filler reading was totally nonsignificant,  $F_1(1, 47) < 1.0$ , and  $F_2(1, 47) = 1.78$ ,  $p > .10$ . Presence of a sentence-final adverbial phrase (Table 5) decreased the probability of understanding a sentence,  $F(1, 92) = 4.55$ ,  $p < .01$ , in apparent contrast to the tendency (nonsignificant) of a final phrase to

TABLE 5  
Percentage of "Got it" Responses

Syntax	Final Adverbial Phrase		Mean
	Present	Absent	
Recent Filler	72	83	78
Distant Filler	65	67	66
Mean	69	75	72

speed comprehension responses. Also, the absence of the sentence-final adverbial phrase may have benefitted the easier Recent Filler sentences more than the Distant Filler sentences,  $\min F'(1,93) = 2.75$ ,  $.10 > p > .05$ . After the fact, both these effects can be understood in terms of a common report made by experimental subjects: They found the longer sentences, particularly those with a final adverbial phrase, to present a serious memory load problem, such that they simply forgot the names of descriptions of individuals mentioned early in the sentence. When such a memory overload occurred, subjects would indicate failure to comprehend a sentence.

Subjects tended to indicate understanding more sentences with a relative pronoun present than absent,  $\min F'(1,87) = 3.14$ ,  $.10 > p > .05$ . (see Table 4). Of greater interest, the effect of the relative pronoun was particularly marked for the Distant Filler sentences,  $\min F'(1,91) = 5.61$ ,  $p < .05$ . Again, this finding indicates that the relative pronoun increases the salience of the head of the relative clause, making it more available to serve as a filler in the Distant Filler sentences.

The interaction among all four experimental factors was significant,  $F(1,47) = 5.10$ ,  $p < .05$ . We will not attempt to interpret this finding.

The final data to be discussed concern the answers subjects made to the questions asked of 1/3 of the comprehended sentences. Table 6 presents the percentages of all answers to these questions which were correct. These percentages seem low, in part because many errors were due to a failure to recall an individual's name, or to make any response at all. Table 7 eliminated those trials on which subjects made no response, or gave an answer which used words not in the sentence questioned. The data in Table 7 thus accurately indicate the accuracy of chosen filler-gap assignments.

TABLE 6

## Percentage of Correct Answers to Questions

Syntax	Verb		Mean
	Ambiguous	Unambiguous	
Recent Filler	58	73	66
Distant Filler	63	78	71

TABLE 7

Percentage of Correct Answers to Questions  
(Considering only within sentence responses)

Syntax	Verb		Mean
	Ambiguous	Unambiguous	
Recent Filler	72	83	78
Distant Filler	71	84	78
Mean	72	84	78



Two points may be noted about the data in Table 6 and 7. First, accuracy was as high on the presumably harder Distant Filler sentences as on the Recent Filler sentences. Recall, though, that questions were asked only when subjects indicated successful comprehension of a sentence, a more frequent event for Recent Filler than for Distant Filler sentences. Second, accuracy was higher for sentences with unambiguous verbs than for sentences with ambiguous verbs, 84 versus 72% in Table 7,  $t(23) = 2.73$ ,  $p < .01$ . This pattern of results may imply that the initial "got it" response does indicate successful syntactic analysis of a sentence, but that other factors, presumably semantic and pragmatic, operate in preserving an initially-understood sentence in memory until a question is presented, and in formulating a response to a question.

### 2.3 Discussion

The basic findings of our experiment are straightforward. Readers more frequently and rapidly indicate comprehending Recent Filler sentences than Distant Filler sentences. Thus, they seem to follow the Most Recent Filler strategy in their preferred analyses of sentences. This effect was found not only for the ambiguous sentences (where assigning the first gap either to the most recent filler, or the more distant filler, would be temporarily permissible), but also for unambiguous sentences, where the semantic control properties of verbs prohibit the incorrect assignments. Thus, readers do not use semantic control information in constraining their initial assignment of filler-gap dependencies. The presence of a relative pronoun significantly facilitated comprehension only in the Distant Filler sentences, as predicted by the Saliency hypothesis which claims that any cue which makes a phrase a more salient filler will aid in assigning that filler to the next-detected gap.

We propose a one-analysis-at-a-time account of the sentence comprehension process. Readers, when they detect a gap, initially assign it to the most salient potential filler, in their efforts to construct an initial analysis of a sentence. In the case of all of our sentences, this means that the gap before the infinitival verb phrase is associated with the most recent potential filler as soon as the gap is identified, and regardless of the semantic control properties of the verb. The parser, however, keeps track of the fact that the more distant filler, the head of the relative clause, still must be assigned to a gap. If a gap appears before the end of the sentence--the gap after the preposition in our Recent Filler sentences--the head is successfully assigned to it. We suggest that it is at this point that a reader indicates comprehending the Recent Filler sentences in our experiment. In a Distant Filler sentence however, the sentence ends (or the sentence-final adverbial phrase begins) before any gap to which the head may be assigned is detected. The reader must adjust the filler-gap assignments once the absence of a second gap is detected. After the head of the relative clause is successfully assigned to a gap in the Distant Filler sentences, the reader can indicate comprehension. The extra tenth of a second taken to comprehend Distant Filler sentences includes part or all of the time taken to revise the initial filler-gap assignment. The fact that a somewhat lower percentage of comprehension ("got it") responses was obtained in the Distant Filler sentences than in the Recent Filler sentences

indicates that subjects occasionally failed to reanalyze the Distant Filler sentences correctly. The findings that the presence or absence of a temporary ambiguity in the Distant Filler sentences did not significantly affect the comprehension-responses (in terms of either speed or percent "got it" responses) but did influence the accuracy of answer-responses suggests that further processing occurred after the initial comprehension-response and that it was only at this stage (after a legitimate structure for the sentence had been computed) that the ambiguity of the verb had any effect on processing.

Our further discussion will focus upon two topics. The first topic concerns the implications of our results for questions about how the use of different sources of information is scheduled in sentence comprehension, and about the potentially distinct levels of processing involved in sentence comprehension. The second topic concerns the possible alternative explanations of our findings about the difference in processing of Distant and Recent Filler sentences that would be consistent with alternative linguistic analyses of our sentences. We conclude with a brief discussion of how conclusions about sentence comprehension can contribute to the development of linguistic theory.

### 3. Levels of Processing in Sentence Comprehension

In our data, the response of indicating comprehension of a sentence was primarily influenced by one variable, the pattern of filler-gap relations, while the response of correctly answering questions about understood sentences was primarily influenced by a different variable, verb ambiguity. Intuitive impressions of sentence comprehension difficulty accord with the question-answering data, and not with the comprehension reaction time data. One has no intuitive awareness of having been garden-pathed in the unambiguous Distant Filler sentences, nor does one feel that these sentences are more complex than the unambiguous Recent Filler sentences. Yet the difference in comprehension time between these sentences is closely comparable to the difference between Distant and Recent Filler sentences with ambiguous verbs, which many people report to be more complex, particularly the Distant Filler sentences.

We suggest that the apparent discrepancy between intuitions about comprehension difficulties and our reaction time data is due to the fact that intuitions and responses indicating comprehensibility tap separate levels, or perhaps separate sequential stages, of processing. Intuitive judgments (and answers to questions) may depend upon the availability of a semantic interpretation of a sentence or part of a sentence. The initial filler-gap structure inappropriately assigned in ambiguous Distant Filler sentences can receive a semantic interpretation, while the incorrect filler-gap assignment in the unambiguous Distant Filler sentences may not lead to even a temporarily coherent semantic interpretation. Intuitive evidence of having been garden-pathed during the analysis of a sentence may depend upon the availability of a semantic interpretation of the inappropriate structure, and will thus appear only for the sentences with ambiguous verbs.

While intuitions may reflect only processes that occur after the reader

or listener has partially interpreted linguistic material, the response indicating that a sentence is comprehensible may only tap some more quickly reached level of processing. We believe that this level includes an analysis of the constituent structure of the sentence, including the assignment of fillers to all identified gaps. What information constrains the analysis of sequential material at this level of processing has not been fully established. Presumably, information about the major grammatical category membership of lexical items and about phrase structure must be used in reaching this level. In order to detect a postverbal gap, for instance, the parser must note that a verb has occurred, and it must utilize information that (some) verbs can take a postverbal noun phrase. In fact, we think that more information than this is used, including subcategorization information about particular verbs. If subcategorization information were not used, the parser would postulate a gap even after an obligatorily intransitive verb such as *die*. Fodor (1978) argues against this position on the basis of intuitive evidence, and argues for a "lexical expectation model" of gap detection. In such a model, the parser uses subcategorization information about a verb and information about the frequency with which various subcategorization options are taken (in "untransformed" sentences) to postulate gaps in its first pass through a sentence. We are currently conducting experiments to determine whether subcategorization information is used at the level of parsing under consideration.

Our evidence indicates that information about the semantic control properties of verbs is not used at the level tapped by the comprehensibility judgments. Rather, semantic control information is used at more advanced levels of processing, particularly a level of creating a semantic interpretation of a sentence that is consistent with the constituent structure created at a more rapidly reached level. The use of semantic control information about a verb lags behind the use of lexical category and subcategorization information about that verb. We suspect that continued investigation of the parser's filler-gap procedures will prove valuable in the attempt to identify other natural classes of information (e.g., prosodic, semantic, pragmatic, etc.) and properties of that information (e.g., frequency of occurrence) that are used at distinct levels of processing.

Our present view of the nature of sentence comprehension falls somewhere between the rigidly structured "autonomy of syntax" (or, more generally, autonomy of processing levels) position of Forster (1979) and the unstructured "fully interactive parallel" model of Marslen-Wilson (1975). According to the strongest form of the interactive model we would expect any useful information to be exploited by the parser as soon as it could be extracted from the input signal. Our data indicate that some information is extracted from the sentence and used before other types of information. Thus, our results suggest the fully interactive view is incorrect in its extreme form,

In Forster's model, each of the three components of the language processing system (the lexical, syntactic, and message processing) operates independently, and there are strict limitations on how information can be passed among different systems. Though there is nothing in our present data that contradicts the strong form of Forster's position, which states that syntactic processing is independent of and prior to semantic processing, we

have argued elsewhere (e.g., Frazier (1978)) that the autonomy principle must be weakened somewhat, especially with respect to the no-feedback constraint which prohibits the passing of any information back to a "lower" or prior stage of processing. For the present, we simply emphasize that we are in complete agreement with Forster on a critical methodological issue. We agree that the goal of psycholinguistic theory is to constrain the operation of the language processor as much as possible, by searching for constraints on the precise nature and timing of the information and decision flow during sentence comprehension (or production).

In practical terms, this means we are committed to searching for counterexamples to a fully interactive parallel processing system. Forster (1979) discusses one kind of evidence that can serve as a counterexample, namely, evidence for the existence of stages in processing at which one variable (e.g., a syntactic variable) has a measurable effect on processing while a second (e.g., semantic) variable does not. When each of these variables can be shown to have an effect upon the final output of the sentence comprehension system, such evidence indicates autonomy of operation of the two variables at the stage of processing in question (and, perhaps, earlier stages). The evidence we present in this paper is of this general form, in that it shows that syntactic information about the existence of potential fillers and gaps and their relation is used at one level of processing, while information about semantic control properties of verbs is not. It goes further, however, than evidence which has been reported previously, in that it specifies rather precisely what types of information are used in making which particular decisions, at which points in time.

#### 4. Alternative Interpretations of the Findings

##### 4.1 Alternative Structural Assumptions

The explanation we have offered for the asymmetry in the processing complexity of Recent Filler and Distant Filler sentences assumes the existence of a gap preceding the final complement verb in all sentences. This assumption presupposes that the verbs used in the relative clauses of our sentences subcategorize for sentential complements. Such a position is consistent with the treatment of these verbs in the "revised extended standard theory" (Chomsky, 1980) and other closely related theories (e.g., Williams, 1980),<sup>4</sup> although we have not addressed certain issues including the possible distinction between gaps which arise from movement rules, and those which are base generated.

Alternative linguistic assumptions are possible. We will first consider the assumption some of the verbs we used take VP complements, and thus are followed by no gap before the complement verb, and then consider the assumption that some of our verbs are followed by two gaps, rather than just one.

4.1.1 VP versus S complements. Various recent analysis claim that the complement of the verbs in our ambiguous Recent Filler sentences consist merely of an infinitival verb phrase, not an infinitival clause with a gap in subject position (Brame, 1976; Bresnan, 1978; Bach, 1979; Gazdar, 1979). Thus, there would be no gap in subject position preceding the final verb

phrase of the Recent Filler sentence, (12):

(12) This is the girl<sub>i</sub> the teacher<sub>j</sub> wanted <sub>vp</sub>[to talk to     <sub>i</sub>.

Under such an analysis, our processing assumption that the gap before the final verb is preferentially filled with the most recent filler, is incoherent. There is no gap before the final verb in the "Recent Filler" sentences.

We can counter such an objection with a chain of assumptions, some motivated by our data and some motivated by other considerations. First, we note that the relative clause verbs of our unambiguous Distant Filler sentences (force, beg, coax, order, etc.) must be followed by a Noun Phrase, either a lexical NP or a gap, as shown by the ungrammaticality of (13):

(13) \*The girl forced to talk.

Second, we assume that a reader, when presented with a verb that requires a following NP, postulates the existence of such an NP on-line, and, when one does not appear, postulates the occurrence of a gap. That is, we assume that subcategorization information about a verb is used very quickly in on-line language processing, unlike information about semantic control properties of verbs. We are in the process of gathering experimental data about this critical assumption. In the meantime, we note a major intuitive difference in the way sentences with verbs such as "struggle" and "comfort" are comprehended. A string such as "The girl struggled the boy" seems immediately to be identified as ungrammatical, while "The girl comforted" gives the initial (and correct) impression of missing a phrase.

Third, we note that indicated comprehensibility and comprehension time are very similar for unambiguous Distant Filler sentences and ambiguous Distant Filler sentences.<sup>5</sup> The unambiguous Distant Filler sentences, we have noted, must have a gap preceding the complement verb. If the difficulty in comprehending them, relative to the Recent Filler sentences, is due to a process of making and then correcting an initially incorrect filler-gap assignment, and if the ambiguous Distant Filler sentences have the same source of difficulty, then the ambiguous Distant Filler sentences must have a gap preceding the complement verb. (See the discussion in Section 4.1.2 and footnote 6, regarding the nature of this gap.)

Fourth, if ambiguous Distant Filler sentences have a gap before the final verb, and if readers postulate such a gap on line, then they must postulate a gap on line for the ambiguous Recent Filler sentences. Prescience would be needed if this were not the case. For both types of sentences, we assume that readers prefer to fill the gap with the most recent filler, appropriately for the Recent Filler sentences but inappropriately for the Distant Filler sentences.

Fifth, and finally, the near-identity of reaction time and comprehensibility data for ambiguous and unambiguous Recent Filler (try, plan, attempt, decide, etc.) sentences indicates that the filler-gap assignment processes are the same in them. Since we have argued that readers must postulate a gap on-line for the ambiguous Recent Filler sentences (as well as for all Distant Filler sentences), we are led to the conclusion that they also

postulate a gap for the unambiguous Recent Filler sentences. This gap must be a subject gap in the complement sentence for the unambiguous Recent Filler sentences, and some of the ambiguous sentences, since the relative clause verbs of these sentences do not admit a gap in object position (see Section 4.1.2). Thus, these sentences require a S-complement analysis, and not a VP-complement analysis. Considerations of homogeneity of analysis suggest that the unambiguous Distant Filler sentences, with which we began this discussion, should also receive an S-complement analysis.

The validity of this argument turns on two critical assumptions. The first assumption is that the similarity of our measures of processing difficulty for ambiguous and unambiguous sentences reflect identical comprehension processes, and that these comprehension processes involve gap-finding and gap-filling. We can bolster this assumption by noting that the presence of a relative pronoun, which can be assumed to affect gap-filling processes, had similar effects on our ambiguous and our unambiguous sentences. It facilitated comprehension of all Distant Filler sentences, but not Recent Filler sentences. This pattern of results is natural on the view that the differences we observed between Recent and Distant Filler sentences, and the lack of any difference between ambiguous and unambiguous sentences, are due to the relative availability of potential fillers, which can be influenced by the presence of a relative pronoun. The pattern of results is unexpected under other views, such as the view that an explicit structural marker will facilitate recovery of sentence structure.

The second critical assumption is that readers do postulate gaps following obligatorily transitive verbs in an on-line fashion. As indicated, we are conducting experiments to test this assumption. If the assumption remains credible, we believe that we have a persuasive argument against linguistic analyses in which some of the sentences we used have no gap before the verb of the complement.

4.1.2 NP-S subcategorization. An older, and rather widely-accepted, linguistic analysis claims that the verbs of the unambiguous Distant Filler sentences (*force, order, persuade, etc.*) subcategorize for an NP object followed by a sentential complement, as in (14a) (Rosenbaum, 1967).

By contrast, the verbs of the unambiguous Recent Filler sentences (*try, plan, attempt, decide, etc.*) are analyzed as subcategorizing for just a sentential complement, as in (14b).

(14a) This is the girl<sub>i</sub> the teacher<sub>j</sub> forced NP — S[ —<sub>i</sub> to talk.]

(14b) This is the girl<sub>i</sub> the teacher<sub>j</sub> decided S[ —<sub>j</sub> to talk to —<sub>i</sub>].

The NP-S subcategorization would entail that the parser must identify two adjacent gaps in the Distant Filler sentences, but not in the Recent Filler sentences. There may be some special difficulty associated with the processing of two adjacent gaps.

While the explanation may be appropriate to the unambiguous sentences, it applies to only some of the ambiguous sentences. Though the verbs beg, ask and choose may be analyzed as subcategorizing for NP-S, the verbs want



and expect may not. The explanation under consideration would have to predict that sentences with the latter verbs would not show a difference in comprehensibility between their Recent Filler and the Distant Filler forms. However, the mean size of the difference was 120 msec for the former verbs, and 95 msec for the latter verbs, a nonsignificant difference. (Each verb exhibited the most recent filler effect). Thus, although we cannot rule out the possibility that different verb structures had some effect upon our subjects' performance, such differences cannot account for our results.<sup>6</sup>

#### 4.2 Alternative Psycholinguistic Assumptions

We have assumed that the processing difficulty of Distant Filler sentences was to be explained by appeal to a process of making an incorrect filler-gap assignment (based upon recency of the filler), and then changing it. We consider three sorts of alternative assumptions. The first two assume that the process we have identified with assigning the most recent filler to a gap is different in kind than the process we have identified with assigning a more distant filler to a gap. The final assumption appeals to inherent difficulties in processing certain categories, rather than to any process of making and breaking filler-gap assignments.

4.2.1 Local Dependencies. One alternative (suggested to us by Emmon Bach) would be to invoke the difference between local ("Equi") grammatical dependencies and unbounded grammatical dependencies to account for our data. According to this hypothesis, in cases of apparent ambiguity the parser would simply opt for a local dependency whenever it was presented with a choice between a local and an unbounded grammatical dependency. Assuming that at least the verbs used in the ambiguous Recent Filler sentences (e.g., want) subcategorize for sentential complements, this explanation of the data would be nearly indistinguishable from our own. The preference for assigning the most recent filler to the first gap encountered is simply a preference for derivations in which local operations have applied. The previously-identified failure of semantic control information to constrain the parser's initial filler-gap assignments appear as the parser's unawareness during its initial filler-gap decisions that unambiguous verbs (e.g., persuade) from Distant Filler sentences cannot undergo a particular type of local operation, namely, Equi-deletion under identity with the subject of the verb. Finally, the observed interaction with relative pronouns could be explained by claiming that the presence of a relative pronoun "reminds" the parser that an unbounded grammatical operation has applied, thereby reducing its tendency to prefer local grammatical dependencies. This hypothesis offers an equally coherent account of the data and will be very difficult to distinguish from our own account. In fact, the only real difference in the two accounts would depend on the ability of the Saliency Hypothesis to predict or account for a wider array of data. For example, if our intuition is correct that stressing a filler renders it more likely to be assigned to the first gap encountered (see above), this would support the Saliency account of our findings. (Pilot experiments which test this prediction are in progress.) Note that if the prediction is confirmed, this would not be incompatible with the "local dependency" account of our data; rather it is simply not predicted by that account. The strongest evidence for the Saliency Hypothesis would go beyond showing that stressing the distant filler facilitates comprehension of Distant



Filler sentences, by showing that stressing the most recent filler also has an effect, say, of speeding comprehension of Recent Filler sentences.

4.2.2 Semantic Dependencies. Clearly, our experimental results do not directly address the question of whether the filler-gap dependencies which were investigated are syntactic or semantic in nature. However, it seems that the most natural account of the results will treat the different types of filler-gap dependencies examined here as being both syntactic or both semantic. If we were to assume that the unbounded dependency was syntactic but that the local dependency was semantic (i.e., that it only involved a "gap" in the semantics, say, in the argument structure of the verb) then the Most Recent Filler strategy would correspond to a rather odd parsing operation, or at least lead to a somewhat unexpected mapping between the grammar and the processor. Further, if both types of filler-gap dependencies were only semantic in nature, then the finding that verb-ambiguity had no effect on comprehension reaction times, but did have an effect on answering responses, seems difficult to rationalize.

4.2.3 Derived node hypothesis. Gazdar (1979) has suggested an interesting hypothesis concerning the processing of empty categories namely, that sentences containing empty categories ("derived nodes" in Gazdar's framework) will be more difficult to process than sentences which do not contain empty categories. In Gazdar's framework, subject relative clauses do not contain any empty categories (derived nodes). Rather, they consist of a head noun phrase followed by a verb phrase. By contrast, object relative clauses do contain an empty category (the gap, "NP/NP", and other derived nodes such as "S/NP", i.e., an S missing an NP). Gazdar's "Derived Node Hypothesis" accounts for the general finding that subject relatives are easier to process than object relatives (e.g., Frauenfelder, Segui and Mehler, 1980).

Gazdar's analysis of our experimental sentences is shown in (15).

(15a) This is  $NP$ [the girl]  $S/NP$ [the teacher]  $VP/NP$ [wanted]  $VP/NP$ [to talk  
 $PP/NP$ [to NP/NP].

(15b) This is  $NP$ [the girl]  $S/NP$ [the teacher]  $VP/NP$ [wanted]  $S/NP$ [NP/NP]  $VP$ [to talk.

Notice that, under this analysis of the sentences, the Derived Node Hypothesis cannot account for our experimental findings. The easier Recent Filler sentences (15a) contain more derived nodes than the more difficult Distant Filler sentences (15b). Further, we have not been able to devise any straightforward modification of the Derived Node Hypothesis which would account for these findings. For example, if we count only terminal derived nodes (gaps, such as "NP/NP") but not nonterminal derived nodes (e.g., "S/NP") as being perceptually complex, then the Recent Filler and Distant Filler sentences should be equally difficult to process, given Gazdar's analysis of the sentences. Alternatively, we might recast the Derived Node Hypothesis as an instruction telling the parser to opt for an underived terminal node whenever confronted with a choice between a derived or an underived terminal node. This parsing strategy would account for the complexity of the ambiguous Distant Filler sentences relative to the ambiguous Recent Filler sentences since, in the ambiguous sentences, the parser is faced with the

choice of whether to postulate a derived terminal in the position after the matrix verb of the relative clause (e.g., wanted in (14)). But this strategy would not account for the complexity of the unambiguous Distant Filler sentences since in the unambiguous sentences there would be no competition between an analysis with derived terminals and one with underived terminals.

## 5. Conclusions

We have argued that the parser copes with filler-gap dependencies by assigning the most recent potential filler to each gap it encounters. We presented initial support for the Saliency Hypothesis, which claims that the processor's preference for recent fillers is a special case of a more general preference for salient fillers. The Saliency Hypothesis potentially offers an explanation for the pervasive preference in natural languages for nested, rather than intersecting, dependencies.

The finding that the unambiguous sentences tested here behave as if they are temporarily ambiguous suggests that semantic control information does not constrain the parser's initial assignment of filler-gap dependencies. This result has important consequences for psycholinguistic theory since it implies that the human sentence parsing mechanism is not totally interactive.

The experimental findings are also interesting from the perspective of linguistic theory because any adequate explanation of them seems to presuppose that verbs which permit lexical subjects in their complements (e.g., want), must be analyzed as subcategorizing for sentential complements even in sentences where no lexical subject appears in the complement. Hence, our results pose a challenge for the VP complement analysis of such verbs.

In the past, psycholinguistics has typically been parasitic on linguistic theory without actively contributing to the development of the theory. Apart from helping to delimit the proper domain of linguistic theory and occasionally offering an explanation for certain properties of natural languages, psycholinguistic investigations have had only a minimal influence on theories of language competence. We suspect that the contribution of psycholinguistics can go beyond this by bringing more novel types of evidence to bear on the linguistic analyses of a construction, particularly in cases where internal linguistic evidence is either lacking or ambiguous.

We envision various extensions of the present investigation which could potentially lead to this type of evidence. By exploring the generality of the Saliency Hypothesis we might determine whether the parsing procedures used to assign filler-gap dependencies are the same procedures employed in the analysis of other coindexing dependencies. If it could be shown that dependencies involving coindexing within one grammatical theory are all subject to the same parsing strategies, are all analyzed in the same stage of processing, are sensitive to the same types of information, etc., this would argue that the dependencies constitute a natural class, at least in terms of processing. Given a well-motivated theory of sentence comprehension which specifies the relation between grammatical information and processing operations, this evidence could be used to argue for that particular grammatical

theory over a theory in which this set of dependencies failed to constitute a natural class.

Psycholinguistic investigation might also aid in the correct formulation of certain grammatical constraints, by showing that the parser utilizes these constraints on-line at a particular processing stage when only certain information is available to the parser. Competing formulations of essentially the same grammatical constraint would often require different types of information to be available to the parser in order for it to recognize the constraint as being relevant to the particular construction under analysis. Thus psycholinguistic investigation could demonstrate that the parser is abiding by some constraint at a particular time in the processing of a sentence, when it would have insufficient information to invoke the constraint, given one statement of the constraint, but not given some competing statement of it. The decision to incorporate some constraint (e.g., Subjacency) into the grammar determines much of the overall framework in which linguistic analysis proceeds and thus additional psycholinguistic information concerning the proper formulation of such constraints would in our opinion prove to be a truly major contribution to linguistic theory.

One final point about the connection between linguistic theory and parsing theory may be in order. Many linguists are reluctant to attribute a sentence potentially unnecessary abstract structure in order to capture a linguistic generalization or to capture some broader linguistic generalization than would otherwise be possible. At first glance, it often appears that the postulation of this extra structure could only have the effect of complicating the sentence comprehension task. After all, if the parser must recover the additional structure, this would seem to require additional processing operations to be performed. A sentential analysis of complements that lack lexical subjects might be taken as a case in point. However, consideration of the processing of such complements suggests that additional structure (the postulation of an S-node) may actually simplify the sentence comprehension process by permitting somewhat different constructions to be attributed a uniform structure. Hence, in certain instances, additional structure might be expected to reduce the uncertainty associated with processing a particular construction and thus to have the overall effect of facilitating the sentence processor.

Clearly extreme caution is warranted in the use of psycholinguistic findings to evaluate linguistic theories or guide linguistic analyses. Perhaps we are overly optimistic in suggesting that psycholinguistics has reached the stage where it can begin to fruitfully address the kinds of issues raised above. However, it often seems that, like the language learner, linguists must proceed on the basis of linguistic data which underdetermines the correct grammatical theory. External data of the general type discussed here could be used to further constrain linguistic theory.

#### Notes

\*We are grateful to Louisa Slowiaczek for helping us to carry out the experiment reported here, and to Maria Slowiaczek and Janet Randall for critical readings.

<sup>1</sup>Whether any phrases are clearly marked as obligatory fillers depends on one's linguistic and psycholinguistic assumptions. Wh-question words are unambiguously marked as fillers, if one assumes that the parser must recover a filler-gap dependence in subject questions like Who laughed?

- (i)  $\bar{S}[\text{COMP}[\text{Who}_i] \text{S}[\text{NP}[e_i] \text{VP}[\text{laughed}]]]$
- (ii) a. Who has the car that those kids decided to fix up?  
b. Who has the car that those kids decided to fix up been stolen by?

(If one does not assume that the parser recovers a filler-gap dependency in subject questions like (i), then in principle the parser might have to wait an indefinitely long time to determine whether a wh-question word is a filler, as illustrated in (ii)). Similarly, relative pronouns (e.g., who, which) unambiguously signal the presence of a filler (the head of the relative) only if one assumes that subject relatives involve filler-gap dependencies (see Gazdar, 1979, for an alternative analysis of subject relatives).

There is no overt lexical marker which indicates the presence of a gap in English. (In some languages, resumptive pronouns may serve this purpose, however in these languages there is often a temporary ambiguity due to the fact that the resumptive pronoun may be mistaken for an unbound person pronoun.) William Cooper (personal communication) reports that in sentences where a subject has been extracted by Wh-movement, the item preceding this extraction site is lengthened; however, items preceding a gap resulting from extraction of an object do not show this effect. (This particular array of data is actually not all that surprising given that we might expect "left-branch" extraction to be particularly difficult for the parser to cope with, especially when they occur in optional constituents where the parser might be expected to have difficulty identifying the type of phrase being parsed.) It is not known whether listeners can exploit this type of prosodic cue to aid in gap detection. In short, though it is quite certain that some fillers (e.g., tough-moved noun phrases) and some gaps (e.g., object gaps) are not superficially marked in either written or spoken language, it is an open question whether any fillers or gaps are superficially and unambiguously marked.

<sup>2</sup>Note that Solan's proposal accounts for the fact that there is no intuitive evidence that one is garden-pathed in a sentence like (i), despite the fact that there is a temporarily permissible analysis of these sentences where the most recent filler may be assigned to the left-most gap, as illustrated by the grammaticality of sentence (ii).

- (i) Mary<sub>i</sub> chose John<sub>j</sub> —<sub>i</sub> to represent —<sub>j</sub>.
- (ii) Mary chose John<sub>j</sub> —<sub>j</sub> to represent her.

<sup>3</sup>It seems unlikely that in situations where a filler could be identified as an obligatory filler shortly after it was first encountered (e.g., who in (i) below) that the parser would nevertheless briefly consider the noun phrases intervening between that noun phrase and an NP-gap as candidate

fillers for the gap.

- (i) Who did John think his brother persuaded Mary to claim  
his grandmother was going to \_\_\_\_\_ convince his girlfriend  
to travel around Europe with \_\_\_\_\_?

In (i) this would predict that at least each of the singly underscored noun phrases would have to be checked before the true filler (who) was assigned to the sentence-final gap (perhaps the doubly underscored noun phrases might be ignored if they had already been assigned to gaps immediately adjacent to them). However, in situations where no item had already been identified as a filler, this type of filler-detection procedure does not seem particularly implausible. These examples illustrate the reason why we will discuss the salience of a phrase as a potential filler: some recent phrase might be rendered less salient as a potential filler for a gap simply by virtue of the fact that some other phrase of the appropriate syntactic category has already been identified as a filler.

The data we are aware of are at least consistent with the hypothesis that phrases which can be "locally determined" to be obligatory fillers (on the basis of information from the phrase in question and, say, just one word following that phrase) are identified as fillers on the first pass through the region of the sentence containing the phrase. This hypothesis would entail that Wh-question words are locally identified as fillers (apart from the possible exception of the examples discussed in note 1) and that the head of a nonsubject relative clause is locally identified as a filler in cases where it is followed by an overt relative pronoun, but not in other circumstances where it will at least in principle be subject to alternative analyses where the noun phrase in question is not a filler (e.g., in (ii) the underscored NP-NP sequence is open to a variety of analyses in which neither of these noun phrases is a filler).

- (ii) Elmer hit the boy the girl...

<sup>4</sup>Williams (1980) argues that there is a predicate variable in initial position of the complements under discussion. His framework is interesting in the present context for a number of reasons. First, within Williams' analysis, the "controller" of the ultimate interpretation of the predicate variable (the antecedent of the predicate in cases of obligatory control) is coindexed with the entire predicate, not with the predicate variable itself. If it could be independently shown that the parser must receive an entire predicate before it coindexes that predicate with an antecedent, this analysis would account for the timing of the processing operations investigated here. Secondly, since control is determined by rules of predication (in the case of verbs used in our unambiguous sentences) or by the ARB rewriting rules of nonobligatory control (in the case of our ambiguous sentences), this theory suggests that the parser might compute most control information, rather than simply utilizing information stored in the lexical entry of particular verbs (in the unambiguous sentences the parser would first determine that it was dealing with a case of thematically-governed predication and then check the lexical entry of the relevant verb to determine the

appropriate antecedent of the predicate. If much of the relevant control information is computed rather than stored in the lexical entry of verbs, this too might offer an explanation for the delay in the parser's use of this information.

<sup>5</sup>In fact, sentences with unambiguous verbs may be comprehended slightly more easily than sentences with ambiguous verbs, and the Recent vs. Distant filler effect may be slightly reduced, although these differences are far from significant statistically. A lexical expectation model of gap-finding (Fodor, 1978) suggest, that a sufficiently powerful experiment would detect just such a difference. All unambiguous distant filler verbs are obligatorily transitive, while some of the verbs used in ambiguous distant filler sentences are only optionally transitive. According to a lexical expectation model, a reader would sometimes fail to posit a post-verbal gap in the latter sentences, slowing their comprehension time and reducing the Recent Filler-Distant Filler difference, since reanalysis would be necessary in both cases when a gap had to be found for the head noun phrase of the relative clause.

<sup>6</sup>Given an NP-S analysis of verbs such as those used in the unambiguous Distant Filler sentences, we might assume that the parser automatically assigns unspecified ("ARB") generic interpretation to the first of two adjacent gaps, as in (i) and (ii), below. After the subject gap has been coindexed with a preceding NP, the parser will coindex the object gap with the subject of the complement only if the subject of the complement is coindexed with something other than the subject of the higher verb. Since this condition obtains in (iii) and (iv), our Distant Filler sentences, the object gap is coindexed with the subject of the complement. This particular type of coindexing could be viewed as a further specification of the "unspecified" interpretation of the noun phrase, possibly resulting from general inferential processing that takes place after initial structural analysis of the sentence.

(i) Jimmy<sub>i</sub> begged \_\_\_\_\_<sub>unspec.</sub> \_\_\_\_\_<sub>i</sub> to go to the movies.

(ii) Sue didn't like the girl<sub>i</sub> the boy<sub>j</sub> begged \_\_\_\_\_<sub>unspec</sub> \_\_\_\_\_<sub>j</sub> to talk to \_\_\_\_\_<sub>i</sub>.

(iii) Sue didn't like the girl<sub>i</sub> the boy<sub>j</sub> begged \_\_\_\_\_<sub>unsp.</sub> \_\_\_\_\_<sub>unsp.</sub> to talk.  
(later i)

(iv). Sue didn't like the girl<sub>i</sub> the boy<sub>j</sub> forced \_\_\_\_\_<sub>unsp.</sub> \_\_\_\_\_<sub>unsp.</sub> to talk.  
(later i)

<sup>7</sup>If verbs like want subcategorize for either VP or S complements, then no Equi-type operation would apply in the complement of verbs like want (i.e., either the complement of want would contain a lexical subject or the complement would be a verb phrase complement). To account for the relative ease of Recent Filler sentences, we might say that the parser will mistakenly apply a local Equi-type operation even to verbs that don't permit any type

of Equi-operation (e.g., want). However, this would predict that the parser tries to apply local Equi-type operations in sentences containing just any verb whatsoever (e.g., die, laugh, etc.). Alternatively, we might try to account for the relative ease of Recent Filler sentences by claiming that the parser opts for a VP complement rather than a sentential complement whenever this is permitted by the grammar. But we're back to the same problems illustrated above in connection with the Derived Node Hypothesis.

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## APPENDIX

The lawyers didn't know about the executive (who) the insurance company wanted/allowed/tried/to get a lot of money from after the accident.

Some people actually enjoy the freaks (who) certain religious organizations want/encourage/try/to fill the airports with on holidays.

Everyone liked the woman (who) the little child/begged/forced/started/to sing those stupid French songs for last Christmas.

A former admiral worked for the movie company (which) the Navy/expected/permitted/agreed/to sink the damaged submarine for during the filming.

Nobody was pleased with the company (that) the trustees/chose/allowed/agreed/to sell group health insurance to next spring.

Everyone was watching the young woman (who) the tennis coach/wanted/urged/tried/to jump across the net to after the match.

Sampson was always the gorilla (that) the ringmaster/chose/forced/attempted/to perform the difficult stunts with during a performance.

The receptionist was worried about the children (who) the psychiatrist had /chosen/urged/tried/to act out a distressing situation with yesterday morning.

That's the man (who) Woody Allen will/beg/permit/try/to play the role of in his next film.

I felt sorry for the girls (who) the drunk sailors/asked/forced/tried to dance the rhumba with last night.

The foreman was inspecting the tractors (that) John had /expected/allowed/tried/ to pull the giant boulder with after the landslide.

The University fired the mathematician (who) the graduate students /asked/urged/refused/ to teach the calculus class for in the spring.

We were surprised to hear about the other people (who) the developer had /begged/permitted/agreed/ to start a new business with this year.

The mayor is the crook (who) the police chief /expected/ordered/decided/ to leave town with after the scandal.

There goes the woman (who) my aunt /expected/hired/agreed/ to do the fancy washing for before the wedding.

Sally finally contacted the firm (that) Harold /begged/persuaded/promised/ to design the new office building for last month.

Harry is the one man (who) the bartender always /expected/permitted/hesitated/ to talk about his problems with every night.

On the train we got to know a professional musician (who) Tommy /asked/ forced/tried/ to play his guitar for in the evening.

There are very few stores (which) Jerry expects / allows/tries/ to make a profit from each year.

John's brother is a talented young man (who) many famous authors /wanted/ encouraged/attempted/ to write a book about after his successful play.

Those are the workers (who) the supervisor /expects/encourages/hesitates/ to complain to the union about very soon.

The president was impressed with the man (who) the space agency /expected/ persuaded/decided/ to learn the latest Russian technology from after the conference.

Those women are the board members (who) the company president /chose/allowed/ promised/ to deliver the committee presentation to at the last meeting.

The old man couldn't forget the invaders (who) the soldiers /wanted/forced/ attempted/ to flee in terror from in World War II.

The owner wanted to sell the horse (that) the jockey /expected/forced/tried/ to win the race with when the track opened again.

The other day I met the lucky young man (who) my old aunt /chose/ helped/ decided/ to travel around the world with over the holidays.

There's one truck driver (who) the waitress /expects/allows/refuses/ to boast to the cook about every evening.

Dr. Johnson was one professor (who) students /begged/urged/continued/ to talk about political questions with after class.

The police department investigated the cops (who) Sam /asked/prompted/decided/ to smoke a little marijuana with at Susan's party.

Mary is one student (who) the teacher /wanted/forced/swore/ to talk to the principal about last semester.

Lou was the barber (who) customers always /expected/encouraged/seemed to chat about the weather with during a haircut.

The New York Times found out about the man (who) the CIA / wanted/urged/ decided/ to remain very quiet about for the next few months.

We all admired the woman (who) Sam/begged/encouraged/started/ to write the screenplay about for MGM.

Tom didn't like the people (who) his partner /asked/hired/started/ to do the tax accounting for when he was on vacation.

Here comes that politician (who) the club president /chose/persuaded/tried/ to speak about the problems of inflation with during the campaign.

The librarian was the one(who) all the boys /wanted/encouraged/tried/ to dance the hustle with at the party.

Lots of people disapproved of the man (who) the city council /chose/invited/decided/ to dedicate the new library to at the opening ceremony.

We were worried about the little girl (who) the other children /expected/forced/agreed/ to take the blame for all the time.

We were the soldiers (who) the lieutenant always used to /beg/force/refuse/ to go on patrol with before an attack.

There used to be one salesman (who) the district manager would /ask/permit/promise/ to fill out the sales records for after closing.

Nobody knows what happened to the man (who) Marie had /expected/coaxed/decided/ to wait on the street corner for last Sunday night.

The district attorney met the prospective witness (who) the prisoner /begged/encouraged/happened/ to speak about his case to before the trial.

He is the famous scientist (who) the National Science Foundation /asked/persuaded/promised/ to build an observatory for within the next few years.

Carter asked if these were really the people (who) his party /expected/ordered/promised/ to cast a vote of confidence for at the convention.

Professor Stein was the kind of speaker (who) serious students /chose/invited/seemed/ to come to the university for if they were wise.

Many serious musicians despise the rock bands (that) promoters /expect/force/seem/ to make lots of money on during summer vacations.

No one ever found out what happened to the families (who) the Red Cross /asked/prompted/tried/ to deliver the food supplies to last winter.

Billy's father seemed to know the truck driver (who) Billy /wanted/coaxed/started/ to honk the horn at during the traffic tie-up.