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Parsing WH-constructions: evidence for on-line gap location

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Abstract—Two experiments investigate how people assign a grammatical meaning to WH-phrases in embedded questions. The first experiment replicates Crain and Fodor's (1985) finding that object NPs take longer to read in a WH-question than in a corresponding declarative sentence, suggesting that people expect not to find an object, presumably because they have associated the object semantic role with the WH-phrase. Experiment 1 also shows that there is no such difficulty at the subject NP, suggesting that the subject semantic role is not associated with the WH-phrase in the same way as the object role. Experiment 2 investigated whether people assign a semantic role to the WH-phrase which cannot be grammatically acceptable; the evidence suggests that people are not prone to make such mistakes.

INTRODUCTION

One central question in human language processing is how WH-constructions are analysed. To understand why this question is so important, it is necessary to understand the interesting characteristics of these constructions. Sentences like those in (1) contain long-distance dependencies: the meaning of a phrase in one position is dependent on information contained in a portion of the sentence which is indefinitely far removed from it.

- (1) a. What — is hitting Mary?
- b. What is Mary hitting —?
- c. What is Mary hitting that woman with —?
- d. What did Tom think that Mary was hitting that woman with —?
- e. What did Harry say that Tom thought that Mary was hitting that woman with —?

The meaning of the WH-phrase 'what' varies depending on structural properties of the sentence that follows it. For example, in (1a) there is no subject other than the WH-phrase; therefore the WH-phrase must fill the semantic role of subject. In (1b), there is a subject noun phrase (Mary), so that semantic role is not available for the WH-phrase; however, there is no object noun phrase; therefore the WH-phrase fills that semantic role in the sentence. In (1c), the preposition 'with' does not have an object; therefore the WH-phrase fills that semantic role. As can be seen from these examples, the distance between the WH-phrase and the position that would normally be occupied by a noun phrase which fills the semantic role assigned to the WH-phrase is not strictly limited. With recursive embedding, as in (1d) and (1e), the distance can be increased indefinitely. Furthermore there is another important characteristic of this dependency relationship; when there is a WH-phrase, there must be a position that a phrase of the same type can occupy

which is not filled by another phrase of that type. (2) is a sentence in which there is no such position.

(2) *What did Mary hit John?

Both subject and object position contain noun phrases and therefore these semantic roles cannot be assigned to the WH-phrase. There is, however, no other position in which a noun phrase can occur whose semantic role can be assigned to the WH-phrase. The WH-phrase therefore remains uninterpreted. This is particularly interesting since there are semantic roles (e.g., instrument) which could be assigned to the WH-phrase if people were free to use a process of inference to decide what a WH-phrase means in the context of a given sentence.

Given these characteristics, in order to understand the WH-construction the hearer must apparently first infer that a particular position in the sentence could, under some circumstances, contain a noun phrase; second, recognize that it does not contain a noun phrase in this sentence, and third, assign the semantic role associated with a noun phrase in this position to the WH-phrase. In demonstrating how people accomplish this feat, we may answer fundamental questions about how humans process language. For example, an adequate model of the processing of WH-constructions would provide information on the general question of whether linguistic knowledge is used to predict upcoming structure (top-down processing), or only to impose structure on the words which are in hand (bottom-up processing), or some combination of these two strategies. In terms of gap-location, if the syntactic analysis is top-down, then the people may use linguistic knowledge to predict that a gap will be present in a certain position; this analysis will be pursued until confirmed or disconfirmed. Alternatively, people may only deduce the presence of a semantic role for the WH-phrase after using all the information present in the string of words which are being processed. The occurrence of one strategy or the other provides a beginning of a specification of the characteristics of the parser.

More directly, by investigating how WH-questions are parsed, we may determine which sorts of information may be used to decide that a 'gap' is present; that is, that there is a position in which a noun phrase may occur and that no noun phrase is present in this position. If it can be determined exactly when a gap is 'located', we may deduce those types of information which allow the gap to be located. Two potential sources of information for locating gaps which will be addressed by the experiments reported in this paper are phrase structure rules and syntactic constraints. Phrase structure rules are generalizations about word order in a given language and may be used to identify the potential positions in which a noun phrase can occur. For example, in English a noun phrase may occur before the tensed verb as the subject, after most verbs as an object, or after a preposition as a prepositional object. Syntactic constraints, on the other hand, identify noun phrase positions which may not contain a gap. There are some phrase structure positions, for a given language, whose associated semantic role may not be associated with a WH-phrase. Such positions must contain an overt noun phrase to which this semantic role is assigned; otherwise, the semantic role cannot be assigned at all in the sentence. A sentence which contains a WH-phrase and only has an empty noun phrase position in such a construction is ungrammatical, since no grammatical meaning can be assigned to the WH-phrase.

An example of one syntactic constraint of English is illustrated in (3).

- (3) a. The story about Susan annoyed John.
- b. *Who did the story about — annoy John?

As can be seen in (3a), 'about' can be followed by a noun phrase such as 'Susan'. However, the semantic role associated with 'Susan' cannot grammatically be assigned to 'who' in (3b). Another syntactic constraint is illustrated in (4).

- (4) a. John thought that Susan was foolish.
- b. *Who did John think that — was foolish?

(4a) shows that a noun phrase can appear as the subject of the embedded clause 'that Susan was foolish'. The semantic role of subject of the embedded clause cannot grammatically be assigned to the WH-phrase 'who' in (4b), however.

The appropriate way to describe such grammatical constraints has been a matter of considerable debate in the linguistics literature. Regardless of the exact nature of their description in grammatical models, an adequate model of human language processing must define precisely how syntactic constraints affect comprehension and production.

Crain and Fodor (1985) have demonstrated a paradigm by which these questions may be investigated. They compared information questions with the corresponding declarative sentence, as in (5).

- (5) a. Who had the little girl expected us to sing those stupid French songs for — at Christmas?
- b. The little girl had expected us to sing those stupid French songs for Cheryl at Christmas.

Subjects were required to read these sentences one word at a time, controlling the pace of presentation themselves (self-paced reading). The general pattern of comprehension times was the same for the question and declarative versions of the sentences, but the reading times at and immediately following the object noun phrase ('us' in (5)) were longer for the WH-question than for the corresponding declarative. The most obvious explanation for this difference is that people expect a gap rather than a noun phrase in the object position, when there is an uninterpreted WH-filler in the sentence. The appearance of the object disconfirms this expectation, which causes longer reading times in this area of the sentence. If a WH-filler has occurred and has not yet been interpreted, people's first hypothesis is apparently that a gap will appear in a noun phrase position.

The self-paced reading paradigm (Aaronson and Scarborough 1976, 1977; Pynte 1978) thus gives us a tool with which we can look at the positions in which gaps are hypothesized. At a noun phrase position where a gap is assumed to exist, the presence of a lexical noun phrase will cause reanalysis and longer processing times.

In this paper I will present two experiments which attempt to resolve several questions about the location of gaps. The questions which are addressed are:

- (A) *Are gaps located in subject and prepositional object positions as they are in object position?*

Crain and Fodor have provided evidence that gaps are mislocated in object position. However, they have not demonstrated that all noun phrase positions are treated in the same fashion by gap location procedures. This is a particularly relevant question for the subject position in which gaps cannot always occur, although they may in the corresponding object position. For example, a gap may not occur in the subject position in a that complement, as demonstrated in (4b)

above. A gap can occur in object position in this sort of clause, as can be seen in (6).

- (6) a. John thought that Susan liked him.
- b. Who did John think that Susan liked —?

In Experiment 1, subject and object positions will be compared to see if the presence of a lexical noun phrase in both these two positions causes reanalysis. The object of a preposition is tested for evidence of reanalysis in Experiment 2.

(B) *What happens once a doubtless gap has been located?*

A doubtless gap (Fodor, 1978) is one where there is enough information to immediately unambiguously decide that a noun phrase must occur for the sentence to be grammatical. Therefore if no noun phrase is present in that position, there has to be a filler for it, such as WH-phrase. At first glance it would seem most reasonable to assume that once a gap has been successfully located, parsing procedures which serve the purpose of locating a gap should cease. However, there are reasons to think that this is too simplistic an assumption. The most important of these reasons is the structure of coordinate phrases. When a gap appears in a coordinate verb phrase, there must be a gap in both conjuncts, as shown by the examples in (7).

- (7) a. The boy admired the girl and drove her to the dance.
- b. Who did the boy admire — and drive — to the dance?
- c. *Who did the boy admire — and drive her to the dance?
- d. *Who did the boy admire the girl and drive — to the dance?

As can be seen in (7b), it is permissible to ask a question about the statement in (7a) as long as both conjuncts are questioned, but it is decidedly odd to ask about only one of the conjuncts as in (7c) or (7d). The important point to notice is that the parser must be able to locate both of the gaps. If procedures for locating a gap are terminated as soon as a gap is located, then the gap in the second conjunct should not be located. If the hypothesis that gap location is terminated as soon as a gap is successfully located is to be maintained, it would have to be proposed that at the start of a conjunction, gap location procedures are re-initiated.

Another problem for the hypothesis that the search for a gap terminates when a gap has been located is presented by the parasitic gap construction (Sag, 1982; Engdahl, 1984). A parasitic gap is a second gap in a sentence, where the two gaps are not in co-ordinate phrases and both gaps assign a semantic role to the WH-phrase, as in (8).

- (8) a. He's the sort of man you greet — without even noticing —.
- b. ?He's the sort of man you greet everybody else without even noticing —.

In (8a), the subject 'you' greets this sort of man without even noticing the man. The second gap is commonly called parasitic, because when there is no earlier gap, as in (8b), the gap is considered to be very awkward; the acceptability of its presence is parasitic on the presence of the first gap. If the location of the initial gap leads to the termination of gap location procedures, then the second gap should rarely, if ever, be noticed; it is detected regularly instead, despite the fact that the verb *greet* must take an object and so the parser has enough information to unambiguously locate the gap well before the second gap is encountered (i.e. the first gap is a doubtless gap).

A second issue concerning processing after the location of a doubtless gap is whether it is the same after a doubtless gap in subject position and after a gap in

object position. The example of parasitic gaps given above has the initial gap in object position. When the gap occurs in subject position, no gap may be parasitic upon it, as in (9).

- (9) a. He's the sort of man who — decides without thinking about himself.
- b. *He's the sort of man who — decides without thinking about —.

As can be seen in (9b), the notion expressed in (9a) cannot be grammatically expressed by means of a parasitic gap in the adverbial complement. Thus, we might predict that after a subject gap, gap location procedures cease, although they do not cease after an object gap.

Crain and Fodor's (1985) results suggest one way to determine whether gap location continues to occur at noun phrase positions following a doubtless gap in subject or object position. If a gap is posited in a position following a doubtless gap, then the presence of an overt noun phrase in that position, disproving the gap hypothesis, should lead to reanalysis and increased processing times. By creating materials with doubtless gaps in subject and object positions, followed by potential gap positions which are in fact filled by overt noun phrases, we can test the hypothesis that local processing load increases at such positions only if the gap occurred at the object noun phrase position. This hypothesis will be examined in Experiment 1.

- (C) *Can (some) syntactic constraints be used to avoid postulating gaps where they cannot grammatically exist?*

There are at least three general approaches to the role that constraints play in comprehension. Fodor (1983) suggests that such constraints may be implemented directly in the architecture of the parsing mechanism. Under this hypothesis, people will never assume that a gap exists in a position where one may not grammatically occur. Furthermore the parser will be unable to recognize a gap that does occur in such a position and assign its semantic role to the WH-phrase using its normal parsing routines. Marcus (1980) proposes a particular parsing architecture which would result automatically in several of the syntactic constraints of English.

Freedman and Forster (1985) propose an alternative hypothesis that gaps may be freely located by syntactic parsing procedures without any check on constraints. Constraints apply only when filling takes place. Under this hypothesis an empty noun phrase position can be detected anywhere, but the semantic role associated with it can only be assigned to a WH-phrase which bears an appropriate structural relationship to the gap.

Frazier *et al.* (1983) have proposed that certain information, including constraints on locations for gaps, is not initially attended to in gap location or gap filling. They tested the hypothesis that control information is not used until the end of the clause, comparing sentences like those in (10).

- (10) a. Mary is one student who the teacher wanted PRO to talk to the principal about —.
- b. Mary is one student who the teacher wanted — to talk to the principal.
- c. Mary is one student who the teacher decided PRO to talk to the principal about —.
- d. Mary is one student who the teacher forced — PRO to talk to the principal.

PRO stands for a gap in a position which cannot contain a lexical noun phrase. The role associated with PRO must always be filled by another noun phrase; the identity

of this noun phrase is normally determined by the identity of the verb in the higher clause (i.e. *decide*, *force*). A gap which is in a position which must either be filled by a lexical noun phrase or be associated with a WH-filler is indicated by —.

Frazier *et al.* tested the hypothesis that when the processing mechanism encounters a potential gap, the gap is initially filled with the most recently encountered potential filler. They assume that not all information is initially checked to see if the filling is appropriate. Thus when the subject gap in the to-complement is detected in (10a) or (10b), since *the teacher* is the most recent potential filler, it is initially assigned the subject role in the to-complement. In (10a), this is the correct decision, and a later gap is detected which the WH-phrase *one student* can fill. In (10b), the initial decision turns out to be incorrect, as there is no later gap. Since the WH-filler must be assigned a semantic role (cf. (2)), while *the teacher* does not need one, the sentence must be reanalyzed.

In (10a) and (10b) the verb *want* does not provide information which could be used to decide on the correct filler to begin with. (10c) and (10d) contain verbs which provide disambiguating information. The subject gap of the to-complement in (10c) follows *decide*, which can only take a to-complement containing an empty pronominal subject (PRO). The control information of the verb indicates that the subject of *decide* (*the teacher*) takes the subject role of the to-complement. Therefore filling the gap with the most recent potential filler will provide the right structure for the sentence, even without consulting the information about subcategorization and control which are presumably accessed with the verb *decide*. *Force*, on the other hand, must be followed by a lexical noun phrase or WH-gap as object (indicated by —). This noun phrase in turn fills the subject gap in the to-complement (indicated by PRO). If people used this lexical information about subcategorization and control, they would assign the object noun phrase role to the WH-filler initially and not have any trouble when no later gap appears.

Frazier *et al.* presented sentences like those in (10) on a computer screen at a rate of 350 ms per word. Subjects had to respond at the end of the sentence when they felt that they had understood the sentence. They found that sentences where the WH-filler had to be assigned the semantic role associated with the first potential gap ((10b) and (10d)) took longer to understand than sentences where the most recent filler could take the semantic role associated with the first potential gap position ((10a) and (10c)). This difficulty in the cases where the strategy of using the most recent filler would fail seems to support the existence of such a strategy. This pattern obtained even when there was lexical information that could have been used to prevent this mistake, as in (10c) and (10d). Frazier *et al.* take this to mean that lexical control information provided by the verb is not initially attended to in parsing. They suggest that several other types of information, such as constraints on potential WH-gap positions, are also not initially attended to.

Although Frazier *et al.* do not discuss it, under one interpretation, their experiment may provide direct support for the claim that constraints on potential gap positions are not initially consulted while assigning a filler to a gap. If we compare the structures associated with the relative clauses in (10b) and (10d), the position of the first gap is not the same (Jacobs and Rosenbaum, 1968; Chomsky, 1981).

- (11) a. [_{NP} one student [_{S'} [who] [_S the teacher wanted [_S [_{NP} t] [_{VP} to talk to the principal]]]]]]]

- b. [_{NP} one student [_S [who] [_S the teacher forced [_{NP} t] [_S [_{NP} PRO] [_{VP} to talk to the principal]]]]]

As can be seen in (11a), with verbs like *want*, the gap (indicated in linguistic structure by *t*) is in a separate clause from the controlling verb *want* and its subject. In (11b) on the other hand, the first gap is in the same clause as the controlling verb *force* and its subject. Frazier *et al.* do not commit themselves as to whether both of these gaps are located and filled by the most recent filler. It is important to note the implication if the object gap is filled using the most recent filler strategy. A subject noun phrase cannot be assigned the semantic role associated with an empty noun phrase contained within the same clause (Chomsky, 1981). This is a constraint on co-reference between positions which, according to some theories, is analogous to constraint on co-reference between WH-fillers and gaps discussed earlier. Frazier *et al.*'s data can therefore be taken to imply that at least some constraints on co-reference do not operate to prevent the development of an analysis of the sentence in which a constraint is violated. The constraint may instead have the effect of subsequently filtering out this incorrect analysis, but according to their data, this filtering process is quite slow. It has apparently not succeeded by the time that the sentence is ended. It is still necessary for some revision to be made, even in the sentences where the constraint applies, before subjects can signify that they have understood the sentence. Frazier *et al.* suggest that use of control and constraint information is deliberately delayed until the end of the clause, so that it can be applied to all instances where it is relevant simultaneously.

In Experiment 2 a constraint on co-reference of WH-fillers and gaps will be investigated to determine if this hypothesis can be supported. If there is evidence of a gap being incorrectly posited in a position which may not grammatically contain a gap, then syntactic constraints on the location of gaps are not necessarily attended to. The hypothesis that constraints are not initially used in processing, based on Frazier *et al.*'s data, suggests that such evidence will be found.

EXPERIMENT 1

Materials

Twenty-four sentence sets were created. A sample set of sentences appears in Table 1. Copies of the full set of materials are available from the author. The basic version (IF-CLAUSE) of the sentence contained one of six main verbs (*ask, tell, wonder, know, be certain, be sure*) which subcategorize for question complements. This verb was followed by an if-clause with three noun phrase positions, subject, object and prepositional object. Each if-clause was constructed so that each of these three positions was not optional: the noun phrase must be present for the sentence to be grammatical. Subject noun phrases are normally obligatory in English. To ensure that none of the object noun phrases could be omitted, verbs were selected for twelve sentences which must be used transitively, as in (12).

- (12) a. Ruth will bring him
b. *Ruth will bring.

For the other twelve sentence sets, verbs were chosen which cannot take an object noun phrase as in (13).

- (13) a. Sandy disagreed.
b. *Sandy disagreed him.

Table 1.
Sample materials for Experiment 1

IF-CLAUSE	My brother wanted to know if Ruth will bring us home to Mom at Christmas.
WH-SUBJ	My brother wanted to know who — will bring us home to Mom at Christmas.
WH-OBJ	My brother wanted to know who Ruth will bring — home to Mom at Christmas.
WH-POBJ	My brother wanted to know who Ruth will bring us home to — at Christmas.

These sentences contained two prepositional phrases. To ensure that the prepositional objects were not optional, prepositions were chosen which cannot be used with the verb in question as a particle (which takes no object), as illustrated in (14).

(14) a. Sandy disagreed with him.

b. *Sandy disagreed with.

The point of making the noun phrase positions obligatory is that this ensures that people have enough information to determine that a noun phrase must occur at each position where a noun phrase appears in these sentences. Thus, if it is missing, it is certain that there is a gap in this position which must be linked to a WH-phrase (i.e., it is a doubtless gap).

Three more versions of each target sentence were constructed by substituting WH-complements for the if-clause. In one of the WH-complements (WH-SUBJ), the subject noun phrase is absent and the WH-phrase (e.g., 'who', 'what') fills the semantic role of subject. In a second (WH-OBJ), the object or first prepositional object noun phrase is absent and its semantic role is filled by the WH-phrase. In the third (WH-POBJ), the final prepositional object noun phrase is missing, and its semantic role is assigned to the WH-phrase.

The three obligatory noun phrases in the target sentences are the target NPs, in whose behavior we are primarily interested. Each target NP starts with or consists of a proper name or pronoun, both of which unambiguously signal the beginning of a noun phrase. Usually the proper name or pronoun is the entire noun phrase, but occasionally it is instead possessive (e.g., 'his', 'Jane's') and serves to unambiguously introduce a longer NP. Although the target has been defined as the entire NP, the actual measurement centers on the first word of the NP in these cases, at which point the information that a NP is being processed should be available to the reader.

Three questions are to be asked in this experiment. First, can the local processing difficulty at object noun phrases where a gap may occur found by Crain and Fodor (1985) be replicated? If people expect a gap to occur in object position in a WH-clause, then they should have more trouble with the presence of a lexical noun phrase (*us*) in this position in a WH-clause (WH-POBJ) than in a similar clause with no WH-filler (IF-CLAUSE), where no such expectation develops. Second, assuming that the Crain and Fodor result is replicated, is there evidence of equivalent local processing difficulty at the subject noun phrase position (*Ruth*); that is, do people treat gap location identically in subject and object position? The use of embedded if- and WH-clauses allows us to ask this question, since the only difference in structure between these two clause types is whether or not there is a WH-filler which must be assigned some semantic role in the clause.

Third, what happens after a doubtless gap has been located? This question is tested by comparing sentences with a doubtless gap in subject position (WH-SUBJ) and in object position (WH-OBJ) to a sentence where no gap has yet occurred. At the object position, we can compare what happens in a WH-clause after a doubtless gap in subject position (WH-SUBJ) versus no preceding gap (WH-POBJ); if, the earlier gap has been located and its location causes gap location procedures to be shut off, we should find a substantial difference between these two versions at the object position (*us*). Essentially, the WH-SUBJ version should act like the IF-CLAUSE version, in which no gap expectation is developed. At the prepositional object position, we may compare what happens after a doubtless gap in subject position (WH-SUBJ) and a doubtless gap in object position (WH-OBJ) to determine if processing differs under these two conditions. It was argued above that there is reason to believe that a doubtless gap in subject position shuts off gap location procedures, while a doubtless gap in object position does not. Thus we would predict that a gap may be expected at the prepositional object noun phrase position in the WH-OBJ version, but not in the WH-SUBJ and the IF-CLAUSE versions. Thus, the prepositional object noun phrase (*Mom*) is unexpected in only the WH-OBJ version. This pattern should be reflected in the reading times.

Subjects

The sample consisted of 48 students at the University of Wisconsin at Madison who were paid for participating. All subjects were native speakers of English and had normal vision, corrected or uncorrected.

Procedure

The data collection for the experiment was controlled by an Apple II plus computer containing a Mountain Hardware Apple Clock. The experimenter was able to record descriptive information about the subject via the keyboard onto a second 40-column screen located out of sight of the subject. The subjects read sentences on an 80-column screen. The words were presented one at a time at a central location on the screen. At the beginning of each sentence, the warning PRESS NEXT WORD WHEN READY appeared on the screen. Six lines below the prompt an asterisk signalled the position in which the first word appeared, to allow the subject to fixate on the appropriate position before the word appeared. After the button labelled NEXT WORD was pressed, the word appeared at this position and the clock was set going by the computer. After the subject read the word, she or he pressed the NEXT WORD button, the clock was read and the reading time recorded. The clock was then reset to zero and the process was repeated for each word in the sentence. The last word in the sentence was not accompanied by a period or other punctuation so that subjects could not with certainty identify it as the last word. When they pressed the NEXT WORD button a pound symbol was displayed to indicate that the sentence was completed.

Subjects were instructed that they might be required to repeat a sentence which they had just read. After a fixed subset of one quarter of the sentences a bell rang, signalling that the sentence was to be repeated. After the subject had repeated the sentence, the experimenter re-initiated the experiment by pressing any button on the keyboard. When the sentence was not to be repeated, an interval of five seconds intervened and then the prompt for the next sentence was displayed.

Four lists were created by rotating the four versions of each sentence through a Latin square. Each list consisted of four fixed practice items, after each of which repetition was required, and four blocks within which the order of sentences was individually randomized for each subject. Since a fixed subset of sentences had to be repeated, randomizing the order of sentence presentation effectively randomized the occurrence of repetition trials. The order of the four blocks was rotated through a Latin Square every four subjects, so that equal numbers of subjects received each order of blocks for each questionnaire.

Results

The experiment included three NP target positions: (1) subject, (2) object or first prepositional object, and (3) final prepositional object. Each NP appeared in three sentence versions which contrasted if-clauses versus two positions of doubtless gap within the WH-clause. Each NP target position was treated separately in a set of planned comparisons with repeated measures within subject using an ANOVA design (Hays, 1981). The comparisons are regarded as statistically significant if $P < 0.05$. Mean reading times for Experiment 1 are summarized in Table 2.¹

For the first NP position, SUBJ, the difference (24 ms) between if- (IF-CLAUSE) and WH-complement (WH-OBJ and WH-POBJ) was not significant, $\min F' < 1$, providing no evidence that people expect a gap in subject position. Since the two positions of the doubtless gap both follow the subject NP, this comparison was not pursued.

At the object position (OBJ), a significant difference (192 ms) appeared between an object NP preceding a doubtless gap in prepositional object position (WH-POBJ) and those object NPs which (1) follow a doubtless gap in subject position (WH-SUBJ), or (2) are located in an if-clause (IF-CLAUSE): in other words between an object where a gap has not yet been located and an object where it is no longer, or never was, necessary to locate a gap, $\min F'(1,62) = 10.52$: $P < 0.01$ ($F(1,47) = 20.84$: $P < 0.001$; $F(1,23) = 21.25$: $P < 0.001$). This replicates Crain and Fodor's finding that people take longer to read an object noun phrase where a gap might have occurred. Additionally, it supports the claim that people do not create an expectation of a doubtless gap after a gap in subject position, combined with the orthogonal contrast of if (IF-CLAUSE) versus WH (WH-SUBJ) at object position (46 ms), which failed to show a significant difference, $\min F' < 1$. There was a significant interaction between if- versus WH-clause and subject versus object positions, $\min F'(1,54) = 5.92$: $P < 0.05$ ($F(1,47) = 14.29$: $P < 0.001$; $F(1,23) = 10.11$: $P < 0.005$). This interaction demonstrates that people treat the location of gaps at subject and object position in different ways.

In all conditions, the prepositional object position (PROBJ) followed a doubtless gap (WH-SUBJ and WH-OBJ) or was in an if-clause (IF-CLAUSE) where no search for a gap is necessary. The hypothesis that the search for a gap does not continue after a gap in subject position while it does continue after a gap in object position was tested by contrasting the version with an object gap (WH-OBJ) with those versions where no search for a gap is anticipated (IF-CLAUSE and WH-SUBJ). No significant difference (49 ms) was found, $\min F' < 1$. The orthogonal contrast (57 ms) between if (IF-CLAUSE) and WH clauses (WH-SUBJ) was also not significant, $\min F' < 1$, providing no support for the distinction between subject

Table 2.

Mean reading times for target noun phrase positions for
Experiment 1

	Target noun phrase positions		
	SUBJ	OBJ	PROBJ
IF-CLAUSE	661	755	755
WH-SUBJ	—	801	812
WH-OBJ	680	—	833
WH-POBJ	689	970	—
	(Ruth)	(us)	(Mom)

and object doubtless gaps as suppressors of gap location procedures. There is a significant interaction between object versus prepositional object position of the target NP and the type of WH-clause for subjects, although the comparison does not reach significance for items, $F1(1,47)=7.67$: $P<0.01$; $F2(1,23)=3.92$: $P=0.06$ (min F' (1,47)=2.59: $P>0.10$), which supports the contention that people do not treat gap location in prepositional object position as they do in object position when no gap has been located.

Discussion

Three questions were asked in Experiment 1. The first two questions can be answered unequivocally. First, there was a decided increase in processing difficulty for object noun phrases in WH-clauses over object noun phrases in if-clauses, which replicates the findings of Crain and Fodor (1985). Second, no corresponding increase in processing load appeared at the subject noun phrase.

The third question can be answered partially. There was an unequivocal difference between a noun phrase which follows a doubtless gap in subject position and one which does not follow any gap. This can be seen in the difference between the object noun phrase in the subject gap version (WH-SUBJ) and the object noun phrase in the prepositional gap version (WH-POBJ). It can thus clearly be stated that whatever difference there may be in the ease of processing a noun phrase in an if-clause and the same phrase in the corresponding WH-clause when there has been a preceding doubtless gap in subject position, this difference is not equivalent to the difference between these two types of clauses when there has not been a preceding gap in the WH-phrase. People do not handle noun phrases following a doubtless gap in subject position as if they had not located that gap.

There was no significant difference between a gap which follows a gap in subject position and one which follows a gap in object position, as can be seen in the comparison between prepositional objects in clauses with a gap in object position (WH-OBJ) and those with a gap in subject position (WH-SUBJ) or no gap (IF-CLAUSE). This lack of significant difference is somewhat problematic given the facts discussed earlier about coordinate structures and parasitic gaps. However, there was a marginal difference (49 ms), although it did not reach significance. This marginal difference may indicate that gap location procedures are still at work, but it seems relatively clear that they do not have the same effect as when they apply to a noun phrase position before a gap has been encountered. Thus we are left with a picture in which the application of gap location procedures is heavily context-

dependent. The exact nature of the differences in gap location procedures between contexts awaits further elucidation.

The most important conclusion which can be drawn from these results concerns the difference between the object and subject noun phrase positions. It has been argued that people have difficulty at the object noun phrase position when there might have been a gap in this position because they expect the gap rather than the lexical noun phrase. The lack of a similar difficulty at the subject noun phrase suggests that people do not expect a gap in subject position or that they do not have any trouble recovering from the expectation at subject position, unlike object position. On the other hand, from the distinct reactions that people show to object noun phrases which follow a gap in subject position as against object noun phrases which do not follow a gap in subject position, it is clear that people have no trouble locating gaps in subject position, expectation or no expectation. Therefore, the parsing routines which serve to identify the subject of a WH-clause must be substantially different from the routines which operate at object position.

There seem to be at least two possible loci of the difference. One possibility is that people do not need to locate a gap in the subject position. If there is no overt subject noun phrase, the WH-phrase can be treated as the subject noun phrase by all parsing routines. Under this hypothesis, people do not in fact start looking for a gap until the presence of the subject noun phrase informs them that they have an unassigned WH-phrase. A second possibility is that people create an expectation for a gap in both subject and object position. However, it is substantially easier to correct this assumption in the case of the subject position than the case of the object position. There might be several reasons for this greater ease; one salient possibility is that the expectation of a gap in object position leads to the creation of a proposition in the semantic interpretation of the WH-clause, whereas the expectation of a subject gap does not. For example, if a person reads the words *I wonder who* and creates the expectation of a subject gap, there is no propositional content for the subject semantic role to be combined with. Therefore this semantic operation cannot be carried out. Only the syntactic expectation has to be rectified when the subject noun phrase is read. When the words *I wonder who the girl greeted* are read, on the other hand, people can create the expectation of a gap and use that expectation to create a complete semantic proposition. Correcting the syntactic expectation may be a good deal easier than correcting the semantic interpretation.²

EXPERIMENT 2

Materials

Twenty target sentences were constructed. Each consisted of a main clause containing one of five main verbs (*tell, ask, wonder, know, find out*) which may occur with an if- or with a WH-clause as complement. For each sentence, two if-clauses were constructed, in which the same prepositional phrase occurred. In one, the prepositional phrase was contained in the subject noun phrase (SUBJ); in the other, the prepositional phrase was located in the verb phrase (VP). The prepositional phrase was preceded by the same number of words in both versions and the words are approximately matched in length (16.75 letters mean for subject complements; 16.35 letters mean for verb phrases). The target noun phrases within

Table 3.
Sample materials for Experiment 2

IF-SUBJ	The teacher asked if the silly story about Greg's older brother was supposed to mean anything.
WH-SUBJ	The teacher asked what the silly story about Greg's older brother was supposed to mean.
IF-VP	The teacher asked if the team laughed about Greg's older brother fumbling the ball.
WH-VP	The teacher asked what the team laughed about Greg's older brother fumbling.

the prepositional phrase must be present for either version to be grammatical; thus, the parser has enough information before the position to predict that a noun phrase must occur in this position or the semantic role associated with the position must be assigned to a WH-phrase. Each target noun phrase consisted of a proper name as a possessor, followed by two or more words (e.g., *Greg's older brother*), or of a proper name conjoined with another noun phrase (e.g., *Gail and her sister*). Comparison were made for the first word of the target noun phrase position only; as in Experiment 1, this word provides enough information for people to determine that a noun phrase is present in this position in the sentence.

From each of the if-clause versions, a WH-version was created by replacing 'if' with 'who' or 'what' and deleting a noun phrase which followed the target noun phrase position. 'What' was used in 10 sentences and 'who' was used in the other 10. An example sentence set is shown in Table 3. Seventy-six filler sentences were constructed; 24 contained if- or WH-clauses, the others had different structures.

Experiment 2 tests, for one particular type of construction, whether gaps are incorrectly posited in positions where they cannot grammatically occur. A gap cannot grammatically occur in a prepositional complement to a subject noun phrase as in (15b), although a noun phrase may appear in the corresponding position in a declarative sentence, as in (15a).

- (15) a. The story about Susan annoyed her boyfriend.
- b. *Who did the story about — annoy her boyfriend?
- c. Her boyfriend laughed about Susan.
- d. Who did her boyfriend laugh about —?

On the other hand, a gap may appear in the place of the noun phrase in (15c) which occurs in the same prepositional phrase, when the prepositional phrase is a complement of the verb rather than of the subject noun phrase.

These two prepositional phrase positions are contrasted, again using the word-by-word self-paced reading task. Since a gap may occur in a prepositional phrase in the verb phrase, we would expect that people will assume that a gap appears there. Thus there will be a local increase in processing load at an overt noun phrase at this location (*Greg's*) in a WH-clause (WH-VP) as against the corresponding if-clause (IF-VP), since the noun phrase forces reanalysis of the gap hypothesis. The difference should be analogous to that found at the object noun phrase by Crain and Fodor (1985) and in Experiment 1. This comparison will thus extend our information about gap location to the prepositional object position in addition to the object and subject positions.

For the subject complement there are several possibilities. One possibility is that

constraints on the positions that gaps can occupy are not used by the parser (Frazier *et al.*, 1983). Instead, the parser may 'expect' that a gap will occur in any position which a noun phrase may occupy. If this is the case, then the information that an overt noun phrase is present in the subject complement will serve as evidence against the gap hypothesis, exactly as in the verb complement, and a comparable increase in processing load may be apparent at the prepositional object (*Greg's*) in the WH-clause version (WH-SUBJ) as against the if-clause version (IF-SUBJ).

Alternatively, the constraint may be used quite rapidly to block the gap hypothesis, possibly while attempting to assign the semantic role associated with the noun phrase position to the WH-phrase (Freedman and Forster, 1985), in which case the increase in processing load may be minimized. A third possibility is that the constraint is implemented in the parsing routines themselves (Fodor, 1983), so that a gap is never hypothesized where no gap may grammatically exist. In this case, there is no reason to expect that the presence of an overt noun phrase will cause a processing load increase at a position where a gap may not grammatically occur. In this case there will be no difference between the prepositional object noun phrase in the subject complement versions of the experimental materials, as opposed to the difference which we expect in the verb phrase complement, where a gap may occur.

Subjects

Forty-eight undergraduate students at the University of Wisconsin at Madison were paid to participate. All were native speakers of English and had normal, corrected or uncorrected, vision.

Procedures

The procedure used was the same as in Experiment 1.

Results

The results of Experiment 2 are summarized in Table 4, which contains mean reading times for the first five words of the embedded (if- or WH-) clause in each version of the experimental sentences. The words preceding the target noun phrase were analysed as well as the target position, since the sentences differed in lexical content as well as structure.

The reading times for each of these positions were subjected to within subject ANOVAs treating SUBJECT versus VP and IF versus WH as main effects. Neither main effect or the interaction between them was significant at the determiner (DET) position; all min F' 's < 1. At the following position (ADJ/N) which contained an adjective in the subject structure and a noun in the VP structure, there were no significant effects: SUBJECT vs. VP structure, min F' < 1; IF vs. WH, min F' < 1; and the interaction between the two, min F' (1,36) = 1.01: $P > 0.25$ (F (1,47) = 3.39: $P > 0.05$; F (1,19) = 1.44: $P < 0.2$). There were no significant differences at the third position (NOUN/V), which contained a noun in the subject complement structure and a verb in the VP structure, min F' < 1 for both main effects and the interaction. At the preposition (PREP), there was a significant effect of IF vs. WH for subjects, although the effect fails to reach significance for items, F (1,47) = 13.62: $P < 0.001$; F (1,19) = 2.56: $P > 0.1$; min F' (1,26) = 2.15: $P > 0.10$. SUBJECT vs. VP is significant for both subjects and items, although the min F' value does not reach

Table 4.

Mean reading times in milliseconds for positions in the embedded clause in Experiment 2

	Positions in the embedded clause				
	DET	ADJ/N	NOUN/V	PREP	TARGET
IF-SUBJ	611	677	752	750	798
WH-SUBJ	616	698	760	880	800
IF-VP	613	735	754	678	782
WH-VP	608	698	736	755	1063
	(the)	(silly/ team)	(story/ laughed)	(about)	(Greg's)

significance, $F(1,47)=4.16$: $P<0.05$; $F(1,19)=4.41$: $P<0.05$; $\min F'(1,55)=2.14$: $P>0.10$. There was no significant interaction, $\min F'<1$. At the target noun phrase (TARGET), there was a significant difference for IF vs. WH, $\min F'(1,40)=4.17$: $P<0.05$ ($F(1,47)=12.18$: $P=0.001$; $F(1,19)=6.35$: $P<0.05$). SUBJECT vs. VP was also significant, $\min F'(1,66)=6.38$: $P<0.05$ ($F(1,47)=9.18$: $P<0.005$; $F(1,19)=20.88$: $P<0.001$). The interaction is significant for subjects, although it does not reach significance for items, $F(1,47)=13.62$: $P<0.001$; $F(1,19)=3.88$: $P>0.05$; $\min F'(1,30)=3.02$: $P<0.1$). This tendency toward an interaction is due to the fact that both the main effects are caused by the exceedingly high score for the WH-version of the VP structure. To break down the question in a different set of orthogonal contrasts, the WH-VP version was significantly different from the other three versions, $\min F'(1,61)=8.52$: $P<0.01$ ($F(1,47)=14.52$: $P<0.001$; $F(1,19)=20.61$: $P<0.001$;). Within the other three versions of the sentence, VP did not significantly differ from subject structure, $\min F'<1$, and IF did not significantly differ from WH, $\min F'<1$.

Discussion

These results, like those of Experiment 1, suggest that there is no overall difference in the processing of if- and WH-clauses; what differences there are lie at particular structural positions, in this case the preposition and the prepositional object positions.

At the prepositional object position, we find a pronounced difference between how people react to the subject and the VP structures in a WH-clause. In the VP structure, the presence of the noun phrase causes real difficulty, whereas in the subject structure, there is no particular difficulty attached to the noun phrase. The explanation for this is presumably that in the VP, people expect a gap rather than the noun phrase. The presence of the overt noun phrase causes reanalysis. Thus the difference that appears here between a noun phrase in a WH-clause vs. an if-clause replicates Crain and Fodor's results. It also extends them to a slightly different structural position; Crain and Fodor only looked at object noun phrases, and here it has been demonstrated that the same result obtains for prepositional objects. The lack of any such difficulty at the prepositional object in the subject structure suggests that the fact that a grammatical gap cannot occur in such a position has prevented the gap hypothesis from coming into existence, as suggested by Fodor (1983), or has allowed the gap hypothesis to be quickly revised in a relatively cost-free way, as proposed by Freedman and Forster (1985). That is, revising the

hypothesis certainly does not take as much effort as is necessary when the counter-evidence to the hypothesis is the occurrence of an overt noun phrase.

The evidence from the prepositional object noun phrase does not distinguish between these two possibilities. It shows that constraints are used quickly and accurately, but does not determine if they serve to block a gap hypothesis or prevent a gap hypothesis from ever coming into existence. What happens at the preposition itself may suggest an answer to this question. There was a significant difference at the preposition position between the SUBJECT and VP versions of the sentences for subjects and items. IF vs. WH was also significant, although only for subjects; however, the latter main effect is probably spurious. In Experiment 1 there is also a possible comparison between a preposition contained in a verb phrase in IF and WH clauses; this comparison is not significant, $\min F' < 1$.³ That suggests that the significant difference among these scores is not a result of being in IF and WH clauses but rather of some co-occurring variable. Despite the lack of a significant interaction, a possible source of difference is that one of the WH-clause prepositions is contained in a subject noun phrase. When the statistical investigation was divided up into a different set of *post hoc* orthogonal contrasts, the preposition in a subject noun phrase and a WH-clause (WH-SUBJ) differed from the preposition in the other three conditions (IF-SUBJ, IF-VP, WH-VP) for subjects, although not for items, $F_1(1,47) = 7.47$; $P < 0.01$; $F_2(1,19) = 3.39$; $P > 0.05$; $\min F'(1,44) = 2.33$; $P > 0.1$; there was no significant difference among the three remaining versions either for IF (IF-SUBJ and IF-VP) vs. WH (WH-SUBJ) or for SUBJECT (IF-SUBJ) vs. VP (IF-VP), $\min F' < 1$ for both comparisons. Thus, it is reasonably consistent with these results that there is a difficulty in processing at the preposition only in a subject complement in a WH-clause. The appearance of the preposition indicates that a noun phrase will follow. This may cause a difficulty in a WH-clause. The subject may initially posit that the noun phrase following will be a gap. However in the subject complement, a gap is not permissible. The additional time required for processing in this case may reflect the effort of blocking the gap hypothesis at this point. That is, the additional processing difficulties at the preposition in a subject complement in a WH-clause may reflect the action of a constraint which is blocking a gap hypothesis.

If this is the true explanation of the longer reading times at this point in the sentence, it would decide between the two possible functions of constraints in processing WH-constructions; constraints act to block the gap hypothesis, rather than preventing it from coming into existence. However, alternative explanations do exist. For example, it is possible that there is a difficulty attendant on entering a construction where a gap cannot be located. This difficulty might be attributed to a need to establish a special memory store for the WH-phrase when it is not needed for an active search for a gap. Under this view, knowledge of constraints would act as a filter at a level of operations over syntactic parsing, rather than as a filter on particular gap hypotheses computed within the construction in which a gap may not occur. Until these issues can be further clarified, the exact role of constraints cannot be fully determined.

However, the results of Experiment 2 do not support a view of processing in which constraints are not initially used in processing, as suggested by Frazier *et al.* Frazier *et al.* specifically suggest that control information and constraints are only applied at the end of a structural unit, such as the clause, so that such information

only need be accessed once, rather than potentially at several points during parsing. Experiment 2 provides evidence that constraints may be used immediately, despite the fact that they may be needed later in the clause as well.

Experiment 2 may show a different pattern of results from that reported by Frazier *et al.* for any one of several reasons. First the two experiments explicitly tested different types of information. It is possible that lexical information about control is not attended to until the end of a clause, while constraints on possible locations for gaps can be used immediately. Under this interpretation, Frazier *et al.*'s explanation of their results ought to be taken to apply solely to the subject gap in the to-complement, which is largely governed by control information. The object gap found in sentences with verbs like *force* is perhaps filled correctly by the WH-phrase, due to the constraint which does not allow the subject noun phrase to co-refer to an empty noun phrase contained in the same clause.

A second possibility is that neither control or constraint information are normally used until the end of a clause, but due to the overall slowness of the self-paced reading presentation (about half as fast as Frazier *et al.*'s presentation), information can be used faster than it normally would be.⁴ Under this explanation, the normal delay in using certain types of information is simply a consequence of not having the time resources to use them.

A last possibility is that both control and constraint information are always used initially in processing and that Frazier *et al.*'s pattern of results must be attributed to a different cause. One possibility might be that, despite Frazier *et al.*'s arguments, the difficulty encountered in the two types of sentence where the WH-phrase must be assigned to an early gap ((10b) and (10d)) are not due to the same source. For example, the gaps following ambiguous verbs like *want* may in fact be initially filled by the most recent filler (since this analysis is possible given control information and constraints), while gaps following unambiguous verbs like *force* may be initially filled correctly. The difficulty for the ambiguous verbs is thus due to the incorrect filling, while the difficulty with the unambiguous verbs is due to another factor, such as the presence of two consecutive gaps. Frazier *et al.* argue against this possibility, showing that verbs like *force* do not significantly differ from verbs like *want*, as would be expected if the presence of two consecutive gaps caused trouble for *force*-type verbs, in addition to the failure of the most recent filler strategy. However, it is quite possible that only the presence of two consecutive gaps is causing problems for these verbs and that, coincidentally, the 'size' of the difficulty is the same as that caused by reanalysis for verbs like *want*.

CONCLUSIONS

In this paper evidence has been provided about the way in which gaps are located in human language processing. Crain and Fodor (1985) have shown that at an object noun phrase in a WH-question, processing is substantially more difficult than in the corresponding declarative sentence. This indicates that people expect a gap to appear in the object position and are surprised when an overt object noun phrase appears in this position. In Experiment 1, this effect is replicated. In Experiment 2, it is shown that the same effect obtains when prepositional phrases in the verb phrase are compared. On the other hand no such processing difficulty occurs at a subject noun phrase. This may be because no gap is expected in this position or

because rectifying the mistake is easier than in the object and prepositional object positions.

Additionally, Experiment 1 tested whether gaps continue to be hypothesized after a doubtless gap is located. The evidence suggests that either gaps are not hypothesized after a gap is located or, if gaps continue to be hypothesized, they do not cause the same difficulties for reanalysis as when a gap is incorrectly hypothesized before a doubtless gap has been located. No difference was found between noun phrases which follow after a doubtless gap in object position and noun phrases following a doubtless gap in subject position, despite linguistic evidence that additional gaps may occur after object gaps but not after subject gaps.

Experiment 2 tested whether gaps are hypothesized in positions in which they cannot occur grammatically. It is clear from the evidence of this experiment that a reader realizes quite quickly and accurately that a gap cannot occur in at least one construction; thus the presence of an overt noun phrase in this position does not cause reanalysis. There is some evidence of processing difficulty immediately before the noun phrase position in question which suggests that the ungrammaticality of a gap in the following noun phrase position is realised at this point. Therefore the gap hypothesis is blocked or cannot come into existence.

What can we say about human language processing, based on this evidence about gap location procedures? This evidence suggests that the development of a gap expectation is heavily dependent on syntactic context. The expectation of a gap develops as soon as there is a verb or preposition which signifies that a noun phrase can follow. If the expectation did not develop virtually instantaneously, then the difficulty caused by the gap expectation would not show up on the next word. Moreover there could not be any signs that people are blocking a gap expectation on the preposition itself in Experiment 2, if syntactic information is not being used to predict upcoming structure. Thus it appears that people use information in the string of words that they are reading to hypothesize ahead to the position of a gap; this implies that people use hypothesis-driven (or top-down) processing, at least for gap location.

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NOTES

1. Reading times for other positions in the embedded clause were also measured. No significant differences obtained at any of these positions; particularly, there was no difference for reading items after a doubtless gap position as against no gap. This suggests that filling a gap is not a time-consuming task.

2. This possibility suggests one possible explanation for the lack of difference between prepositional object noun phrases in WH-OBJ and WH-POBJ versions discussed above. Even if gap location does continue only after gaps in object position, the fact that a semantic role has already been assigned to the WH-filler may slow down or prevent the assignment of the additional role to the later gap. Therefore only a syntactic expectation will have to be reanalyzed, as with subject gap mislocation, no significant difference in processing time occurs due to this reanalysis.

3. The comparison between prepositions in Experiment 1 is for only those items which contain two prepositional phrases (12 items). The first preposition occurs before the OBJ target noun phrase, while people are still looking for a gap in the WH-OBJ and WH-POBJ versions of the sentence, as they are in the corresponding comparison in Experiment 2. Additionally, the preposition does not occur after an object noun phrase which has caused reanalysis, unlike the second preposition (WH-POBJ).

4. If the use of constraints is dependent on the availability of time to apply the information to a position, then we would expect that the fast readers in the self-paced reading task would show more evidences of developing a gap expectation than the slower readers. In a post-hoc examination of the fastest readers (10 subjects whose mean reading time for the entire experiment was less than 500 ms), the same pattern of results obtained, although the interaction (84 ms) did not quite reach significance ($P=0.05$).

	IF	WH
SUBJ	414	418
VP	405	496

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