JOURNAL OF MEMORY AND LANGUAGE **35,** 454–475 (1996)
ARTICLE NO. 0025

Plausibility and the Processing of Unbounded Dependencies: An Eye-Tracking Study

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Two eye-tracking experiments investigated processing of unbounded dependency constructions. Experiment 1 employed sentences like *That's the garage/pistol with which the heartless killer shot the man yesterday afternoon.* Readers experienced greater processing difficulty in implausible sentences than in plausible sentences immediately after encountering the verb *shot.* This demonstrated that they did not wait until the purported gap location after *man* before forming the unbounded dependency. Experiment 2 considered sentences which locally appear to have an unbounded dependency that turns out to be incorrect. Data from this experiment demonstrated that readers formed the unbounded dependency immediately, even though they had to reanalyze later. However, there was no evidence that readers formed this unbounded dependency when it was rendered ungrammatical by island-constraint information. We argue that the processor constructs unbounded dependencies in a manner that is maximally efficient from the point of view of incremental processing.

This paper is concerned with the processing of *unbounded dependencies,* as found in (1) below:

Which man do you believe Mary loves a lot? (1)

Unbounded dependencies also occur in other constructions like relative clauses, topicalizations and *it*-clefts. Sentences like (1) are of great linguistic interest, because they present a serious challenge to simple accounts of the syntax of language. The problem is that the phrase *which man* is a long way from the verb *loves,* even though they bear a close linguistic relationship. Roughly, *which man* is the object argument of *loves.* In most constructions, verbs are very close to their arguments, but in unbounded dependencies there is no limit to the number of words or clauses that can separate them. Linguistic theories have to account for this, preferably without making many additional theoretical assumptions.

Unbounded dependencies pose an analogous problem for theories of language comprehension. The processor has to determine that the verb and its argument are related, even though they are separated from each other in the sentence. In this paper, we present experiments that investigate how this relationship is constructed. Our first experiment addresses the question of whether this relationship can be constructed as soon as the processor encounters the verb. Our second experiment asks whether the processor delays forming this relationship if the fragment is ambiguous and it is locally unclear whether the relationship is correct or not. It also considers whether the formation of this relationship can be blocked by constraints on possible unbounded dependencies known as island constraints.

Unbounded dependency constructions contain a phrase (like *which man* in [1]) that can be arbitrarily far from the word with which it is associated. We call this phrase the *filler* (Fodor, 1978; Wanner & Maratsos, 1978). The word with which the filler is associated is often a verb (like *loves* in [1]), but can also be a preposition;

The order of authorship is arbitrary. We gratefully acknowledge Melody Terras for her assistance in data collection and analysis. We are particularly indebted to Keith Edwards for extremely capable technical assistance. We also acknowledge Simon Garrod, Simon Liversedge, Don Mitchell, Keith Rayner, an anonymous reviewer, and the members of the Human Communication Research Centre Sentence Processing Group at the Universities of Edinburgh and Glasgow for their advice and encouragement. This research was supported by ESRC Grant No. R000234542 and a British Academy Post-Doctoral Fellowship (both awarded to the second author). Address correspondence and reprint requests to Martin J. Pickering, Human Communication Research Centre, Department of Psychology, University of Glasgow, 56 Hillhead St., Glasgow, G12 9YR, UK.

0749-596X/96 $18.00

in our examples, it will always be a verb. It is uncontroversial that the filler and the verb have to be associated in some manner for the sentence as a whole to be interpreted, but it is less clear how this association actually occurs.

Sentence comprehension is essentially an incremental process. Garden-path phenomena (Bever, 1970; Frazier, 1979; Frazier & Rayner, 1982) indicate that syntactic processing occurs while a sentence is encountered. Other experiments demonstrate that many aspects of semantic interpretation occur over sentence fragments (e.g., Altmann & Steedman, 1988; Garrod, Freudenthal, & Boyle, 1994; Marslen-Wilson, 1973, 1975; Trueswell, Tanenhaus, & Garnsey, 1994). The processor conducts a considerable amount of linguistic processing as it encounters each new word. One might therefore expect that the processor associates the filler and the verb as soon as it encounters the verb and provides an interpretation for the sentence fragment at this point.

For this model to be correct, two different components must hold true. First, the processor must be able to construct a simple link between the filler and the verb. This may seem straightforward, but in fact many theories of unbounded dependencies assume that the filler is only indirectly linked to the verb via an intermediary element known as a *gap*. Second, the processor has to choose to form this link between filler and verb immediately, even if there is a chance that this link is in fact incorrect. Many unbounded dependency constructions are locally ambiguous; it is then impossible to be sure that forming the link will turn out to be correct. On this model, the processor forms the link anyway. Below we discuss these two components in turn.

When Can the Unbounded Dependency Be Formed?

On the incremental account, the processor must always associate filler and verb as soon as it encounters the verb. Following Pickering (1993), we call this *Immediate Association.* The immediate association hypothesis has traditionally not been adopted within psycholinguistic theory (e.g., Clifton & Frazier, 1989; Fodor, 1978). Most researchers in sentence processing have assumed that the processor draws upon linguistic information that is represented in a manner compatible with transformational grammar (e.g., Chomsky, 1965, 1981). Transformational grammar assumes a quite complicated account of the grammar of unbounded dependencies. It assumes that the filler occurs at its "canonical" location at an underlying level of representation (D-Structure). This location is where the filler is found in other sentence types, near to the verb. In (1), the underlying location for *which man* is immediately after *loves* (cf. the "echo" question *You believe Mary loves <u>which man</u> a lot?*). It is then moved to the beginning of the sentence by means of a transformation. In modern transformational grammar (Government-Binding Theory: Chomsky, 1981), the filler leaves a gap (known as a *wh*-trace) at its underlying location. This gap (Ø) is coindexed with the filler, giving the following representation:

[Which man]$_i$ do you believe Mary loves [Ø]$_i$ a lot? (2)

Transformational grammar clearly regards unbounded dependency constructions as special; most other constructions do not involve transformations or gaps.

Most accounts of the processing of unbounded dependencies draw upon transformational grammar and assume that the mental representation of unbounded dependencies incorporates gaps. For instance, Fodor (1978, 1989) defined the process of forming an unbounded dependency as the association of filler with gap. The term *gap-filling* is often treated as a neutral description of the process of unbounded dependency formation, even though it assumes that the transformational description of such constructions is correct. We return to the relationship between processing accounts and linguistic analysis in the General Discussion below.

Experimental evidence is generally interpreted in terms of gap-filling. For example, there have been many demonstrations of the so-called *filled-gap effect* (Boland, Tanenhaus, Garnsey, & Carlson, 1995; Bourdages, 1992; Crain & Fodor, 1985; Frazier & Clifton, 1989;

Stowe, 1986). Localized difficulty occurs on *us* in (3b) compared with (3a) below (Stowe, 1986, Experiment 1):

My brother wanted to know if Ruth will bring us home to Mom at Christmas. (3a)

My brother wanted to know who Ruth will bring us home to at Christmas. (3b)

In (3b), Stowe suggested that after the processor encounters *bring*, it inserts a gap right after it, and immediately fills the gap with the filler *who*. The word *us* indicates that this analysis is not correct, and so the processor performs immediate reanalysis, causing measurable disruption.

Following Fodor (1978), it is generally assumed that gap-filling occurs in the following way (remember that we are ignoring ambiguity for the present). The identification of a filler causes the processor to search for a gap. When it finds the location of the gap, it positions the gap and associates the filler with the gap. Only then can it interpret the filler as an argument of the verb. The unbounded dependency is therefore not formed until the gap location is reached. Pickering (1993) calls this account *standard gap-filling.*

Standard gap-filling contrasts with immediate association, where the filler is associated with the verb directly. Hence, standard gap-filling is incompatible with the simple incremental account discussed above. However, for the examples that we have considered, immediate association and gap-filling make the same predictions. The reason is that the gap is adjacent to the verb, and it is assumed that the gap can be sited as soon as the verb is processed. Thus, previously reported evidence supporting gap-filling is also consistent with the immediate association hypothesis.

Pickering and Barry (1991) demonstrated that standard gap-filling and immediate association make different predictions when the purported gap is not adjacent to the verb. Consider (4) below:

In which tin did you put the cake last night? (4)

The "canonical" word order for (4) is *you put the cake in the tin last night.* Hence transformational grammar assumes the representation in (5):

[In which tin]$_i$ did you put the cake [Ø]$_i$ last night? (5)

Standard gap-filling predicts that the filler is not associated with the verb at *put.* Instead, the unbounded dependency can only be formed after the processor has reached *cake* and sited the gap.

In contrast, immediate association predicts that the processor links the filler and verb at *put.* Pickering and Barry (1991) provided evidence, based on intuitions about processing difficulty, for immediate association. In particular, they demonstrated that sentences that contain nested patterns of associations according to standard gap-filling, but disjoint patterns according to immediate association, are not hard to process, and do not behave like the nested constructions discussed by Chomsky (1965). However, they provided no experimental evidence for immediate association.

To summarize, evidence from sentence processing to date is compatible with two accounts of how the processor forms unbounded dependencies. Standard gap-filling predicts that the processor must wait until it reaches the location of the gap before it can form the unbounded dependency. Immediate association predicts that the processor can form the unbounded dependency as soon as it encounters the verb. If the gap is not adjacent to the verb (as in [4] above), then the accounts make different predictions about the time course of processing.

Local Ambiguity in Unbounded Dependency Constructions

On the incremental account, the processor forms unbounded dependencies as soon as the verb is reached. If it is locally ambiguous whether the filler forms an unbounded dependency with the verb, the account predicts that the processor will assume that the unbounded dependency is real, and will correct later if necessary. In this paper, we limit our investigation to the question of whether the processor ever assumes the unbounded dependency is real in cases of local ambiguity; we do not seek to resolve the question of whether the processor forms the unbounded dependency under all conditions.

In (1), repeated below, the processor may consider the possibility that there is an unbounded dependency between *which man* and *believe:*

Which man do you believe Mary loves a lot? (1)

Hence, this sentence contains a local ambiguity. If the processor forms this unbounded dependency, it will have to reverse its decision once the presence of the word *Mary* indicates that *which man* is not an argument of *believe.* If the processor forms unbounded dependencies as soon as possible, then it will be garden pathed on occasions like this. Intuitively, there is no strong garden path in this instance, but experimental evidence (e.g., Frazier & Rayner, 1982; Rayner & Frazier, 1987) demonstrates that syntactic misanalysis can lead to processing disruption without readers being aware of it.

Fodor (1978) called this strategy the *first-resort* strategy. In fact, her account assumed standard gap-filling, but her strategies are also consistent with immediate association. The processor forms the unbounded dependency as soon as it reaches the verb (or preposition). In cases like (1), the processor will be garden pathed. The first-resort strategy contrasts with the *second-resort* strategy, whereby the processor only forms the unbounded dependency if it is not ruled out by the next constituent, and the *last-resort* strategy, whereby the processor does not form the unbounded dependency unless it has no alternative (e.g., when it reaches the end of the sentence).

The processor may make use of lexical information, with the processor using a more zealous strategy if the verb preferentially subcategorizes for a (currently missing, i.e., non-subject) argument of the same category as the filler. In this paper, we shall not consider the issue of lexical preferences in detail, but rather shall ask whether the processor ever uses a first-resort strategy.

Experimental work provides suggestive evidence for first-resort processing, at least with transitive preference verbs. First, there is the filled-gap effect, as discussed above. A problem is that most demonstrations involve self-paced reading, which might not reflect the processes of normal reading. Pickering, Barton, and Shillcock (1994) did find some evidence for a filled-gap effect in normal reading, but their results may reflect the initial process of forming the unbounded dependency rather than reanalysis (see the discussion of [14] below). Another problem is that all experiments employed control materials containing different constructions from the experimental sentences. For instance, Stowe (1986) contrasted sentences containing an embedded *wh*-question like (3b) above with control sentences like (3a) that contain an embedded *if*-question. We simply do not know if the materials differ in ways irrelevant to the question of interest (e.g., with respect to the frequency of use of the sentence types).

Some evidence for first-resort processing comes from studies that manipulate plausibility. Tanenhaus, Carlson, and Trueswell (1989) described a number of experiments that find plausibility effects as soon as the verb is reached, in a version of word-by-word self-paced reading where subjects monitor when the sentence stops making sense (see also Boland, Tanenhaus, & Garnsey, 1990; Stowe, Tanenhaus, & Carlson, 1991; and cf. Garnsey, Tanenhaus, & Chapman, 1989, for comparable findings using event-related potentials). However, this method is further removed from normal reading than standard self-paced reading. Using this task, Boland et al. (1995) found that plausibility effects only occur on the verb if the filler cannot plausibly fill any argument associated with the verb. For example, subjects often found (6a) implausible at the verb, but not (6b):

Which prize did the salesman visit . . . (6a)
Which movie did your brother remind . . . (6b)

In (6a), *which prize* has to be the object of *visit,* so a reader can be certain that the full sentence will be implausible. In contrast, *remind* takes an NP object and an infinitival complement. If the sentence continued *Bill to watch,* for instance, then *which movie* would not be the object of *remind*, and the sentence would not be implausible. Boland et al.'s (1995) results suggest that the processor did not form the unbounded dependency in (6b). However, the task requires subjects to determine whether the fragment could make sense as part of a complete sentence. We cannot be sure that similar effects would occur in normal reading.

This problem is particularly relevant with respect to Boland et al.'s (1995) Experiment 4. They found that subjects often judged (7) below implausible before reaching the preposition *to:*

Which public library did John donate some cheap liquor to last week? (7)

The processor must have decided that people do not donate liquor to libraries before encountering *to.* Hence it must have formed the unbounded dependency before reaching the preposition. This conclusion is incompatible with both standard gap-filling and immediate association. However, the task may precipitate unusual processing strategies unconnected with parsing. Subjects may well reason that the fragment *Which public library did John donate some cheap liquor* . . . is unlikely to be the beginning of a plausible sentence, and thus conclude that it does not make sense. They may, for instance, read *liquor* and then anticipate that the next word will be the preposition *to,* and make their judgment on this basis. In addition, this result depends crucially on subjects' not having treated *donate* as taking two NP objects, as in *Which campus party did John donate the cheap liquor?* This sentence is marginally acceptable for some speakers of American English, including one of the authors (M.T.).

Finally, cross-modal priming in speech (Nicol & Pickering, 1993; Nicol & Swinney, 1989) supports a first-resort strategy. Lexical decision to an associate of the filler is sped up immediately after an unbounded dependency is formed. This suggests that the unbounded dependency is formed rapidly. However, these results have been questioned by McKoon, Ratcliff, and Ward (1994; McKoon & Ratcliff, 1994; but cf. Nicol, Fodor, & Swinney, 1994).

In conclusion, there is some evidence that the processor employs a first-resort strategy with transitive-preference verbs. The evidence does not determine whether this strategy is regularly employed during normal reading. Our two experiments both address this question. However, Experiment 1 is primarily concerned with the question of whether the processor employs immediate association or standard gap-filling, and the sentences employed probably do not contain any relevant local ambiguity. Thus, it only tested the claim that the processor can use a first-resort strategy when there is no local ambiguity. Experiment 2 tested the claim that a first-resort strategy is employed when the possible unbounded dependency turns out to be incorrect.

Both experiments investigated processing of unbounded dependency constructions by manipulating plausibility. More specifically, we manipulated whether the sentence fragment at the verb would be plausible or implausible if the unbounded dependency had been formed. This allows us to monitor processing without having to compare sentences containing different construction types (cf. Pickering & Traxler, 1996). Of course, any effects of plausibility would show that the unbounded dependency has been semantically interpreted as well as syntactically analyzed.

EXPERIMENT 1

Experiment 1 addressed the question of whether the processor performs immediate association or standard gap-filling. We were interested in the processes involved in normal reading, and hence tracked eye movements. We wished to determine whether the processor forms the unbounded dependency on encountering the verb, or whether it waits until the gap location, and therefore manipulated the plausibility of the experimental materials (see Boland et al., 1995; Garnsey et al., 1989). We employed materials like (8a)–(8d):

That's the pistol with which the heartless killer shot the hapless man yesterday afternoon. (8a)

That's the garage with which the heartless killer shot the hapless man yesterday afternoon. (8b)
That's the garage in which the heartless killer shot the hapless man yesterday afternoon. (8c)
That's the pistol in which the heartless killer shot the hapless man yesterday afternoon. (8d)

Clearly, (8a) and (8c) make sense, whereas (8b) and (8d) are implausible (or semantically anomalous). Sentences (8c) and (8d) controlled for possible low-level lexical effects due to combinations of *pistol, garage,* and *shot.*

The "canonical" sentence related to (8a) is *The heartless killer shot the hapless man with the pistol yesterday afternoon.* Hence, the gap associated with the extracted phrase *with which* is located after *man.* Sentence (8b) is similar. In (8c) and (8d), the extracted phrase is an adjunct, and *shot* does not subcategorize for it. It is possible that the gap location is after *yesterday afternoon* in these sentences, as in *The killer shot the man yesterday afternoon in the garage.* However, the gap location is available after *man,* as the sentence is incrementally processed, so first-resort standard gap-filling would site the gap right after *man* is reached. In all stimuli, the final phrase is a temporal expression, and the extracted adjunct refers to a location. In English, there is a clear preference for locative adjuncts to precede temporal ones. This supports the assumption that the gap should be between *man* and *yesterday.*

An obvious prediction is that (8b) and (8d) will take longer to read than (8a) and (8c). The more interesting issues are when and where the plausibility effect occurs. A plausibility effect could appear as soon as the verb *shot* is processed only if the processor uses immediate association and a first-resort strategy, interprets the sentence fragment immediately, and integrates that interpretation with general knowledge. Finally, this result would indicate that the interpretation of sentence fragments has very rapid effects on eye movements during normal reading. In contrast, standard gap-filling predicts no plausibility effect before the word *man* is encountered. A plausibility effect would appear around *man yesterday* if the processor uses standard gap-filling and a first-resort strategy, together with immediate interpretation of the fragment.

Method

Subjects. Twenty-four normally sighted English speakers were paid to participate. Some had taken part in other eye-tracking experiments.

Stimuli. We constructed 28 sets of four sentences for Experiment 1 like (8a)–(8d): see Appendix A. A prepositional phrase served as an adjunct or argument of the embedded verb in all materials. The plausibility manipulation involved two different head nouns (e.g., *pistol* and *garage*) crossed with two prepositional phrases (e.g., *in which* and *with which*). The head nouns were matched for length between plausibility conditions. Each noun appeared in both a plausible and an implausible sentence. Differences in word frequency, therefore, could not produce any differences between the plausibility conditions. Note that all regions of interest were identical across sentences within a material set, and that the words in the plausible sentences were identical to those in the implausible sentences, though they appeared in different combinations in the individual conditions. One version of each material appeared in each of four lists of items. All sentences were presented on two lines, with the line break after the word *which.*

Regions. For analysis, we defined one region as the verb (e.g., *shot*), because plausibility effects could occur there if readers performed first-resort immediate association. If readers also interpreted the fragment immediately, then a plausibility effect could appear in a measure of initial processing. We defined *man yesterday* as another region, because plausibility effects could appear there if readers performed standard gap-filling. Defining the region in this way provided the best chance of finding an effect around the purported gap location. The other regions resulted from the positioning of the line break and the two critical regions. Note that all regions included the character spaces before the first word in the region.

Norming. To assess the plausibility of the association between the head noun (e.g., *garage/pistol*) and the verb (e.g., *shot*), 20 raters read 112 questions like (9):

With which pistol did the killer shoot the man? (9)

Raters wrote down a number between zero and seven that indicated how much sense each question made. We eliminated sets of items when any item produced a mean rating between 2.0 and 5.0.

Procedure. An SRI Dual Purkinje Generation 5.5 eye-tracker monitored subjects' eye movements. The tracker has angular resolution of 10‘ arc. The tracker monitored only the right eye's gaze location. A PC displayed materials on a VDU 70 cm from subjects' eyes. The VDU displayed four characters per degree of visual angle. The tracker monitored subjects' gaze location every millisecond and the software sampled the tracker's output to establish the sequence of eye fixations and their start and finish times.

Before the experiment started, subjects read an explanation of eye-tracking and a set of instructions. The instructions told them to read at their normal rate and comprehend the sentences as well as they could. The experimenter then seated the subject at the eye-tracker and used bite bars and forehead restraints to immobilize the subject's head. Next, subjects completed a calibration procedure. Before each trial, a small "+" symbol appeared near the upper-left-hand corner of the screen. Immediately after subjects fixated the "+" symbol, the computer displayed a target sentence, with the first character of the sentence replacing the "+" on the screen. The "+" symbol also served as an automatic calibration check, as the computer did not display the text until it detected stable fixation on the "+" symbol. If readers could not fixate the "+" symbol, the experimenter recalibrated the eye-tracker. When subjects finished reading each sentence, they pressed a key, and the computer either displayed a comprehension question (e.g., *Did the young man hit the ball?*), on about half of the trials, balanced across conditions, or proceeded to the next trial. Half of these questions had "yes" answers, half had "no." Subjects received no feedback on their answers. Subjects responded to the questions by pressing a button. After subjects completed each quarter of the experiment, the experimenter recalibrated the equipment and subjects had a short break. Thus, the eye-tracker was recalibrated a minimum of four times during the experiment and usually more.

The computer displayed each experimental list in a fixed random order together with 28 sentences like *The doctor explained to the handler that the tiger attacked and wounded several antelope before it was recaptured,* and 15 additional fillers of various syntactic types. All sentences were displayed on two lines of text.

Analyses. An automatic procedure pooled short contiguous fixations. The procedure incorporated fixations of less than 80 ms into larger fixations within one character, and then deleted fixations of less than 40 ms that fell within three characters of any other fixation. Following Rayner and Pollatsek (1989), we presume that readers do not extract much information during such brief fixations. Before analyzing the eye-movement data, we eliminated the occasional trial when the subject failed to read the sentence or when tracker loss ensued. More specifically, we removed trials where two or more adjacent regions had zero first-pass reading time. This procedure removed 5.2% of the data.

First-pass reading time is the sum of the fixations occurring within a region before the eye left the region. If the eye fixated a point beyond the end of a region before landing in the region for the first time, then the first-pass time for that region was zero. *Total reading time* is the sum of all fixations in a region. Our main analyses included 0-ms fixation times. Subsidiary analyses comprised an *eye–gaze* measure for first-fixation and first-pass reading time. If the target word was not directly fixated, then the closest fixation within four character spaces to the left of the region boundary, but before the first fixation after the target word, was counted as the fixation during which the word was processed. If no such fixation occurred, then the trial was eliminated. Research on perceptual span demonstrates that when readers do not fixate on a target word, they identify it on the prior fixation when that fixation lies within three or four characters of the target (Rayner & Pollatsek, 1989).[1]

Results

Table 1 represents subjects' mean first-fixation times in the critical regions (e.g., *shot* and *man yesterday*). Figure 1 represents subjects' mean first-pass reading times. Figure 2 represents subjects' mean total reading times. The mean first-fixation time on the verb was 21.5 ms longer in implausible sentences than in plausible sentences [$F_1(1,23) = 4.23$, $p < .05$, $MS_e = 1315$; $F_2(1,27) = 8.24$, $p < .01$, $MS_e = 960$]. Mean first-pass reading time on the verb was 4.3 ms/character longer in implausible sentences [$F_1(1,23) = 4.55$, $p < .05$, $MS_e = 48$; $F_2(1,27) = 10.68$, $p < .01$, $MS_e = 29$]. Mean total reading time on the verb was 13.1 ms/character longer in the implausible sentences [$F_1(1,23) = 15.54$, $p < .001$, $MS_e = 132$; $F_2(1,27) = 18.90$, $p < .001$, $MS_e = 144$]. This pattern of reaction times suggested that readers formed an association between the filler and the verb as soon as they encountered the verb.

The analyses revealed no statistically significant differences between plausible and implausible sentences on any of the reading time measures in the region *man yesterday*, where the gap would be [on first fixation, $F_1(1,23) = 1.30$ and $F_2 < 1$; on first pass, both $F < 1$; on total time, both $p > .25$]. No statistically significant differences between plausible and implausible sentences occurred in the region preceding the verb in the first-pass or first-fixation measures.

A subsidiary analysis revealed that readers skipped the verb during their first pass through the sentence more often in plausible sentences than in implausible sentences. Readers skipped the verb 3.1 times out of 14 when the sentence was plausible, and 2.2 times out of 14 when the sentence was implausible [$F_1(1,23) = 7.27$, $p < .05$, $MS_e = 1.4$; $F_2(1,27) = 10.00$, $p < .01$, $MS_e = .87$].

TABLE 1

EXPERIMENT 1: MEAN-FIRST FIXATION TIME BY SENTENCE TYPE AND REGION (ms)

Sentence type	Region: 3 (e.g., *shot*)	Region: 5 (e.g., *man yesterdar*)
Plausible	196	237
Implausible	217	248

Note. Example sentence: That's the pistol with which the heartless killer shot the hapless man yesterday afternoon.

Because of this difference in fixation probability on the verb, we performed a second set of analyses using the eye-gaze measure (see above). We removed an additional 1.0% of the data, for trials when there was no fixation on either the verb or the four characters before the verb during first pass. Eye–gaze analyses revealed an effect of plausibility in the first pass eye–gaze measure [$F_1(1,23) = 3.67$, $p < .07$, $MS_e = 1742$; $F_2(1,23) = 18.98$, $p < .001$, $MS_e = 456$]. The effect was only significant by items for the first-fixation eye–gaze measure [$F_1(1,23) = 1.68$, $p > .20$, $MS_e = 1188$; $F_2(1,27) = 5.07$, $p < .05$, $MS_e = 714$].

Discussion

Experiment 1 demonstrated processing difficulty around the verb on first-fixation and first-pass measures in the implausible condition compared with the plausible condition. This indicated that the processor formed the unbounded dependency immediately after it encountered the verb. Hence the processor used the first-resort immediate association strategy (Pickering, 1993) and immediately interpreted the fragment on this analysis. Therefore, immediate association must be a general characteristic of the sentence processor.

More generally, the results showed that the processor can employ a first-resort strategy when the unbounded dependency is not locally ambiguous. These results do not determine

[1] Our main analyses divided the raw fixation durations by the number of characters in the region to produce a millisecond per character dependent measure. This procedure produces similar weightings for items of different lengths. Because our critical regions were equally long across conditions, we avoid problems with ms/character transformation identified by Trueswell et al. (1994). We did not perform the ms/character transform for the eye–gaze analyses, because the eye–gaze fixation procedure samples regions of different lengths for the same item.

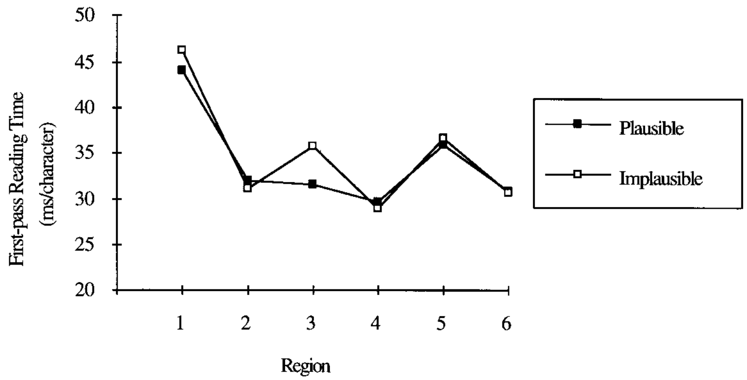

FIG. 1. Experiment 1: Mean first-pass reading time by region and condition. Region 3 corresponds to the word *shot* in the example sentence. Region 5 corresponds to the words *man yesterday* in the example sentence.

whether the processor always uses a first-resort strategy.

The results are incompatible with standard gap-filling, because standard gap-filling predicts no plausibility effects before the purported gap location. In addition, the data do not support any of three other models: (1) The processor performed association in two stages, at the verb and at the gap (Nicol, 1993); (2) the processor sometimes performed association at the verb, and sometimes at the gap; and (3) the processor waited until a potential end-of-sentence before forming an unbounded dependency (cf. Bourdages, 1992).

Experiment 1 provided good evidence for the process of incremental interpretation and its effects on eye movements. The processor detected the implausibility of the sentence fragment as soon as it reached the verb. Notice that our manipulation of the preposition rules out any low-level explanation of our effects in terms of lexical associations between the noun in the filler and the verb.

Somewhat surprisingly, Experiment 1 produced a difference in first-pass fixation probability on the verb between the plausible and implausible sentences. The skipping effect by itself provided evidence for differences in processing of plausible and implausible sentences associated with the unbounded dependency. The most likely explanation for this effect is that readers sometimes processed the verb re-

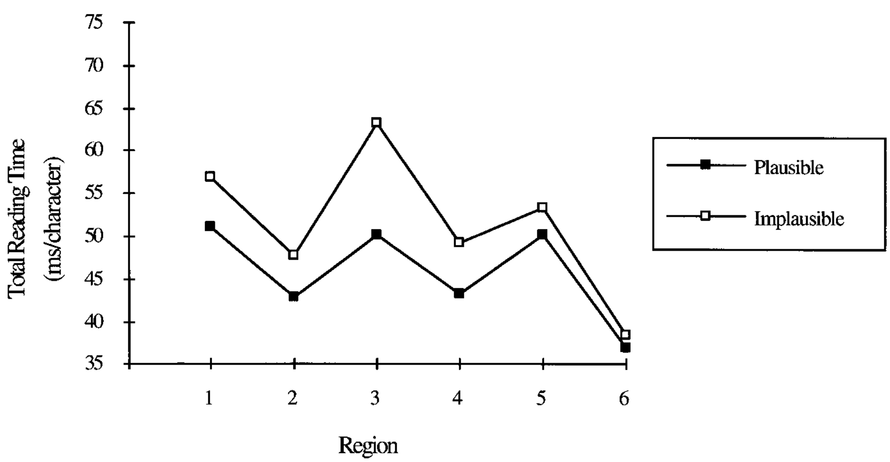

FIG. 2. Experiment 1: Mean total reading time by region and condition. Region 3 corresponds to the word *shot* in the example sentence. Region 5 corresponds to the words *man yesterday* in the example sentence.

gion while fixating the end of the preceding word. We therefore predicted that significant differences between the conditions would emerge on the fixated trials if the regions were extended to include the end of the preceding word. This prediction was borne out by the eye–gaze analyses.

Local Ambiguity and Island Constraints

Our next question is whether the processor can still employ a first-resort strategy when the possible unbounded dependency may turn out to be erroneous. Previous research (see above) suggested that the processor can use a first-resort strategy in such cases, but it has not demonstrated that this strategy is used in normal reading. A demonstration of this would provide strong evidence for incremental processing in sentence comprehension.

Consider (9) below:

We like the book that the author wrote unceasingly and with great dedication about while waiting for a contract. (9)

This sentence contains a real unbounded dependency between the filler *the book that* and the preposition *about.* However, at the verb *wrote,* there is a possible unbounded dependency between the filler and the verb. In Fodor's (1978) terms, there is a "doubtful gap" after *wrote.* The first resort strategy predicts that the processor will form the possible unbounded dependency between the filler and the verb at *wrote.* In this case, this analysis is plausible, because an author is likely to write something (e.g., a book). When the processor reaches the preposition *about*, it realizes that this analysis cannot be correct (i.e., that it has been garden pathed). In Experiment 2 below, we manipulated the plausibility of this possible unbounded dependency.

Our final question concerns the processing of unbounded dependencies that are in fact ungrammatical. Consider (10) below:

*Which fish did the woman who cooked eat rice? (10)

Descriptively, (10) is ungrammatical because it is impossible to form an unbounded dependency between a filler (here, *which fish*) and a verb that is embedded within a relative clause modifying a subject (here, *cooked*). The ungrammaticality of (10) is perhaps surprising in that the sentence would have a clear meaning, as expressed by the grammatical echo question *The woman who cooked which fish ate rice?* Ross (1967) said that subject relative clauses like *who cooked which fish* are *islands,* because it is impossible to "move" a filler out of such a clause. Hence the grammar encodes *island constraint* information, which blocks sentences that would otherwise be grammatical. Note that sentence (10) is a *strong* island, because it is completely unacceptable. There are also *weak* islands, of marginal grammaticality, like (11) below (e.g., Szabolsci & Zwarts, 1993):

?Which man did you read no book about? (11)

We focus on strong islands in this paper.

What does the processor do when it encounters a possible unbounded dependency that in fact violates an island constraint? Such a situation occurs in (12) below:

We like the book that the author who wrote unceasingly and with great dedication saw while waiting for a contract. (12)

If there were no island constraints, then (12) would have an ambiguity like (9) above. After *wrote,* there might be an unbounded dependency between *wrote* and *book* (as in *The author who wrote the book . . .*).

It is possible that the use of the island constraint information is *delayed.* If, in addition, the processor uses a first-resort strategy (with transitive-preference verbs), then the unbounded dependency will be formed at *wrote.* At some later point, the processor would realize that this was the wrong analysis, and undo the unbounded dependency. It is not completely clear when this would occur. One possibility is that it would undo the unbounded dependency when it reached the main verb *saw,* because now the filler might associate with this verb. Alternatively, the processor might undo the unbounded dependency earlier, while processing *unceasingly and with great dedication.* In either case, the processor would eventually reach the correct analysis, where the filler associates with *saw,* and *wrote* is intransitive.

On the other hand, the processor might use island constraint information *immediately.* If so, it would never form the illegal unbounded dependency. If the processor used a first-resort strategy with immediate use of island constraint information, then it would form the legal unbounded dependency in (9) but not the illegal unbounded dependency in (12).

Assuming that the processor attempts to perform sentence comprehension in as incremental a manner as possible, we predict that the processor adopts a first-resort strategy, at least with transitive-preference verbs, even when the possible unbounded dependency may turn out to be a garden path. Hence we predict immediate formation of the unbounded dependency in (9) above. However, it would not be efficient to consider an ungrammatical analysis, even momentarily, and so we predict that the processor employs strong island constraint information immediately. Similarly, it should simply fail to parse sentences like (10), and never entertain the possibility that they might be grammatical.

On this basis, the processor would never consider the illegal unbounded dependency in (12). But linguistic considerations have suggested that the processor might delay use of island constraint information. It might initially construct illegal unbounded dependencies, only to rule them out later. In transformational grammar, sentences that violate island constraints are generated by one component of the grammar, but are filtered out by another component (see Chomsky, 1981). As with the issue of gaps, linguistic theory suggests the possibility that the processor might employ a parsing strategy that appears inefficient from the point of view of incremental interpretation.

Freedman and Forster (1985) proposed that the processor initially "overgenerates" sentences like (10), and then rules them out by processes corresponding to the application of the island constraints. They claimed that the processor computes a level of representation at which it treats sentences that violate island constraints as grammatical. They employed a sentence-matching task, and found that readers' responses to sentences that violated island constraints closely resembled their responses to grammatical sentences. Their account fits well with the delayed use of island constraint information. However, Crain and Fodor (1987) argued that their results could be explained in terms of how easy it was to correct the sentences into grammatical sentences (see also Forster & Stevenson, 1987; Stowe, 1992).

There is little on-line experimental work on the processing of island constraint information, and what there is seems to conflict (see Fodor, 1989; Pickering et al., 1994). One word-by-word self-paced reading experiment found no filled-gap effect in (13) below (Stowe, 1986, Experiment 2):

The teacher asked if the silly story about Greg's older brother was supposed to mean anything. (13a)
The teacher asked what the silly story about Greg's older brother was supposed to mean. (13b)

In (13b), island-constraint information precludes the unbounded dependency between *what* and *about* which could otherwise be formed when the processor reaches *about* (cf. the echo question *The silly story about what meant very little?*). No increase in reading time occurred at *Greg's* in (13b) compared with (13a), though a filled-gap effect did appear in control sentences (and in her Experiment 1: See [3] above). This result supported the immediate use of island constraint information. In contrast, Pickering et al. (1994) found some tentative evidence for a filled-gap effect in island environments using eye tracking:

I realize what the artist who painted the large mural ate today. (14a)
I realize that the artist who painted the large mural ate cakes. (14b)

First-pass time on *painted the* was greater in (14a) than (14b). This may have been due to the processor forming an illegal unbounded dependency between *what* and *painted* and then undoing it when it reached *the.* However, these results might also simply have demonstrated that the verb *painted* showed that the correct analysis of the unfolding sentence was complex.

Clifton and Frazier (1989) found evidence for delayed use of island-constraint information, using an end-of-sentence grammatically judgment task. Subjects responded to (15b) more quickly than to (15a):

What did John think the girl who always won received? (15a)
What did John think the girl who always excelled received? (15b)

The verb *excelled* is intransitive, and so cannot have an extracted object, but *won* can have one in principle, though in this environment the unbounded dependency is ruled out by island-constraint information. The finding of difficulty with (15a) suggested that subjects did try to treat *what* as the object of *won.* However, it is also possible that their finding reflects the fact that *excelled* is frequently used transitively, unlike *won,* and hence that (15b) violates verb preferences. The results of on-line research are as controversial as those produced by sentence-matching.

In conclusion, Experiment 1 and other experimental work provided some evidence that the processor uses a first-resort strategy with transitive-preference verbs at least. However, we do not know whether the processor uses this strategy in normal reading when the unbounded dependency may turn out to be erroneous. It is also unclear whether the processor employs island constraint information immediately during the formation of unbounded dependencies, or whether the use of this information is delayed. Considerations of incrementality and efficiency suggest that the processor would adopt a first-resort strategy if the unbounded dependency were possible, but would not construct an unbounded dependency if it were ruled out by strong island-constraint information. Experiment 2 tested these predictions.

Experiment 2

Experiment 2 considered the processing of unbounded dependencies that initially appear to be possible, but are subsequently shown to be wrong. We contrasted these potential unbounded dependencies with sentences where there was a potential unbounded dependency only if the processor initially ignored strong island-constraint information. We tested whether readers initially formed unbounded dependencies if they were possibly erroneous and if they were ruled out by strong island constraints. As before, we manipulated the plausibility of the potential unbounded dependency, by using materials like (16):

WAITING FOR A PUBLISHING CONTRACT
The big city was a fascinating subject for the new book. (16)
We like the book that the author wrote unceasingly and with great dedication about while waiting for a contract. (16a)
We like the city that the author wrote unceasingly and with great dedication about while waiting for a contract. (16b)
We like the book that the author who wrote unceasingly and with great dedication saw while waiting for a contract. (16c)
We like the city that the author who wrote unceasingly and with great dedication saw while waiting for a contract. (16d)

To improve readability, we introduced a context sentence and a title. The context produces a short coherent discourse and satisfies the referential presuppositions of the experimental sentence.

We manipulated plausibility in the *non-island* conditions (16a and 16b) by varying the extracted noun (e.g., *book/city*). We matched the two nouns for length and frequency. If readers formed an unbounded dependency between the nouns and the verb *wrote,* then the resulting interpretation would be plausible for (16a) and implausible for (16b). The introductory sentence mentions both the plausible and implausible nouns from the target sentences (e.g., *book* and *city*). Half of the introductory sentences mentioned the plausible noun first, and half mention the implausible noun first.

The *island* conditions (16c and 16d) contain a potential unbounded dependency within an island constraint environment (as described above). If readers ignore island constraint information during initial parsing, then (16c) contains a more plausible filler–verb association than (16d).

If we assume that readers take longer to process implausible associations than plausible associations (cf. Pickering & Traxler, 1996), then we can make predictions about processing of sentences (16a–16d). Consider first sentences (16a) and (16b), the non-island sentences. If readers use a first-resort strategy, and therefore form associations between the filler (e.g., *book/city*) and the verb (e.g., *wrote*) immediately after reaching the verb, then a difference between sentences with plausible and implausible associations should appear around the verb in a measure of initial processing. Next, consider sentences (16c) and (16d), which contain island-constraint information. If readers use a first-resort strategy, and ignore island-constraint information during the early stages of parsing sentences, then a similar plausibility difference should appear around the verb (e.g., *wrote*) in a measure of initial processing. If island-constraint information is used immediately during parsing, then no plausibility effect should appear around the verb, because the island-constraint information rules out any association between the filler (e.g., *book/city*) and the verb (e.g., *wrote*).

Next consider the process of recovery from misanalysis. Pickering and Traxler (1996) argued that readers have more difficulty abandoning a misanalysis if that misanalysis is plausible than if it is implausible, because readers semantically commit to a plausible analysis more than an implausible analysis. In the non-island sentences (16a) and (16b), the disambiguating region is *about while.* If readers misanalyze these sentences, then they should take longer to process this region when the misanalysis is plausible than when the misanalysis is implausible. If readers misanalyze the island sentences, then similar effects should occur when the island-constraint information is brought to bear. We suggested that this would be most likely to happen soon after the word *saw* is reached. However, reanalysis might occur during the words immediately before *saw.*

Method

Subjects. Thirty-two normally sighted native English speakers were paid to participate. Some subjects had taken part in other eye-tracking studies.

Stimuli. We constructed 28 sets of experimental sentences, together with titles and introductory sentences.[2] Only the extracted noun differed between the plausible and implausible sentences. The island and non-island sentences diverged in the final two regions (to different degrees in different material sets). We then constructed four lists of items, with exactly one version of each item appearing in each list.

Norming. To assess the plausibility of the ambiguous NP as direct object of the verb in the relative clause, 20 raters read a typewritten list of 104 sentences (e.g., *The author wrote the book*). About half of the sentences related to this experiment and half related to a different study. To ensure that the ultimately correct reading of the entire experimental sentences was equally plausible between conditions, some of our sentences were “detransformed” versions of the experimental sentences (e.g., *The author wrote about the book*). Raters wrote down a number between zero and seven that indicated how much sense each sentence made. We eliminated pairs of experimental items when either item produced a mean rating between 2.0 and 5.0. We found no significant differences between conditions in the “detransformed” versions of the sentences. Hence, the conditions differed in plausibility on the misanalysis, but did not differ on the ultimately correct analysis.

Procedure. The data collection procedures were identical to those in Experiment 1. All the experimental sentences were displayed on two

[2] All materials can be obtained from the authors on request.

TABLE 2
EXPERIMENT 2: MEAN FIRST FIXATION TIMES BY SENTENCE TYPE AND REGION (ms)

	Region		
Sentence type	3 (e.g., *wrote unceasingly*)	4 (e.g., *and with great dedication*)	5 (e.g., *about while/saw while*)
Non-island, plausible	222	205	238
Non-island, implausible	255	219	223
Island, plausible	233	210	243
Island, implausible	223	209	239

Note. Example of non-island sentence: We like the book that the author wrote unceasingly and with great dedication about while waiting for a contract. Example of island sentence: We like the book that the author who wrote unceasingly and with great dedication saw while waiting for a contract.

lines, and were split within the region after the verb (e.g., *wrote*) and before the disambiguating preposition (e.g., *about*). At least two words separated the verb from the line break and at least two words followed the line break before the disambiguating preposition or verb.

The 28 experimental materials were displayed along with 6 two-sentence filler passages and 28 two-sentence passages [like (17)] from another experiment in a pseudo-random order.

The janitor polished the bronze statues of/for the old maths professor that the principal hated and the dean of the art school. As the janitor polished(,) the professor that the principal hated reviewed the spring term teaching schedule. (17)

Analyses. In the first stage of analysis, we determined which line of text subjects read. This involved some judgment, because subjects' eyes occasionally landed between two lines of text, and because slight head movements sometimes caused small, systematic changes in the recording of fixation location. In the vast majority of cases, determining which line readers actually fixated caused no difficulty whatsoever.

The regions that we analyzed, *wrote unceasingly, and with great dedication,* and *about while/saw while,* were identical in the plausible-no island and implausible-no island conditions, and in the plausible-island and implausible-island conditions.[3] We removed one item from the analyses because of an error in the display. We also removed 5.1% of the data, according to the same criteria as Experiment 1.

Our main analyses included 0-ms fixations that occurred when readers skipped a region. We performed a second set of analyses after removing 0-ms fixations. The results of this second set of analyses matched the results of the first set almost exactly, so we do not report these analyses.

Results

Table 2 represents subjects' mean first-fixation times for regions 3, 4, and 5 for both non-island and island sentences. Figure 3 represent mean first-pass reading time and Fig. 4 mean total reading time for the non-island sentences. Figure 5 represents mean first-pass reading time and Fig. 6 mean total reading time for the island sentences. The data were subjected to 2 (island: island vs non-island constraint sentences) × 2 (plausibility: plausible vs implausible misanalysis) × 2 (region: 3 vs 5) ANOVAs. Statistically significant three-way interactions demonstrated that the patterns of fixation times differed between island and non-island sentences. Interactions of island constraint, plausibility, and region appeared in the first-fixation [$F_1(1,31) = 7.37$, $p < .01$, $MS_e = 1615$; $F_2(1,26) = 7.59$, $p < .01$, $MS_e = 1225$]

[3] As in Experiment 1, we employed the ms/character transform. Note that the region *about while* in the island conditions differs from the comparable region *saw while* in the island conditions, but we make no direct comparison between these regions.

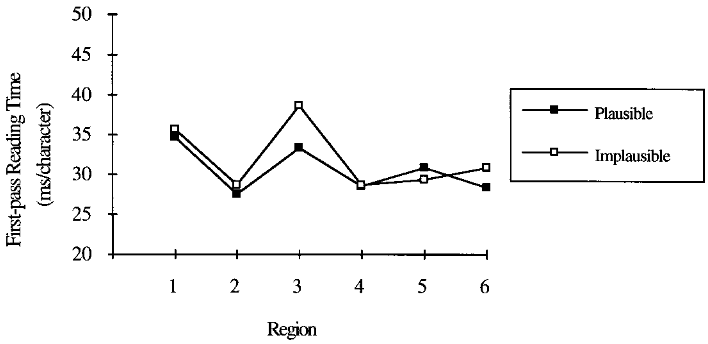

FIG. 3. Experiment 2: Mean first-pass reading time by region and condition for non-island sentences. Region 3 corresponds to the words *wrote unceasingly* in the example sentence. Region 5 corresponds to the words *about while* in the example sentence.

and total reading time data [$F_1(1,31) = 11.17$, $p < .01$, $MS_e = 251$; $F_2(1,26) = 8.53$, $p < .01$, $MS_e = 268$]. This three way interaction was weaker in the first-pass reading time data [$F_1(1,31) = 3.29$, $p < .08$, $MS_e = 63$; $F_2(1,26) = 2.02$, $p > .16$, $MS_e = 74$]. The non-island sentences produced interactions of plausibility and region on first fixation, first-pass, and total reading time. In the first-fixation time data, the implausible sentences' 32.7-ms disadvantage in the region *wrote unceasingly* became a 15.4-ms advantage in the region *about while* [$F_1(1,31) = 11.81$, $p < .01$, $MS_e = 1569$; $F_2(1,26) = 12.06$, $p < .01$, $MS_e = 1311$]. In the first-pass reading time data, the implausible sentences' 5.3 ms/character disadvantage at the verb became a 1.5 ms/character advantage at the preposition [$F_1(1,31) = 3.80$, $p < .06$, $MS_e = 97$; $F_2(1,26) = 4.77$, $p < .05$, $MS_e = 65$]. In the total reading time data, a 15.6 ms/character disadvantage became a 9.3 ms/character advantage [$F_1(1,31) = 16.89$, $p < .001$, $MS_e = 294$; $F_2(1,26) = 12.50$, $p < .01$, $MS_e = 334$]. Data from the island sentences produced no such interactions on any of the reading time measures (all $F < 1$).

To determine if and when readers formed the filler–verb association, we subjected data from region 3 (e.g., *wrote unceasingly*) to 2 (plausibility) × 2 (island constraint) ANOVAs. These analyses produced statistically reliable interactions of plausibility and island constraint in the first-fixation data [$F_1(1,31) = 6.97$, $p < .01$, $MS_e = 2157$; $F_2(1,26) = 8.87$, $p < .01$, $MS_e = 1388$]. In the non-island sentences (e.g., [16a] & [16b]), readers' initial fixations in the verb region (e.g., *wrote unceasingly*) were longer when the filler–verb association was implausible than

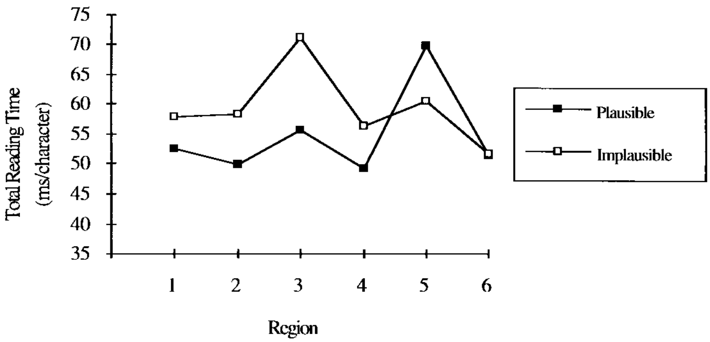

FIG. 4. Experiment 2: Mean total reading time by region and condition for non-island sentences. Region 3 corresponds to the words *wrote unceasingly* in the example sentence. Region 5 corresponds to the words *about while* in the example sentence.

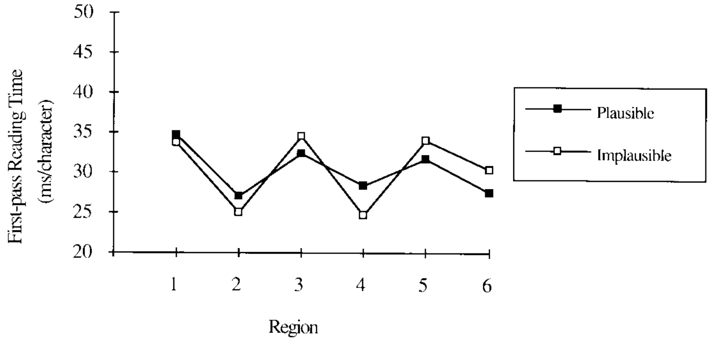

FIG. 5. Experiment 2: Mean first-pass reading times by region and condition for island sentences. Region 3 corresponds to the words *wrote unceasingly* in the example sentence. Region 5 corresponds to the words *saw while* in the example sentence.

when it was plausible [$F_1(1,31) = 7.94$, $p < .01$, $MS_e = 2157$; $F_2(1,26) = 10.68$, $p < .01$, $MS_e = 1388$]. In sentences where island-constraint information ruled out the filler–verb association (e.g., [16c] and [16d]), no plausibility effect appeared in the verb region (both $F < 1$). Similarly, we found no plausibility effect in region 4 (e.g., *and with great dedication*) on first-fixation, first-pass, or total reading time (all $F < 1$). We also found no plausibility effects in region 5 (e.g., *saw while*) on first-fixation time (both $F < 1$), first-pass reading time (both $p > .1$), or total reading time (both $p > .2$). Our results, then, suggest that readers consider the potential (but inappropriate) filler–verb association immediately when they encounter the verb in sentences like (16a) and (16b) where island-constraint information does not rule out that association. By contrast, the data provide no evidence that readers consider the potential (but inappropriate) filler–verb association at any time during processing of sentences like (16c) and (16d) where island-constraint information does rule out that association.

We also found some evidence for a difference between the plausible and implausible sentences in region 5 (e.g., *about while*). Here, reading times for the implausible sentences were generally faster than reading times for the plausible sentences. This difference approached statistical significance in the total-time data, where readers spent 9.3 ms/character longer processing the region *about while* in the plausible sentences [$F_1(1,31) = 5.02$, $p < .05$, $MS_e = 275$; $F_2(1,26) = 2.14$, $p > .15$, $MS_e = 563$].

Discussion

The three-way interaction of island constraint, plausibility, and region demonstrated that readers' responses to sentences where the

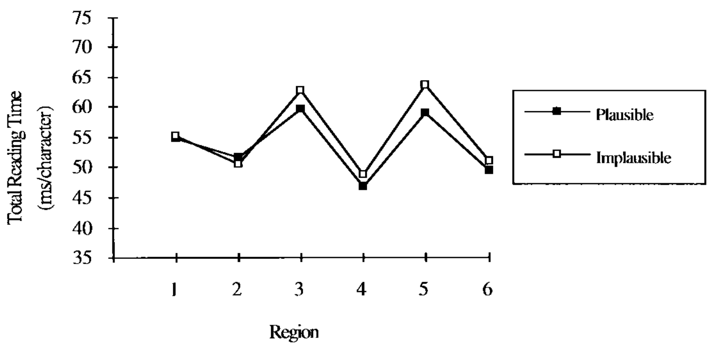

FIG. 6. Experiment 2: Mean total reading times by region and condition for island sentences. Region 3 corresponds to the words *wrote unceasingly* in the example sentence. Region 5 corresponds to the words *saw while* in the example sentence.

unbounded dependency is possible differ from their responses to sentences where the unbounded dependency is ruled out by strong island-constraint information. The interaction of plausibility and island constraint in region 3 (e.g., *wrote unceasingly*) on first fixation indicated that readers' responses to island and non-island sentences began to differ as soon as the unbounded dependency could be formed. The simple effects demonstrated that readers formed the unbounded dependency according to the first-resort strategy in the non-island sentences. There was no suggestion that readers formed the unbounded dependency in the island sentences.

Thus, Experiment 2 provides clear evidence for first-resort processing of unbounded dependencies when the unbounded dependency is grammatically possible. The plausibility effect in Experiment 2 resembles the corresponding effect in Experiment 1, but in this experiment, the unbounded dependency eventually turned out to be incorrect. As subjects would not have learned to use a first-resort strategy during Experiment 2 (since all the unbounded dependencies between the head noun and the verb were eventually ruled out), we can be more certain that the strategy is an automatic part of human sentence processing.

Experiment 2 provides no evidence for misanalysis in cases where the doubtful unbounded dependency is ruled out by strong island-constraint information. There was no evidence for a plausibility effect in the ambiguous region, the following region, at disambiguation, or as a cross-over between the ambiguous and disambiguating regions for (16c) and (16d). The interaction of island constraint, plausibility, and region coupled with clear effects of plausibility in the non-island conditions (16a) and (16b) strongly suggests that lack of sensitivity or statistical power did not produce a Type II Error in the analyses of the island conditions (16c) and (16d). We conclude, therefore, that no semantic processing takes place on the misanalysis if that misanalysis requires ignoring the strong island-constraint information implicated in this study. The most parsimonious explanation is that the processor employs strong island-constraint information immediately and thus avoids misanalysis. These findings are compatible with Stowe (1986), but are less compatible with Clifton and Frazier (1989) and Pickering et al. (1994).

The results of Experiment 2 are consistent with Pickering and Traxler's (1996) proposal that readers have less difficulty adopting, and more difficulty abandoning, plausible misanalyses. The data do not provide conclusive evidence for their proposal, however, as the simple effect of plausibility in the disambiguating region emerged only marginally in the total time measure.

General Discussion

Experiment 1 showed that the processor performs immediate association by forming the unbounded dependency as soon as it reaches the verb. The processor does not wait until the purported gap location before forming the unbounded dependency. Indeed, there was no evidence that the gap location played any special role during processing. Experiment 1 also demonstrated that the processor can employ a first-resort strategy, when there is no local ambiguity.

Experiment 2 showed that the processor can still employ a first-resort strategy in cases of local ambiguity when the possible unbounded dependency may turn out to be erroneous. It demonstrated that this strategy is employed in normal reading. It also showed that the processor does not employ the same strategy if the unbounded dependency is ruled out by strong island-constraint information. Under these conditions, there was no evidence that the unbounded dependency was formed. Hence we suggest that strong island-constraint information is employed immediately by the processor.

Therefore our results support the claim that the processor can employ a first-resort immediate-association strategy that is sensitive to strong island-constraint information during normal reading. We make no claim about whether this strategy is always employed, or whether it is restricted to cases where the verb preferentially takes an argument of the same category as the filler. Below, we suggest how these findings can be modeled in relation to the sentence processor and to the way in which linguistic information is mentally represented. We consider immediate association, first-resort strategy, and the role of island-constraint information in turn.

Immediate Association

Immediate association is compatible with two more detailed theories, discussed by Pickering (1993). Under *predictive gap-filling,* the processor makes use of a grammar that contains gaps, such as Government-Binding Theory (Chomsky, 1981). Consider (5) again:

[In which tin]$_i$ did you put the cake [Ø]$_i$ last night? (5)

Under standard gap-filling, it is impossible for the processor to form the unbounded dependency before it reaches *cake.* But under predictive gap-filling, the processor encounters the verb *put* and then immediately locates the gap downstream, beyond words that have not been reached yet (Gibson & Hickok, 1993; cf. Crocker, 1994; Gorrell, 1993). This account is consistent with immediate association. Pickering argued that it is unparsimonious, since it postulates a theoretical entity (a gap) for which there is no processing evidence.

Predictive gap-filling might be the preferred model if linguistic evidence incontrovertibly supported the existence of gaps. However, outside the transformational tradition, many well-motivated linguistic theories do not assume gaps (e.g., "Flexible" Categorial Grammars: Moortgat, 1988; Pickering & Barry, 1993; Steedman, 1987; Word Grammar: Hudson, 1990; some versions of Head-Driven Phrase Structure Grammar: Pollard & Sag, 1993, chapter 9; recent Lexical-Functional Grammar: Kaplan & Zaenen, 1988). On these accounts, the filler is associated with the verb directly. We can represent the sentence in (5) as follows (Pickering & Barry, 1991):

[In which tin]$_i$ did you [put]$_i$ the cake last night? (18)

This representation indicates the *direct association* between filler and verb. It ignores differences between different gap-free linguistic theories. However, we must note that the representation does not encode any information about which argument of the verb is taken by the filler. Gap-free linguistic theories treat this issue in different ways. See Pickering and Barry (1991) and Pickering (1993) for an approach taken by flexible categorial grammar.

Immediate association is compatible with both direct association and predictive gap-filling. However, direct association is most parsimonious from a processing point of view, in that there is no reason to assume the existence of gaps. Pickering (1993) provided a detailed description of how immediate association can be modeled within an account of incremental interpretation. This approach employs a theory of grammar known as Dependency Categorial Grammar (Pickering & Barry, 1993), in which the fundamental linguistic notion is that of units called *dependency constituents,* which are based on dependencies between words. Sentence processing involves the formation of these units in an incremental manner (cf. Ades & Steedman, 1982). Within this framework, immediate association follows automatically.

First-Resort Strategy

Many accounts that argue for a first-resort strategy essentially stipulate it as a characteristic of the processing of unbounded dependencies. For instance, Clifton and Frazier (1989) proposed the Active Filler Strategy (a first-resort strategy applied without reference to lexical preferences), but did not relate it to other parsing principles like Minimal Attachment or Late Closure. This separation may be a consequence of the transformational approach to unbounded dependencies, which regards them as a special construction involving movement, fundamentally distinct from other constructions that do not involve movement.

In contrast, Pickering (1994) argued that a first-resort strategy fell out from a general assumption about parsing called the *Principle of Dependency Formation.* This principle holds equally for local and unbounded dependencies, and is based on the assumption that the processor attempts to form dependency constituents as quickly as possible. Pickering argued that this strategy is adopted because it maximizes the amount of incremental interpretation that can take place during comprehension, as only dependency constituents can be given a unified interpretation.

The principle of dependency formation predicts that a number of traditional garden-path sentences are initially given a particular analysis. For example the processor initially resolves the subordinate-clause "Late-Closure" ambiguity below by attaching *the magazine about fishing* as the object of the subordinate verb *edited:*

As the woman edited the magazine about fishing amused all the reporters. (19)

On this analysis, the processor can form a single dependency constituent, and so it prefers this analysis over the alternative where the NP is treated as the subject of the main clause. Similar predictions are made for some other ambiguous sentences (e.g., reduced complement ambiguities). However, when both analyses lead to a single dependency constituent (as in reduced relatives and PP-attachment ambiguities, for instance), the processor makes the decision with reference to nonsyntactic information like plausibility and discourse context. Pickering (1994) discussed the experimental evidence in favor of this proposal.

The principle of dependency formation predicts that the processor uses the first-resort strategy with unbounded dependencies. In brief, if the processor forms an unbounded dependency, it constructs a single dependency constituent, but if it has an unattached filler, then it has to retain two dependency constituents, one consisting of the filler, the other consisting of the rest of the sentence fragment. Hence the first-resort strategy is adopted, because it allows the formation of a single dependency constituent and therefore maximizes incremental interpretation. This account provides a unified account of the processing of local and unbounded dependencies. Unbounded dependencies are not processed by some method analogous to transformations in linguistic theory, but are treated like other constructions.

Island Constraints

Experiment 2 suggested that strong island constraint information is accessed during core parsing processes. This suggests that sentences that violate strong island constraints are not generated by the grammar. Our results provide no evidence for linguistic theories that "overgenerate" strong island-constraint violations in the basic grammar but rule them out as part of a special component of the grammar concerned with constraints on movement (e.g., Chomsky, 1981).

Many linguistic theories claim that sentences that violate strong island constraints are simply not generated by any component of the grammar (e.g., Generalized Phrase Structure Grammar: Gazdar, Klein, Pullum, & Sag, 1985; "flexible" categorial grammars: e.g., Steedman, 1987). Sentences that violate island constraints are no different from other ungrammatical sentences (e.g., **Walks John*). However, providing a grammar that rules out all strong islands is very difficult. Our results tentatively suggest that such an approach to strong island constraints might be appropriate. Note that it is impossible to be sure that the processor treats all strong islands in the same way. We have only considered sentences where there is a possible unbounded dependency into a subject relative clause.

Dependency categorial grammar rules out this type of strong island-constraint violation. The reason is that there is no dependency constituent containing *the book that* and *the author who wrote* in (16c) (see Pickering & Barry, 1993, for details). Hence *We like the book that the author who wrote* cannot form a dependency constituent during incremental processing. Note, however, that dependency categorial grammar does allow the formation of some weak island violations, like (11) above. Thus, we predict that the processor will delay before using this weak island-constraint information.

APPENDIX A: EXPERIMENT 1 MATERIALS

Each item consists of one of each pair of words divided by a slash. The line break occurred after *which.* Material 1 corresponds to sentences (14a)–(14d) in the text.

1. That is the very small pistol/garage with/in which the heartless killer shot the hapless man yesterday afternoon.

2. That is the extremely large beam/room with/in which Prince John barred the heavy oaken door last year.
3. That is the wide stick/ocean with/in which the scuba diver battered the dangerous shark two years ago.
4. That is the large reel/park with/in which the fisherman caught the very aggressive trout early this year.
5. You saw the Australian dogs/farm with/on which the rancher herded the stupid and scared sheep last year.
6. That is the builder's mallet/office with/in which the young boy hammered the rusty old nails this week.
7. That is the large knife/hotel with/in which the cook sliced the meat last night.
8. That is the small tool/shed with/in which the assistant mended the rickety ladder this morning.
9. That is the large knife/house with/in which the fishmonger gutted the enormous salmon this afternoon.
10. That is the impressive baton/arena with/in which the young man hit the spinning ball early this evening.
11. That is the long chain/train with/into which the removers hoisted the grand piano this morning.
12. That is the smelly bait/lake with/in which the angler hooked the very hungry pike last summer.
13. That is the very old sling/house with/in which the strong woman hurled the smooth black stone late last night.
14. That is the small axe/hut with/in which the peasant chopped the wood last winter.
15. That is the formidable dagger/castle with/in which the murderer stabbed the mysterious man two weeks ago.
16. That is the enormous whip/cage with/in which the lion tamer lashed the frightened animal two nights ago.
17. That is the modern lighter/mansion with/in which the butler lit the roaring fire early this morning.
18. That is the colourful carpet/office with/in which the interior decorator covered the wooden floor two days ago.
19. That is the long lance/field with/in which the hunter speared the boar early last month.
20. That is the Japanese camera/valley with/in which the tourist photographed the flaming red flower yesterday.
21. That is the tiny tack/room with/in which the secretary pinned the urgent notice late last night.
22. That is the rugged cane/cave with/in which the stupid biologist poked the hibernating bear last winter.
23. That is the very small brush/attic with/in which the famous artist painted the beautiful portrait last year.
24. That is the cheery candle/lounge with/in which I decorated the beautiful birthday cake late last night.
25. That is the bright green pencil/meadow with/in which the artist sketched the rural landscape during the summer.
26. That is the large round shovel/island with/on which the fierce pirate dug the very deep hole at midnight.
27. That is the long pencil/cavern with/on which the explorer drew the treasure map late last century.
28. That is the narrow torpedo/harbour with/in which the submarine sank the enemy ship during the war.

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(Received January 18, 1995)
(Revision received May 17, 1995)