Subjacency as a Processing Phenomenon

Robert Kluender

Department of Linguistics, University of California, San Diego, California, USA

Marta Kutas

Departments of Cognitive Science and of Neurosciences, University of California, San Diego, California, USA

In this study we investigated the hypothesis that standard subjacency effects in so-called "*wh*-islands" are not necessarily due to an innate syntactic constraint, i.e. a problem of language competence, but rather to limits on the human sentence processor, i.e. a problem of performance. We did so by gathering global acceptability judgements and by measuring event-related brain potentials (ERPs) in response to both yes/no- and *wh*-questions containing embedded *that*-, *if*- and *wh*-clauses. The embedding of any one of these clause types within a yes/no-question typically results in a well-formed sentence. The well-formedness of *wh*-questions, on the other hand, depends in large part on the type of embedded clause into which a syntactic dependency is formed: dependencies into embedded *that*-clauses are usually considered grammatical, while dependencies into embedded *if*-clauses are considered marginal and dependencies into *wh*-clauses ("*wh*-islands") ungrammatical. We predicted that these differences in grammaticality across *wh*-question types could be derived from an interaction of (a) the lexical semantic processing effects induced by the choice of *that*, *if* or *who/what* at

---

---

the embedded clause boundary with (b) the syntactic processing effects of maintaining a dependency between a main clause *wh*-phrase ("filler") and an embedded clause position ("gap") across an embedded clause boundary. In our acceptability judgement studies (Experiments 1 and 2), we correspondingly found main effects of embedded clause type, main effects of question type and an interaction of the two. In our ERP study (Experiment 3), lexicosemantic processing effects were indexed by differential N400 amplitude at the embedded clause boundary: the N400 response to the interrogative pronouns *who* and *what* was greater than the N400 response to the complementiser *if*, which was in turn greater than the N400 response to the complementiser *that*. Syntactic processing effects of holding a *wh*-filler in working memory pending assignment to a gap, or of retrieving it from memory for purposes of gap assignment, were indexed by a negative component between 300 and 500 msec that was largest over left anterior regions. An interaction of the two effects was seen in the assignment of main clause fillers to embedded clause gaps; while gap assignment at this position in *wh*-questions was also indexed by left anterior negativity, this negativity was modulated in the same way as the lexically induced N400 elicited at the clause boundary: largest in *wh*-clauses, smallest in *that*-clauses and intermediate in size in *if*-clauses. Similar effects were seen in the ERPs to sentence-final words of *wh*-questions. We take these findings as evidence that subjacency violations in *wh*-island contexts may be attributed to the interaction of lexical semantic processing factors at the embedded clause boundary with the necessity of holding a filler in working memory.

INTRODUCTION

Chomsky (1993) has recently suggested that it may not be possible to obtain well-defined criteria for determining well-formedness in language by relying on primary linguistic data (i.e. grammaticality judgements) alone. Instead, he has proposed that to arrive at such criteria, linguists should turn to more sophisticated and experimentally rigorous methodologies like event-related brain potentials (ERPs). With this study we hope to demonstrate the ability of ERP measures to provide evidence for or against specific linguistic hypotheses, and ultimately to help constrain linguistic theory. In particular, we used ERP measures in conjunction with behavioural data to investigate the hypothesis that at least some of the phenomena usually attributed to the principle of subjacency (Chomsky, 1977), long considered part of an innate universal grammar, may instead be a fairly standard manifestation of difficulty in processing.

For the purposes of addressing this question, let us first review the analysis of unbounded dependencies within linguistic theory. Included under this rubric are a number of related processes, including question formation (1) and relative clause formation (2), along with certain others that need not concern us here:

1. *Who* did John say [that he thought [he had gotten hors d'oeuvres for⎯⎯ at the reception]]?

2. That's the woman [*who* John said [that he thought [he had gotten hors d'oeuvres for ⎯⎯ at the reception]]].

The "dependency" aspect of "unbounded dependency" has to do with the fact that the italicised constituents in the above examples and the underlined positions where they would ordinarily occur in a straightforward declarative sentence (i.e. "John said that he thought he had gotten hors d'oeuvres for **that woman** at the reception") are dependent on each other for their interpretation. For example, a constituent like *who*, referred to as a "filler", cannot be assigned an unambiguous semantic ("thematic") role or grammatical function within its sentence until and unless an association with the underlined position, referred to as a "gap", can be established (Fodor, 1978). In other words, since the structure of both spoken and written language is sequential in nature, when the filler *who* is first encountered, it is impossible to know whether it is a semantic (thematic) agent, patient or beneficiary, or whether it embodies the grammatical function of subject, direct object or prepositional object in the sentence. For this, the hearer/reader must be able to form some sort of mental representation of the entire sentence; in order for this to occur, the hearer/reader must be able to detect the gapped position and associate it with the filler. A filler is uninterpretable without an associated gap. Thus if the gap in (1) is filled with an independent constituent, the result is an ill-formed sentence, as in (3) (we adopt here the standard linguistic convention of indicating the ill-formedness of a sentence with a preceding asterisk):

3. **Who* did John say [that he thought [he had gotten hors d'oeuvres for **that woman** at the reception]]?

Likewise, a gap is uninterpretable without an associated filler: eliminating the filler from (2) also yields an ill-formed sentence, as in (4):

4. *John said [that he thought [he had gotten hors d'oeuvres for ⎯⎯ at the reception]].

The "unbounded" aspect of "unbounded dependency" has to do with the fact that this relationship of dependency seems to be possible over an unbounded distance. To illustrate this point, in the following example we temporarily abandon our convention of italicising the filler, and italicise the material intervening between the filler and the gap instead:

5. Who *did she claim* [*they said* [*that John swore* [*he thought* [*he had gotten hors d'oeuvres for* ⎯⎯ at the reception]]]]?

The maintenance of the dependency relationship appears to be unaffected by the number of intervening embedded clauses, indicated by square brackets. Thus the upper limit on how far a filler may be separated from

its gap seems at first blush to be determined only by constraints on working memory capacity.

However, this turns out to be an oversimplification. In the previous examples, only declarative clauses intervened between filler and gap, but this does not exhaust the range of possibilities: both interrogative (6) and relative clauses (7) can be embedded as well:

6. Did John forget [*what* he had gotten _____ for that woman at the reception]?
7. Did John drop the hors d'oeuvres [*which* he had gotten _____ for that woman at the reception]?

When embedded interrogative and relative clauses intervene between filler and gap, as they do in (8) and (9), respectively, they appear to disrupt the dependency relationship:

8. *Who_a did John forget [*what$_b$* he had gotten _____ $_b$ for _____ $_a$ *at the reception*]?
9. *Who_a did John drop the hors d'oeuvres [*which$_b$* he had gotten _____ $_b$ for _____ $_a$ at the reception]?

Embedded contexts such as these have been referred to as syntactic "islands" (Ross, 1968), under the metaphorical implication that they are isolated from superordinate clauses for purposes of unbounded dependency formation, i.e. they may not contain gaps associated with fillers in superordinate clauses. Thus the embedded *wh*-interrogative in (8) is referred to as a "*wh*-island"; the example in (9), containing a relative clause modifying the head noun *the hors d'oeuvres*, is typically referred to as a "complex noun phrase (NP) island" (Ross, 1968).

That this is not merely a semantic problem of interpretability can be demonstrated by comparing these examples to their corresponding "echo questions", i.e. the questioning of specific constituents via focus intonation to seek confirmation of information that was missed or unexpected in preceding statements.

10. John forgot [*what$_a$* he had gotten _____ $_a$ for **who** at the reception]?
11. John dropped the hors d'oeuvres [*which$_a$* he had gotten _____ $_a$ for **who** at the reception]?

In this case, we have placed *who* in boldface in order to highlight the fact that is not associated with a gap, since it already occupies the prepositional object position and clearly takes the thematic role of beneficiary. Therefore, it is not the case that examples (8) and (9) involve impossible semantic representations, since examples (10) and (11) with roughly the same semantic representation are well-formed and easy to interpret. Rather, the problem seems to lie in syntactic parsing due to the presence

of a dependency between a main clause filler and a gap in the embedded clause of (8) and (9).

Facts such as these have been subsumed under the principle of subjacency (Chomsky, 1973; 1977; 1981; 1986), and this syntactic interpretation of the phenomenon has dominated linguistic theory for over 20 years. What has remained constant in the various formulations of subjacency is that it constrains the number of crucially defined nodes in hierarchical constituent structure that may intervene between a filler and its gap.[1] While a number of additional semantic and pragmatic factors that influence the well-formedness of such constructions have been pointed out (Erteschik Shir, 1977; 1981; Erteschik Shir & Lappin, 1979; Kuno, 1976; 1987), for the most part these have been considered peripheral rather than central to the discussion. More recently, syntactic analyses have been put forward that incorporate semantic and pragmatic aspects in the analysis of these constructions (Cinque, 1990; Kroch, 1989; Pesetsky, 1987; Rizzi, 1990), while other proposals have argued that the correct analysis is in fact purely semantic (Deane, 1991; Kiss, 1993; Kluender, 1992; Szabolcsi & Zwarts, 1990). In addition, it has been suggested that syntactic principles like subjacency may have a functional basis in processing considerations (Berwick & Weinberg, 1984; Frazier, 1985; Newmeyer, 1990; 1991). However, it is generally assumed that while such considerations may have played a role in the evolution of constraints on the possible forms human language can take, they no longer have a causal synchronic role to play. Among most generative linguists, such principles are instead assumed to be innately specified (for discussion, see Fodor, 1989).

The present study was designed to test the hypothesis that the ill-formedness of unbounded dependencies into embedded *wh*-interrogatives (*wh*-islands) as in (8) or into relative clauses (complex noun phrase islands) as in (9) derives not from innate syntactic constraints, but rather from conventionalised real-time processing difficulties (Kluender, 1990; 1991; 1992; Kutas & Kluender, in press). In particular, we hypothesised that embedded interrogative clauses constitute syntactic islands because the *wh*-filler in an embedded interrogative clause [*what* in (8)] interferes with the processing of the dependency between the main clause filler *who* and

---

[1] Under earlier versions of the principle of subjacency (Chomsky, 1973; 1977; 1981), well-formedness was a categorical distinction: no part of an unbounded dependency could cross more than one "bounding node" at a time, where a bounding node was defined as a noun phrase (NP) or sentential (S) node. In more recent versions of subjacency (Chomsky, 1986), well-formedness has become a continuous distinction. Bounding nodes, or "barriers" as they are now called, are cumulative in their effects: the more barriers crossed, the worse the structure becomes.

the embedded clause gap. Similarly, relative clauses constitute syntactic islands because both the head noun [*the hors d'oeuvres* in (9)] and the relative pronoun [*which* in (9)] disrupt processing of the dependency between the main clause filler *who* and the embedded clause gap.

We are not merely claiming that syntactically ill-formed structures are hard to process. This is uncontroversially but trivially true. The question we pose instead is whether the ill-formedness of subjacency violations is a result of an innate syntactic constraint, i.e. a problem of competence, or whether it arises from processing difficulty, i.e. a problem of performance. For example, centre-embedded relative clauses like (12) are notoriously difficult to process, but freely generated by the grammar:

12. The woman$_a$ [the man$_b$ [the host knew ——— $_b$] brought ——— $_a$] left the party early.

There is no need for innate syntactic constraints to rule out centre-embedded structures such as this one; performance constraints on working memory capacity suffice. This is evidenced by the fact that when centre-embedded structures are made easy to process, as in (13), they seem perfectly grammatical:

13. The woman$_a$ [someone$_b$ [I knew ——— $_b$] brought ——— $_a$] left the party early.

We are relying on the same explanation for *wh*-islands and complex NP islands. Complex NP islands like (14), which also involves the embedding of a relative clause, have traditionally been ruled out by innate constraints in syntactic theory:

14. *What$_a$ do the editors really need to locate the linguist [who$_b$ ——— $_b$ reviewed ——— $_a$]?

But what if such structures could, just like centre-embedded relatives, be ruled out by processing limitations? The many island violation exceptions noted in the literature attest to this possibility. When complex NP islands are made easy to process, as in (15), they seem perfectly fine, just as in the case of centre-embedded relatives:

15. What$_a$ do we really need to find someone$_b$ [——— $_b$ to review ——— $_a$]?

The ill-formedness of (14) could then be tied to the same conventional, independent processing restrictions which rule out structures like (12), and have nothing to do with innate syntactic constraints. There would then be no need for extra statements in the grammar designed to rule out these structures specifically.

The mechanism that we propose to account for these facts is the following. It has been suggested that carrying a filler across a declarative clause boundary in grammatical sentences like (1) and (2) causes an increase in processing load (Frazier & Clifton, 1989). It is also known that filler–gap assignment interacts with working memory capacity (King & Just, 1991). Taken together, these results are consistent with Just and Carpenter's (1992) model of working memory, in which any additional processing task superimposed on a working memory task will compete for a limited set of mental resources, taxing the system and impairing performance.[2] We suggest that this situation is exacerbated at an embedded interrogative or relative clause boundary when interrogative or relative pronouns and/or the head nouns of relative clauses refer to entities or situations in the world of discourse. In general, whenever such referring expressions are encountered in written or spoken discourse, a mental representation of the referent must either be established or re-accessed (Heim, 1982; Karttunen, 1976), and establishing or reactivating discourse referents involves mental processing. In Just and Carpenter's model of working memory, the processing cost of activating the mental referent of any expression intervening between filler and gap should interfere with the maintenance of the filler–gap relationship, just as the processing cost of crossing a clause boundary does. Crucially for our purposes, however, when a filler is being held in working memory and a clause boundary is being crossed, which already taxes the parser, the occurrence at the clause boundary[3] of an expression whose referent must simultaneously be activated represents an additional processing load. Our claim is that only when such an expression occurs at a clause boundary will this interference be perceived as ungrammaticality rather than as mere processing difficulty, due to the convergence of multiple processing tasks at this point in the sentence. Consider the examples in (16):

16a. Isn't he sure [that the TA explained it to **them** in lab]?
  b. Isn't he sure [if the TA explained it to **them** in lab]?
  c. Isn't he sure [*what* the TA explained ——— to **them** in lab]?

The yes/no-questions in (16) are equivalent in well-formedness and vary only in the type of embedded clause boundary they contain: a declarative clause introduced by a *that* complementiser in (16a), an interrogative

---

[2] Here we do not mean to imply that the mental resources we refer to in the text constitute a common pool. We are referring instead to some subset of resources involved at least in language processing, and perhaps in other cognitive operations as well.

[3] To be more precise, by "at the clause boundary" we will henceforth mean in a position preceding the inflectional phrase (IP) in extended X'-theory (Chomsky, 1986), namely in either the head or specifier position of a complementiser phrase (CP).

clause introduced by an *if* complementiser in (16b) and an interrogative clause introduced by the interrogative pronoun *what* in (16c). When a dependency is formed between the main clause and the embedded prepositional object position occupied by **them** in (16), however, the results vary according to the type of embedded clause boundary crossed, as shown in (17):

17a. *Who* isn't he sure [that the TA explained it to ____ in lab]?
  b. ?*Who* isn't he sure [if the TA explained it to ____ in lab]?
  c. *Who_a isn't he sure [$what_b$ the TA explained ____ $_b$ *to* ____ $_a$ in lab]?

Sentence (17a) is traditionally considered well-formed, (17b) marginal and (17c) completely impossible.

Our hypothesis is that these distinctions are related to the nature of the element that introduces the embedded clause (the complementisers *that* and *if* and the interrogative pronoun *what*) and that therefore intervenes between the main clause filler *who* and its gap. The complementiser *that* in (16a) and (17a) can be deleted without altering the semantic content of the sentence as a whole. The same is not true of the complementiser *if* in (16b) and (17b). This points to a difference in semantic content between the two. The complementiser *that* merely signals that a proposition follows; even in lexical semantic accounts, it is considered "neutral" (with regard to perspective and subjectivity), "public", "objective" and "factual" (derived from a component of "knowing" in semantic structure) (Wierzbicka, 1988). The complementiser *if*, on the other hand, is more semantically articulated than the complementiser *that* in so far as it indexes a possible state of affairs in the world. In contrast to the two complementisers, the interrogative pronoun *what* in (16c) and (17c) refers to actual entities in the world of discourse. Since the interrogative pronoun is such a referring expression, it requires the activation of its referent in mental representation. This takes up additional processing resources. When such a referring expression occurs at a clause boundary which must be parsed while a filler is simultaneously being held in working memory, as in (17c), the convergence of multiple processing tasks temporarily overloads the system and gives rise to processing difficulty perceived as ungrammaticality. Thus we predict that carrying the main clause filler *who* across the embedded clause boundary should be most difficult in (17c), somewhat easier in (17b) and least problematic in (17a).

In order to tease apart these multiple processing tasks experimentally, we need to show evidence of three different kinds. First, we need to establish that the complementisers *that* and *if* and the interrogative pronouns *who* and *what* are indeed processed differently at embedded clause boundaries based on their semantic content. Second, we need to

establish that there is a processing cost associated with holding a filler in working memory. Third, we need to establish that these two processes interact.

The studies that we report on were designed to provide these types of evidence, and used stimuli like those in (16) and (17). We were able to look for evidence of the first type by comparing the initial elements in the embedded clauses of (16a), (16b) and (16c) (*that*, *if*, *what*, respectively). The lack of a dependency from the main clause into the embedded clause of the yes/no-questions in (16) allowed us to look for purely lexical semantic effects of embedded clause type. We were able to look for evidence of the second type by comparing various positions across the embedded clauses of (16a), (16b) and (16c) and of (17a), (17b) and (17c). Doing so enabled us to ascertain the effects of holding the embedded clause filler *what* in working memory pending its assignment to the direct object gap following *explained* in (16c) and (17c). Evidence of the second type was also available by comparing various positions in (17a), (17b) and (17c) to the same positions in (16a), (16b) and (16c), respectively. Since the embedded clauses in these comparisons were parallel in structure, we were able to ascertain the processing effects of question type, i.e. of holding the main clause filler *who* in working memory pending its assignment to the embedded prepositional object gap following *to* in (17a), (17b) and (17c). Finally, by comparing the positions immediately following the prepositional object gap (*in*) and at sentence end (*lab*) across the *wh*-questions of (17), and by contrasting these with comparable positions in (16), we were able to determine to what extent earlier lexical semantic effects of embedded clause type interacted with the processing effects of holding the main clause filler in working memory and assigning it to the embedded prepositional object gap.

The first two studies that we report on were behavioural in nature, whereas the third was electrophysiological. From an electrophysiological perspective, we have already presented evidence of the second type elsewhere (Kluender & Kutas, 1993). While we will summarise this evidence below, we will focus in this ERP study on evidence of the first and third types, as well as on corroborative evidence of all three types from our behavioural studies of global acceptability ratings.

EXPERIMENT 1

This study was done primarily to norm the materials that we used subsequently in the electrophysiological study (Experiment 3). We were interested in subjects' perceived acceptability of the stimulus sentences, but did not want our ERP subjects to make acceptability judgements themselves, for reasons outlined in the Methods section of Experiment 3.

Experiment 1 was, therefore, conducted on a separate pool of subject volunteers but with essentially the same stimulus presentation method as Experiment 3.

Methods

Subjects

Eight subjects (five males, three females) aged 18–30 years were paid for their participation. All of them were native speakers of English with normal or corrected-to-normal vision. Five were right-handed, two left-handed and one ambidextrous according to self-report and as tested by the Edinburgh Inventory (Oldfield, 1971). One of the right-handed subjects had a left-handed father.

Materials

In total, 295 sets of five parallel questions (main clause yes/no-questions with embedded interrogative *if-* or *wh-*clauses, and main clause *wh-*questions with embedded declarative *that-* or interrogative *if-*and *wh-*clauses) were constructed from 11 verbs that can take embedded interrogative clauses as complements (*ask, be sure, decide, figure out, find out, forget, know, remember, see, tell* and *wonder*). Conditions (1), (2) and (3) are traditionally considered fully grammatical, condition (4) marginal in grammaticality and condition (5) ungrammatical.

Sets containing subject gaps

1a. yes/no-*if*:   Couldn't you decide [if you should sing something for Grandma at the family reunion]?

2a. yes/no-*wh*:   Couldn't you decide [*who* _____ should sing something for Grandma at the family reunion]?

3a. *wh-that*:   Who did you decide [that you should sing something for _____ at the family reunion]?

4a. *wh-if*:   ?*Who* couldn't you decide [if you should sing something for _____ at the family reunion]?

5a. *wh*-island: *Who$_a$ couldn't you decide [*who$_b$* _____ $_b$ should sing something for _____ $_a$ at the family reunion]?

Sets containing object gaps

1b. yes/no-*if*:   Do you wonder [if they caught him at it by accident]?

2b. yes/no-*wh*:   Do you wonder [*who* they caught _____ at it by accident]?

3b. *wh-that*:   What do you suppose [that they caught him at _____ by accident]?

4b. *wh-if*:   ?*What* do you wonder [if they caught him at _____ by accident]?

5b. *wh*-island: *What$_a$ do you wonder [*who$_b$* they caught _____ $_b$ at _____ $_a$ by accident]?

Filler yes/no-*that* **questions**

Can you believe that his coach clocked him at under four minutes a mile at his last training session?

As the verbs used in the embedded clause can take more than one complement, namely both a direct object and a prepositional complement, there were several potential gap sites available in each embedded clause. Roughly half of the sentences in conditions (2) and (5) contained embedded *wh-*clauses with subject gaps (2a and 5a), and the other half contained embedded *wh-*clauses with direct object gaps (2b and 5b). In addition, conditions (3), (4) and (5) contained dependencies between the main clause filler and the embedded prepositional object gap position. The five conditions were matched as closely as possible in lexical content subject to subcategorisation constraints and pragmatic plausibility.[4]

The experimental sentences were supplemented by six sets of 60 filler sentences each: grammatical yes/no-questions with embedded declarative *that-*clauses (shown above with the experimental conditions); *wh-*questions containing a dependency within the main clause and an embedded conditional *if-*clause; multi-*wh-*questions containing a dependency within the main clause and one within the embedded clause; complex noun phrase islands (dependencies into both *that-* and *wh-*relative clauses); *that-*trace violations with dependencies from the main clause into the subject position of an embedded declarative *that-*clause; and yes/no-questions with either embedded *that-*, *if-* or *wh-*clauses that had missing noun phrase constituents. Though not matched in lexical content with the experimental sentences, the filler sentences likewise contained embedded verbs that take both direct and prepositional objects, and included the same set of prepositions. Thus the filler sentences represented variations on the basic syntactic

---

[4] Certain lexical changes had to be made in the *wh-that* condition for these reasons. The verbs *ask* and *wonder* could not be used in this condition as they do not subcategorise for declarative clause complements and were therefore replaced by either *imagine* or *suppose*. In certain instances, *see* was also replaced by *realise* in the *wh-that* condition for reasons of naturalness. For pragmatic reasons, a greater number of main clause auxiliary verbs in the *wh-that* condition were made affirmative rather than negative (85% vs roughly 50% in the other conditions). This is due to the fact that it makes little sense to ask questions like "What can't you figure out that you should ask the boss about before the meeting tomorrow?" (versus the more logical "What did you figure out that you should ask the boss about before the meeting tomorrow?").

framework of the experimental conditions. Ideally, the grammatical yes/no-questions with embedded *that*-clauses would instead have formed part of the experimental set, but this was impossible for purely practical reasons of running time limitations. Comparisons were therefore made between filler yes/no-*that* questions and experimental yes/no-*if*- and yes/no-*wh*-questions where relevant, to complete the experimental paradigm.

The 295 sets of experimental sentences were placed in a Latin square design to create five parallel lists of 295 experimental sentences such that no one subject saw more than one sentence from each set. The 360 filler sentences were added to each list, and the lists were then randomised and divided into 20 sets of about 33 questions each.

Procedure

The subjects were run in two sessions lasting about 2–2½ h each. At each session, the subjects saw 10 sets of about 33 questions each from the list they had been assigned to. Which half of a list was presented in the first session was counterbalanced across subjects. The presentation of stimuli in this study was essentially the same as that used in the ERP study (Experiment 3).

During a session, the subjects were seated in a comfortable chair in a sound-attenuated chamber at a distance of 110 cm from a monitor under the control of an AT computer. An illuminated rectangular border appeared uninterruptedly in the middle of the monitor during presentation of the questions for purposes of fixation. One second before onset of the first word of a question, a warning sign of three asterisks appeared on the screen for 500 msec in the same location as the ensuing words. Questions were presented one word at a time for a duration of 200 msec each, with a total stimulus onset asynchrony of 600 msec. The subjects were given 5500 msec between questions to make forced-choice acceptability judgements. Then the warning sign for the next question appeared on the screen. The subjects were first given a practice set of 33 questions, and rest breaks were interspersed between question sets whenever the subjects desired them.

At the beginning of each session, the subjects were given an instruction sheet which outlined how they were to make their judgements of acceptability, and how they were to register them. Use of the words "grammatical" and "ungrammatical" was eschewed in favour of "acceptable" and "unacceptable"; these were defined simply as "sounds right" or "doesn't sound right". The subjects were also told that the question of experimental interest was which questions *they* thought were acceptable, not what their English teachers had *told* them was acceptable. This was done to avoid the use of prescriptive norms in evaluating sentences, since all of the *wh*-questions involved preposition stranding. A question involving preposition

stranding was given as an example of an acceptable sentence, even though subjects "may have been told in school never to end a sentence with a preposition".

The subjects held buttons in either hand. At each session, the button in one hand was designated for accepting sentences, and the button in the other hand was used for rejecting sentences. Use of the dominant hand for accepting and rejecting sentences was counterbalanced across sessions. The subjects were instructed to wait until they saw the final question mark before responding, and then to respond as quickly as possible by pressing the appropriate button to accept or reject the sentence. They were also instructed to pay as close attention to the questions as possible. Since the questions were presented one word at a time, missing even one word could easily have prevented them from making the required acceptability judgement at sentence end.

Data Analysis

The subjects' acceptability judgements on all questions were recorded, and the percentage of questions judged acceptable in each condition was calculated for each subject. These were later subjected to analyses of variance.

Results

An analysis of variance (ANOVA) with two within-group factors, including two levels of question type (yes/no-question vs *wh*-question) and three levels of embedded clause type (*that* vs *if* vs *who/what*), showed main effects of question type and of embedded clause type as well as an interaction between the two (Fig. 1).

The *wh*-questions were consistently assigned lower acceptability ratings than corresponding yes/no-questions regardless of traditional grammatical status [main effect of question type: $F(1,7) = 117.66$, $P < 0.001$]; two-way comparisons revealed that *wh*-questions were rejected significantly more often than yes/no-questions for each embedded clause type [*wh-that* vs yes/no-*that*, $F(1,7) = 22.89$, $P < 0.002$; *wh-if* vs yes/no-*if*, $F(1,7) = 109.98$, $P < 0.001$; *wh*-island vs yes/no-*wh*, $F(1,7) = 191.91$, $P < 0.001$]. The significant main effect of embedded clause type [$F(2,14) = 28.45$, $P < 0.001$] indicated that, overall, questions with embedded *that*-clauses were considered more acceptable than sentences with embedded *if*-clauses, which were in turn rated more acceptable than sentences with embedded *wh*-clauses. Analyses conducted separately within each question type showed that all two-way comparisons between embedded clause types (with one exception, to be discussed below) were significantly different
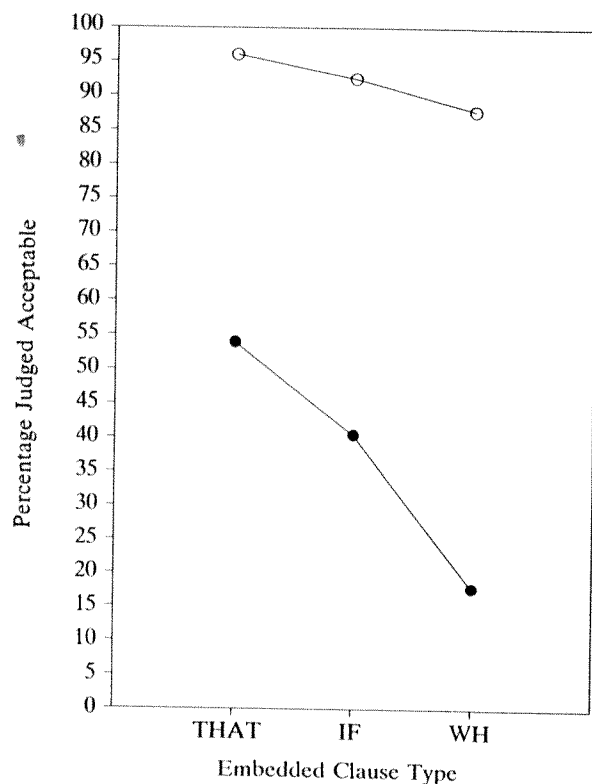
FIG. 1.   Percentage of yes/no-question (○) and wh-questions (●) with embedded *that-*, *if-* and *wh*-clauses judged acceptable in a forced-choice task performed under time pressure in response to RSVP stimuli.

from each other in both yes/no questions [$F(2,14) = 9.62$, $P < 0.002$; *who/ what* vs *that*, $F(1,7) = 15.51$, $P < 0.006$; *who/what* vs *if*, $F(1,7) = 6.14$, $P < 0.042$; *if* vs *that*, $F(1,7) = 4.68$, $P < 0.067$] and *wh*-questions [$F(2,14) = 16.85$, $P < 0.001$; *who/what* vs *that*, $F(1,7) = 21.35$, $P < 0.002$; *who/ what* vs *if*, $F(1,7) = 14.65$, $P < 0.007$; *if* vs *that*, $F(1,7) = 8.07$, $P < 0.025$].[5] However, as indicated by the significant two-way question type × embedded clause type interaction [$F(2,14) = 7.9$, $P < 0.007$], the difference in

---

[5] Although we realise that these comparisons are non-orthogonal, we report them here for purposes of comparison with Experiment 2.

acceptability between question types was greatest for *wh*-clauses, least for *that*-clauses and intermediate for *if*-clauses.

Discussion

Recall that our processing interpretation of subjacency violations in *wh*-islands crucially depends on the existence of three types of evidence. First, the complementisers *that* and *if* and the interrogative pronouns *who* and *what* must show evidence of differential processing at embedded clause boundaries based on their semantic content. Second, there must be a measurable processing cost associated with holding a filler in working memory. Finally, there must be an interaction of these two effects.

The results of this study not only appeared to provide all three types of evidence, but were also somewhat surprising in that question types traditionally taken to be perfectly grammatical were judged less acceptable than other question types traditionally considered to be equally grammatical. For example, the percentage of acceptable ratings assigned to yes/no-questions varied as a function of embedded clause type. This suggests that lexical choice plays a role in the acceptability of clausal embedding, independent of unbounded dependency formation. Further, there was a large difference in the percentage of acceptable ratings assigned to yes/no-*that* questions versus *wh-that* questions. This result suggests that the demands made by an unbounded dependency on working memory cause a decrease in acceptability regardless of grammaticality in traditional syntactic accounts. The interaction between question type and embedded clause type suggests that the typical judgements of grammatical, marginal and ungrammatical for *wh-that*, *wh-if* and *wh*-island questions, respectively, may be due to an interaction of lexical semantic factors at the embedded clause boundary [by which we mean, to reiterate, the head or specifier position of the embedded complementiser phrase (CP)] with the maintenance of the filler–gap dependency ranging from the main clause into the embedded clause.

However, these results could possibly be due to the rather unnatural mode of sentence presentation, one word at a time at a relatively slow rate. This could account for the large difference seen between the percentage of yes/no-*that* and *wh-that* questions judged acceptable, for example; one can justifiably argue that the processing effects of working memory on acceptability are being artificially induced by the paradigm itself. It must also be borne in mind that subjects were asked to make forced-choice decisions of acceptability under time pressure; this could easily skew the results as well. Experiment 2 was designed to address both of these concerns.

EXPERIMENT 2

Methods

Subjects

Twenty subjects between the ages of 17 and 29 were either given course credit or paid for their participation in this study. Fifteen were right-handed, three were left-handed and two were ambidextrous according to self-report and as tested by the Edinburgh Inventory (Oldfield, 1971). Three of the right-handed subjects had left-handed relatives in the immediate family. All were native speakers of English.

Materials

The materials were the same as those used in Experiment 1.

Procedure

Each subject saw the equivalent of only one session of the previous study (i.e. one half of one of the five lists). This was necessitated by a radical change in procedure. The questions were presented in full, one question at a time on a CRT, and the subjects could study them as long as they wished. Instead of a forced-choice acceptability judgement, the subjects were asked to give scalar acceptability ratings. The way this worked was as follows. Immediately underneath each question presented was a line extending across the screen. At the left end of the line was the phrase "This question is absolutely unacceptable", and at the right end the phrase "This question is perfectly acceptable". An upward-pointing movable arrow appeared at a random position underneath this line; the subjects were instructed to place the arrow at the appropriate location along the line corresponding to perceived degree of acceptability. The subjects then hit the "enter" key, the rating was entered in the database, and the next question appeared with the arrow in a new random position underneath the line.

The justification for this procedure was embedded in a fanciful written scenario involving extraterrestrial aliens who were having difficulty mastering English question formation, and who could more easily comprehend geometric relationships than linguistic categories. The subjects were given examples of "perfectly acceptable" question types (*Who do you think I saw at school?*, *What did you say you did last night?*, *What do you think it's made of?*) and "absolutely unacceptable" question types (*Who do you think that Mary hit John?*, *Who did that is dating a married man surprise you?*) not included in the stimulus corpus in order to establish end-points.

During a practice session including the same sample set of 33 questions used in Experiment 1, the subjects were monitored in order to make sure that they were using the entire range of the scale and not just the end-points. They were again instructed to ignore prescriptive norms against preposition stranding. Most subjects were able to rate all the sentences within 1 h.

Data Analysis

The line along which the subjects placed the movable arrow was associated with 40 discrete underlying data points. When the subjects hit the "enter" key, the number associated with that particular point was entered in the database: "perfectly acceptable" questions were assigned 40 points, whereas "absolutely unacceptable" questions were assigned 1 point. The mean ratings in each condition were stored on computer, calculated for each subject, and then subjected to analyses of variance.

Results

Despite the very different mode of presentation and rating procedure used, the pattern of results obtained in Experiment 2 basically replicated those obtained in Experiment 1. An ANOVA with two within-group factors, including two levels of question type (yes/no-question vs *wh*-question) and three levels of embedded clause type (*that* vs *if* vs *who/what*), again showed main effects of question type and embedded clause type and an interaction between the two (Fig. 2).

The main effect of question type again showed that *wh*-questions were assigned consistently lower acceptability ratings than yes/no-questions [$F(1,19) = 167.10$, $P < 0.001$]. Analyses conducted separately for each embedded clause type showed that there was a significant difference between question types in each case, regardless of traditional grammatical status [*wh-that* vs yes/no-*that*, $F(1,19) = 133.84$, $P < 0.001$; *wh-if* vs yes/no-*if*, $F(1,19) = 118.45$, $P < 0.001$; *wh*-island vs yes/no-*wh*, $F(1,19) = 154.89$, $P < 0.001$]. The significant main effect of embedded clause type reflected higher acceptability for *that*-clauses relative to *wh*-clauses, with *if*-clauses being of intermediate acceptability [$F(2,38) = 40.57$, $P < 0.001$]. Analyses conducted separately within question types again showed that all two-way differences either reached or approached significance both within yes/no-questions [$F(2,38) = 21.26$, $P < 0.001$; *who/what* vs *that*, $F(1,19) = 38.81$, $P < 0.001$; *who/what* vs *if*, $F(1,19) = 3.69$, $P < 0.07$; *if* vs *that*, $F(1,19) = 19.47$, $P < 0.001$] and within *wh*-questions [$F(2,38) = 27.28$, $P < 0.001$; *who/what* vs *that*, $F(1,19) = 42.04$, $P < 0.001$; *who/what* vs *if*, $F(1,19) = 12.99$, $P < 0.002$; *if* vs *that*, $F(1,19) = 19.43$, $P < 0.001$]. The
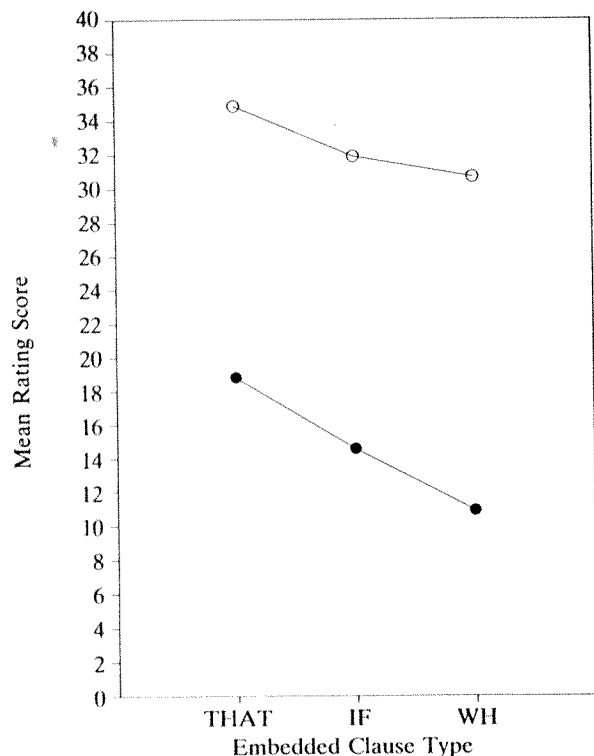
FIG. 2 Mean acceptability rating scores for yes/no-questions (○) and wh-questions (●) with embedded that-, if- and wh-clauses when questions were presented in their entirety without time constraints. Ratings were made on a linear scale with 40 underlying data points, 40 being "perfectly acceptable" and 0 "absolutely unacceptable."

significant interaction between question type and embedded clause type indicated that the difference between question types was greater for wh-clauses than for that-clauses, with if-clauses falling somewhere in between $[F(2,38) = 5.43, P < 0.01]$.

Discussion

The implication of these findings is that the results of Experiment 1 cannot be attributed to the experimental paradigm used in that case, i.e. rapid serial visual presentation (RSVP). Experiment 2 strengthened the hypoth-

eses (a) that lexical choice in clausal embedding affects overall acceptability and (b) that the mere existence of a long-distance dependency and the concomitant demands it makes on working memory are major factors in perceived acceptability, even when subjects can view questions *in toto* and have as much time as they need to make acceptability judgements. The interaction of these effects in both Experiments 1 and 2 lends support to our claim that subjacency, at least in *wh*-islands, may be reducible to processing considerations.

Although the difference between the yes/no-*wh* and yes/no-*if* conditions was only marginally significant in Experiment 2 ($P < 0.07$), the same comparison was significant in Experiment 1 ($P < 0.042$); conversely, the difference between the yes/no-*if* and yes/no-*that* conditions was significant in Experiment 2 ($P < 0.001$) but only marginally so in Experiment 1 ($P < 0.067$). The yes/no-*wh* versus yes/no-*that* comparison was significant in both Experiments 1 and 2 ($P < 0.006$ and $P < 0.001$, respectively). Here we are faced with the confound of the yes/no-*that* condition, which in these behavioural studies, as in the ERP study to follow, was not matched with the other experimental conditions for lexical content. Unfortunately, this confound can only be removed by future replication of these results with completely controlled conditions. However, note that across these two behavioural studies the yes/no-*that* condition did not consistently diverge from the yes/no-*if* and yes/no-*wh* conditions, nor did the yes/no-*if* condition consistently pattern with the yes/no-*wh* condition, as would have to be the case if the differences seen were due solely to this confound. Thus although the effects of embedded clause type are overall somewhat weaker in yes/no-questions than in *wh*-questions, one can still see a definite trend of lexical semantic effects in yes/no-questions.

EXPERIMENT 3

So far, we have seen evidence from two behavioural studies of global acceptability which indicates that (1) the complementisers *that* and *if* and the interrogative pronouns *who* and *what* are processed differentially at embedded clause boundaries; (2) there is a processing cost associated with holding a filler in working memory, even in off-line tasks; and (3) these two processing effects interact. We now turn to our ERP study, in which we sought to show electrophysiological evidence of the same three types.

In looking for electrophysiological evidence of the first type (i.e. lexical semantic effects of embedded clause type), we had certain expectations based on the results of prior research. In particular, we expected that these differences in semantic content might be indexed by differences in N400 amplitude. The N400 is known to be sensitive to aspects of semantic processing (for a review, see Kutas & Van Petten, 1988) as well as to

lexical class differences: the N400 to open-class or content words is larger than that to closed-class or function words (Kutas, Van Petten, & Besson, 1988; Neville, Mills, & Lawson, 1992; Van Petten & Kutas, 1991). However, although closed-class words elicit smaller N400s than open-class words, they still reliably elicit an N400 effect (Van Petten & Kutas, 1991). So far in ERP research on the open versus closed class distinction, only the coarsest cut has been made in the lexicon. But evidence in the psycholinguistic literature suggests that, with factors like frequency of occurrence held constant, one might expect processing differences related to semantic content not only within the open class (Gentner, 1991) but also within the closed class (Friederici, 1985). For example, referential closed-class expressions like pronouns might be expected to act more like open-class words than conjunctions or complementisers in on-line processing. If this is true, then one might expect this difference to surface in differential N400 amplitude. This is exactly what we have predicted elsewhere (Kluender, 1990; 1992) in regard to interrogative pronouns like *who* or *what* relative to complementisers like *that* or *if*. In addition, the more semantically articulated character of *if* might also be expected to elicit a differential N400 relative to the semantically neutral *that*. For these reasons, we were looking for differences in N400 amplitude at the embedded clause boundary of our stimulus sentences.

Methods

Subjects

Thirty right-handed subjects (16 males, 14 females) between the ages of 18 and 31 were paid $5.00 an hour for their participation. All of the subjects were native speakers of English with normal or corrected-to-normal vision. They were all right-handed by self-report and as tested by the Edinburgh Inventory (Oldfield, 1971), but 15 (8 males, 7 females) had left-handed family members, while the other 15 (8 males, 7 females) did not.

Stimuli

The materials were the same as in Experiment 1. Points of comparison for ERP measures are indicated below in capital letters; note that except for sentence-final words, all comparisons in this study were between function words.

Sets containing subject gaps

1a. yes/no-*if*:   Couldn't YOU decide [IF YOU should sing something FOR Grandma AT the family REUNION]?

2a. yes/no-*wh*:   Couldn't YOU decide [WHO _____ SHOULD sing something FOR Grandma AT the family REUNION]?

3a. *wh-that*:   *Who* did YOU decide [THAT YOU should sing something FOR _____ AT the family REUNION]?

4a. *wh-if*:   ?*Who* couldn't YOU decide [IF YOU should sing something FOR _____ AT the family REUNION]?

5a. *wh*-island: **Who$_a$* couldn't YOU decide [WHO$_b$ _____ $_b$ SHOULD sing something FOR _____ $_a$ AT the family REUNION]?

Sets containing object gaps

1b. yes/no-*if*:   Do YOU wonder [IF THEY caught him AT it BY ACCIDENT]?

2b. yes/no-*wh*:   Do YOU wonder [WHO THEY caught _____ AT it BY ACCIDENT]?

3b. *wh-that*:   *What* do YOU suppose [THAT THEY caught him AT _____ BY ACCIDENT]?

4b. *wh-if*:   ?*What* do YOU wonder [IF THEY caught him AT _____ BY ACCIDENT]?

5b. *wh*-island: **What$_a$* do YOU wonder [WHO$_b$ THEY caught _____ $_b$ AT _____ $_a$ BY ACCIDENT]?

Filler yes/no-*that* **questions**

   Can YOU believe [THAT HIS coach clocked him AT under four minutes a mile AT his last training SESSION?

Procedure

The subjects were run in two sessions lasting about 3½ h each. Assignment of the subjects to lists was counterbalanced for family history of left-handedness and gender. Presentation of the stimuli was the same as in Experiment 1, with the following exceptions.

Most importantly, the ERP subjects were not asked to provide acceptability ratings of the questions that they read in order to avoid any judgemental bias in the electrophysiological record of sentence processing. The intention was specifically to avoid categorisation of the stimuli into "grammatical" and "ungrammatical" sets by the subjects. There are two problems with such a task. First, subjects can stop paying attention to a sentence without penalty as soon as it can be identified as ungrammatical, i.e. before it has reached completion. As in this study we were particularly interested in the electrophysiological responses to words occurring in the latter half of the sentences; for example, at gap location and in sentence-final position, this would have been an undesirable result. Second, the very act of making such a binary decision mid-sentence is likely to elicit a P300 component; a larger P300 is typically elicited in discrimination tasks by the more infrequent of two stimulus types (for a review, see Hillyard & Picton, 1987). Thus the occurrence of a P300 mid-sentence would have overlapped with and possibly washed out the ERPs associated with sentence processing alone.

Thus instead of an acceptability judgement task, a target probe word followed 1.5 sec after the onset of each sentence-final word. The end-of-sentence probe task required the subjects to indicate whether the target word had occurred in the immediately preceding question by pressing a button in one hand for occurring targets and in the other hand for non-occurring targets. The hand designated to signal occurring targets was counterbalanced both across subjects and across sessions. The subjects were instructed to respond as quickly and accurately as possible, and were also told that trying to extract as much meaning as possible from the questions they saw would help them in the probe word task. The task was thus orthogonal to the question of experimental interest, but obliged the subject to pay close attention to each word of the sentence, and encouraged them to read the sentences for meaning. Five seconds after onset of the target word to the previous question, the warning sign for the next question appeared on the screen (500 msec earlier than in Experiment 1).

Electrophysiological Recording

The electroencephalogram (EEG) was recorded with tin electrodes mounted in a commercially available elastic cap. Midline frontal (Fz), central (Cz) and parietal (Pz) recording sites were used, along with lateral pairs of electrodes over the posterior temporal (T5, T6) and occipital (O1, O2) scalp as defined by the 10-20 system (Jasper, 1958). Three additional lateral pairs were used: (1) a frontal pair placed midway between F7/8 and T3/4 (approximately over Broca's area and its right hemisphere homologue; BL and BR); (2) a temporoparietal pair which were placed 30% of the interaural distance lateral and 12.5% of the inion–nasion distance posterior to Cz (approximately over Wernicke's area and its right hemisphere homologue; WL and WR); and (3) a central pair which was 33% lateral to Cz (approximately over Brodmann's area 41; L41 and R41). Each scalp site was referred to an off-line average of the left and right mastoids (Van Petten & Kutas, 1988). Vertical eye movements and blinks were monitored via an electrode placed below the right eye and referred to the left mastoid. Horizontal eye movements were monitored via a right-to-left bipolar montage at the external canthi.

The EEG was amplified by a Grass Model 12 polygraph with half-amplitude cut-offs of 0.01 and 100 Hz, digitised on-line at a sampling rate of 250 Hz, and stored on magnetic tape along with stimulus codes for subsequent averaging. Trials with eye movement, muscle or amplifier blocking artifacts were rejected prior to averaging; approximately 5% of the trials were lost for these reasons.

Data Analysis

Mean voltage was measured by computer algorithm relative to a 100 msec pre-stimulus baseline in a latency range of 300–500 msec post-stimulus for both right hemisphere and left anterior negativities, and in a latency range of 500–900 msec post-stimulus for late positivities. The latency window for negativities was chosen on the basis of prior research. Neville et al. (1991) and Osterhout and Holcomb (1992) also used a latency window of 300–500 msec for their left anterior negativities. Although the right hemisphere negativities in our data extended beyond the latency window of 300 to 500 or 600 msec typically used to measure N400 effects, using a larger latency range would not have altered the main effects or interactions reported. The statistical analyses consisted of five-way ANOVAs with one between-group factor of family history of handedness (subjects with and without left-handed family members) and four within-group factors, including two levels of question type (yes/no-and wh-questions), three levels of embedded clause type (that, if- and wh-clauses), five levels of lateral anterior/posterior sites (BL/R, L/R41, WL/R, T5/6 and O1/2), and two levels of hemisphere (left or right). Where interactions of question type or embedded clause type with anterior/posterior lateral position or hemisphere are of interest, the Huynh–Feldt correction for lack of sphericity (Huynh & Feldt, 1976) has been applied, and the original degrees of freedom are reported with the corrected probability level.

Results and Discussion

Recall that in conducting this study we were looking for the same three types of evidence in the ERP record that we had found in our previous behavioural studies of acceptability: differential processing of embedded complementisers and interrogative pronouns, a processing measure related to holding a filler in working memory, and an interaction of the two. We have organised the results of Experiment 3 in a way that reflects these three types of evidence. We will present and discuss in turn (a) effects seen at the embedded clause boundary, (b) effects related to the processing of a filler–gap dependency, and (c) an interaction of these two types of effects at positions later in the sentence.

Right Hemisphere Negativities at the Embedded Clause Boundary

Results. Visual inspection of the waveforms suggested two different ERP effects within the same latency range of 300–500 msec: in yes/no-questions, a difference between *that*, *if* and *who/what* in the amplitude of

the negativity elicited over the right hemisphere (Fig. 3), and a positivity in both yes/no-questions and *wh*-questions to *if* most prominent over the posterior regions of the left hemisphere (Figs 3 and 4). Note that the negativity in Fig. 3 shows the classic N400 pattern of distribution, namely larger over the right hemisphere and over posterior regions.

A five-way ANOVA with one between-group factor of familial handedness and four within-group factors, including two levels of question type, three levels of embedded clause type, five levels of lateral anterior/posterior position and two levels of hemisphere, revealed main effects of embedded clause type $[F(2,56) = 8.16, P < 0.008]$ and of anterior/posterior position $[F(4,112) = 8.71, P < 0.005]$. The main effect of embedded clause type reflected the fact that across question types, the ERPs in this latency range were most negative to *who/what* and most positive to *if*. There were also significant interactions of embedded clause type × anterior/posterior $[F(8,224) = 3.89, P < 0.012]$, embedded clause type × hemisphere $[F(2,56) = 12.95, P < 0.001]$, question type × embedded clause type × anterior/posterior $[F(8,224) = 2.77, P < 0.047]$, question type × embedded clause type × hemisphere $[F(2,56) = 6.04, P < 0.004]$, and embedded clause type × anterior/posterior × hemisphere $[F(8,224) = 4.05, P < 0.001]$. Marginal interactions of familial handedness × question type × anterior/posterior × hemisphere $[F(4,112) = 2.48, P < 0.068]$ and of question type × embedded clause type × anterior/posterior × hemisphere $[F(8,224) = 2.04, P < 0.077]$ were also in evidence.

Since the nature of these interactions was quite complex, involving elements both of the right hemisphere negativity to *who/what* in yes/no-questions, and of the posterior left-lateralised positivity to *if* across question types, separate ANOVAs were done within question types. Within yes/no-questions, a four-way ANOVA with one between-group factor of familial handedness and three within-group factors, including three levels of embedded clause type, five levels of anterior/posterior position and two levels of hemisphere, showed a main effect of embedded clause type $[F(2,56) = 6.49, P < 0.003]$. This was again due to the fact that the ERPs were most negative to *who/what* and most positive to *if*.

As can be seen in Fig. 3, the ERPs over the two hemispheres are quite different, primarily in response to *if*. Over the posterior regions of the left hemisphere there is a large positivity to *if* (and some N400 activity to *who/what* over the left occipital), whereas over the right hemisphere there is more negativity in the ERPs to both *who/what* and *if* relative to *that*. Since we had predicted a three-way difference in N400 amplitude to *that*, *if* and *who/what*, and since the N400 is typically larger over the right hemisphere, we analysed these right hemisphere negativities separately within yes/no-questions to see if the apparent difference between *that* and *if* was signifi-
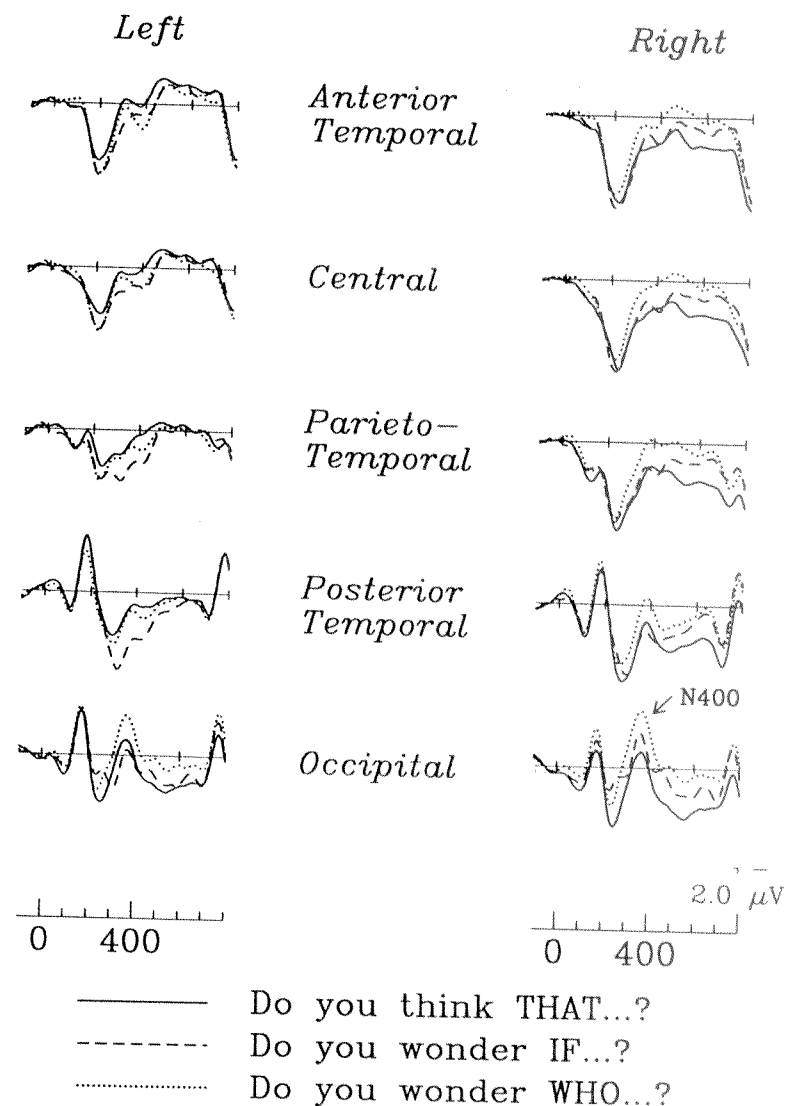

FIG. 3 Grand average ERPs (*n* = 30) elicited by *that*-complementisers (solid line), *if*-complementisers (dashed line) and the interrogative pronouns *who* and *what* (dotted line) at the embedded clause boundary in yes/no-questions.
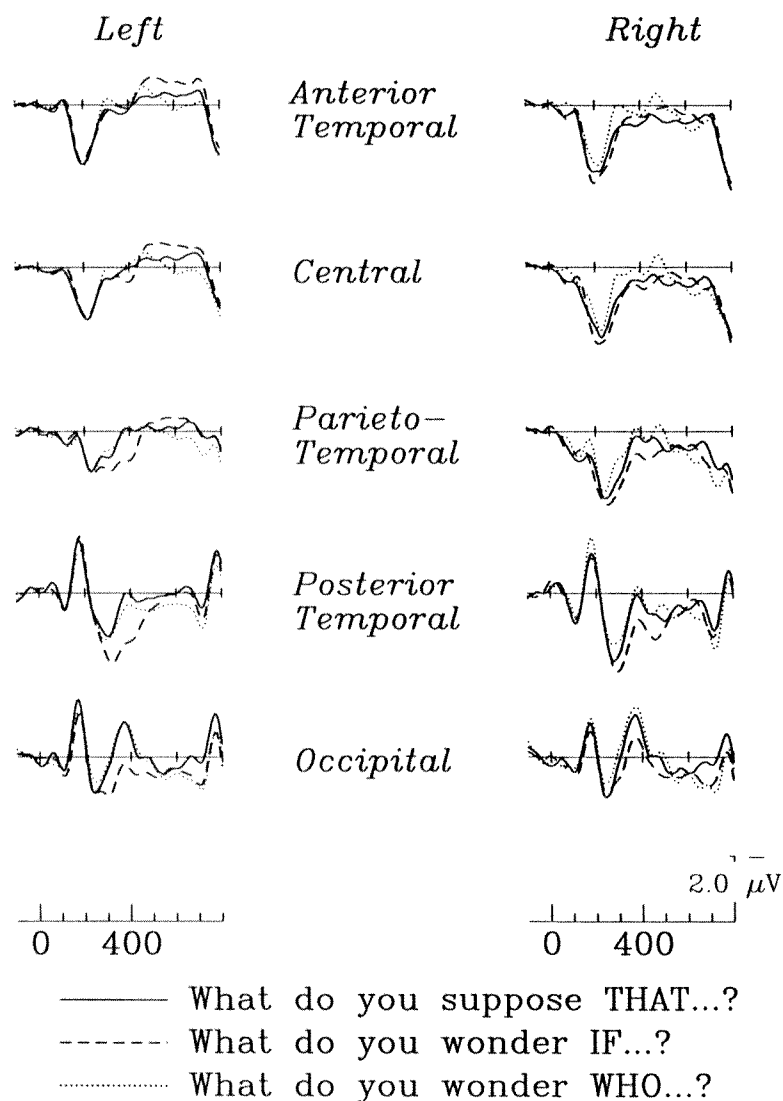
FIG. 4 Grand average ERPs (*n* = 30) elicited by *that*-complementisers (solid line), *if*-complementisers (dashed line) and the interrogative pronouns *who* and *what* (dotted line) at the embedded clause boundary in *wh*-questions.

cant. A three-way ANOVA with one between-group factor of familial handedness and two within-group factors of embedded clause type and anterior/posterior position showed a main effect of embedded clause type $[F(2,56) = 11.41, P < 0.001]$. However, two-way comparisons indicated that while *who/what* was again more negative than the other two conditions, *that* and *if* did not differ from each other [*who/what* vs *that*, $F(1,28) = 22.18, P < 0.001$; *if* vs *that*, $F(1,28) = 1.25$, NS].

The lack of a significant difference between *that* and *if* was due to the fact that at all right hemisphere sites other than the occipital, the response to *if* did not diverge from the response to *that* until sometime after 400 msec post-stimulus. This was in turn due to the positivity elicited by *if* over posterior regions, which occurred within the same latency range of 300–500 msec as the right hemisphere negativity. Between 500 and 700 msec post-stimulus, the ERP to *if* was more negative than the ERP to *that*, and this is confirmed by a main effect of embedded clause type in a three-way ANOVA on measurements taken between 500 and 700 msec post-stimulus $[F(2,56) = 12.27, P < 0.001]$. Two-way comparisons confirmed that *if* was significantly different from *that* in this latency range [*who/what* vs *that*, $F(1,28) = 27.92, P < 0.001$; *if* vs *that*, $F(1,28) = 9.13$, $P < 0.005$]. Over the right occipital electrode, there was a three-way difference between *that*, *if* and *who/what* in the 300–500 msec latency range despite the influence of the posterior positivity to *if*.

Within *wh*-questions (Fig. 4), a four-way ANOVA with one between-group factor of familial handedness and three within-group factors, including three levels of embedded clause position, five levels of anterior/posterior position and two levels of hemisphere, showed a main effect of embedded clause type $[F(2,56) = 4.53, P < 0.015]$. This was due to the fact that the ERPs to *if* were more positive than to *that* or to *who/what*.

Discussion.   The results discussed here point to differential processing of the complementisers *that* and *if* and the interrogative pronouns *who* or *what* at embedded clause boundaries. Note that although we saw evidence of such off-line effects in behavioural Experiments 1 and 2, the ERP record provides us with the first indication of an on-line processing difference. We had predicted (Kluender, 1990; 1992) that the lexical semantic differences among these three types of function words, namely the semantically neutral character of *that* versus the more semantically specified character of *if* versus the referential nature of *who* or *what*, would surface electrophysiologically as differences in N400 amplitude, since the N400 is known to be sensitive to semantic factors at both the word and sentence level. Furthermore, it was predicted that such differences in N400 amplitude would be observed in perfectly grammatical sentences with or without

dependency formation. On the whole, these predictions turned out to be accurate, though the co-occurrence of the left-lateralised positivity to *if* over posterior regions in the same latency range of 300–500 msec obscured the effect somewhat. Although differences in N400 amplitude between open- and closed-class words have previously been demonstrated (Kutas et al., 1988), to our knowledge this is the first time that differential amplitude has been shown for words within the closed class.

We therefore believe that the best interpretation of these results is one that attributes the differences in right hemisphere negativity to the lexical semantic differences found across conditions at the embedded clause boundary. Alternative explanations based on purported differences in grammaticality, semantic interpretability, preceding context, cloze probability, frequency, or dependency formation across conditions seem less plausible. The fact that N400-like effects were seen at the embedded clause boundary in fully grammatical and semantically interpretable yes/no-questions tends to rule out explanations based on either grammaticality or semantic interpretability. Although the subjects were not tested on their comprehension, they were encouraged to read the sentences for meaning to aid them in the end-of-sentence probe word task, and they gave no indication of devising strategies to scan sentences for probe words in order to avoid semantic interpretation of the sentences they were reading, particularly the grammatical ones. In fact, a number of them commented specifically on the content of the stimulus sentences after the experiment, noting that there were lots of political and military questions, that the questions seemed rather downbeat, etc. Preceding context was exactly the same in the yes/no-*if*, yes/no-*wh*, *wh-if* and *wh*-island conditions, and very nearly the same in the yes/no-*that* and *wh-that* conditions. Recall that *wh-that* questions had a higher percentage of affirmative main clause auxiliaries than conditions containing interrogative *if-* and *wh*-clauses, and *imagine* and *suppose* were substituted for main clause *ask* and *wonder*; the yes/no-*that* condition consisted of filler yes/no-questions that differed from the experimental sentences both in choice of main clause verb and in the fact that all main clause auxiliaries were affirmative. Nonetheless, it seems impossible to account for all the observed differences in right hemisphere negativity in terms of preceding context. An account based on cloze probability, a known correlate of N400 amplitude (Kutas & Hillyard, 1984; Kutas, Lindamood, & Hillyard, 1984), would have to prove that a *wh*-complement has a lower cloze probability than an *if-* or *that*-complement following the verbs used in this study. However, (infinitival) *wh*-complements occur with at least equal frequency and in most cases with greater frequency than (finite) *that*-complements after those verbs used in the present study for which published norms (Connine et al., 1984) are

available (5 out of 11; no norms are available for *if*-clauses).[6] N400 amplitude is known to correlate inversely with word frequency when semantic context is weak or absent, but in sentence contexts this is true only for the first few open-class or content words occurring in a sentence (Van Petten, 1989; Van Petten & Kutas, 1990). In this study, all comparisons were between closed-class words which were preceded by at least one open-class word in the main clause, typically the main clause verb.[7] However, even if we ignore the effects of sentential context on frequency-related N400 amplitude, word frequency alone will not account for the differential right hemisphere negativity in this comparison: *if* and *what/who* are roughly equivalent in frequency (2199 vs 1965/2678, average 2321 per million) but differ from each other in the ERP. Finally, an explanation in terms of dependency formation is ruled out by the fact that dependency formation is not involved at all in the comparison between *if* and *that* in yes/no-questions, where an N400-like difference was also seen.

The lack of N400 differences in the ERPs to these same function words at the embedded clause boundary of *wh*-questions seems somewhat puzzling. One possible explanation for the absence of effects is that the extra processing load caused by the existence of a long-distance dependency in the main clause of *wh*-questions somehow overrides the lexical semantic effects seen in yes/no-questions. This explanation is plausible on several counts. First, although individual words contribute to global sentence interpretation, it is clear that the whole is greater than the sum of the parts. For example, we mentioned above that lexical frequency effects seen at early positions in a sentence disappear as sentential context accrues (Van Petten, 1989; Van Petten & Kutas, 1990). Second, evidence to be discussed below indicates that the existence of a long-distance dependency in a sentence does affect its processing. Third, other (unrelated) comparisons in our data reveal that the existence of a long-distance dependency

---

[6] Note, however, that the published norms in Connine et al. (1984) were for main clause declarative sentences, not for main clause yes/no- or *wh*-questions as in the present study.

[7] The main clause verb is the first open-class word in half of the experimental sentences and in two-thirds of the filler yes/no-questions. Thus the fact that different sets of main clause verbs are used in the yes/no-*if* and yes/no-*that* conditions (*ask, be sure, decide, figure out, find out, forget, know, remember, see, tell* and *wonder* in the experimental sentences versus *admit, be glad, believe, claim, forget, maintain, regret, say* and *think* in the filler sentences) might be expected to influence N400 amplitude at the immediately following embedded clause boundary if it could be shown that there are major differences in mean frequency between the two sets of verbs. This possibility can also be ruled out, however: the two sets of verbs are matched in mean frequency (646 per million in the filler set versus 622 per million in the experimental set).

in the main clause also results in the attenuation of lexical effects seen at the main clause subject position.

More puzzling is the left-lateralised positivity in response to *if*. This fairly striking effect, most clearly seen over left posterior temporal regions, was also elicited in a filler condition containing a *wh*-dependency within the main clause and an embedded conditional *if*-clause. The morphology, latency and distribution of the positivity were nearly identical in all three cases. Considering it highly unlikely that an ERP effect might be tied to a particular lexical item, we wondered if it might be an index of general counterfactuality instead. However, when we tested this hypothesis by comparing modal verbs (*can*, *could*, *will* and *would*) to other types of auxiliary words (various inflected forms of *be*, *do* and *have*), and contracted negative auxiliary verbs to their affirmative counterparts, no such effect was seen in either yes/no- or *wh*-questions. This must therefore remain an open question for further research.

Effects of Left Anterior Negativity (LAN)

Results. We now turn to the second piece of evidence needed for a processing account of subjacency effects in *wh*-islands: an ERP index of the necessity to hold a filler in working memory. Again, we saw indications of this in off-line acceptability judgements gathered in Experiments 1 and 2, but since holding a filler in working memory is a real-time processing problem, one would like to see an on-line measure of processing cost.

As mentioned earlier, we have already presented these particular data elsewhere (Kluender & Kutas, 1993). Thus in this section we will merely summarise the results we obtained and refer the reader to the original article for more detailed discussion and for analyses. To begin, we will provide an overview of the relevant comparisons by reviewing our experimental conditions, which we repeat here for convenience. Only the points of comparison that are relevant to this effect are capitalised in this set of examples; fillers are italicised.

A five-way analysis of variance was done with all conditions factored in. However, for ease of exposition, we will describe the embedded clause data in terms of partial comparisons within question types, within embedded clause types, or within sets containing subject or object gaps. When separate analyses were done within question types (Figs 5, 6, and 7) or within embedded clause types (Fig. 8), both subject and object gap sentences were included in the analysis, and this is what is shown in the figures. However, separate analyses of subject or object gap sentences revealed that the significant LAN effects within question types were due to object gap sentences.

Sets containing subject gaps

1a. yes/no-*if*: Couldn't YOU decide [if YOU should sing something FOR Grandma AT the family reunion]?

2a. yes/no-*wh*: Couldn't YOU decide [*who* _____ SHOULD sing something FOR Grandma AT the family reunion]?

3a. *wh-that*: *Who* did YOU decide [that YOU should sing something FOR _____ AT the family reunion]?

4a. *wh-if*: ?*Who* couldn't YOU decide [if YOU should sing something FOR _____ AT the family reunion]?

5a. *wh*-island: *Who_a couldn't YOU decide [who_b _____ $_b$ SHOULD sing something FOR _____ $_a$ AT the family reunion]?

Sets containing object gaps

1b. yes/no-*if*: Do YOU wonder [if THEY caught him AT it BY accident]?

2b. yes/no-*wh*: Do YOU wonder [*who* THEY caught _____ AT it BY accident]?

3b. *wh-that*: *What* do YOU suppose [that THEY caught him AT _____ BY accident]?

4b. *wh-if*: ?*What* do YOU wonder [if THEY caught him AT _____ BY accident]?

5b. *wh*-island: *$What_a$ do YOU wonder [who_b THEY caught _____ $_b$ AT _____ $_a$ BY accident]?

Filler yes/no-*that* **questions**

Can YOU believe [that HIS coach clocked him AT under four minutes a mile AT his last training session?

First, recall that half the experimental stimuli with embedded interrogative *wh*-clauses contained subject fillers and gaps (2a and 5a) and half contained object fillers and gaps (2b and 5b). The difference between the two is that object fillers were separated from their gaps by several intervening words, while subject fillers were immediately adjacent to their gaps. One would therefore expect the processing load of object fillers held in working memory to be greater than that of subject fillers, since subject fillers can be assigned immediately to their gaps while object fillers cannot. Note further that all the main clause fillers [*who* in (3a), (4a) and (5a); *what* in (3b), (4b) and (5b)] were associated with the prepositional object position in the embedded clause, and had to be held in working memory across the embedded clause boundary.

Looking now at the main clause subject position (the first YOU in all conditions), we see that we can compare the subject in yes/no-questions [(1a) and (2a), (1b) and (2b), and the filler sentence] with the same position in *wh*-questions [(3a), (4a) and (5a), and (3b), (4b) and (5b)]. At

this point, all the questions are completely well-formed and normal-sounding. When these positions were compared across question types, the ERPs to the subjects of *wh*-questions were more negative over anterior regions of the left hemisphere than the ERPs to the subjects of yes/no-questions. We do not show this effect here because it involves some additional complications discussed in Kluender and Kutas (1993). However, as an initial working hypothesis in line with our predictions, let us assume that this effect indexes the presence of the filler in *wh*-questions. At the subject position of the main clause, it becomes clear that this filler must be held in working memory; it cannot be the main clause subject since this position is already filled. This filler must therefore be associated with a gap further downstream in the sentence, though at this point it is unclear what grammatical function it will serve or what thematic role it will fill.

If this is the case, then we would expect embedded fillers associated with direct object gaps to show a similar effect at the embedded clause subject position [THEY in the set containing object gaps]. There are a number of ways this can be shown, since this position can be compared either within or across question types. We made both types of comparisons. Within yes/no-questions, when THEY in (2b) was compared to the same position in (1b) and to HIS in the filler sentence, the ERP to THEY in (2b) was more negative over the anterior regions of the left hemisphere than the ERP to THEY in (1b) and to HIS in the filler sentence, as shown in Fig. 5 for the whole head. Figure 6 shows only the three most anterior channels of the left hemisphere in close-up.

All three yes/no-questions are grammatical, so a difference in grammaticality cannot be causing the difference in the ERP. However, (2b) differs from (1b) and the filler sentence in that it contains the interrogative pronoun *who* at the embedded clause boundary where the other two sentences have complementisers. This difference could thus simply be due to the presence of an interrogative pronoun, and need not necessarily have anything to do with holding a filler in working memory. The way to test this hypothesis is to see what happens in the ERP record at the position following an interrogative pronoun in an embedded clause with a subject gap, as in (2a). Here there is an interrogative pronoun present, just as in (2b), but this filler does not need to be held in working memory because it can immediately be assigned to its adjacent gap. So if the effect of left anterior negativity is caused by the mere presence of an interrogative pronoun, then it should be seen when the function word SHOULD in (2a) is compared to the YOU following the *if* complementiser in (1a), and to the HIS following the *that* complementiser in the filler sentence. On the other hand, if left anterior negativity is caused by the need to hold a filler in working memory, then no such effect should be seen at this position.
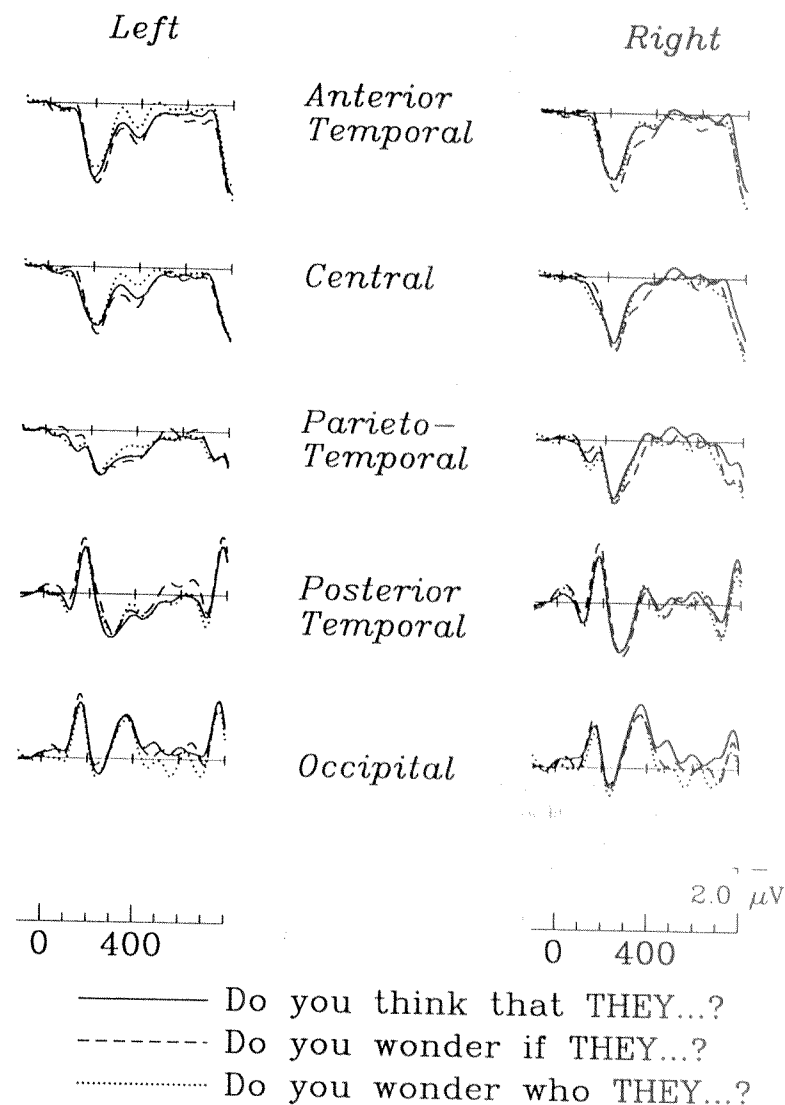

FIG. 5   Grand average ERPs (*n* = 30) to function words (capitalised) immediately following *that*-complementisers (solid line), *if*-complementisers (dashed line) and the interrogative pronouns *who* and *what* (dotted line) embedded in yes/no-questions.

──────── Do you think that THEY...?
- - - - - Do you wonder if THEY...?
.... Do you wonder who THEY...?

605

L. Anterior
Temporal

L. Central

L. Parieto-
Temporal

2.0 μV

0   200   400   600

——————— Do you think that THEY...?
- - - - - - Do you wonder if THEY...?
·············· Do you wonder who THEY...?

FIG. 6 Grand average ERPs (*n* = 30) recorded at three left hemisphere sites to function words (capitalised) immediately following *that*-complementisers (solid line), *if*-complementisers (dashed line) and the interrogative pronouns *who* and *what* (dotted line) embedded in yes/no-questions (cf. Fig. 5).
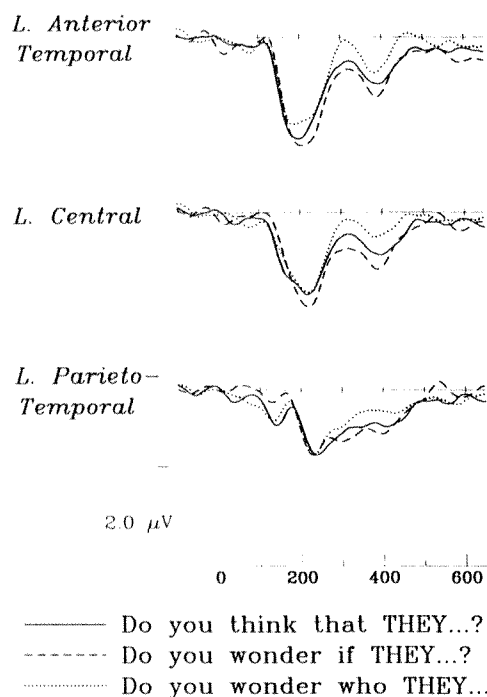
There was no significant difference in the ERP over the left anterior region when this comparison was made. This indicates that the left anterior negativity we see in Fig. 6 must be related to the greater working memory load associated with object fillers, which are separated from their gaps by several words. To reiterate, subject fillers can immediately be associated with their adjacent gaps and hence do not need to be stored in working memory.

So far, we have considered the embedded subject position within yes/no-questions; the same position can be compared within *wh*-questions [THEY in (3b), (4b), (5b)]. In this case, all three conditions contain dependencies from the main clause filler *what* into the prepositional object position, so they are equivalent in that they all require this filler to be held
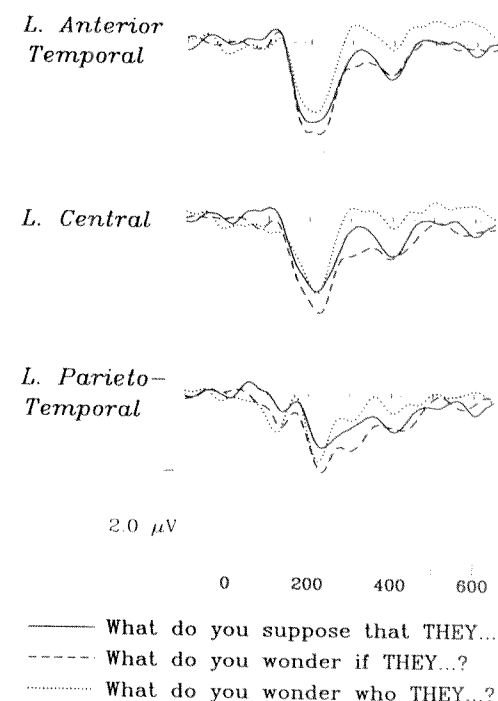
L. Anterior
Temporal

L. Central

L. Parieto-
Temporal

2.0 μV

0   200   400   600

——————— What do you suppose that THEY...?
- - - - - What do you wonder if THEY...?
·············· What do you wonder who THEY...?

FIG. 7 Grand average ERPs (*n* = 30) recorded at three left hemisphere sites to function words (capitalised) immediately following *that*-complementisers (solid line), *if*-complementisers (dashed line) and the interrogative pronouns *who* and *what* (dotted line) embedded in *wh*-questions.

in working memory. However, the subject THEY in (5b) follows another filler (*who*) at the embedded clause boundary which is associated with the direct object position. So in (5b) two fillers have to be stored in working memory pending assignment to a gap, while in (3b) and (4b) only the one main clause filler *what* needs to be stored. The result in the ERP is that the embedded subject (THEY) in (5b) is again more negative over the anterior regions of the left hemisphere relative to the same position in (3b) and (4b), as shown in Fig. 7.

At this point in the sentence, one can already tell that (5b) is going to be problematic, and probably ungrammatical. However, the left anterior negativity in the ERP cannot be due to a perception of ungrammaticality in the *wh*-question because the morphology, latency and distribution of

the effect are the same as those elicited by the same position (the embedded subject THEY) in a perfectly grammatical yes/no-question in our previous comparison (Fig. 6). Another way to demonstrate this is to look at an equivalent position following a subject filler and gap in the equally ungrammatical (5a). If left anterior negativity is due to a perception of ungrammaticality, then it should also be evident when we compare the embedded verb SHOULD following a subject gap in (5a) to the embedded subject YOU in the grammatical (3a) and marginally grammatical (4a). If left anterior negativity is related to holding a filler in working memory, then we should see no left anterior negative difference. This is because (3a), (4a) and (5a) are all equivalent in requiring that the main clause filler *who* be held in working memory, while the embedded clause filler *who* makes no such demands on working memory. There was no significant difference of left anterior negativity in the ERP when this comparison was made. This is because once again the embedded subject filler *who* in (5a) can be assigned to its adjacent gap as soon as the following verb SHOULD is encountered, and hence does not need to be stored in working memory. Once again we conclude that what causes the left anterior negativity is the need to store a filler in working memory irrespective of its grammatical status.

Thus far we have compared the second words of embedded clauses both within yes/no-questions and within *wh*-questions. However, it is also possible to compare this same position across question types, holding embedded clause type constant. Thus we can compare (3) to the filler sentence, (4) to (1), and (5) to (2). In this case, *wh*-questions differ from yes/no-questions in the presence of the main clause filler that must be held in working memory pending assignment to the prepositional object gap in the embedded clause. The embedded clauses, however, are the same across question types. Thus it was not necessary in this comparison to separate embedded clauses containing object gaps from those containing subject gaps, since *wh*-questions and yes/no-questions were matched on this dimension. The only relevant difference was the main clause filler held in working memory in *wh*-questions. These comparisons are shown in Fig. 8.

Here once again we see the three anterior channels of the left hemisphere in the top three rows, with the most anterior channel of the right hemisphere added for comparison in the bottom row. For each of the *wh*-questions, a left anterior negativity is elicited relative to the corresponding yes/no-question. No such effect is seen over the anterior regions of the right hemisphere in the bottom row of channels. This indicates once again the left anterior negativity must be associated with holding a filler in working memory, since this is the only dimension on which the conditions differ. Recall that the comparison of *wh*-islands (5) to yes/no-questions
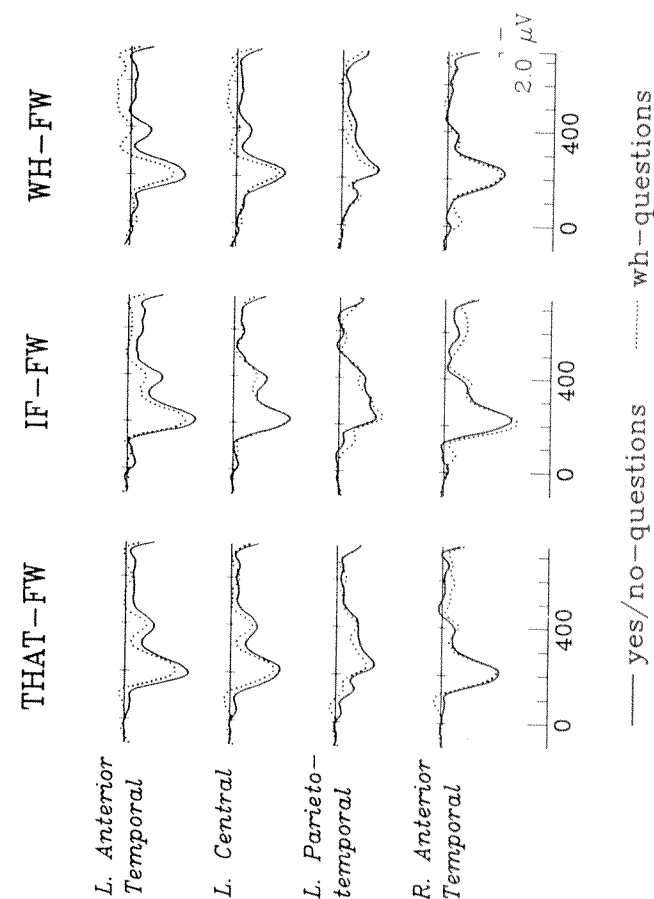

THAT–FW   IF–FW   WH–FW

L. Anterior Temporal

L. Central

L. Parieto-temporal

R. Anterior Temporal

——— yes/no-questions   ········ wh-questions

FIG. 8   Grand average ERPs (*n* = 30) recorded at three left hemisphere sites (top three rows) and one right hemisphere site (bottom row) in response to the function words immediately following *that*-complementisers (left column), *if*-complementisers (middle column) and the interrogative pronouns *who* and *what* (right column) embedded in yes/no-questions (solid line) or *wh*-questions (dotted line).

with embedded *wh*-clauses (2) in the right column of Fig. 8 includes embedded clauses containing both object gaps and subject gaps.

Finally, we compared positions not only immediately following fillers but also immediately following gaps. Based on the above results, we hypothesised that if the left anterior negative (or "LAN") effect was associated with holding a filler in working memory, then it might also be seen when a filler has to be retrieved from working memory for purposes of gap assignment. To test this hypothesis, we compared positions immediately following direct object gaps both within grammatical yes/no-questions [AT following the direct object gap in (2b) relative to the same position following the direct object *him* in (1b) and in the filler sentence], and within ungrammatical *wh*-questions [AT following the direct object gap in (5b) relative to the same position following the direct object *him* in (3b) and (4b)]. These comparisons again yielded a LAN effect in response to the conditions containing direct object gaps irrespective of the grammatical status of the gap being filled; that is, in the grammatical (2b) relative to (1b) and the filler sentence, and in the ungrammatical (5b) relative to (3b) and (4b). This latter comparison can be seen in the middle column of Fig. 10. This indicates that left anterior negativity is associated not only with holding a filler in working memory, but also with retrieving it from memory for purposes of gap assignment.

Discussion.   With this summary of findings we hope to have demonstrated that the LAN effect in our data can reasonably be viewed as the second type of evidence that we sought in the ERP record, namely a measure of the processing cost involved in holding a filler in working memory. In the next section, we will discuss the third type of evidence required for a processing account of subjacency, namely an interaction of the LAN effect with the lexical semantics of the elements at the embedded clause boundary.

Modulation of Left Anterior Negativity at Gap Location

Results.   In this section, we will demonstrate that the processing of an unbounded dependency, as measured by the LAN effect, interacts with the lexical semantics of complementisers and interrogative pronouns at the embedded clause boundary. Returning to our examples in the previous section, at the initial word of the sentence-ending adjunct ["AT the reunion" in (3a), (4a) and (5a), or "BY accident" in (3b), (4b) and (5b)], all three *wh*-question conditions, including *wh*-islands with subject gaps (5a), are equivalent in that all contain a prepositional object gap that must be filled by the main clause filler. In contrast, at this point in yes/no-questions [(1a) and (1b), (2a) and (2b), and the filler yes/no-*that* condi-

tion], there are no gaps to be filled and no fillers to be held in or retrieved from memory. Based on the evidence presented in the previous section, at this position one would therefore expect a difference in left anterior negativity across question types, since *wh*-questions involve gap-filling, whereas yes/no-questions do not. Furthermore, if we are to look for evidence of an interaction between the processing cost of holding a filler in working memory, as indexed by negativity over the anterior regions of the left hemisphere, and lexical semantic effects of embedded clause type, this would appear to be a good place to look for it.

Accordingly, one might predict a four-way interaction of question type $\times$ embedded clause type $\times$ anterior/posterior position $\times$ hemisphere at this position in the sentence. This is what was indicated [$F(8,224) = 2.83$, $P < 0.018$] in a five-way ANOVA with one between-group factor of familial handedness and four within-group factors, including two levels of question type, three levels of embedded clause type, five levels of anterior/posterior position and two levels of hemisphere. In addition, the ANOVA showed a main effect of anterior/posterior [$F(4,112) = 5.48$, $P < 0.008$] and interactions of question type $\times$ embedded clause type [$F(2,56) = 4.09$, $P < 0.022$], question type $\times$ anterior/posterior [$F(4,112) = 7.62$, $P < 0.009$] and anterior/posterior $\times$ hemisphere [$F(4,112) = 3.20$, $P < 0.047$].

Visual inspection of the waveforms suggested that there were no differences across conditions in the yes/no-questions, and that the four-way interaction was therefore entirely due to the LAN effect in *wh*-questions (Fig. 9). For this reason, separate ANOVAs were done within question types as well. Within yes/no-questions, a four-way ANOVA with one between-group factor of familial handedness and three within-group factors, including three levels of embedded clause type, five levels of anterior/posterior position and two levels of hemisphere, showed a main effect of embedded clause type $\times$ anterior/posterior [$F(4,112) = 5.53$, $P < 0.007$] and a marginal interaction of embedded clause type $\times$ anterior/posterior $\times$ hemisphere [$F(8,224) = 2.19$, $P < 0.059$].[8] Within *wh*-questions, a four-way ANOVA showed a significant main effect of anterior/posterior [$F(4,112) = 6.06$, $P < 0.005$], a marginal main effect of embedded clause type [$F(2,56) = 2.95$, $P < 0.061$], an interaction of anterior/posterior $\times$ hemisphere [$F(4,112) = 3.39$, $P < 0.023$] and an interaction of embedded clause type $\times$ anterior/posterior $\times$ hemisphere that reached significance [$F(8,224) = 2.53$, $P < 0.044$]. Two-way comparisons within *wh*-questions showed that both the *wh*-island condition and the *wh-if* condition differed from the *wh-that*

[8] However, as reported in Kluender and Kutas (1993), this marginal interaction is due to embedded clauses with direct object gaps, not to embedded clauses with subject gaps (see following discussion).
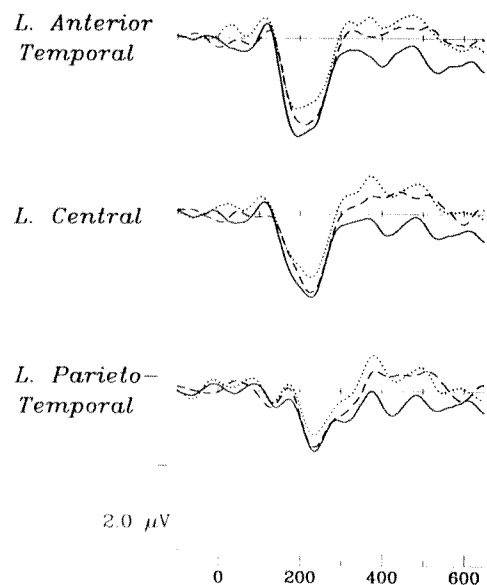
L. Anterior
Temporal

L. Central

L. Parieto–
Temporal

2.0 μV

0   200   400   600

—— What do you suppose that they caught him at ___ BY...?

– – – What do you wonder if they caught him at ___ BY...?

.... What do you wonder who they caught ___ at ___ BY...?

FIG. 9   Grand average ERPs (n = 30) from three left hemisphere sites elicited by the initial function word of a sentence-ending adjunct phrase immediately following the prepositional object gap in all three wh-conditions.

condition [main effect of embedded clause type: wh-island vs wh-that, $F(1,28) = 7.97$, $P < 0.009$; wh-if vs wh-that, $F(1,28) = 0.69$, NS; embedded clause type × anterior/posterior × hemisphere: wh-island vs wh-that, $F(4,112) = 3.12$, $P < 0.052$; wh-if vs wh-that, $F(4,112) = 4.12$, $P < 0.021$].

Discussion.   In wh-questions, the amplitude of the LAN effect following prepositional object gaps varied as a function of the word that appeared in the embedded COMP position: the LAN effect was largest in the wh-island condition, smallest in the wh-that condition and intermediate in the wh-if condition (though the difference between this condition and the wh-island condition was not statistically significant). Figure 10 charts the

THEY   AT   BY

L. Anterior
Temporal

L. Central

L. Parieto–
Temporal

2.0 μV

0   400   0   400   0   400

—— What do you suppose that THEY caught him AT ___ BY...?

– – – What do you wonder if THEY caught him AT ___ BY...?

.... What do you wonder who THEY caught ___ AT ___ BY...?

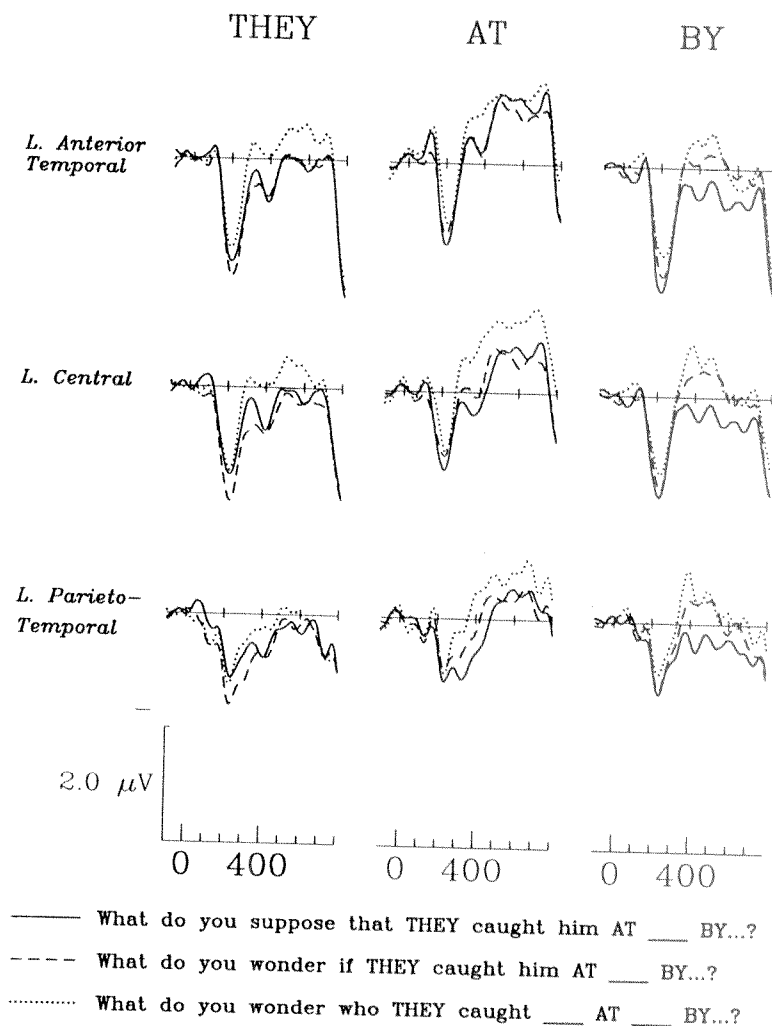FIG. 10   Grand average ERPs (n = 30) from three left hemisphere sites elicited by three different positions in wh-questions: the function word immediately following embedded complementisers and interrogative pronouns (THEY), the preposition immediately following the embedded direct object position (AT) and the initial function word of a sentence-ending adjunct phrase immediately following the prepositional object gap in all three conditions (BY).

course of the LAN effect across the embedded clause: in the left column we see the same LAN effect shown in Fig. 7 following the interrogative pronoun at the embedded clause boundary; in the middle column the LAN effect elicited by filling of the direct object gap (referred to in the previous section); and in the right column the modulation of the LAN effect at filling of the prepositional object gap.

There are several interesting aspects of these results that bear discussion. First, dependencies into embedded *if*-clauses are usually considered only marginally ungrammatical, and often fully grammatical, so it is significant that they pattern with the *wh*-island condition here, even though they differ from it structurally in having an unfilled specifier position. The more semantically specified complementiser head of an embedded *if*-clause appears to have an effect on gap location similar to that of a referential interrogative pronoun in specifier position. These results can therefore be interpreted as providing evidence in support of the hypothesis that lexical semantic information interacts with structural information not only in shaping sentence processing, but also in recognition of syntactic ill-formedness.

Since the modulation of the LAN mirrors the differences in grammaticality across the three *wh*-question conditions, one may justifiably wonder if the modulation is therefore merely an index of grammaticality *per se* independent of processing considerations. ERPs to the same position (i.e. the initial word of a sentence-ending adjunct) in yes/no-questions argue against such an interpretation. Collapsed across all yes/no-question conditions, the ERPs to the initial word of the sentence-ending adjunct show no LAN effect and no modulation. However, as reported in Kluender and Kutas (1993), grammatical yes/no-questions containing embedded interrogative *wh*-clauses with direct object gaps (2b) do elicit a LAN effect relative to yes/no-*if* questions (1a and 1b) and filler yes/no-*that* questions at this same position. Grammatical yes/no-questions containing embedded interrogative *wh*-clauses with subject gaps (2a) show no such effect. Thus once again we see that the appearance of a LAN effect is orthogonal to the grammaticality of the eliciting condition. Although there is no preceding gap at this point in the sentence in any of the yes/no-question conditions, a LAN effect is seen only in those sentences in which a filler must be held in working memory pending assignment to an object gap.[9]

In contrast, in *wh*-questions, there is a significant LAN effect both in *wh*-islands containing object gaps (5b) and in *wh*-islands containing subject

---

[9] As suggested in Kluender and Kutas (1993), this would mean that those areas of the brain that subserve working memory functions continue to be active for some time after gap filling has occurred.

gaps (5a). This means that the nature of the embedded *wh*-island dependency has no noticeable effect on the processing of the prepositional object gap associated with the main clause filler. In other words, the modulation of the LAN effect is due solely to the lexical properties of the embedded interrogative pronoun, rather than to the nature of the gap that it fills, i.e. a subject gap or an object gap. The LAN effect at the prepositional object gap seems to be impervious to the type of preceding embedded dependency (i.e. the dependency between the embedded filler and the embedded subject or direct object position). This presumably has to do with the fact that the LAN effect at this position is indexing the dependency between the main clause filler and the embedded prepositional object position.

In other words, syntactic domains in on-line sentence processing seem to be kept remarkably distinct in cases of overlap. The existence of the superordinate dependency between the main clause filler and the embedded prepositional object position seems to have little if any bearing on the processing of the embedded dependencies. This is evidenced by the fact that very similar effects are seen following embedded fillers (cf. Figs 6 and 7) as well as after direct object gaps in matching yes/no- and *wh*-questions. Similarly, the existence of the intervening embedded dependency between the embedded clause filler and the embedded subject or direct object position seems to have no effect on the processing of the superordinate dependency at the position following prepositional object gaps. This makes the influence of non-local lexical semantic effects on the processing of an unbounded dependency all the more striking.

Effects of Global Sentence Interpretation

Results. If lexical semantic factors influence the processing of unbounded dependencies, one would expect to see such effects not only modulating gap location, but also influencing global sentence interpretation at sentence end. This section presents and discusses ERP measures of the processing of sentence-final words.

In the 300–500 msec latency range, a five-way ANOVA with one between-group factor of familial handedness and four within-group factors, including two levels of question type, three levels of embedded clause type, five levels of anterior/posterior position and two levels of hemisphere, showed main effects of question type $[F(1,28) = 12.5, P < 0.001]$, embedded clause type $[F(2,56) = 3.62, P < 0.033]$ and anterior/posterior $[F(4,112) = 4.78, P < 0.035]$, with interactions of question type $\times$ embedded clause type $[F(2,56) = 3.73, P < 0.03]$, question type $\times$ anterior/posterior $[F(4,112) = 9.97, P < 0.001]$ and embedded clause type $\times$ anterior/posterior $[F(8,224) = 7.1, P < 0.001]$. In the 500–900 msec latency range, a five-way ANOVA showed main effects of question type

$[F(1,28) = 4.27, P < 0.048]$, anterior/posterior $[F(4,112) = 3.39, P < 0.043]$ and hemisphere $[F(1,28) = 22.65, P < 0.001]$, with interactions of question type × embedded clause type $[F(2,56) = 3.87, P < 0.027]$, question type × anterior/posterior $[F(4,112) = 11.0, P < 0.001]$, embedded clause type × anterior/posterior $[F(8,224) = 10.19, P < 0.001]$ and familial handedness × embedded clause type × anterior/posterior $[F(8,224) = 3.58, P < 0.017]$.

These results are fairly inscrutable due to the highly variable nature of responses across subjects: both N400-like responses over the posterior regions and late positivities over the anterior regions in response to sentence-final words in *if-* and *wh*-clauses. Both of these patterns appear to correlate partially but not perfectly with family history of handedness. As a result, when all subjects are averaged together, very little difference is seen in the ERPs across conditions in yes/no-questions, and no differences at all are seen in *wh*-questions. For example, in response to sentence-final words in *wh*-questions, half the subjects showed enhanced N400 amplitude in the *wh-if* and *wh*-island conditions, while the other half showed either an enhanced late positive component (LPC) to the *wh-if* and *wh*-island conditions, or else no discernible difference across conditions. This variability correlated in part with family history of handedness (recall that all the subjects were right-handed): N400 effects were seen in 10 of the 15 subjects who had only right-handed family members in the immediate family (RR) and in 5 of the 15 subjects who had left-handed family members (RL); conversely, positive differences were seen in only 5 of the 15 RR subjects but in 10 of the 15 RL subjects. Figure 11 shows grand averages from subjects with negative ERPs to sentence-final words, and Fig. 12 shows grand averages from subjects with positive ERPs to sentence-final words.

We have so far been unable to find any other factor that correlates significantly with this differential response to sentence-final words in our subjects. Having said this, we would still like to point out that our subjects when sorted in this way showed a three-way difference in the amplitude of the response to the sentence-final word of *wh*-questions, whether it was an N400 or a late positivity. To this end, a three-way ANOVA was done with three within-subjects factors, including three levels of embedded clause type, five levels of anterior/posterior position and two levels of hemisphere. In N400 subjects, the *wh*-island condition elicited the most negative ERPs, the *wh-that* condition the least negative ERPs and the *wh-if* condition an ERP intermediate between the other two [main effect of embedded clause type: $F(2,28) = 11.38, P < 0.001$]. The opposite pattern was seen in LPC subjects in response to sentence-final words of *wh*-questions: here the *wh*-island condition elicited the most positive ERPs, the *wh-that* condition the least positive ERPs and the *wh-if* condition an
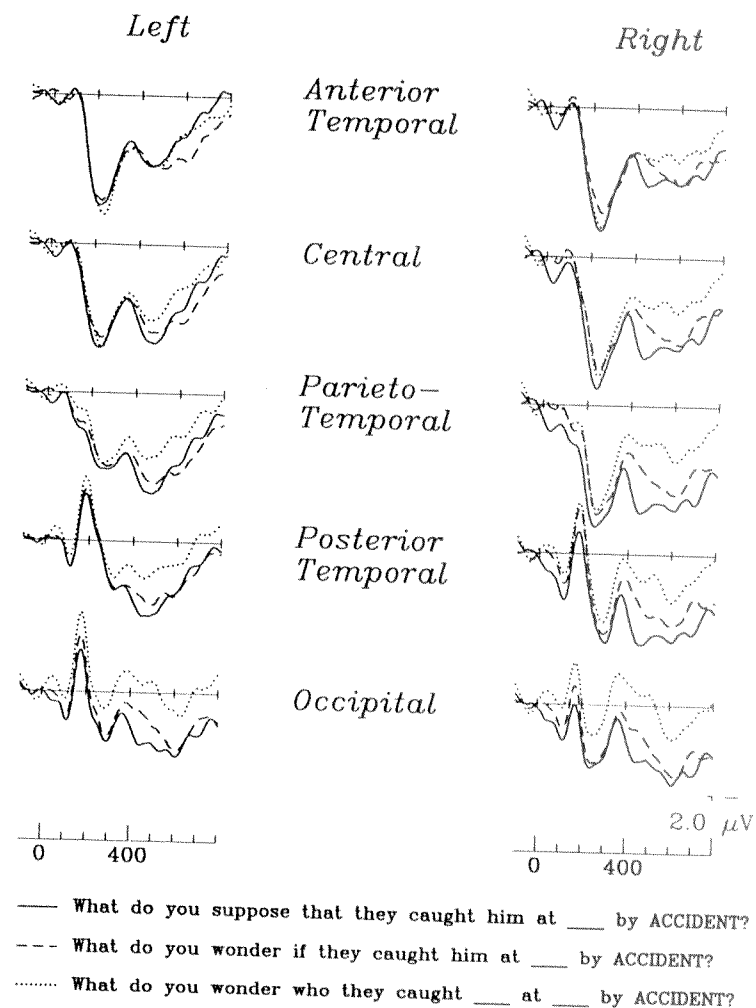

FIG. 11   Grand average ERPs of subjects showing a differential N400 component to sentence-final content words in the three *wh*-question conditions.

Left   Right

Anterior
Temporal

Central

Parieto–
Temporal

Posterior
Temporal

Occipital

2.0 μV

0   400   0   400

—— What do you suppose that they caught him at ____ by ACCIDENT?

– – – What do you wonder if they caught him at ____ by ACCIDENT?

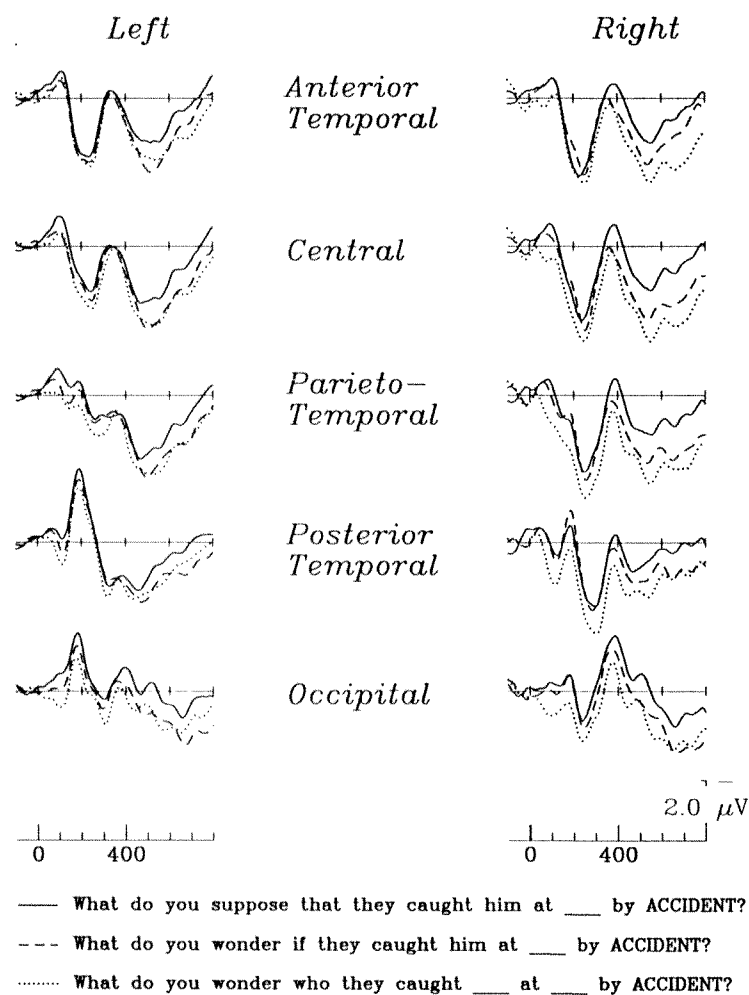········ What do you wonder who they caught ____ at ____ by ACCIDENT?

FIG. 12 Grand average ERPs of subjects showing a differential late positive component (LPC) to sentence-final content words in the three *wh*-question conditions.

618

ERP again intermediate between the other two [main effect of embedded clause type: $F(2,28) = 9.17$, $P < 0.001$].

Discussion. All of the stimuli in this study ended in a content word, and these final content words were identical across experimental conditions; the final words of the filler yes/no-*that* condition were different from those of the experimental conditions but matched in frequency. Thus any differences seen at this position in *wh*-questions can reflect only the sum of what has gone before. In this sense, the responses to final words can be taken as an indication of global sentence interpretation. When subjects are grouped according to whether they show a negative (N400) or a positive (LPC) response at sentence end, there is a trend towards a monotonic increase in the amplitude of the response across conditions in both cases. However, the interpretation of these final word effects is problematic in so far as the baselines in these comparisons are uneven, and the polarity of the response itself cannot be correlated unequivocally with any known variable.

The modulation of either response type could, in principle, be taken as an electrophysiological measure of sensitivity to perceived degrees of syntactic well-formedness in the traditional sense. As indicated earlier, filler–gap dependencies are traditionally considered fully grammatical into *that*-clauses, marginal into *if*-clauses and ungrammatical into embedded *wh*-interrogative clauses. However, in line with our processing account of subjacency effects in *wh*-islands, we believe that these traditional distinctions of relative grammaticality can be recast in terms of processing distinctions. Namely, we feel that the amplitude differences seen in the final word are more accurately described as indexing an encumbered end-of-sentence wrap-up reflecting earlier differences in lexical choice at the embedded clause boundary, and an interaction of that choice with filler–gap assignment. There are two reasons why this interpretation seems preferable. The first has to do with the general occurrence of N400 effects at sentence end. Although it is true that larger N400s are seen in response to the final words of ungrammatical sentences (Osterhout & Holcomb, 1992), it is also the case that larger N400s are seen in response to the final words of garden-path sentences that are syntactically well-formed but hard to process, such as *The boat sailed down the river sank* (Osterhout, 1990). The other more compelling reason has to do with the results of our behavioural Experiments 1 and 2, which showed an interaction of lexical effects and filler–gap dependencies in off-line global acceptability ratings.

One further thing that we would like to comment on is the fact that while all of our subjects showed differential ERPs to the sentence-final words of our three *wh*-question conditions, in half the N400 component

was modulated and in the other half the late positive component was modulated. Thus in half of the subjects the ungrammatical *wh*-island condition elicited the greatest late positivity, and in the other half it elicited the greatest N400. This raises some questions about the current distinction made between the N400 as an index of semantic processing and the LPC as an index of morphosyntactic processing (Neville et al., 1991; Osterhout & Holcomb, 1992; Hagoort et al., this issue). It is certainly possible that half of our subjects perceived the questions to be semantically ill-formed, whereas the other half perceived them to be syntactically ill-formed. More research will be required in order to tease apart these two factors. In the meantime, we would merely like to point out that these data differ from those reported in Osterhout (1990) and Osterhout and Holcomb (1992), which showed consistent negativities at the end of ungrammatical sentences.

CONCLUSION

In summary, let us once more briefly review the types of evidence that we sought for a processing interpretation of core subjacency phenomena, in particular of *wh*-islands. First, we looked for differential processing of the complementisers *that* and *if* and of the interrogative pronouns *who/what*. We found main effects of embedded clause type in yes/no-questions in both of our acceptability judgement studies (Experiments 1 and 2), and differential amplitude in N400-like responses over the right hemisphere to complementisers and interrogative pronouns in yes/no-questions (Experiment 3). These differences went in the predicted directions in both cases, namely the acceptability ratings showed a pattern of *who/what* < *if* < *that*, while the amplitude of the right hemisphere negativity showed a pattern of *who/what* > *if* > *that*. This result is fairly striking, and also represents the first time that N400-like differences have been seen within the closed class of so-called function words. This raises questions about other possible ERP differences within lexical classes and suggests that our interpretation of an embedded clause boundary as a particularly sensitive processing juncture may be on the right track.

Second, we looked for a measure of the processing cost involved in holding a filler in working memory. Again we found supporting evidence both in our acceptability studies and in our ERP study. In the acceptability rating studies, we found very large main effects of question type, indicating that the processing cost of holding a filler in working memory affects even off-line evaluative tasks. In the ERP study, we found a consistent effect of left anterior negativity associated with entering a filler in working memory, storing it there, and subsequently retrieving it for purposes of gap assignment.

Third, we looked for evidence that the differential processing of complementisers and interrogative pronouns would interact in some way with the processing effects of holding a filler in working memory outlined earlier. Once again we found interactions in all three of our studies. In the acceptability rating studies, we found that the main effects of embedded clause type in our stimulus materials (reflecting the differential processing of lexical semantic factors) interacted with main effects of question type (reflecting the processing cost of using working memory to store and retrieve fillers) to yield the equivalent of typical grammaticality judgements in regard to *wh*-island configurations. In the ERP study, we found that the LAN effect associated with the processing of an unbounded dependency could be modulated by lexical factors subsequent to their actual occurrence in sequential processing, namely in the direction *who/ what* > *if* > *that*. In addition, we found indications of these same factors on global sentence interpretation: half our subjects showed amplitude differences in the late positive component and the other half showed amplitude differences in the N400 component, both in the direction *who/ what* > *if* > *that*.

In closing, here are a number of other reports of left anterior negativity in the ERP literature which we would like briefly to discuss. Both Lang et al. (1987; 1988) and Ruchkin et al. (1990; 1992) have reported slow potentials elicited by working memory tasks that involve aspects of language. When this is the case, the potentials are negative in polarity, frontal in distribution, and lateralised to the left. Ruchkin et al. (1992) have shown that the amplitudes of these left anterior negativities correlate with working memory load, in line with our hypothesis.

Recently, King and Kutas (1992; 1993) reported that object relative clauses such as (18) show slow left-lateralised frontal negativities when they are compared to subject relative clauses like (19):

18. The reporter [*who* the senator harshly attacked _____] admitted the error.
19. The reporter [*who* _____ harshly attacked the senator] admitted the error.

The difference between the two conditions lies of course in the fact that the object relatives require the maintenance of a filler in working memory, while the filler in subject relatives can immediately be assigned to its adjacent gap. Since the two conditions are matched in length, which was not the case in out study, King and Kutas have been able to chart the time-course of this negativity across the sentence. It begins at the word following the filler [*the senator* in (18)], just as in our data, and continues throughout the dependency. Interestingly, when these same across-the-sentence aver-

ages are reduced to individual word epochs, the LAN effect shows a similar morphology, latency and distribution to that seen in our data.

A number of left anterior negativities have turned up in other ERP studies of syntactic processing as well. Neville et al. (1991) reported a LAN effect when sentences of the following type were compared:

20a. The scientist criticised [Max's PROOF of the theorem].
  b. *What* did the scientist criticise [a PROOF of ____]?
  c. **What* did the scientist criticise [Max's PROOF of ____]?

Here the LAN effect was elicited by the word PROOF in (20c) relative to the same word in (20a); this could easily index the existence of a dependency in (20c) from the main clause filler *what* into the prepositional object position of the embedding, since this dependency is not present in the declarative version (20a). However, Neville et al. also reported a greater left anterior negativity to the word PROOF in (20c) relative to the same word in (20b). Here the two conditions are equivalent in the presence of an unbounded dependency, so the same explanation will not work in this case.

However, note that there may be a difference between (20b) and (20c) that is relevant to our processing account of subjacency: the main clause filler *what* in (20c) must be held in working memory across a name associated with a unique discourse referent (*Max's*) at the noun phrase boundary. There is no such discourse referent involved in the processing of (20b). More precisely, *Max's* in (20c) occupies the specifier position of the determiner phrase (or DP) in much the same way that an interrogative pronoun occupies the specifier position of the complementiser phrase (CP) in a *wh*-island configuration. Likewise, the determiner *a* in (20b) occupies the head position of DP much like the complementiser *that* occupies the head of CP in an embedded declarative clause. Thus it is possible that the left anterior negativity seen in (20c) is due to the necessity of storing the main clause filler *what* in working memory in both (20b) and (20c); however, it is larger at PROOF in (20c) relative to the same word in (20b) because of the activation of the discourse referent for *Max's*, the specifier of DP, in (20c). This would be analogous to effects seen at equivalent positions in our data (see Figs 7 and 10).

There are three other reported LAN effects that we would like to comment on. The first is from a study by Urbach (1993). Urbach compared the ERPs to reduced relative clauses such as the following:

21a. The cook [helped in the kitchen] WAS busy.
  b. The cook [helping in the kitchen] WAS busy.
22a. The instructor [taught] WAS Spanish.
  b. The language [taught] WAS Spanish.

There is a garden-path effect in (21a) and (22a) which is lacking in (21b)

and (22b) due to various morphological, semantic and pragmatic manipulations. When comparisons were made at the word WAS in both (21) and (22), WAS in (21a) elicited both a late positivity (Osterhout & Holcomb, 1992; Hagoort et al., this issue) and a left anterior negativity relative to the WAS in (21b). The WAS in (22a), on the other hand, elicited only a late positive component relative to the WAS in (22b).

What is the difference? In the garden-path sentences (21a) and (22a), the main clause subject is initially assigned to the embedded participial form (*helped* or *taught*, respectively) under early closure (Frazier, 1978). When one arrives at the main clause verb (WAS), however, one must reanalyse one's initial parse of the sentence. This somewhat unexpected realisation is presumably indexed by the late positivity in both (21a) and (22a). More crucially, however, one must locate a subject in prior discourse to assign to the main clause verb (WAS). We claim that this is what is indexed in (21a) by the LAN effect: the parser's backward search through working memory to find a recently activated and appropriate discourse entity that can fill the role of subject. Note that the distance between the main clause verb and the main clause subject is greater in (21a) than in (22a), where the main clause subject is hence more readily available in recent memory. Hence no LAN effect is elicited in (22a).

If this account is correct, it may also explain an otherwise puzzling finding of Osterhout and Holcomb (1992). They, too, looked at garden-path sentences with reduced relative clauses such as the following:

23a. The broker [persuaded TO sell the stock] WAS sent to jail.
  b. The broker [hoped TO sell the stock] WAS sent to jail.

Comparisons were made both at TO within the reduced relative clause and at WAS in the main clause. TO in (23a) is ill-formed on the preferred main clause reading of *persuaded*, and it consequently elicits a late positivity relative to the TO in (23b), which appears well-formed on the main clause reading of *hoped*. At WAS, however, the parser becomes aware that it has been garden-pathed: (23a) is in fact well-formed on the less preferred reduced relative reading of *persuaded*, while (23b) turns out to be ill-formed and unsalvageable, since *hoped*, does not allow a reduced relative reading. In this case, the WAS in (23b) elicits a late positivity relative to the WAS in (23a), but it also elicits a LAN effect. Our suggestion is that the LAN seen here indexes a desperate attempt on the part of the parser to seek an appropriate discourse referent in recent memory for the main clause verb WAS. The only available noun phrase, *the broker*, remains inextricably linked to the embedded verb *hoped*, since the verb is not subject to a reduced relative interpretation and will itself be without a subject if deprived of *the broker*. Since there is no alternative parse available, the parser ends up vainly thrashing about in working memory for some reasonable way out of the dilemma. In (23a), by way of contrast,

persuaded is completely amenable to a reduced relative reading, and so *broker* is simply reassigned to the main clause verb WAS. Note, however, that in view of Urbach's (1993) data, we would expect WAS in (23a) to elicit a LAN effect when compared to some shorter reduced relative like (24):

24. The broker [nailed] WAS sent to jail.

Finally, Neville et al. (1991) also reported data in which a late positivity co-occurred with a left anterior negativity. This pattern was seen in phrase structure violations of the following kind:

25a. The scientist criticised [a proof OF the theorem].
  b. *The scientist criticised [Max's OF proof the theorem].

In this comparison, (25b) differs from (25a) on two counts: there is a specifier (*Max's*) in (25b), and the order of the head noun *proof* and the prepositional case marker *of* has been reversed. In this case, it is more difficult to tell what is causing the left anterior negativity of OF in (25b) relative to the OF in (25a), and what is causing the late positivity. Given our interpretation of the dual ERP effects in the Urbach (1993) and Osterhout and Holcomb (1992) data, one not implausible possibility is that at OF in (25b), the parser first notices that a constituent is missing (namely, the head noun of the noun phrase), triggering a late positivity, and then begins a futile search in recent working memory for an appropriate filler, yielding a LAN effect. However, the unknown influence of the specifier *Max's* would still need to be determined.

In conclusion, we feel that our interpretation of the LAN effect is really the only possible one for our data. Furthermore, we feel that this interpretation helps to illuminate otherwise puzzling effects in the language ERP literature.

Obviously, much work lies ahead of us in attempting to tease apart the linguistic and/or non-linguistic factors involved in the various components seen in language-processing research: the N400, late positive components, left anterior negativities and the N280 (Neville, Mills, & Lawson, 1992). Within the linguistic domain, many questions remain open.[10] Among the

---

[10] There are relevant theoretical questions as well, having to do with other types of syntactic islands in English and with cross-linguistic variation in island effects. We will not address these questions here, though we are aware of the need to do so and intend to do so in future. In the meantime, we will merely state our belief that the large majority of strong islands (i.e. subject islands, adjunct islands and complex NP islands) in English are amenable to a similar processing account. As for cross-linguistic differences, it has been widely demonstrated in the theoretical literature that many of these are only apparent, and that the supposed parameterisation of subjacency may well be epiphenomenal (Adams, 1984; Chomsky, 1986; Chung & McCloskey, 1983; Cinque, 1990; Grimshaw, 1986; Kluender, 1992).

questions that this study has raised are: Can the N400 and perhaps the N280 be used to characterise differences not only between but also within lexical classes? What is the nature of the left-lateralised positivity elicited by the complementiser *if* over the posterior regions? What is the range of syntactic processes that will elicit a left anterior negativity, what commonality do they share, and what is the time-course of this effect? If subjects respond differentially with negative or positive ERPs to the same ungrammatical stimuli at sentence-final positions, what does this difference index, and will the same be true of other sentence positions?

Across cognitive domains, the questions are equally compelling. In very interesting recent work, Osterhout (1993) has shown similarities between the late positivities elicited by (morpho)syntactic violations and the P300 elicited by physical stimulus changes. If the hypothesis of Kluender and Kutas (1993) is correct, then left anterior negativity is a reflection of the role of working memory within linguistic contexts. There has also been work showing N400-like effects in semantic matching tasks involving pictures of objects and photographs of famous individuals (Barrett & Rugg, 1989; 1990). These various lines of research and those of related neural imaging technologies promise future insights into the place of language within the larger context of human cognition.

REFERENCES

Adams, M. (1984). Multiple interrogation in Italian. *The Linguistic Review, 4*, 1–28.

Barrett, S.E., & Rugg, M.D. (1989). Event-related potentials and the semantic matching of faces. *Brain and Cognition, 14*, 201–212.

Barrett, S.E., & Rugg, M.D. (1990). Event-related potentials and the semantic matching of pictures. *Neuropsychologia, 27*, 913–922.

Berwick, R., & Weinberg, A. (1984). *The grammatical basis of linguistic performance*. Cambridge, MA: MIT Press.

Chomsky, N. (1973). Conditions on transformations. In S. Anderson & P. Kiparsky (Eds), *A Festschrift for Morris Halle*. New York: Holt, Rinehart and Winston.

Chomsky, N. (1977). On *wh*-movement. In P. Culicover, T. Wasow, & A. Akmajian (Eds), *Formal syntax*. Orlando, FL: Academic Press.

Chomsky, N. (1981). *Lectures on Government and Binding*. Dordrecht: Foris.

Chomsky, N. (1986). *Barriers*. Cambridge, MA: MIT Press.

Chomsky, N. (1993). Prospects for minimalism. Lecture given at the University of California, Irvine, 8 March.

Chung, S., & McCloskey, J. (1983). On the interpretation of certain island facts in GPSG. *Linguistic Inquiry, 14*, 704–713.

Cinque, G. (1990). *Types of A'-dependencies*. Cambridge, MA: MIT Press.

Connine, C., Ferreira, F., Jones, C., Clifton, C., & Frazier, L. (1984). Verb frame preferences: Descriptive norms. *Journal of Psycholinguistic Research, 13*, 307–319.

Deane, P. (1991). Limits to attention: A cognitive theory of island phenomena. *Cognitive Linguistics, 2,* 1–63.

Erteschik Shir, N. (1977). *On the nature of island constraints.* Bloomington, IN: Indiana University Linguistics Club.

Erteschik Shir, N. (1981). More on extractability from quasi-NPs. *Linguistic Inquiry, 12,* 665–670.

Erteschik Shir, N., & Lappin, S. (1979). Dominance and the functional explanation of island phenomena. *Theoretical Linguistics, 6,* 41–86.

Fodor, J.D. (1978). Parsing strategies and constraints on transformations. *Linguistic Inquiry, 9,* 427–473.

Fodor, J.D. (1989). Empty categories in sentence processing. *Language and Cognitive Processes, 4,* 155–209 (special issue).

Frazier, L. (1978). *On comprehending sentences: Syntactic parsing strategies.* Unpublished doctoral dissertation, University of Connecticut.

Frazier, L. (1985). Syntactic complexity. In D. Dowty, L. Karttunen, & A. Zwicky (Eds), *Natural language parsing.* Cambridge: Cambridge University Press.

Frazier, L., & Clifton, C. (1989). Successive cyclicity in the grammar and the parser. *Language and Cognitive Processes, 4,* 93–126.

Friederici, A.D. (1985). Levels of processing and vocabulary types: Evidence from on-line comprehension in normals and agrammatics. *Cognition, 19,* 133–166.

Gentner, D. (1981). Some interesting differences between verbs and nouns. *Cognition and Brain Theory, 4,* 161–178.

Grimshaw, J. (1986). Subjacency and the *S/S'* parameter. *Linguistic Inquiry, 17,* 364–369.

Heim, I.R. (1982). *The semantics of definite and indefinite noun phrases.* Doctoral dissertation, University of Massachusetts at Amherst. Amherst, MA: Graduate Linguistics Student Association.

Hillyard, S.A., & Picton, T.W. (1987). Electrophysiology of cognition. In F. Plum (Ed.), *Handbook of physiology. Section 1: The nervous system, Vol. 5: Higher functions of the brain, Part 2.* Washington, DC: American Physiological Society.

Huynh, H., & Feldt, L.S. (1976). Estimation of the Box correction for degrees of freedom from sample data in randomized block and split-plot designs. *Journal of Educational Statistics, 1,* 69–82.

Jasper, H.H. (1958). The ten–twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology, 10,* 371–375.

Just, M., & Carpenter, P. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99,* 122–149.

Karttunen, L. (1976). Discourse referents. In J.D. McCawley (Ed.), *Notes from the linguistic underground (Syntax and Semantics 7).* New York: Academic Press.

King, J., & Just, M. (1991). Individual differences in syntactic processing: The role of working memory. *Journal of Memory and Language, 30,* 580–602.

King, J., & Kutas, M. (1992, October). ERP responses to sentences that vary in syntactic complexity: Differences between good and poor comprehenders. Poster presented at the *Annual Conference of the Society for Psychophysiological Research,* San Diego, CA.

King, J., & Kutas, M. (1993, March). Bridging gaps with longer spans: Enhancing ERP studies of parsing. Poster presented at the *Sixth Annual CUNY Sentence Processing Conference,* University of Massachusetts, Amherst, MA.

Kiss, K.E. (1993). *Wh-*movement and specificity. *Natural Language and Linguistic Theory, 11,* 85–120.

Kluender, R. (1990). A neurophysiological investigation of *wh-*islands. In K. Hall, J.-P. Koenig, M. Meacham, S. Reinman, & L.A. Sutton (Eds), *Proceedings of the 16th Annual Meeting of the Berkeley Linguistics Society.* Berkeley, CA: BLS.

Kluender, R. (1991). *Cognitive constraints on variables in syntax.* Unpublished doctoral dissertation, University of California, San Diego.

Kluender, R. (1992). Deriving island constraints from principles of predication. In H. Goodluck & M. Rochemont (Eds), *Island constraints: Theory, acquisition, and processing.* Dordrecht: Kluwer.

Kluender, R., & Kutas, M. (1993). Bridging the gap: Evidence from ERPs on the processing of unbounded dependencies. *Journal of Cognitive Neuroscience, 5,* 196–214.

Kroch, A. (1989). *Amount, quantification, referentiality, and long wh-movement.* Unpublished manuscript, University of Pennsylvania.

Kuno, S. (1976). Subject, theme, and the speaker's empathy—a reexamination of relativization phenomena. In C.N. Li (Ed.), *Subject and topic.* New York: Academic Press.

Kuno, S. (1987). *Functional syntax: Anaphora, discourse and empathy.* Chicago, IL: University of Chicago Press.

Kutas, M., & Hillyard, S.A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307,* 161–163.

Kutas, M., & Kluender, R. (in press). What is who violating? A reconsideration of linguistic violations in light of event-related potentials. In H.J. Heinze, T. Münte, & G.R. Mangun (Eds), *Cognitive Electrophysiology.* Boston, MA: Birkhäuser Boston.

Kutas, M., & Van Petten, C. (1988). Event-related brain potential studies of language. *Advances in Psychophysiology, 3,* 139–187.

Kutas, M., Lindamood, T., & Hillyard, S.A. (1984). Word expectancy and event-related brain potentials during sentence processing. In S. Kornblum & J. Requin (Eds), *Preparatory states and processes.* Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Kutas, M., Van Petten, C., & Besson, M. (1988). Event-related potential asymmetries during the reading of sentences. *Electroencephalography and Neurophysiology, 69,* 218–233.

Lang, M., Lang, W., Uhl, F., Kornhuber, A., Deecke, L., & Kornhuber, H.H. (1987). Slow negative potential shifts indicating verbal cognitive learning in a concept formation task. *Human Neurobiology, 6,* 183–190.

Lang, M., Lang, W., Uhl, F., Kornhuber, A., Deecke, L., & Kornhuber, H.H. (1988). Left frontal lobe in verbal associative learning: A slow potential study. *Experimental Brain Research, 70,* 99–108.

Neville, H.J., Nicol, J.L., Barss, A., Forster, K.I., & Garrett, M.F. (1991). Syntactically based sentence processing classes: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 3,* 151–165.

Neville, H.J., Mills, D.L., & Lawson, D.S. (1992). Fractionating language: Different neural subsystems with different sensitive periods. *Cerebral Cortex, 2,* 244–258.

Newmeyer, F. (1990). Speaker–hearer asymmetry as a factor in language evolution: A functional explanation for formal principles of grammar. In K. Hall, J.-P. Koenig, M. Meacham, S. Reinman, & L.A. Sutton (Eds), *Proceedings of the Sixteenth Annual Meeting of the Berkeley Linguistics Society,* pp. 241–247. Berkeley, CA: Berkeley Linguistics Society.

Newmeyer, F. (1991). Functional explanation in linguistics and the origin of language. *Language and Communications, 11,* 3–28.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9,* 97–113.

Osterhout, L. (1990). *Event related brain potentials elicited during sentence comprehension.* Unpublished doctoral dissertation, Tufts University.

Osterhout, L. (1993, March). Event-related brain potentials elicited by failure to agree. Talk given at the *Sixth Annual CUNY Sentence Processing Conference.* University of Massachusetts, Amherst, MA.

Osterhout, L., & Holcomb, P. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, *31*, 785–806.

Pesetsky, D. (1987). *Wh-in-situ*: Movement and unselective binding. In E. Reuland & A.G.B. ter Meulen (Eds), *The representation of indefiniteness*. Cambridge, MA: MIT Press.

Rizzi, L. (1990). *Relativized minimality*. Cambridge, MA: MIT Press.

Ross, J.R. (1968). *Constraints on variables in syntax*. Bloomington, IN: Indiana University Linguistics Club.

Ruchkin, D.S., Johnson, R. Jr, Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: An event-related brain potential study. *Electroencephalography and Clinical Neurophysiology*, *76*, 419–439.

Ruchkin, D.S., Johnson, R. Jr, Grafman, J., Canoune, H., & Ritter, W. (1992). Distinctions and similarities among working memory processes: An event-related potential study. *Cognitive Brain Research*, *1*, 53–66.

Szabolcsi, A., & Zwarts, F. (1990). Semantic properties of composed functions and the distribution of *wh*-phrases. In *Proceedings of the Seventh Amsterdam Colloquium*. Amsterdam: ITLI.

Urbach, T.P. (1993, March). Access to non-syntactic information during parsing: Evidence from event-related potentials (ERPs) in garden-path sentences. Poster presented at the *Sixth Annual CUNY Sentence Processing Conference*, University of Massachusetts, Amherst, MA.

Van Petten, C. (1989). *Context effects in word recognition: Studies using event-related brain potentials*. Unpublished doctoral dissertation, University of California, San Diego, CA.

Van Petten, C., & Kutas, M. (1990). Interactions between sentence context and word frequency in event-related brain potentials. *Memory and Cognition*, *18*, 380–393.

Van Petten, C., & Kutas, M. (1991). Influences of semantic and syntactic context on open and closed class words. *Memory and Cognition*, *19*, 95–112.

Wierzbicka, A. (1988). *The semantics of grammar*. Amsterdam: John Benjamins.

APPENDIX

Since 1835 stimulus sentences were used in each of the studies reported in this article, this appendix contains only a representative sample. The first two sets show all five parallel experimental conditions: the first set contains a subject gap in the embedded clause, and the second set contains a direct object gap. In subsequent sets, only conditions (1) and (3) are indicated. The constituent questioned in the embedded clause (i.e. subject or direct object) is italicised in condition (1), and from this conditions (2), (4) and (5) can be generated. Condition (3) is included separately to illustrate the type of idiosyncratic changes necessitated by the use of an embedded declarative clause in this condition rather than an interrogative embedded clause as in conditions (1), (2), (4) and (5). Following these 50 examples of experimental conditions are 50 of the filler yes/no-that questions.

1. Experimental conditions

1a. Can't you figure out if *you* should tell the boss about the mistake before the meeting?

2a. Can't you figure out *who* _____ should tell the boss about the mistake before the meeting?

3a. What did you figure out that you should tell the boss about _____ before the meeting?

4a. What can't you figure out if you should tell the boss about _____ before the meeting?

5a. What can't you figure out *who* _____ should tell the boss about _____ before the meeting?

1b. Couldn't the senator figure out if they had discovered *anything* about his mistress in the press room?

2b. Couldn't the senator figure out *what* they had discovered _____ about his mistress in the press room?

3b. Who did the senator figure out that they had discovered something about _____ in the press room?

4b. Who couldn't the senator figure out if they had discovered anything about _____ in the press room?

5b. Who couldn't the senator figure out *what* they had discovered _____ about _____ in the press room?

1b. Will the housing office see if they can nag *the cleaning staff* about it even though it is too late at this point?

3b. What did the housing office see that they could nag the cleaning staff about _____ even though it is too late at this point?

1b. Can't you remember if he advised *them* against it on previous occasions?

3b. What do you remember that he advised them against _____ on previous occasions?

1a. Can't your parents remember if *the mayor* dismissed the unrest as outside agitation during the 1968 Democratic convention?

3a. What do your parents remember that the mayor dismissed the unrest as _____ during the 1968 Democratic convention?

1b. Did she ask if she could use *the knife* as a screwdriver to repair the vacuum cleaner?

3b. What did she suppose that she could use the knife as _____ to repair the vacuum cleaner?

1b. Will you see if you can disguise *it* as an error so that it is not discovered?

3b. What did you realize that you could disguise it as _____ so that it is not discovered?

1b. Do you wonder if they caught *him* at it by accident?

3b. What do you suppose that they caught him at _____ by accident?

1a. Did the government official claim to forget if *anyone* had financed the deal for him the previous year?

3a. Who did the government official claim to forget that someone had financed the deal for _____ the previous year?

1b. Does his wife forget if he sketched *this* for his mother while he was still alive?

3b. Who did his wife forget that he sketched this for _____ while he was still alive?

1b. Did the refugees wonder if the agency would be able to find *apartments* for them in the downtown area?

3b. Who did the refugees suppose that the agency would be able to find apartments for _____ in the downtown area?

1a. Did the detectives ask if *anyone* might want to kill her for talking if her testimony became public?

3a. What did the detectives imagine that someone might want to kill her for _____ if her testimony became public?

1a. Couldn't he tell if *they* were making fun of him for being late again when he arrived?

3a. What couldn't he tell that they were making fun of him for _____ when he arrived?

1b. Couldn't she decide if she should sue *them* for her accident when they denied responsibility?

3b. What did she decide that she should sue them for _____ when they denied responsibility?

1b. Can't he remember if they busted *him* for drugs in college?
3b. What does he remember that they busted him for _____ in college?

1a. Is she wondering if *her husband* will fetch a drink for her without being prompted?
3a. Who is she supposing that her husband will fetch a drink for _____ without being prompted?

1b. Wasn't he sure if she intended to leave *it* for him on the desk?
3b. Who wasn't he sure that she intended to leave it for _____ on the desk?

1a. Did the investigators wonder if *he* might be trading influence for monetary favors on the side?
3a. What did the investigators suppose that he might be trading influence for _____ on the side?

1a. Can't the government decide if *it* should preserve the wilderness for future generations on account of the budget crisis?
3a. Who did the government decide that it can't preserve the wilderness for _____ on account of the budget crisis?

1b. Was the committee about to decide if they should nominate *her* for office this year?
3b. What was the committee about to decide that they should nominate her for _____ this year?

1b. Aren't you sure if the commission wants to check *those parts* for flaws before the reactor goes into operation?
3b. What aren't you sure that the commission wants to check those parts for _____ before the reactor goes into operation?

1a. Couldn't he tell if *that* had exempted him from service when he was drafted?
3a. What could he tell that had exempted him from _____ when he was drafted?

1b. Are the airline officials trying to find out if the hijackers took *anything* from the passengers during the flight?
3b. Who did the airline officials find out that the hijackers took something from _____ during the flight?

1b. Did the doctors wonder if they should conceal *the news* from him until things got better?
3b. Who did the doctors suppose that they should conceal the news from _____ until things got better?

1b. Weren't his parents ever able to determine if he had stolen *anything* from them before he disappeared?
3b. Who weren't his parents ever able to prove that he had stolen anything from _____ before he disappeared?

1a. Isn't it clear if *anyone* would want to feature him in a film at this point in his career?
3a. What isn't it clear that anyone would want to feature him in _____ at this point in his career?

1b. Wasn't the planning team sure if they could include *him* in this project without running a security check?
3b. What wasn't the planning team sure that they could include him in _____ without running a security check?

1b. Do you wonder if he still sees *anything* in her after all this time?
3b. Who do you suppose that he still sees something in _____ after all this time?

1b. Couldn't the secretary remember if she was supposed to enclose *anything* in the letter this time?

3b. What did the secretary remember that she was supposed to enclose something in _____ this time?

1a. Did the insurance company want to know if *he* had crashed his car into a parked vehicle that night?
3a. What did the insurance company know that he had crashed his car into _____ that night?

1b. Did they want to see if they could shame *him* into volunteering by threatening to close up shop?
3b. What did they realize that they could shame him into _____ by threatening to close up shop?

1a. Couldn't the family decide if *they* should inform her of her fiance's death in her condition?
3a. What did the family decide that they shouldn't inform her of _____ in her condition?

1a. Will you try to find out if *they* attacked him on that point at the conference?
3a. What did you find out that they attacked him on _____ at the conference?

1a. Did the terrorists wonder if *they* could plant a bomb on her without it being detected?
3a. Who did the terrorists suppose that they could plant a bomb on _____ without it being detected?

1b. Wasn't she sure if they were trying to pin *the whole thing* on her in order to save their own skins?
3b. Who was she sure that they were trying to pin the whole thing on _____ in order to save their own skins?

1a. Can't you figure out if *she* has been taking stuff out of your drawer when you are not in the office?
3a. What did you figure out that she has been taking stuff out of _____ when you are not in the office?

1a. Did the dying man ask if *someone* would bring a cigar to him before he took his final breath?
3a. What did the dying man imagine that someone would bring _____ to him before he took his final breath?

1a. Do you forget if *you* voiced that complaint to the administration at the meeting?
3a. Who did you forget that we voiced that complaint to _____ at the meeting?

1b. Can't she decide if she should reveal *her beauty secrets* to the public at this time?
3b. Who did she decide that she could reveal her beauty secrets to _____ at this time?

1a. Will the Pentagon see if *the President* can present the medal to him in person?
3a. Who did the Pentagon realize that the President could present the medal to _____ in person?

1a. Can't they decide if *they* should demote him to lieutenant for not following orders?
3a. What did they decide that they should demote him to _____ for not following orders?

1a. Do you wonder if *he* is going to accompany her to the opening this evening?
3a. What do you imagine that he is going to accompany her to _____ this evening?

1b. Don't you know if you can compare *your brother* to your father in terms of stubbornness?
3b. Who do you know that you can compare your brother to _____ in terms of stubbornness?

1a. Can't they decide if *they* should surrender it to the police before it is found missing?
3a. Who did they decide that they should surrender it to _____ before it is found missing?

1a. Did they wonder if *management* would route that memo to her since she was known to be such a troublemaker?

3a. Who did they suppose that management wouldn't route that memo to _____ since she was known to be such a troublemaker?

1b. Will he have to see if he can subcontract *that* out to the electrician this time?
3b. Who did he see that he could subcontract that out to _____ this time?

1b. Is he trying to figure out if he should discuss *it* with her at this point?
3b. Who did he figure out that he should discuss it with _____ at this point?

1a. Has he forgotten if *the waiter* splattered him with tomato sauce at the party the other night?
3a. What has he forgotten that the waiter splattered him with _____ at the party the other night?

1b. Does he want to see if he can saddle *one of his friends* with his sister for the afternoon?
3b. Who does he realize that he can saddle one of his friends with _____ for the afternoon?

1b. Are you going to ask if he wants us to coordinate *our efforts* with them in order to save time?
3b. Who do you imagine that he wants us to coordinate our efforts with _____ in order to save time?

2. Filler yes/no-*that* questions

Does your doctor think that you should consult a lawyer about the accident that you had last month?

Is her family claiming that they noticed nothing strange about her behavior when she came home?

Did she regret that she had needled him about his poor taste in clothes on their last date?

Are they saying that they have to vaccinate you against typhoid fever before you can leave on your trip?

Is the defendant maintaining that the lawyers prejudiced the jury against her during the trial?

Do they believe that he purposely misrepresented his version of the story as objective fact in order to mislead the jury?

Did the professor really claim that he could pass her off as royalty in six months' time?

Can you believe that his coach clocked him at under four minutes a mile at his last training session?

Does he regret that he flung the money at her feet when she claimed to be in love with the baron?

Are you saying that I have to spell it out for you in plain English?

Did that elderly couple forget that they were supposed to be managing the apartment building for you all this time?

Do you admit that you commended him for undoing the mess he created in the first place?

Did the police maintain that they were jailing him for drunk driving in this case?

Are you forgetting that they singled you out for criticism after the last assignment?

Do you think that they will criticize him for his role in the latest scandal?

Did they maintain that they were flunking him for cheating when he left school?

Are you glad that she is going to find a suit for you to wear?

Did she regret that she had xeroxed a copy of it for him after the meeting?

Are you claiming that they compensated you adequately for the damages that you suffered?

Did your employer say that he would pay you for overtime when you took the job?

Does he think that she is marrying him for his charm and good looks with her track record?

Is she glad that they are going to prepare her for the competition in the spring?

Do you admit that you evicted those people from their apartments when they began a rent strike?

Are they claiming that they have to isolate criminals from society for purposes of rehabilitation?

Was she glad that she got something from him for Christmas?

Are you forgetting that she inherited nothing from her father when he died?

Did he maintain that he could undo you in sales this year?

Can you believe that the management is going to let that klutz partner her in Swan Lake at the gala?

Did the chef forget that you have to baste this bird in its own juices for several hours?

Do her parents regret that they locked her up in that closet for so long?

Did the developers claim that they have to divide the property into several lots in order to make a profit?

Can you believe that he was able to lure them into this shady deal with all their experience?

Does he maintain that he can disabuse her of all her illusions in one fell swoop?

Can you believe that he was unable to convince her of his innocence after all this time?

Do you think that you can pin him down on the particulars for a change?

Does he regret that he cheated them out of their life savings in this scam?

Is the White House claiming that he leaked the news to the press behind their backs?

Have you forgotten that you faxed a copy of that contract to the corporate office on Friday?

Does your entrepreneur friend admit that he has devoted his life to the pursuit of power and prestige without any regard for social concerns?

Does the government think that it can allocate fewer funds to education without jeopardizing standards?

Are you glad that you broached that subject with him when you met?

Did she maintain that she could break the board with her bare hands in one blow?

Have the other OPEC nations forgotten that the Saudis glutted the market with crude oil a few years back?

Did they say that they would confront the boss with the facts at the staff meeting?

Is he glad that they bombarded him with questions at the news conference?

Did the president maintain that he wanted to normalize relations with the Soviet Union at the next summit?

Are you forgetting that he padded the account with personal expenses on his last trip?

Do you think that you can merge this file with the other one by using this program?

Are they saying that they will replace you with someone else if you go on maternity leave?