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Electrophysiological Indices of Syntactic Processing Difficulty

by

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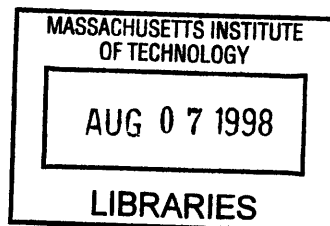
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ABSTRACT

Two types of processing difficulty are examined by means of electrical recordings taken from the scalp. One type of difficulty seems to be related to syntactic structural anomalies and another is related with memory load due to syntactic complexity. An experiment dealing with structural difficulty reveals the sensitivity of the parser with the argument status of the elements being processed. Memory constraints come into play when processing complex but structurally sound text strings. A number of experiments in this thesis examine a purported metric of complexity, namely, a left anterior negativity. It is argued that the predictive aspects of the parser is responsible for the complexity metric.

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Chapter 1: language and event-related potentials

Event-related potentials have proven useful in the past two decades as a means for studying sentence processing. ERPs are the voltage changes observed in an electroencephalographic recording after the presentation of some stimulus. Voltage changes differ in latency, amplitude, and polarity depending on the type of processing difficulty encountered. Aspects of language that reportedly elicit different ERPs are: word frequency, semantic congruity, structural complexity, and structural well-formedness (discussed below). In addition, electroencephalographic techniques eliminate decision time and motor response times as a source of noise when collecting reaction time data from subjects. The effects of cognitive events are recorded as they occur.

It is proposed here that since event-related brain potentials (ERPs) have proven useful in examining processing difficulty of different types, they can be used to shed light on the kinds of problems the parser faces at different points in a parse.

This thesis is divided into two parts. The first examines the constraints on the structural well-formedness of a construction containing reflexives and their (potential) antecedents. It is hoped that evoked potentials can provide previously unavailable evidence on the nature of those constraints.

The second part explores the use of event-related potentials in a type of processing difficulty that putatively involves the use of memory in syntactic parsing. The questions focus on what kinds of memory are involved in parsing operations, and how they constrain parsing.

Event-Related Potentials in language

The aspects of language use that elicit reliable ERPs are not yet fully understood, but a substantial toolbox of recognized evoked potentials now exists. ERPs have been shown to be sensitive to the occurrence of unlikely events. "Unlikely" can

mean a word that occurs rarely, a word that occurs rarely in a given semantic context, or a word that signals a syntactic structure that is incompatible with one currently being entertained. A second kind of sensitivity may be that of difficulty. "Difficulty" may refer to something like unresolved syntactic dependencies among words. Let us address each of these possibilities in turn.

Semantic Anomaly vs. Surprise

Kutas and Hillyard (1980), citing previous research, note that unexpected or surprising stimuli elicit a P300 wave. This means that a positive spike of some variable amplitude appears 300ms after the presentation of a low-frequency stimulus. For example, if a certain stimulus appears on only 10% of all trials in an experiment, a P300 will result whenever it appears.

Semantic anomalies, however, elicit a different ERP, namely, an N(egative)400. When a word that is inappropriate for a given context appears, a bilateral posterior negativity is produced, the peak amplitude of which occurs approximately 400 ms after the onset of the word.

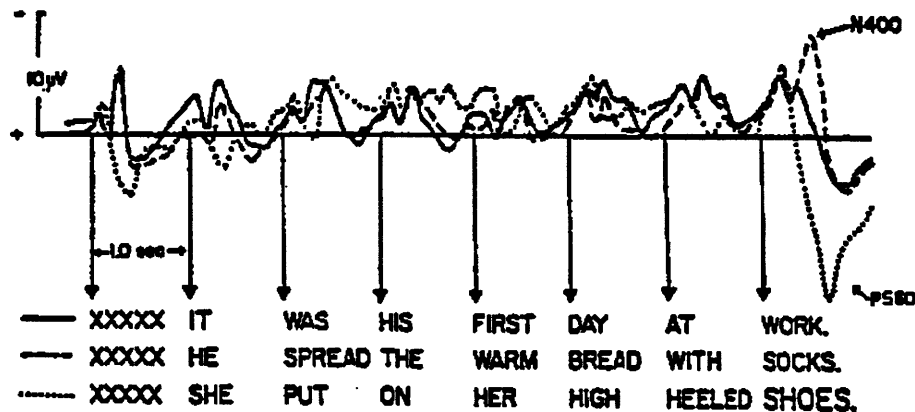


Figure 1
Word by word ERPs from Kutas & Hillyard (1980). An N400 was elicited by a semantically incongruous ending (socks).

- (3) a. It was his first day at work.
- b. He spread the warm bread with socks.
- c. She put on her high heeled SHOES.

In one condition, a given sentence contained a semantically anomalous (but syntactically correct) word, as in (3b). Kutas and Hillyard discovered that the more semantically incongruous a word was, the larger the amplitude of the N400. If a semantically appropriate word appeared in a physically unexpected form, say, in capitalization (3c), a complex wave form, with peaks at +210, +360, and +560ms, was reliably produced. They concluded that the N400 was related to semantic processing, and distinct from the so-called "surprise" (P560) phenomenon.¹

The N400 isn't strictly associated with anomalies in meaning. It has more to do with how much an item is expected given semantic context. For experimental purposes, a quantitative value can be put on the expectancy of a given lexical item in a given context by determining its Cloze probability. This requires that a large group of subjects fill in the missing terminal word of a presented sentence. The Cloze probability of a word is the proportion of subjects who chose the word to complete the sentence.

Kutas and Hillyard (1984) noted that the amplitude of the N400 for a given lexical item is inversely proportional to its Cloze probability (or contextual priming). To put this another way, the less a word is expected, the higher the N400 spike.

The end of (4b) elicited a higher spike than (4a). While *dog* in (4b) is not anomalous, it is less expected than *paint*.

- (4) a. Don't touch the wet paint.
- b. Don't touch the wet dog.

The N400 amplitude is reduced for those words which are semantically related to the word with the highest Cloze probability (Besson, Kutas, & Van Petten; 1992).

- (5) a. I've tried public transportation, but I prefer to drive my modem.
- b. I've tried public transportation, but I prefer to drive my own tire.
- c. I've tried public transportation, but I prefer to drive my own car.

¹ The authors speculate that the N400 is triggered when some kind of "reprocessing" is necessary, when a search for a satisfactory interpretation is launched in order to recover the sentence.

While (5a) and (5b) are both anomalous endings, (5b) will have a reduced amplitude N400 because it is related to the most expected answer, *car*.

The less often a word is heard/read in ordinary usage, the greater the N400 (Rugg, 1990). Given some neutral context, rare words will elicit greater N400 waves than their more frequent counterparts. However, Van Petten and Kutas (1990) showed that contextual priming could make N400 effects for low-frequency words go away.

Morphological Violation

Where verbs appear with the wrong inflectional marking, a left anterior negativity has been shown to arise (Rösler et al., 1993; Penke et al. 1997; Kluender et al. (1998)).

- (6) a. Der Präsident wurde begrüßt. (The president is being greeted.)
- b. *Der Lehrer wurde gefallen. (The teacher is being fallen.)
- c. Der Clown hat gelacht. (The clown has laughed.)
- d. *Der Dichter hat gegangen. (The poet has gone.)

Figure 1. Grand averages of ERPs in the syntactic violation condition (subcategorization errors). Superimposed are the ERPs obtained with auxiliary *wurde* and either a syntactically correct (continuous line) or a syntactically incorrect completion (broken line). Center inlay shows electrode locations: midline frontal (Fz), midline parietal (Pz), Broca-left (Bl), "Broca"-right (Br), Wernicke-left (Wl), "Wernicke"-right (Wr), and electrooculogram (EOG). Panels with event-related activity are arranged according to the placement of electrodes. Dashed vertical lines indicate (from left to right) 0, 300, 900, and 1500 msec after target onset. Negativity in this and the following figures is up.

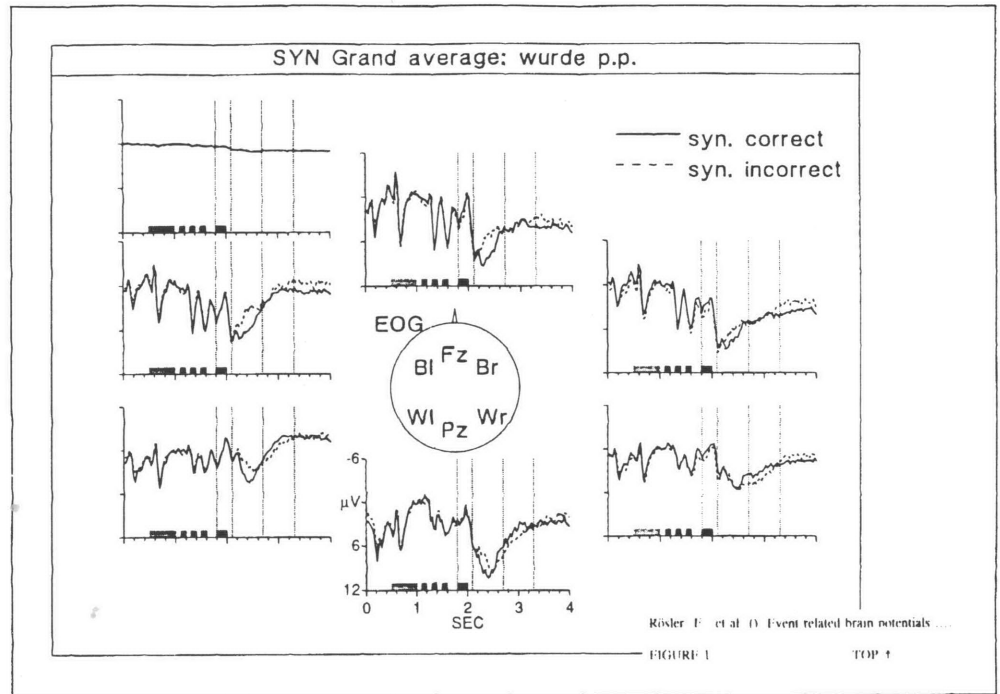


Figure 2
Example of evoked potential to morpho-syntactic violation.
Taken from Rösler et al. (1993)

In (6b), the violation is due to the impossibility of the unaccusative past participle, *fallen*, to be passivized. (6d) violates the requirement that unaccusative verbs use *be* as an auxiliary. Unaccusativity is a lexical property of the particular verb in question. While this particular set of violations is not critical to this thesis, a left anterior negativity like the one involved here will be seen to arise on other contexts.

Syntactic Violation

Hagoort, Brown, Goothusen (1993) investigated stimuli which violated syntactic rather than semantic context expectations. In particular, their violations were violations of subject-verb agreement. For example, (19a) is an ungrammatical sentence due to failure of agreement between the subject (*the old man*) and the verb

(*buy*). The grammatical form (19b) shows the correct agreement; *buys* is marked for third person singular, which agrees with the subject.²

- (7) a.*On a rainy day the old man buy life insurance
 b. On a rainy day the old man buys life insurance

The investigators compared ERPs at the "critical word"³, that is the word in the sentence which first indicated that there was (or was not) an agreement violation. They detected a positivity for the "disagreeing" sentence at 500-700ms distributed bilaterally over parietal regions, and strongest in the left hemisphere. The left hemisphere has widely been implicated in language processing (Osterhout & Holcomb, 1993). This positivity for a syntactic violation has come to be known as the P600 effect.

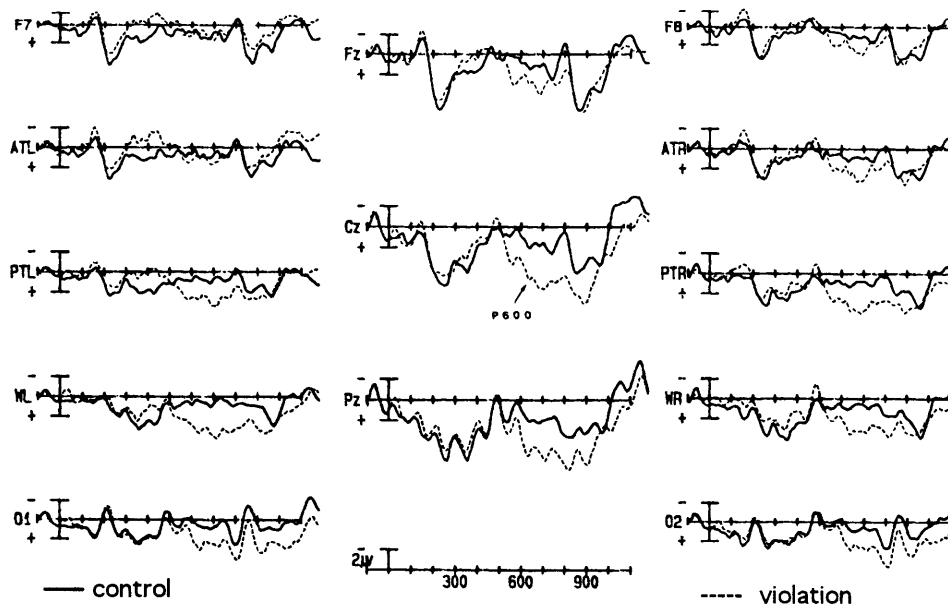


Figure 3
 Example of a phrase structure (syntactic) violation. Taken from Osterhout (1990).

²Hagoort et al. carried out the study in Dutch. For simplicity, we give English examples.

³Since Hagoort et al. used Dutch, their stimuli had the verb (*buy/buys*) precede the subject NP (*the old man*). Therefore, they were able to use *man* as the critical word. Thus the form of the critical word was identical in the agreeing and non-agreeing sentences.

Osterhout and Holcomb (1992) presented subjects with sentences which contained infinitival embedded clauses. One class (8a) was an infinitival embedded sentence, the other (8b) was a reduced relative without a matrix verb.

- (8) a. The woman struggled to prepare the meal.
- b. *The woman persuaded to answer the door.

The sentences were presented one word at a time on a computer screen. The ERPs recorded after the presentation of to were significantly different, and they showed an interaction effect of electrode site and hemisphere. Specifically, they found that a P600 spike appeared after *to* of the garden-path sentences (the (8b) type). While this type of sentence would be grammatical if completed (e.g., *The woman [who was] persuaded to open the door met John first*). The P600 suggests that the initial parse failed. It further suggests that this is a failure of a different type from that of simply encountering an unexpected word (although an unexpected word is exactly what was encountered). In other words, the P600 appears to be a sign that the subject has taken a sentence to have a structural violation.

Osterhout and Holcomb (1991) also report that the garden-path onsets elicited an N400 in the posterior left-hemisphere. They speculate that the P600 effect in the garden-path sentences (8b) is a result of the parser beginning to "reprocess" the sentence. This is reminiscent of the speculations offered by Kutas and Hillyard (1980) concerning their N400 findings. If the notion of reprocessing is correctly applied here, it shows us that there are two distinct responses to structural and meaning-related processing. This distinction is one we rely on in our examination of binding phenomena, which is explained in the next chapter.

Chapter 2: An ERP investigation of Binding and Coreference

Abstract

This study examines the nature of violations in processing one class of binding construction, namely, those involving reflexives and their antecedents. When arguments of verbs appear at the point where a syntactic violation is detected, a centro-parietal positivity occurs, peaking at 600 ms after the presentation of the stimulus (P600), as is consistent with other types of syntactic anomalies. However, nonarguments in similar sentences fail to elicit the same response. For example, the reflexive in *John's brothers like himself* is in an argument position and elicits the P600 when compared to its grammatical counterpart. The nonargument, participating in the same type of mismatch, *John's brothers like Bill and himself*, does not elicit the same positivity. This provides evidence that there are two processes involved in parsing this binding construction, one syntactic, and another yet unidentified, perhaps involving meaning or pragmatics.

Introduction

Linguistic theory is primarily concerned with determining the structure for certain phrases and how that structure disallows erroneous permutations while allowing others. The nature of the operations that govern permutations are not specified with respect to the underlying neuronal processes. Yet, for any given linguistic phenomenon, there are a sizable number of plausible theories that account for it. It is reasonable that some of these theories are going to be more compatible with the fashion that the brain deals with language than others. Therefore, although it is not the current practice, in principle, physiological evidence could help to choose among theories and may even contribute to the creation of a new theory.

One technique that has shown promise in this regard is event-related brain potentials (ERPs). ERPs are changes in voltage recorded at the scalp which are time-locked to specific stimulus events. When such events fall into one of two conditions that differ along a single factor, it can be surmised that differences in the two patterns of electrical activity is a reflection of a difference along this factor. Using this logic, recent experiments involving ERPs have shown a sensitivity to certain grammatical and semantic processes in spoken and written language (see Osterhout & Holcomb, 1995, for a review). Briefly, it has been shown that a negative-going wave with a peak latency of 400 ms (N400) is larger in amplitude to words that are not supported by a given semantic context. So, for example, words in isolation, words towards the beginnings of sentences, and especially semantically anomalous words (in sentences) all produce large N400s (e.g., Kutas & Hillyard, 1980; Van Petten & Kutas, 1990). One interpretation of this pattern of findings is that the N400 reflects the process of semantic integration -- the more difficult this process, the larger the N400 (e.g., Holcomb, 1993). Conversely, a different ERP component, the P600 (a positive-going wave peaking around 600 ms), has been shown to be sensitive to certain syntactic

processes (e.g., Osterhout & Holcomb, 1992; Hagoort & Brown, 1993), its relative amplitude being larger whenever a reader or listener detects a structural violation.

At this point in history, we can begin to apply this tool to map linguistic phenomena to neurological processes. The current study is concerned with the status of certain linguistic elements as **arguments**. The notion of argumenthood in linguistic theory is basic, because certain syntactic constraints apply only to arguments, and can only apply to arguments. A definition of arguments is offered on page 18. It remains to be seen whether this notion is simply an artifact of theory building or whether it is reflected in neurology.

In the current study, Argument-Based Binding Theory,¹ as described by Reinhart and Reuland (1993) provides the means of exploring this phenomenon. Binding relations express a certain kind of dependency among elements of a sentence. The distribution of words like *himself* and *each other* in sentences respects some rather strict constraints. There are a number of proposals that attempt to characterize these restrictions. Argument-Based Binding Theory posits that the restrictions are a combination of both syntactic and pragmatic constraints. The nature of these constraints is not obvious from judgments of well-formedness, on which this proposal is based. There is no one-to-one pairing of judgments to underlying mechanisms; Argument-Based Binding derives the syntactic/pragmatic distinction from theoretical considerations. Since ERPs have been shown to be sensitive to syntactic and nonsyntactic violations of expectancy, they may help determine whether the theory is partitioning English anaphora in the right way.

Before any theoretical considerations can be undertaken, it must be observed whether there is a characteristic ERP response to binding violations, as has been the case for subject-verb agreement, (Hagoort, Brown, & Groothusen, 1993)

¹our appellation, not Reinhart & Reuland's, to draw attention to this experimentally-crucial feature. With respect to other Binding Theories, it might best be distinguished as "Predicate-based."

gender/number mismatch (Osterhout & Mobley 1994), and phrase structure violations (Neville et al., 1991; Osterhout & Holcomb, 1992). This is the first aim of the current study. Given that, what is the nature of the response? Since binding relations are also relations of coreference², the second purpose of this study is to determine whether such violations are primarily syntactic or meaning-related. Finally, if there are indications of both syntactic and pragmatic violations, are these dependent on the notion of argumenthood? In other words, are the responses to violations distributed along the lines predicted by Argument-Based Binding Theory?

Distribution of Anaphora

Binding theory (Chomsky, 1981,1988; Higginbotham, 1980, 1988; Manzini, 1992) is about the distribution of items which do not have inherent reference. For example, certain pronouns³ (e.g. *him*, *her*) and reflexives (e.g. *himself*, *herself*) are not meaningful without being bound to something with reference, whereas *John* or *book* alone pick out entities in the world. As will be discussed in greater detail below, pronouns and reflexives usually occur in complementary distribution. An asterisk indicates an ungrammatical utterance. Noun phrases bearing the same index are coreferential.

1.
 - a. $Mary_i$ forgave herself_i
 - b. * $Mary_i$ forgave her_i
 - c. * $Mary_i$ forgave herself_j
 - d. $Mary_i$ forgave her_j

When *Mary* and the direct object refer to the same person, a reflexive pronoun is permissible as direct object (1a), but a pronoun is not (1b). When *Mary* and the direct object refer to different people, only a pronoun is permissible as direct object (1d). This complementarity of pronoun and reflexive is observed in all but a few notable cases, such as the following.

2.
 - a. $John_i$ kept the gun near him_i / himself_i at all times.

² When two linguistic elements corefer, they pick out the same real-world entity. Notice that coindexed elements needn't pick out real-world entities: "No one saw himself in the mirror." (Alec Marantz, PC)

³ Pronouns here refer to pronouns with non-anaphoric reference.

- b. John_i knew no one liked Bill and him_i / himself_i after what had happened.

If the general rule is that a reflexive cannot appear where a pronoun can appear, what is it about the sentences in (2) that allows either to appear in object position? The proposal by Reinhart and Reuland (1993) casts the reflexives in (1) as arguments of the verbs they follow, whereas in (2), they are not arguments. What constitutes an argument will be described shortly. The key idea is that the syntactic constraint governing the distribution of these reflexives applies only to arguments. Thus, complementary distribution of such pronouns holds in examples like (1), but is not necessarily observed in sentences like (2).

The proposed argument/nonargument distinction provides an opportunity to investigate cases in which reflexives either violate or respect syntactic constraints, and cases in which they are free of such constraints. In the following sections, we trace an outline of this view of Binding Theory. We then review some of the relevant ERP literature to assess the known types of electrophysiological responses to linguistic stimuli. Using this information, we arrive at a methodology for asking about the types of violations evoked by illicit binding constructions.

Binding Theory

A theory of binding describes the syntactic restrictions on when pronouns in a sentence can refer to the same person or thing. Below is a brief description of the aspects relevant to the current experiment, and the terminology used.

An anaphor is a referentially-dependent noun phrase (NP). This class, by definition, includes reflexives (3a) and reciprocals (3b). An anaphor bearing the same index as an NP (and in a certain configuration with the NP) is said to be bound (to the NP). In (3a), the reflexive *himself* is bound to the NP *John* and in (3b) the reciprocal *each other* is bound to the NP *John and Mary*.

- (3) a. John_i likes himself_i
b. [John and Mary]_i like [each other]_i

Condition A

Condition A of Binding Theory says that reflexive arguments must have a co-indexed coargument in their predicates.⁴ . The examples that follow use brackets to indicate the relevant predicate.

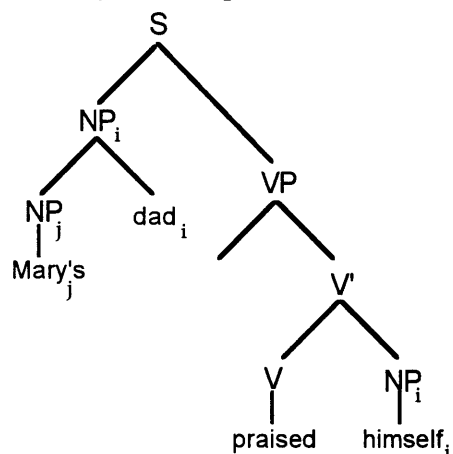
⁴See Appendix A for a more formal definition.

- (4) a. John_i said that [he_i saw himself_i]
 b. *John_i said that [Mary saw himself_i]
 c. John said that [Mary_i saw herself_i]

(4a) is an acceptable construction because in the relevant domain for *himself*, there is a coargument, namely, *he*. (4b) is ungrammatical because *Mary* cannot serve as any such coargument and *John* is not in the local domain. In (4c), where *Mary* agrees in gender with *herself*, the anaphor is properly bound.

There are structural conditions which can have an effect here, as well as the domain-specific type just seen. Consider (5).

- (5) a. Mary's dad_i praised himself_i
 b. *Mary's_i dad praised herself_i



In (5), the whole sentence seems to be the relevant domain, yet in (5b) the necessary antecedent is unavailable. This is because the subject NP receives its index (or identity) from its head, which is *dad*. The coargument of *herself* is therefore *dad* and not *Mary*. In other words, Condition A does not "see" *Mary*.⁵

In summary, example (5) shows that there is a structural requirement at work in the syntax, which exists in addition to the locality requirement seen in (4).

Argument / nonargument distinction

All of the preceding examples have had the anaphor in an argument position. This was done purposefully, because our Condition A only applies to arguments. An argument position is one which is licensed by the verb. Its appearance is mandatory.

⁵Readers familiar with Binding Theory may note that this characterization does not rely on the notion of c-command, although what has been presented so far is compatible with it. (Reinhart, 1976; Aoun & Sportiche, 1983; Chomsky, 1981)

For example, in (6) and (7), "the book" is an argument of both "put" and "saw". (cf.: **John put.* and **John saw.*)

(6) John put the book on the table

(7) John saw the book on the table

The locative phrase *on the table* however, is an argument only for *put*, as can be seen by its optional deletion only with *saw*.

(8)*John put the book.

(9) John saw the book.

Similarly, an object may be omitted after the verb *eat* (12), but can't be omitted after the verb *kissed* (13).

(10) John ate.

(11) *John kissed.

This is an aspect of language use which does not follow from discourse considerations. (10) is taken to mean John ate something, but that something need not be mentioned. Similarly, in principle (11) could be taken to mean John kissed someone, but in fact, *kissed* is not used in this way. The surface argument structure (e.g. syntactically required objects) of a verb is not determined solely by semantics.

The syntactic dichotomy between arguments and nonarguments is stressed here because this notion is the real focus of investigation in this paper, while Argument Based Binding Theory is only the means.

Logophoricity

We now turn to examining reflexives in non-argument positions. Below is a minimal pair in which both a reflexive and a pronoun are in argument positions.

(12) a. Max likes jokes about him

b. Max likes jokes about himself

In (12a), the reflexive is an object of a preposition, not a verb. *Jokes about him* is the object of the verb. *About him / himself* is predicated of *jokes* and not *likes*.

Reflexives like the one in (12a), which are not arguments of their predicates,⁶ are called logophors, and they are interchangeable with appropriate pronouns⁷.

Another way in which an anaphor escapes being the argument of a verb is by being in a conjoined argument phrase, as in (13b). The conjoined phrase is the object (argument) of the predicate; neither of its constituents is the object (argument).

⁶For our purposes, predicates must contain verbs.

⁷"Appropriate" means only that such a logophor and the pronoun will share gender and number features, because those are among the semantic features of the shared referent.

- (13) a. *Max said the queen invited [himself] to tea
 b. Max said the queen invited [Lucie and himself] to tea
 c. Max said the queen invited [Lucie and him] to tea

In (13a), *himself* is an argument of *invited* but does not have a co-indexed coargument in its syntactic domain. That is, although *Max* could be coindexed with *himself*, *Max* is not in the local domain of *himself*. Thus (13a) is ruled out by Condition A. In (13b), [*Lucie and himself*] is an argument of *invited*, not [*Lucie*] and [*himself*] as individual elements. *Himself* is not a syntactic argument and is free to vary with the pronoun *him*, as in (13c).

- (14) The pilot's_i mechanics browbeat Max and himself_i after the race.

The conjoined reflexive (logophor) is subject to some constraint however, since (14) is not acceptable, according to Reinhart & Reuland. There is an intuition that *pilot* isn't really who the sentence is about, and that it isn't a proper antecedent for the logophor. This is a kind of discourse constraint that works independently from the syntax. For present purposes, we will avoid attempting a formalization of this. (See Kuno (1987) and Zribi-Hertz (1989)). There seems to be some variability in speakers' judgments of this type of construction. The only important fact here is that whatever constrains the logophor, it is not Binding Theory or any other syntactic constraint. Any violation involving a logophor, should therefore be extra-syntactic.

The current study

This discussion leaves us in a position to make some hypotheses about the electrophysiological responses that might arise from binding violations.

- (15) a. John likes himself
 b. John likes *him

him in (15b) ought to elicit a posterior positivity with respect to (15a). However, any difference observed may be due to the difference in lexical items alone. It seems that we must use reflexives:

- (16) a. John likes himself
b. John likes *herself / *themselves

There are two problems here. One is differing lexical items,⁸ the other arises from the possibility that the violation is due to gender or number mismatch, and not to Condition A alone. In fact, Osterhout & Mobley (1995) report an experiment which used sentences like (17):

- (17) a. The actress served herself / *themselves at the luncheon.
b. The actresses served *herself / themselves at the luncheon.

This construction eliminates the problem of measuring across different lexical items since the singular and plural reflexive appear an equal number of times in both grammatical and ungrammatical sentences. The violation arises due to an intended coreference between the reflexive and the subject. However, it does not eliminate the possibility of a second (unnamed referent) which the experimental subject assumes to be the antecedent for the reflexive. Depending on the subject's interpretation, either a feature mismatch or a binding violation may be responsible for any ungrammaticality. Indeed, fixing the referent may have been a crucial element in this task, which was grammaticality judgment. When subjects in a second experiment were asked to simply read the stimuli for comprehension, the mismatch sentences did not elicit a P600. Subject-verb mismatches in the same experiment did. Thus, agreement mismatches alone may not be sufficient to elicit a P600 in antecedent reflexive constructions. Failing to find a referent, or coindexing with the wrong referent may be what is required. (See Osterhout & Mobley (1995) for discussion.)

What is needed is a comparison in which two possible referents are made explicit, and one is ungrammatically linked to the reflexive (See (18)). The task for the subjects must be to determine whether the subject or the possessive modifier is receiving the action of the sentence, using number agreement as the relevant clue.

⁸ A difference in ERPs can be expected simply because the stimuli are different, and not due to experimental manipulation. This would potentially increase Type II error.

This will increase the likelihood that the subjects make the intended coreference and experience a Condition A violation in (18a).⁹

- (18) a. *John's_i brothers like [himself_i]
- b. John's brothers_i like [themselves_i]

This provides the needed comparison of syntactic arguments. Next, we need a similar comparison using logophors. Where the anaphor in argument position is bad, the coargument ought to be good, or bad for nonsyntactic reasons.

- (19) a. #John's_i brothers like [Bill and himself_i]
- b. John's brothers_i like [Bill and themselves_i]

(18a): Condition A rules this out. It requires *himself* to have a coargument in its predicate, but the only possible antecedent, *John*, is not an argument of the predicate.

(19a): Binding Theory does not play a role here.¹⁰ Condition A only applies to reflexive-marked predicates, and the logophor does not do this, at least at a syntactic level. If this sentence is awkward, it is due, supposedly, to the fact that the pragmatic center of the sentence (the subject) is not coreferential with the logophor. This sort of discourse requirement is outside the domain of syntactic considerations.

Therefore, the prediction is that the brain potentials elicited by the reflexives in (18) will be different from those of (19). Drawing further on the ERP literature, it seems reasonable to assume that Binding Theory violations (18) will elicit a pattern similar to those resulting from other syntactic violations, namely the P600. The waveform predicted to arise from a pragmatic violation (19) is trickier. Without a formal characterization of the pragmatic requirements on anaphora (and without a relevant body of ERP experimentation), it is difficult to know what to expect. Perhaps

⁹If subjects nevertheless experience an agreement violation, then we should expect no difference in the evoked potentials from (18) and (19).

¹⁰Condition B applies only to reflexive predicates, and the indexing indicates that the arguments of the predicate are not coreferential. Condition B does not apply here.

since pragmatics are related to meaning and discourse integration, some N400 type of effect might be predicted. However, if there idiosyncratic variations in evaluating pragmatic constraints, or if there is individual variation in localization of function, we would expect that any effect would wash out in averaging.

Method

Subjects

Forty volunteers participated in this study (22 female). Ages ranged from 18 to 29 ($M=20$). All were right handed, native speakers of English with normal or corrected to normal vision. Subjects either participated for course credit or were paid.

Materials

One hundred twenty quadruplet sets of sentences were constructed after the fashion of (20), for a total of 480 sentences.

- (20) a. The pilot's mechanics brow-beat themselves after the race.
b. The pilot's mechanics brow-beat himself after the race.
c. The pilot's mechanics brow-beat Paxton and themselves after the race.
d. The pilot's mechanics brow-beat Paxton and himself after the race.

A possessive noun preceded the subject. One was singular and one was plural. The grammatical number of these items were counterbalanced. The third word was the verb. The verbs were chosen to be optionally transitive or reflexive, but subcategorization frequencies were not controlled. The fifth word was either a disagreeing/agreeing anaphor, or a conjoined phrase consisting of a proper noun and disagreeing/agreeing logophor. Following was a prepositional phrase. The prepositional phrases varied in length and content across quadruplets, but not within quadruplets.

Notice that in (20b), for example, the subject must accept some kind of grammatical error upon reading the reflexive, either preserving the subject as argument and violating number agreement (*mechanics* as antecedent), or violating the subject-as-argument restriction and preserving number agreement (*pilot* as antecedent). Subjects were instructed to rely on number agreement to determine who received the action of each sentence. (See Appendix B for instructions given.) In short, the subjects were told that each subject contained a singular noun and a plural noun. The reflexive would be either singular or plural. The task is to determine who received the action of the sentence based on number agreement. Since the options in the subsequent question were always the two nouns in the

subject, and presented in the same order, experimental subjects were encouraged to anticipate the question and response. It was hoped that by encouraging subjects to make this determination at the time of reading the reflexive, the intended coreference would be made, regardless of whether there were a binding theory violation. Indeed, it was part of the design that subjects who did not make the intended coreference, as revealed by their accuracy in answering questions (to all conditions) would not be included in the final analyses.

Four lists of stimuli were used, and each contained exactly one member of each quadruplet set. Each subject saw only one list. Therefore, a given subject read 60 sentences containing anaphors. Half of these anaphors disagreed in number with the subjects. Half (30) of the subjects were plural. The same counterbalancing existed in the logophor sentences.

There were also 30 filler sentences per list. These were sentences from an unrelated experiment, and one-third of these were followed by questions, as in the main experiment. All of these items were grammatical, although half were designed to elicit some mild processing difficulty.

Procedure

The subject was seated in an arm chair before a computer screen. Each trial began with a fixation point in the center of the screen, which lasted 500 ms. It was followed by the first word of the trial sentence. Each word appeared centered on the screen for 300 ms, followed by a blank screen for 350 ms. The screen was blank 1350 ms following the last word, which was indicated by a period following the last letter. In one-third of the trials, immediately following were a comprehension question and two possible answers, which appeared in their entirety. The presentation of a question was pseudo-randomized.

- (21) a. The pilot's mechanics brow-beat himself after the race.
- b. Who was brow-beaten after the race? pilot(s) / mechanic(s)

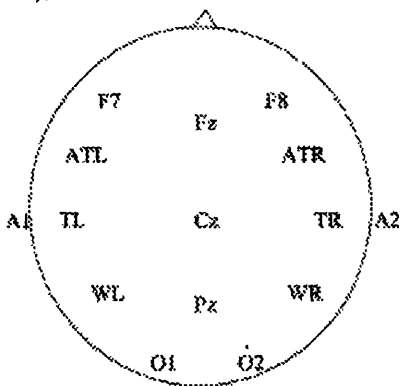
The task was to push either the left or the right button on a button box held in the lap. The question remained on-screen until the subject responded. In this example, the answer to (21b) would be the depression of the left button, since *pilot(s)* is the leftmost of the two choices. The number of the two choices was made ambiguous, as in (21b) in order to force the subjects to match the reflexive to the antecedents, and not to simply match number features. In other words, it wasn't enough to remember that the subject was plural, and match it to the plural choice of

answers. In order to reduce the difficulty of the task, the noun answers were always presented in the same order as the nouns had appeared in the sentence.

A ten trial practice session preceded the experimental run. The stimuli had the same structure as the experimental run, except that half of the reflexives did not agree with their subjects' genders instead of number. Subjects were given feedback regarding their accuracy. Any subject making two or more mistakes repeated all practice trials.

Data acquisition

The International 10-20 System was used for scalp sites including midline sites (Fz, Cz, and Pz) and four lateral sites (F7, F8, O1, and O2). Six nonstandard placements were also used. WL and WR: left and right temporo-parietal cortex (30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz); TR and



TL: left and right temporal cortex (33% of the interaural distance lateral to Cz; ATR and ATL: one-half the distance between F7-F8 and T3-T4). Eye movements and blinks were monitored by means of an electrode beneath the left eye and one to the right of the right eye. The reference electrode was placed on the left mastoid bone. A second electrode on the right mastoid was used to determine whether lateral asymmetries

arose due to the use of the single reference electrode. Electrode potentials were amplified by a Grass Model 12 amplifier with a bandpass of 0.01 to 100 Hz (3db cutoff).

Data analysis

Because our hypotheses concerned the P600 and the N400, our comparisons were based on measurements taken only in windows surrounding those peaks. For N400 effects, we measured between 350 and 450 ms. For P600 effects, which are slow waves, we used a larger window, 550 to 750 ms. Because of possible component overlap, we did not attempt to use larger windows. The comparisons are based on average amplitude within those windows.

A two-way repeated measures ANOVA was conducted for all sites (29 levels of electrode position) and then separately for midline sites (3 levels of electrode position: frontal, central, parietal) with two levels for agreement. Lateral sites were examined using a three-way repeated measures ANOVA involving two levels for

agreement, two levels of hemisphere, and five electrode positions. The Huynh-Feldt correction was applied to effects involving more than one degree of freedom. Non significant results are not reported unless specifically predicted.

Results

Data were processed from 40 subjects. Performance in answering questions ranged from 57% to 97% accuracy. Subjects with the lowest accuracy scores obviously failed to perform the task. They were removed from analysis. In order to avoid a gratuitous acceptance criterion, only the top half of subjects were evaluated. King & Kutas (1995) have shown that interpretable effects seen in the data of good comprehenders are absent from poor comprehenders' data. The good comprehenders in this study had accuracy scores at or above 84%.

Within reflexive type comparisons (agree vs. disagree)

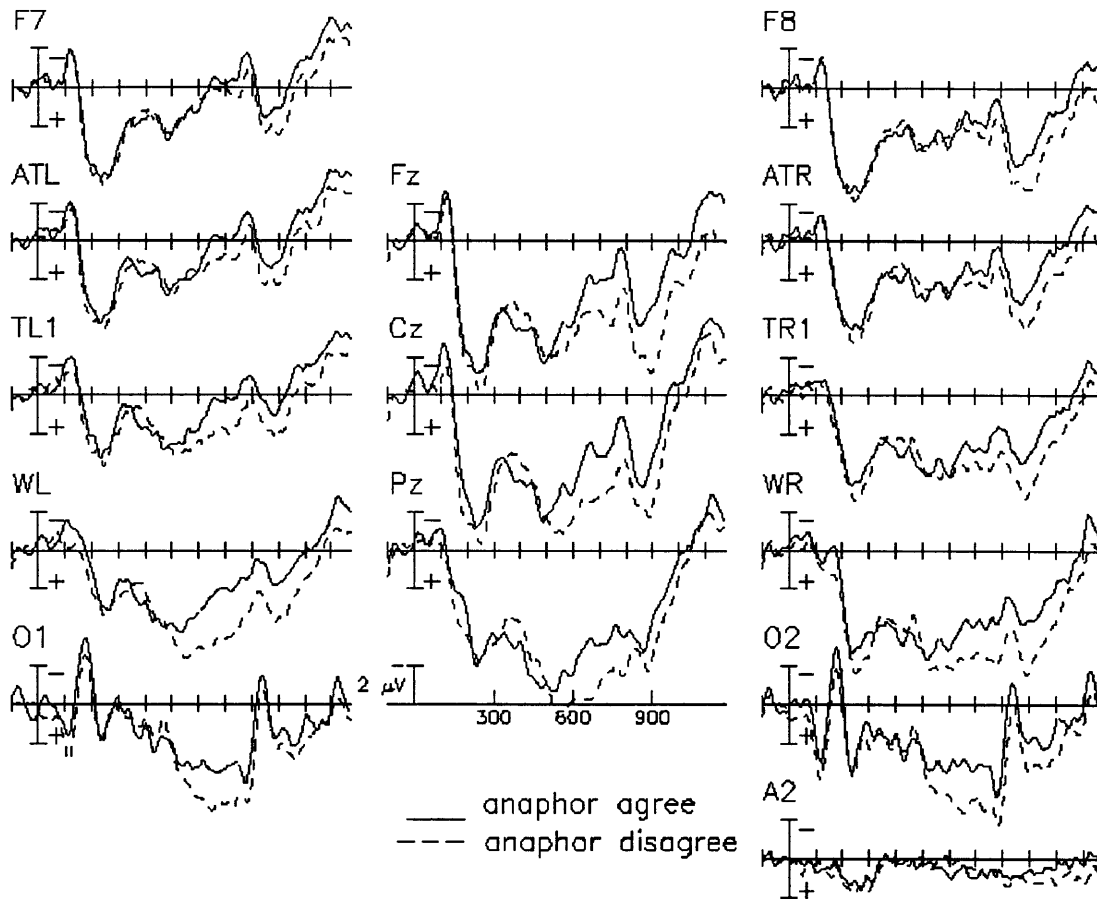


Figure 1

ERPs from Anaphor-agree vs. anaphor disagree comparison, good comprehenders. 0 mark corresponds to presentation of the anaphor.

Anaphor agree vs. anaphor disagree comparison (see Figure 1)

Recording during and after the presentation of the anaphor:

John's brothers fed themselves.

as compared to

John's brothers fed himself.

Prediction: Positivity peaking at 600 ms.

Effect: Positivity between 550-750 ms, bilateral distribution, most pronounced at central and posterior sites.

P600 window (550-750 ms):

Plotted in Figure 1 are the ERPs following the presentation of the anaphor from the disagreeing and agreeing conditions. Repeated measures ANOVA over all cortical sites showed an effect for condition (more positivity when the reflexive disagreed

with the sentential subject than when it agreed), ($F_{[1,19]}=4.46, p<.05$). There was an interaction of condition and electrode site ($F_{[12,228]}=2.77, p=.002$). ANOVA for 10 lateral sites showed an effect for hemisphere ($F_{[1,19]}=11.33, p<.01$). While the difference between conditions for left sites was greater than those for the right (1.06 vs. 0.56) there was no condition by hemisphere interaction ($F_{[1,19]}=1.19, p=.289$). MANOVA for midline sites (Fz, Cz, and Pz) showed an effect of condition ($F_{[1,19]}=6.78, p=.017$).

N400 window (350-450ms):

As can be seen in Figure 1, differences between the conditions in this epoch were small or nonexistent. They were not statistically reliable ($p<.157$).

Logophor agree vs. Logophor disagree

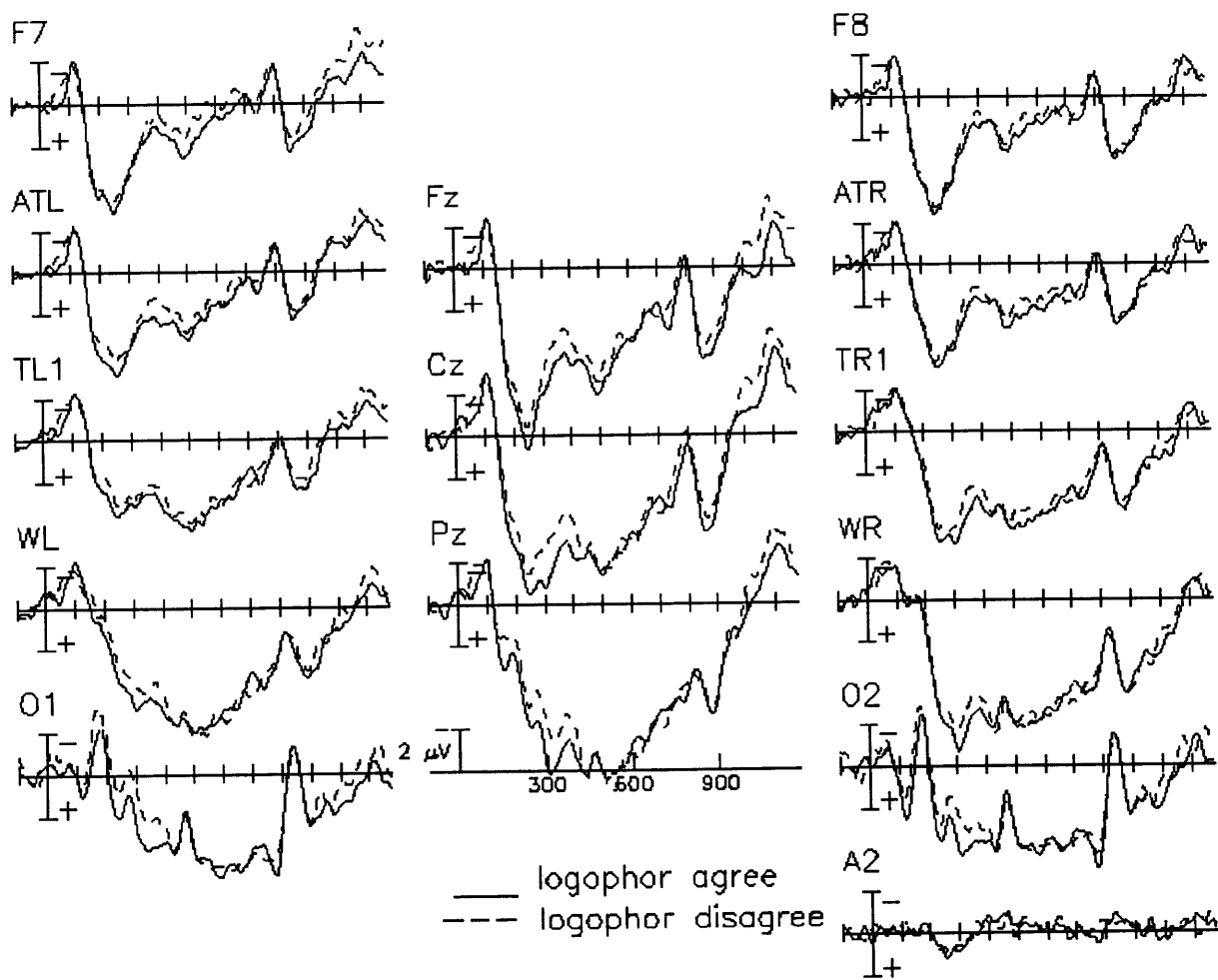


Figure 2

ERPs from logophor-agree vs. logophor-disagree comparison, good comprehenders. 0 mark corresponds to presentation of the logophor.

Recording after the presentation of the logophor:
John's brothers fed Bill and themselves.
as compared to
John's brothers fed Bill and himself.

Prediction: No P600, possible N400
Effect: None.

P600 (550-750 ms)

As can be seen in Figure 2 there are few if any differences in this epoch. This observation was born out in the ANOVA; there were no significant effects involving the condition variable ($p > .57$) other than a marginal effect for hemisphere ($F_{[1,19]}=3.85, p=.065$).

N400 (350-450ms)

Repeated measures ANOVA over all cortical sites showed no effect for condition ($F_{[1,19]}=.40, p=.53$), and no condition by site interaction ($F_{[12,228]}=.25, p=.99$). An N400 trend appeared to be developing, most prominently manifest at the midline sites. ANOVA for midline sites (Fz, Cz, and Pz) showed no effect of condition ($F_{[1,19]}=.54, p=.471$).

Between reflexive type comparisons (anaphors vs. logophors)

Our design created agree-disagree comparisons which involved sentences that were structurally identical; only agreement differences signaled referential possibilities, and these differences were counterbalanced. In order to make these comparisons possible, this design forfeits the means of making clean between-type (i.e. anaphor versus logophor) comparisons. However, we present them with the following caveats:

Structural differences: ERP differences may be due simply to whether the reflexive was in a conjoined NP vs. a non-conjoined NP.

Baseline differences: the preceding two words are different for the two types (i.e., the logophor was always preceded by the conjunction *and* and the anaphor was always preceded by a verb). Such differences may carry over into the ERP epoch of the word of interest making unambiguous interpretation of results difficult.

Cloze probability: Kutas & Hillyard (1984) report that the negativity elicited by a word is inversely proportional to the predictability of the word given its context. In the current experiment, an anaphor appeared directly after the matrix verb 50% of the time, whereas the logophor appeared after an "and" 100% of the time.

Therefore, the logophor might be expected to elicit less negativity¹¹ than the anaphor, due to predictability alone.

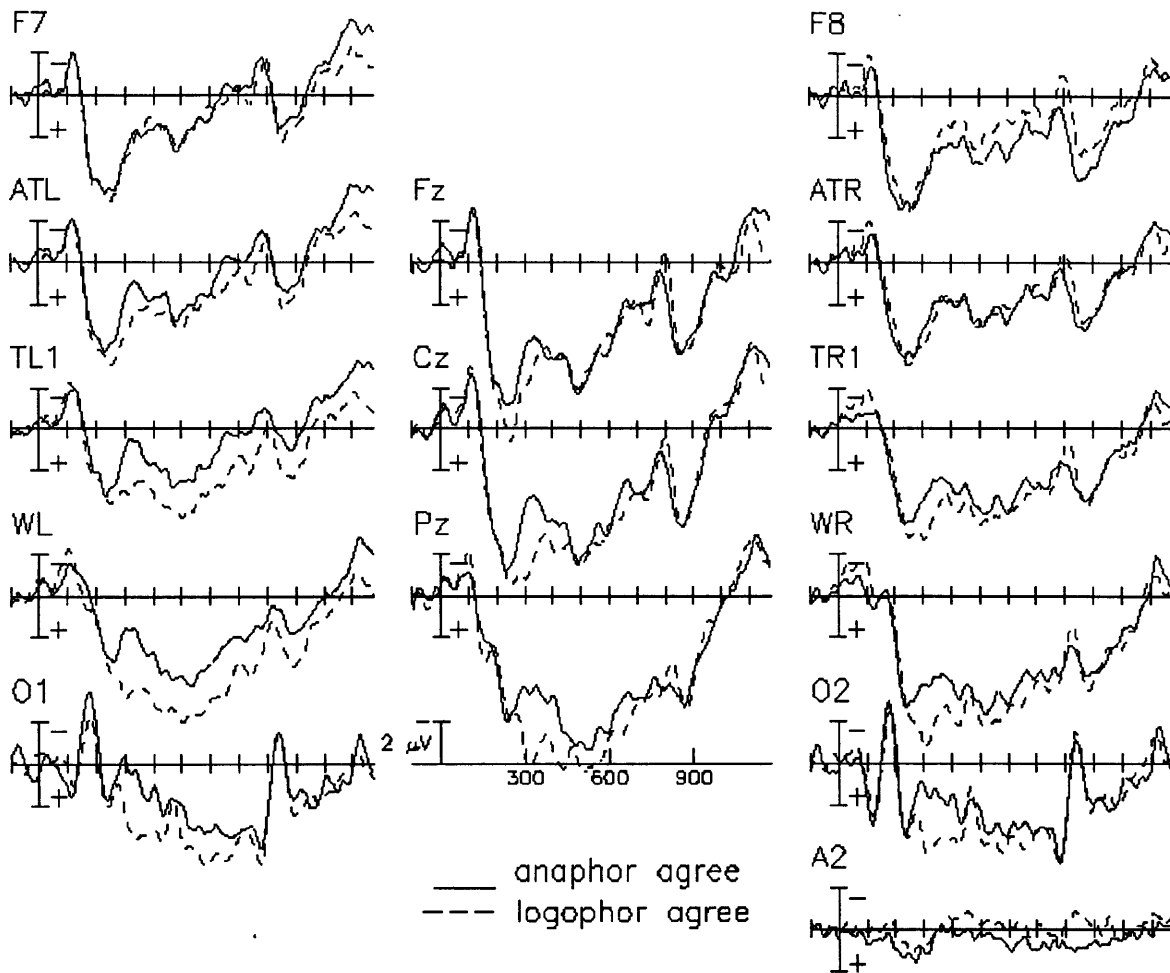


Figure 3

ERPs from anaphor-agree vs. logophor-agree comparison, good comprehenders. 0 mark corresponds to presentation of the reflexive.

Logophor agree vs. anaphor agree comparison (See Figure 3)

Recording after the presentation of the reflexive:

John's brothers fed Bill and themselves.

as compared to

John's brothers fed themselves.

Prediction: The binding theory we studied predicts no P600 here and makes no other predictions. A positivity for the logophor is predicted by Cloze probability considerations (see Discussion).

¹¹or more positivity, as is produced by a P300. Note, however, that the observed positivity is not related to the appearance of a stimulus, but a type of word, namely any instance of a reflexive-this seems to be higher level than P3.

Effect: Logophor is significantly more positive than anaphor only at WL (Wernicke's Area), unlike the wider distribution for the anaphor agree/disagree comparison (P600). The onset of the positivity is earlier than the onset of the positivity in the anaphor agree/disagree comparison.

P600 window 550-750 ms:

Repeated measures ANOVA over all cortical sites showed an effect for the interaction of condition by site ($F_{[12,228]}=4.16, p=.004$). In the lateral analysis, there was an effect for hemisphere ($F_{[1,19]}=13.13, p=.002$) and a marginal hemisphere by condition interaction ($F_{[1,19]}=4.1, p=.057$). Hemispheric differences were stronger (more positive) for the anaphor-agree condition.

N400 window 350-450 ms:

Repeated measures ANOVA showed an effect for the condition by site interaction ($F_{[12,228]}=6.19, p<.001$) for all cortical sites as well as for the midline ($F_{[2,38]}=8.23, p=.008$).

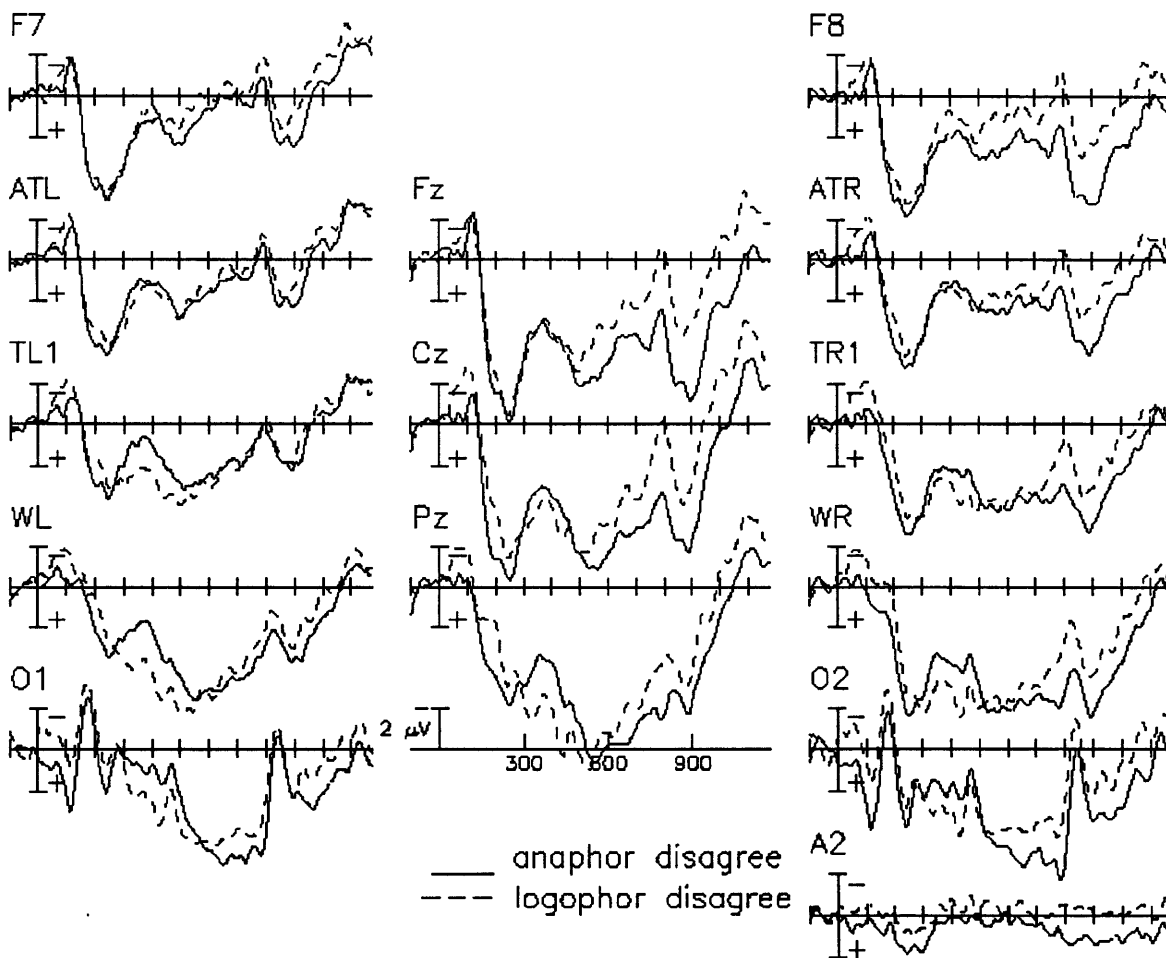


Figure 4

ERPs from anaphor-disagree vs logophor-disagree comparison, good comprehenders. 0 mark corresponds to presentation of the reflexive.

Anaphor disagree vs. Logophor disagree comparison (See Figure 4)

Recording after the presentation of the reflexive:

John's brothers fed himself.

as compared to

John's brothers fed Bill and himself.

Prediction: P600 for anaphor.

Effect: There a positivity elicited by condition at midline sites. (The discussion section suggests that the positivity associated with Cloze probability (logophor condition) masks the effect.)

P600 window (550-750 ms):

Repeated measures ANOVA over all cortical sites show no effect for condition (whether the reflexive was an anaphor or logophor), ($F_{[1,19]}=.01$, $p=.915$).

N400 window (350-450 ms):

Repeated measures ANOVA over all cortical sites showed an effect for condition ($F_{[1,19]}=5.84$, $p=.026$), and an effect for the condition by site interaction ($F_{[12,228]}=6.16$, $p=.001$) There was also a condition by site interaction for the midline ($F_{[2,38]}=11.03$, $p=.003$). In the lateral analyses, there was no effect for hemisphere, ($F_{[1,19]}=3.03$, $p=.098$) and none for the hemisphere-condition interaction ($F_{[1,19]}=.40$, $p=.54$).

Discussion

The responses given by poor comprehenders indicated that they did not parse the sentences with the intended coreference. Thus their data are not meaningful with respect to the experimental hypotheses. In addition, there was a significant effect of the group factor in two comparisons when both groups were examined together. We conclude therefore that only the data from the good comprehenders bear on the hypotheses under consideration, and we center our discussion on their results.

Results for Good Comprehenders

Agree-disagree comparisons

The argument/nonargument distinction presented in Reinhart and Reuland (1993), coupled with evidence from the ERP literature suggests that a P600 should be expected in the anaphor-agree/disagree conditions. This was borne out. This alone

is of significance in that this is the first observation of the effect of a Binding Theory violation, and it seems to pattern after the effect observed in agreement violation (Hagoort, Brown, & Groothusen, 1993) phrase structure violations (Holcomb & Osterhout, 1992), ECP and Subjacency violations (McKinnon & Osterhout, 1996). The present finding further supports the theoretical assumption that binding violations of this type are syntactic violations. They are not bad simply due to problems fixing coreference.

Following Reinhart and Reuland, if the logophor violations are pragmatic and not syntactic, then there should be no P600 observed between the logophor agree/disagree conditions. This prediction was also borne out here.

The fact that there was no N400 effect for the anaphor-agree/disagree comparison is consistent with earlier findings that grammatical violations don't yield an N400, which is associated more with "semantic processing." It is interesting, however, that there is no N400 effect between the logophor conditions. Apparently, the type of pragmatic violation imputed to these sentences is not the same as other types of semantic violations reported in previous studies (Kutas & Hillyard, 1980; Nigam et al., 1992; Van Petten & Kutas, 1990, 1991).

Between type comparisons (logophor vs anaphor)

This study was designed to give clean comparisons only within reflexive type. However, the argument presented thus far makes two implicit between-type predictions. The first is that while some difference ought to be expected for the processing of the different types of reflexives, there ought to be no P600 for the agree-agree comparison. Neither is ungrammatical. However, there ought to be some indication of a P600 between the two "disagree" conditions, as only one of them is syntactically malformed. This latter prediction is surprising without the invocation of binding theory. Without the notion of violations arising from improper coreference, these sentences are simply examples of number agreement violations, which is present in both conditions.

These comparisons were not included in the design of the study because of the possibility of an ERP response to reflexive type alone, which would increase Type II error. Nevertheless, the results of these comparisons are compatible with the two weak predictions.

Logophor-anaphor agree comparison

A comparison of the two agreeing conditions revealed that there is no overall effect of type of reflexive (logophor versus anaphor). There is, however, an effect observed at Wernicke's area, in which the logophor is more positive than the anaphor. The fact that it is a slow-going positive wave makes it a potential P600.

The observed effect is most likely not a P600 for the following reasons:

Distribution:

The late positivity is highly localized to WL. Previous reports of P600 effects (Osterhout & Holcomb, 1992; Hagoort, Brown, & Groothusen, 1993) note that the distribution is more widespread. In fact, the P600 we report for the anaphor comparison has a wider distribution than this positivity. This observation is confirmed by the fact that there was a main effect of condition in the anaphor agree/disagree comparison but not in the current comparison.

Latency:

The classical P600 effect shows the onset of the positive shift occurring between 400-500 ms. This same latency was observed in the anaphor agree-disagree comparison. In the current comparison, the shift is seen starting at 250 ms. Kutas & Hillyard (1980) report that differences due to frequency/context (Cloze probability) begin as early as 200 ms, and this seems concordant with our observations here.¹²

Logophor-anaphor disagree comparison

The logophor-anaphor disagree comparison is interesting because the theory predicts a P600 for the anaphor and not the logophor, even though each is coreferential with an impossible antecedent. By hypothesis, the violation for the anaphor condition is syntactic and the violation for the logophor is pragmatic.

We suggest the positivity at the logophor is due to its greater relative predictability (as in logophor-anaphor agree comparison) and that there is a P600 for the anaphor (as in the anaphor agree/disagree comparison). The positivities

¹²This so-called predictability hypothesis predicts that an early negativity ought to also be present in the poor comprehenders. While the P600 is dependent on successful performance in the experimental task (cf. between group differences in the anaphor agree/disagree comparison), predictability is orthogonal to coreference. We therefore expect that the difference observed in the current (logophor-anaphor agree) comparison to also be present in the data from poor comprehenders. This means that they will show differences for type (logophor-anaphor) but not for agreement match/mismatch. This is borne out in the data (which for brevity's sake are not reported here). Logophors are more positive than anaphors in both the agreeing and disagreeing conditions in the poor comprehenders' data.

predicted in both conditions are consistent with the hypothesis that both conditions elicit a P600. However, the "predictability" hypothesis predicts an earlier onset for the logophor positivity than that seen in a typical P600. In Figure 4, it is evident that a positivity begins around 300 ms. That positivity becomes weaker as the epoch progresses. In fact, around 600 ms, it crosses over the anaphor wave and becomes less positive, significantly so at the midline sites. In summary, the positivity for the logophors is strongest in the early portion of the epoch, while the positivity for the anaphor occurs later in the epoch. This is consistent with the hypothesis that a probability-induced positivity exists for the logophor while a P600 is elicited by the anaphor.

Conclusion

There were two main predicted effects: first, that there should be a P600 for the anaphor agree/disagree comparison and second, that there should be no P600 for logophor agree/disagree comparison. Both of these predictions were confirmed in the data from the good comprehenders. By hypothesis, the first comparison contains a syntactic violation and the second a non-syntactic violation. The results, taken with other experiments involving the P600, suggests that the comparisons involving arguments are mediated by processes sensitive to syntactic constraints, while the processes for nonarguments are either insensitive to those constraints, or sensitive in a very different way.

Two further comparisons (anaphor-agree vs. logophor-agree and anaphor-disagree vs. logophor-disagree) seem to be consistent with the predictions that there ought to be no indication of ungrammaticality for the agree-agree comparison, and that one ought to exist for the disagree-disagree comparison. The agree-agree comparison appears not to show a P600, but rather an earlier positivity most likely sensitive to between-type probabilistic differences in this experiment. Furthermore, the results for the disagree comparison were consistent with the hypothesis that the anaphor-disagree sentences had syntactic violations and the logophor-disagree sentences did not.

Why is this interesting? There now seems to be evidence that language processing is sensitive to the environments that arguments appear in. Yet the notion of argumenthood is not superficially derived from the speech stream. For example, reflexives in conjoined NPs, like those appearing in this study, are in the same distribution as single NPs. Some tip-off to the parser might be available if the conjoined noun phrases in which logophors appear did not themselves have to

appear in argument positions. In other words, if CNPs sometimes appeared in non argument positions, it might be surmised that reflexives they contained are non arguments in that configuration, and perhaps in all configurations. In fact, a survey of the 1989 AP news wire releases reveals no CNPs containing reflexives (himself, herself, themselves) in nonargument positions. This is surprising, since sentences like *John erected a fence around Mary and himself* are neither implausible nor difficult to understand. In sum, there is a mysterious lack of distributional evidence regarding the argument status of reflexives in CNPs.¹³

In summary, we believe that our results show that:

- (a) Condition A is a syntactic constraint.
- (b) Constraints on logophor antecedents are not syntactic.
- (c) The structural property of argumenthood is crucially involved in computation.
- (d) There is good reason to expect that electrophysiological investigations can play an important role in the establishment and testing of theories concerning the nature of language and how it is represented in the brain.

¹³Only seventy percent of these reflexives had local antecedents, which could be argued to be the kind of distributional evidence we are looking for. However, this is begging the question, since it is not orthogonal to the predicted consequence of nonargumenthood for reflexives.

Section II

Chapter 3: Memory in parsing

In the preceding chapter, we saw that event-related potentials could be useful in revealing grammatical knowledge. The history of this methodology with respect to parsing has been rather murky. There have been two problems which impeded this research. The first has been a lack of a sufficiently formal understanding of memory use in parsing, i.e., predicting relative difficulty at a given point in a parse. The second a lack of understanding the electrophysiological correlates of memory.

This section makes use of Just and Carpenter (1992) notions of working memory for language, primarily because a series of experiments to be described shortly make it a plausible model. For specific predictions of processing complexity with respect to working memory, Gibson (1998) is followed.

Shared Resource Model

There is a view in the processing literature that holds that the storage of items and their manipulation draw upon a common resource. Baddely & Hitch (1974) noticed that subjects required to remember several digits while listening to rapidly spoken sentences did poorly in responding to comprehension questions.

This prompted Just and Carpenter (1992) to speculate that some working memory resources could be shared by numerous subsystems. Any given process is constrained by the number of items currently being stored, and the number of items being stored is limited by the number of on-going processes. Here, an item could be a word pending integration in the current parse and a process could be a parse or integration of sentence meaning into a discourse environment.

There is a rule-based system that controls the activations between nodes in an interconnected network. Nodes are working memory items and the rules are directed activations between nodes. For example, when the subject of the sentence is active, a

production rule begins to activate the main verb node in anticipation of encountering it in the speech/text stream. Rules apply to nodes iteratively, increasing or decreasing their levels of activation. The activation of some target nodes is dependent on the pattern of activation of source nodes. The total level of activation is constrained by a person's working memory capacity. If that capacity is exceeded, then the level of activation of all active nodes is scaled back. The reduction for each node is proportional to its activation level. This makes processing slower, as more cycles are needed to bring the relevant nodes to threshold.

Processing difficulty is encountered if the distance between two related items is great. This means that there is less activation available for the first item by the time the second it reached. The integration of the two items will take longer than if they had been separated by a shorter distance. The idea of distance leading to processing difficulty is a theme in the research that is described in this chapter.

A key notion for Just & Carpenter is the capacity a system has for storage and manipulation. With respect to language, this is indexed by "reading span." Subjects are asked to read aloud sets of sentences and to remember the final word of each sentence. After a certain number of sentences in each set has been read, the subject is asked to repeat all the final words of that set. The subject's score is based on the number of words he can successfully recall.

In King and Just (1991), subjects rehearsed one or two unrelated words while reading sentences containing subject and object relatives (as in (1a) and (1b)).

- (1) a. The reporter who attacked the senator admitted the error.
- b. The reporter who the senator attacked admitted the error.

For subject relatives, performance of high-span readers was unaffected. Low-span performance was worse with one or more words as opposed to zero words. For object relatives, both reading groups were impaired with one or more words as opposed to zero.

Gibson (1998) model of prediction, retention, and integration

Gibson (1998) makes specific predictions about regions of processing difficulty. There are two kinds of computational costs incurred in a parse: predicting and remembering categories on one hand and integrating categories with their licensors on the other. The former predicts processing breakdown and garden path effects while the latter predicts reading time increases. The model is presented for concreteness.

(2) The reporter who attacked the senator admitted the error.

A	B	C	D	E	F	G	H	I
The	reporter	who	attacked	the	senator	admitted	the	error
$M_B(0)$	*	$M_D(0)$ $M_{gap}(0)$	* *	$M_F(0)$	*	$M_I(0)$	$M_I(0)$	*
1M	0	2M(0)	1M(0)	1M(0)	0	1M(0)	1M(0)	0

$M()$ cost in memory units (as described by some function M).

M_D cost predicting the category of the word in column D.

(1) number of discourse items crossed since the prediction was made (argument of M).

* the point at which the prediction immediately to the left is realised.

In this theory, the cost associated with maintaining the prediction of an upcoming category is 1 memory unit (described by some function M). Gibson does not specify what that function should be. For most sentences, a linear function works: load is proportional to the number of categories predicted.¹

The cost of retaining each prediction after encountering a new discourse item (certain NPs or a tensed verb) is $1M(1)$, that is, one times the function $M(1)$. For example, in (3), the prediction of the relative clause gap (after *met*) which is made at *who*, has a cost of $1M(3)$ at *Susan*. *John*, *told*, and *Susan* all count as new discourse items.

(3) The man who John told Susan he met is a pilot.

¹Although there is evidence that the function is asymptotic for large argument values.

There is no cost associated with a matrix verb, as each sentence must contain one and its cost is assumed by Gibson (1998) to be part of minimal parser operations. In example (2C), there is a cost for predicting the gap that the filler *who* is associated with and the verb which licenses the gap ($2M(0)$). At (2D), these two predictions are satisfied, causing the load to go to 0. At the same time, the direct object (2F) is predicted, leaving the total load at $1M(0)$.

(5) The reporter who the senator attacked admitted the error.

A	B	C	D	E	F	G	H	I
The	reporter	who	the	senator	attacked	admitted	the	error
$M(0)$	*	$M_F(0)$ $M_{gap}(0)$	$M_F(0)$ $M_{gap}(0)$ $M_E(0)$	$M_F(1)$ $M_{gap}(1)$ *	*	$M_I(0)$	$M_I(0)$	*
$1M(0)$	0	$2M(0)$	$3M(0)$	$2M(1)$	0	$1M(0)$	$1M(0)$	0

The cost in (5C), is the same as that in (2C). This is carried over in (5D) and is added to the cost of predicting the relative clause subject (5E). At (5E), the RC subject prediction is realised, but now "senator" drives up the load as a new discourse item, yielding $2M(1)$. This is a higher load than any other position in (2).

Support for this metric comes from self-paced reading time studies in which complex integrations at the verb require more time than simpler ones. In the current example, the integration cost at (2C) "attacked" is $1I(0) + 1I(1)$:

$1I(0)$: integrating the subject gap with the filler, with 0 intervening discourse items.

$1I(1)$: integrating the subject with the verb, with the verb itself considered one new discourse referent.

I cost of integrating one item (as described by some function I).

I_D cost predicting the category of the word in column D.

(1) the number of new discourse items crossed since the prediction was made(argument of I).

Compare this to the integration cost at "attacked" at (5F), $1I(1) + 1I(2)$:

$1I(1)$: integrating "senator" with the verb after one new discourse referent ("attacked") has been encountered.

1I(2): integrating the gap with the verb with two new discourse referents intervening ("senator" and "attacked").

We will see shortly that there is some reason to believe that electrical recordings from the scalp are sensitive to differences in working memory loads. If this is true, then we may have evidence for the predicted increases in memory load. Hopefully, we will be able to detect not only when load goes up, but how much it goes up, and how long it persists. This would provide the most direct evidence we have so far for analyzing parsing complexity and the on-line use of grammatical knowledge.

ERP evidence of memory in language

Ruchkin et al.

Ruchkin, Johnson, Grafman, Canoune, & Ritter (1992) studied the effects of increasing the memory load requirements in tasks requiring subjects to determine whether two successive stimuli were equivalent.

The first task involved a (non-word) syllable string target presented on a computer screen. After the target disappeared, a probe, which was either the target string or some other string, was presented in the same place. The subject had to decide whether the probe matched the target.

The second condition used the spatial configuration of letters on a computer screen as a target. The probe was a configuration of asterisks. The subject had to decide whether the probe configuration matched that of the target configuration. Both the phonological (word) task and the spatial task had three levels of complexity, as shown in Table 1. Note that the consonants used in the two tasks are identical, thereby reducing the likelihood that any differences between tasks would be due to stimuli identity.

Complexity	Phonological	Spatial
3	MEUPO	MM PP UU
4	RUDIZOHA	RR ZZ HH DD
5	CUHOFAPATI	CC TT FF HH PP

Table 1

Sample targets for the two tasks (Ruchkin et al., 1992). In the phonological condition, subjects decided whether non-word probes matched targets. In the spatial condition, subjects decided whether asterisk configurations matched target configurations.

Recordings of brain waves took place between the presentation of target and probe. Both tasks elicited slow waves, that is, long-lasting differences in relative amplitude without any peak architecture in the wave. However, both tasks elicited distinct topologies, suggesting that the working memory involved in the two tasks are neurally distinct.

The slow wave in the spatial task (not shown here) was maximal in parietal regions and was indexed to load, i.e., the more complex conditions elicited more negative going waves during the retention period.

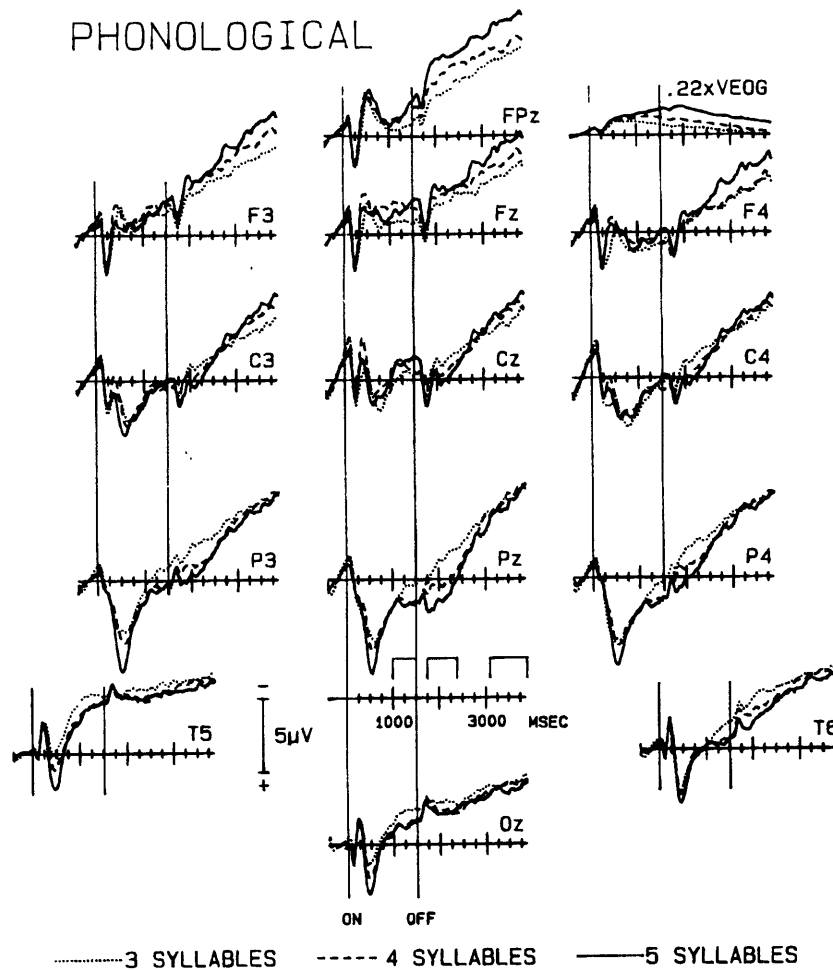


Figure 1

Figure 1 shows four frontal sites and three central sites (Ruchkin et al., 1992). F3 is the left anterior site. Fz is central anterior and F4 is right anterior. Negative is plotted up. Note that load effects are largest at the left anterior and anterior central sites.

There were four slow waves elicited by the phonological task, one of which was an anterior negativity, larger on the left, which was indexed to the number of syllables presented. This slow wave has since become the subject of interest in a number of language-related experiments.

Filler-gap constructions

Kluender & Kutas (1993) discovered that a slow-going² negative wave appeared in filler-gap constructions, reminiscent of the one observed by Ruchkin et al. (6a) is

²not identified by features with high slopes.

an example of a filler-gap construction. The filler is *who*. The gap is the missing word following *find*. Notice in (6b) that it is not permissible to omit the argument to *found*. In (6a), it is permissible because the gap is somehow licensed by the filler, *who*.

- (6) a. Who did John find ___ ?
 b. *John found ___ .

Kluender & Kutas compared sentences such as those in (7).

- (7) a. Have you forgotten that he dragged her to a movie that weekend?
 b. Who have you forgotten that he dragged ___ to a movie that weekend?

They compared the recordings made at *you*. The scalp potential was more negative at left anterior sites in (7b) than (7a). (See Fig. 2.)

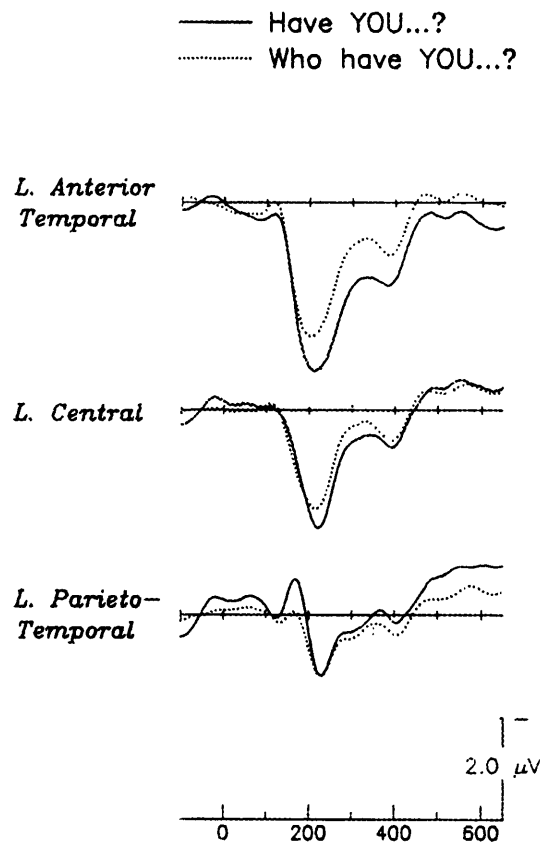


Figure 2

Electric potentials recorded during the epoch that "you" was presented (Kluender & Kutas, 1992). This epoch in the filler-gap condition was more negative than in the yes-no question. Negative is plotted up.

The speculation made in this study is that the left anterior negativity was related to holding an item in working memory prior to associating it with the gap position. Unfortunately, this comparison contains a confound, namely that the word preceding the point of measurement was in a different sentence position in each condition. The preceding word in the control condition was the first word of the sentence. Van Petten & Kutas (1991) have shown that sentence-initial words have greater amplitude N400s than non-initial words. While this effect is greatly reduced for closed class words like you, it potential affects subsequent measurements because in order to compare two wave forms, it is necessary to assume that the preceding (100 ms) epoch contains data points that hover around 0 volts. If one wave is more negative in the baseline epoch and nondifferent in the critical epoch, then it will appear more positive in the critical epoch. In Figure 2, this would have the effect of pulling the solid line down.

A second comparison in this experiment had a related baseline issue.

— Who has she forgotten that THE...?
 - - - Who has she forgotten if THE...?
 ····· Who has she forgotten what THE...?

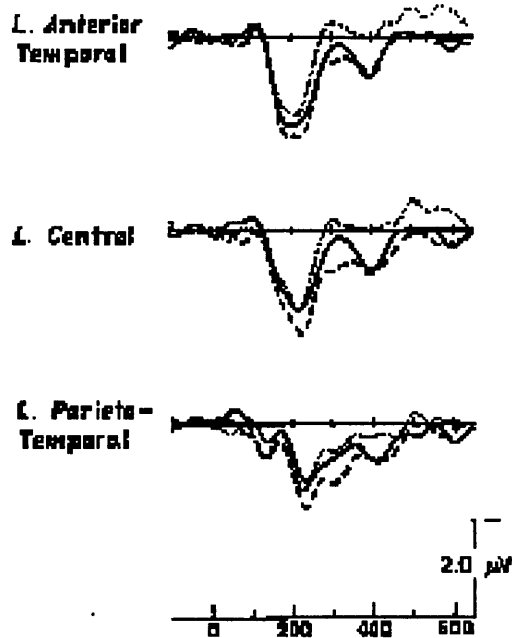


Figure 3

solid: Who has she forgotten that the boss referred that matter to __ for further study?
dashed: Who has she forgotten if the boss referred that matter to __ for further study?
dotted: Who has she forgotten what the boss referred __ to __ for further study?

In this comparison, the *what* condition elicited a greater negativity than the other than the *that* or *if* conditions. We can see that the baselines for the comparison were all different at the *the*, as we can expect a different ERP for different lexical items. A further problem with this comparison is that the *what* signals a Subjacency violation. McKinnon & Osterhout (1996) show that there is an early negativity at the *what* when compared to a *what* in a nonviolation condition. This shows that we might expect a negativity due to the violation alone, regardless of whether the control condition contained a nonfiller. The Kluender & Kutas results are difficult to interpret given these confounds.

Nevertheless, the results of this experiment were similar to a study by Neville et al. (1991) who compared (8a) to (8b).

- (8) a. The scientist criticized Max's proof of the theorem.
 b. *What did the scientist criticize Max's proof of _ ?

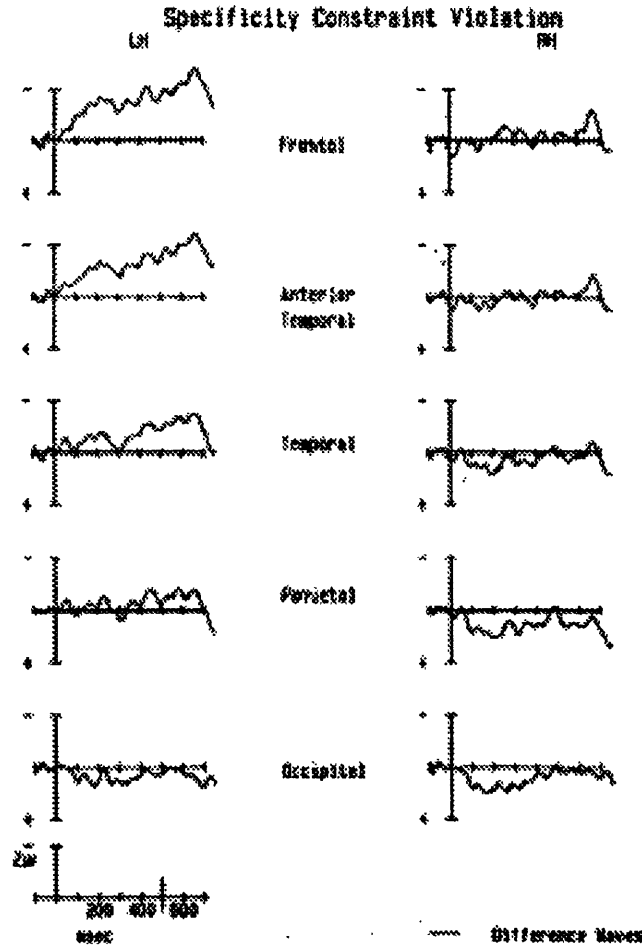


Figure 4

In Figure 4, the plots are difference waves. This means that each point is the result of subtracting the control from the violation condition. The measurement was taken at the word following the specifier, which is *proof* in (8). In this epoch, a slow negativity was present, and it was strongest over the left anterior region, much as was observed in Kluender & Kutas. It was observed at the earliest portions of the epoch. If it were true that this finding were complementary to the Kluender & Kutas study, the negativity would have been present in epochs preceding *proof*. These data are not reported, however.

Subject-object relative clauses

King & Kutas (1995) reported a LAN effect inside relative clauses.

- (9) a. subject-subject
 The reporter who __ harshly attacked the senator admitted the error.
- b. subject-object
 The reporter who the senator harshly attacked__ admitted the error.

In (9a), the filler, *who*, may be associated with the subject gap of the relative clause upon encountering *harshly*. In (9b), the filler must be held in memory for three words (*the senator harshly*) before a gap can be identified (after *attacked*). Thus, the subject-object relative is said to create a greater load for working memory (c.f. Gibson 1998).

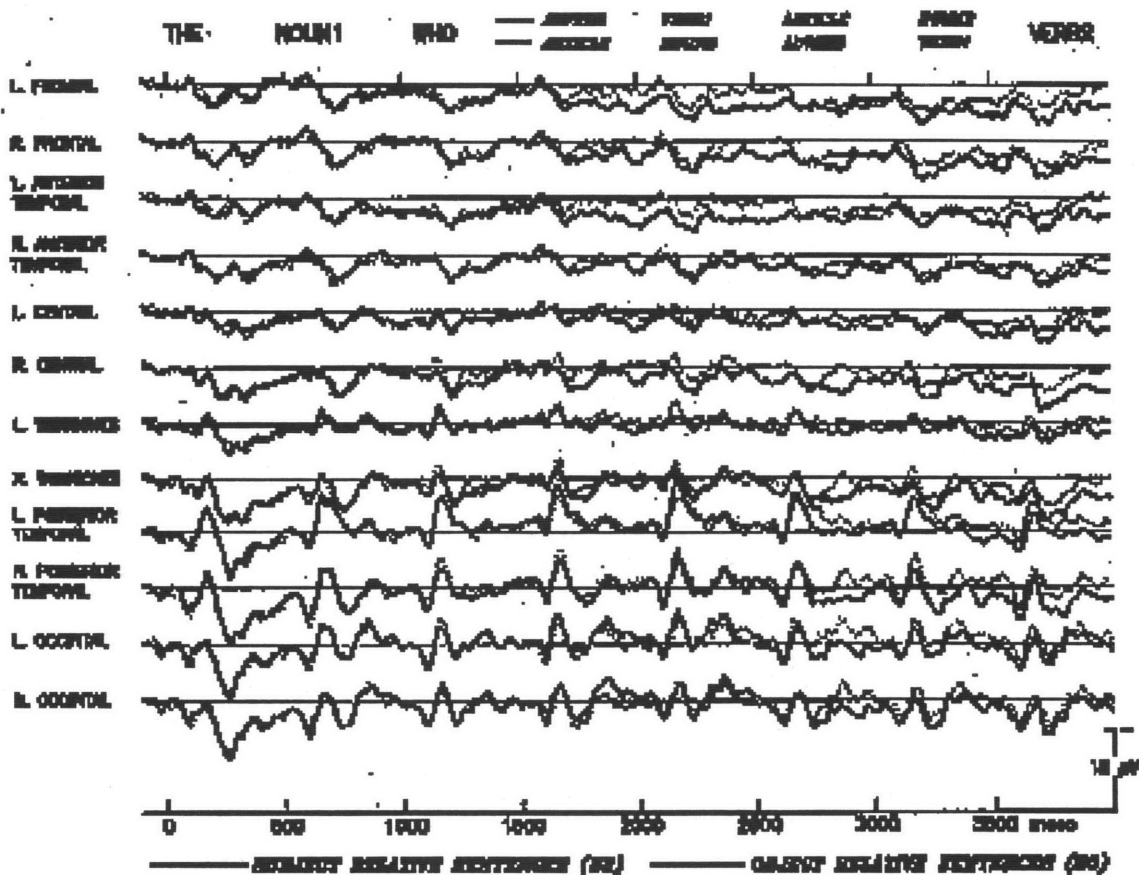


Figure 5

In multi-word recordings, subjects showed a greater negativity in anterior regions for the S-O condition than in the S-S condition.

As can be seen in Fig. 5, differences emerged for the S-O and S-S sentences at left anterior sites, with the ERPs in the S-O regions being more negative. Unfortunately, these comparisons are between different lexical items. Open class words such as *harshly* are known to elicit greater negativity than closed class words like *the*, at least in posterior regions (Van Petten & Kutas, 1990).

Below is a plot of the relative clause epoch and matrix clause predicate, which has been filtered at 20Hz to preserve latency information.³ (The data come from an unreported attempt at replication using a subset of their stimuli.) This is the left-most anterior site.

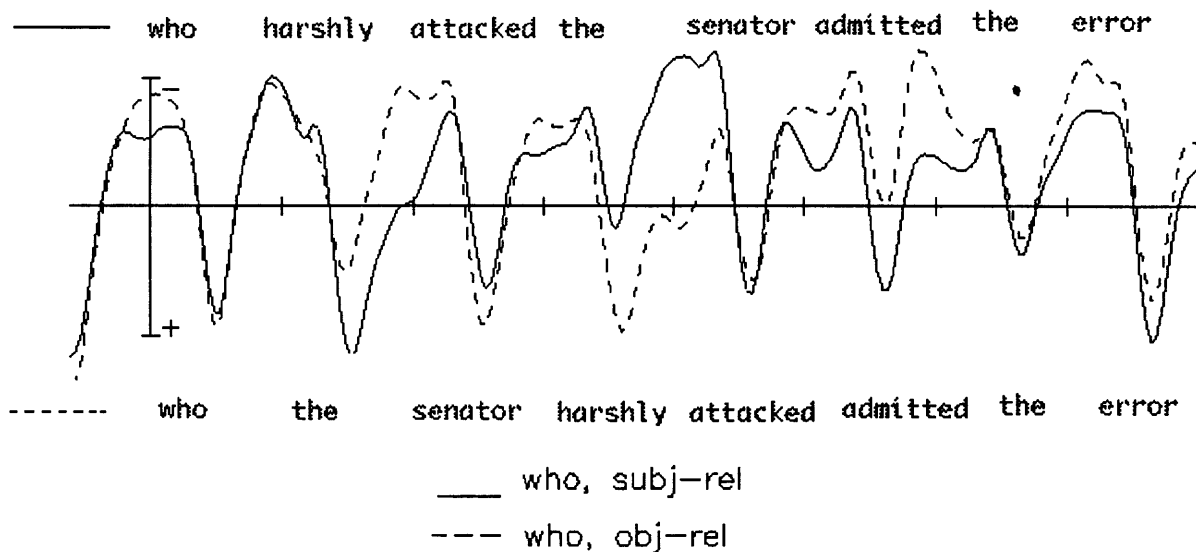


Figure 6
cal bar 2.5 μ V/side, baseline -300 to 0, ticks 650 ms, epoch -300 to 4000 ms

There was a left anterior negativity associated with the words immediately following the *who*. As can be seen in Fig. 6, this negativity is elicited by *the* in the object relative condition. It is suppressed in the subsequent epoch. The same is true of the next comparison of article and adverb. The article in the subject relative elicits the negativity. This negativity is much stronger than the one reported in King &

³Our software performs a Fourier transform to separate out unwanted frequency components and drops them. The remaining frequencies are reintegrated. A running average is then performed, which means the each point is given the average value of adjacent points. This allows effects occurring in later times to be propagated backwards.

Kutas. Notice that this negativity is not consistent with previous literature (Van Petten & Kutas, 1990). Articles such as *the* are expected to elicit no difference in anterior regions. In Figure 7, an N400 is observed for the second *the* in posterior regions. This is also unexpected. King and Kutas do not offer an explanation for this but point out that no similar N400 occurs for the first article-adverb pair. They suggest that this is an indication that an additional process is occurring in the first comparison, namely, one related to increased memory load.

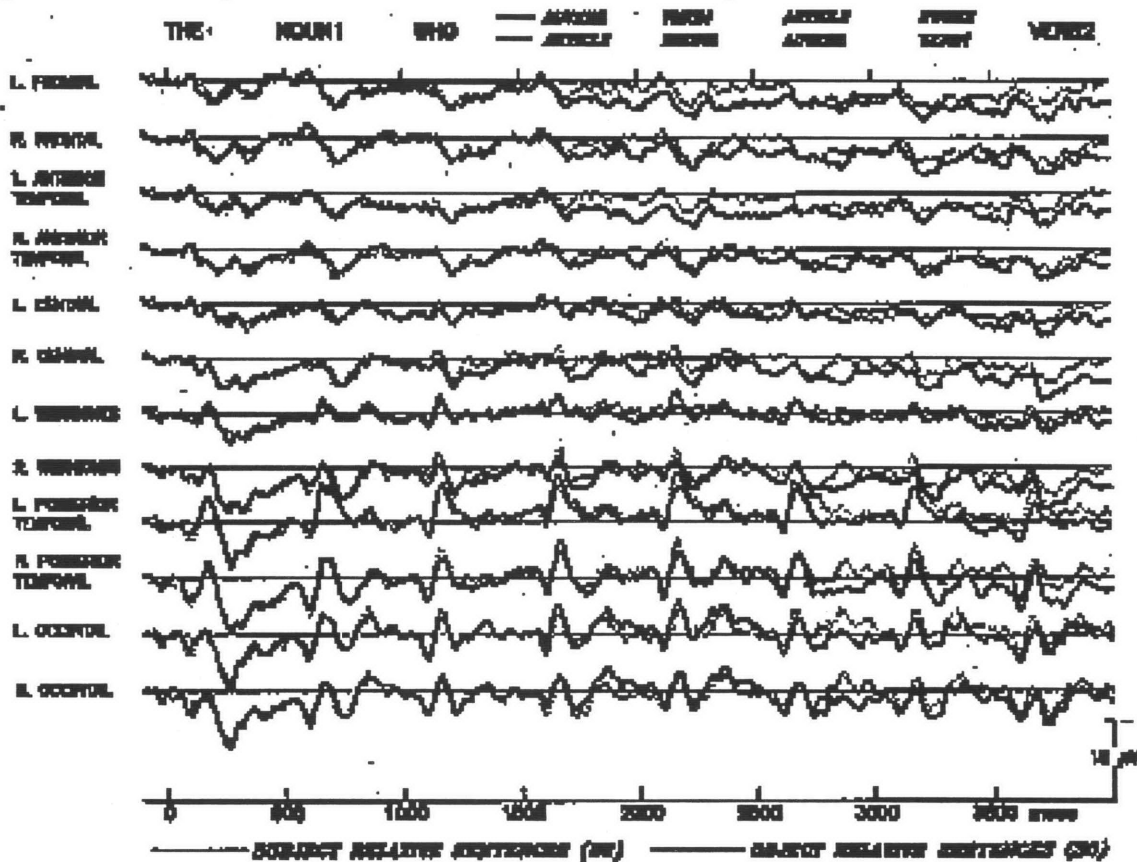


Figure 7

In single-word recordings, subjects showed a greater negativity in anterior regions for the article. The last article-adverb pair showed evidence of an N400.

While it is not clear to what to attribute the results of the S-O relative comparison, the negativity seen following the matrix verb (*admitted*) in the object relative condition, can only be due to word order effects in the relative clause, since the words thereafter are identical. A late negativity was also observed in Kluender & Kutas. Unfortunately, this persistent negativity is not explained by any current

sentence processing theory.⁴ It may be the case that a LAN was elicited by the S-O comparison, but extraneous factors made it impossible to detect with confidence and it became apparent only where the words in the comparison were identical. In summary, while this study does not provide evidence for a memory-related LAN, it does make clear that there is some ERP phenomenon associated with subject-object relative comparisons.

In order to continue this line of research, the first task is to understand what the extraneous factors are in order to eliminate them from subsequent studies. Only then can we begin to manipulate the comparisons to draw out the driving forces behind the effect. Developing an ERP tool which indexes memory use is appealing because of the promise of determining the role of working memory in parsing and what the specialized nature of this resource is, if any, in parsing tasks.

⁴Note that Gibson (1998) predicts reading time slowdowns at the gap.

Chapter 3: Discourse-linking in filler-gap constructions

Abstract

An electroencephalographic left anterior negativity (LAN) has been observed following the detection of a filler in past experiments (Kluender & Kutas, 1993; King & Kutas, 1994). For example, a negativity appears at *you* in *Who did you say liked Susan?* when compared to the same word in *Did you say John liked Susan?* This is putatively an index of the working memory required to store the filler, pending later integration with its gap position. However, Osterhout & McKinnon (1996), failed to produce this result using *which-NPs* as fillers. A hypothesis considered in the current experiment, following Pesetsky (1987), is that the *which-NP* does not share the same syntactic relationship to its gap. However, no LAN was observed for either the *who*-type fillers or for the *which-NP* fillers, confirming the Osterhout & McKinnon finding, and casting further doubts on the findings of Kluender & Kutas (1993).

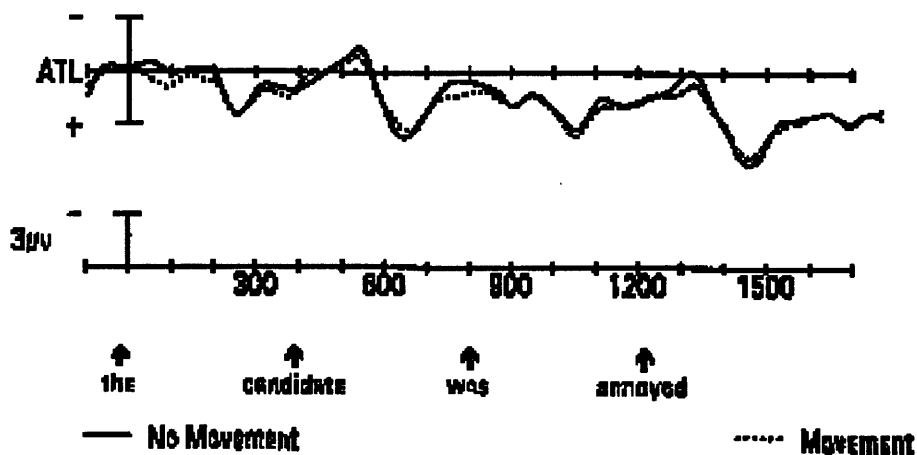
Introduction

Studies cited in the previous chapter suggest that filler-gap constructions may elicit left anterior negativities, possibly indexing working memory use. However, not all filler-gap constructions studied experimentally have elicited such an ERP.

McKinnon & Osterhout (1996) studied Subjacency violations¹ with sentences like (1a-b). They used controls (1c-d).

- (1) a. I wonder which of his staff members the candidate was annoyed when his son was questioned by ____.
b. I wonder whether the candidate was annoyed when his son was questioned by a staff member.
c. a. I wonder which of his staff members the candidate was annoyed that his son was questioned by ____.
d. I wonder whether the candidate was annoyed that his son was questioned by a staff member.

In (1c-d), there is an example of the type of comparison which is related to the LAN studies just cited. In (1c), there is a filler-gap construction using *which*-PP. (1d) contains identical words except that the *which* has been replaced by *whether*, which does not participate in a filler-gap construction. However, McKinnon & Osterhout found no reliable differences when comparing the epochs preceding *that* in (1c-1d) or *when* in (1a-1b).



¹The point at which this violation is revealed follows the region relevant to this discussion, so the reader is referred to the original study for description of the nature of this violation.

Figure 1

From this, McKinnon & Osterhout conclude that the LAN effects observed in earlier studies were artifactual. The King & Kutas comparisons were over different lexical items, and the problems associated with that are discussed in Chapter 2. The Kluender & Kutas comparisons had used epochs with different lexical items or word positions for baselines.

However, there are a number of other ways in which McKinnon & Osterhout's study differed from these two. The least interesting, from a syntactic perspective, is that a majority of their which-NP items contained inanimate rather than animate objects. Unpublished results of a filler-gap experiment that I did suggest that there is a difference in the ERPs between the two. *What* fillers in embedded sentences were less negative than *who* fillers.

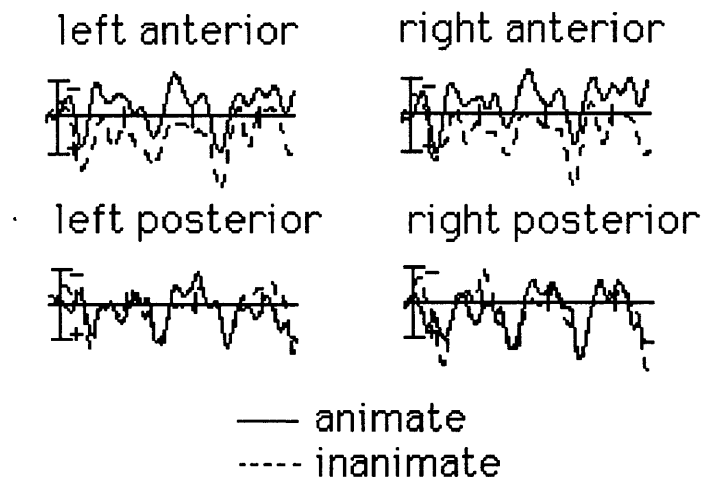


Figure 2
2.5 μ V/side, ticks 650 ms

The McKinnon & Osterhout study is also unique in its use of the *which*-NP construction as opposed to *who/what*. There are widely recognized distinctions between highly specific WH phrases, such as the *which*-NP, and less specific phrases such as those headed by *who*, *what*, etc. This topic has been discussed extensively in the linguistic literature (Pesetsky, 1987; Rizzi,

1990; Cinque, 1991; Manzini, 1992). In laying out his rationale for the 1993 study, Kluender (1990, 1992) recasts these distinctions as processing phenomena.

Consider the following observations:

- (2) a. ?Which cars don't you remember how he fixed?
- b. *What don't you remember how he fixed?

(2a) is considered either acceptable or awkward by native speakers, while (2b) is considered worse (a Subjacency violation). The difference is between using *which cars* and *what* as extracted elements. Kluender argues that *which cars* limits the answers to a more restricted set of possible referents than *what*.

Consider the difference in acceptability in the following sentences, which are listed from best to worst (taken from Bolinger (1972) in Kluender (1990)). The extracted item is increasingly less specific going from (3a) to (3d).

- (3) a. It's the marine corps that I know the officers in.
- b. Which service branch do you know the officers in?
- c. How many service branches do you know the officers in?
- d. What do you know the officers in?

Pesetsky (1987) suggests that this difference is reflected structurally. The contrast seen in (4) may be evidence that the *what* and *which-NP* undergo different types of movement at a level of semantic analysis (LF). In this case, antecedent government exists for *who* and its trace in (4a) and a binding relationship between two argument positions for *which man* and its trace in (4b).

- (4) a. *Mary asked what who read.
- b. Mary asked what which man read.

The actual mechanisms for this difference are not tested in the current experiment, so the reader is referred to Pesetsky (1987) and Cinque (1992) for discussion of this and related problems. In addition, this hypothesis, as we shall see, did not prove to be fruitful. Let it suffice to say that linguistic theory

suggests that the *what* and *which*-NP enter structurally dissimilar filler-gap relations. While not predicting the disparity in the Kluender & Kutas and the McKinnon & Osterhout studies, it can be used as an ad hoc explanation.

The following study was designed to reveal any ERP difference between a discourse-linked filler (5b) and one that is not (5c). Specifically, in order to reconcile the previous studies, we predicted that only a non discourse-linked filler (5c) will elicit a LAN with respect to its control (5a).

- (5) a. Emily wondered **whether** the performer in the concert had imitated a popstar for the audience's amusement.
- b. Emily wondered **which popstar** the performer in the concert had imitated for the audience's amusement.
- c. Emily wondered **who** the performer in the concert had imitated for the audience's amusement.

According to the discourse-linking hypothesis, the following predictions are made:

- 5 a-b: little or no difference between *which* and *whether*
- 5 a-c: *who* elicits greater negativity than *whether*
- 5 b-c: *who* elicits greater negativity than *which*

Method

Subjects. Twenty-nine subjects (14 male) were recruited from Tufts psychology subject pools or paid for their participation. Each participant was right-handed and had learned only English in infancy. The age range was 18 to 32.

Materials.

There were two sets of 168 sentences, 90 of which are experimental sentences, and 78 of which are fillers. Each set contains one member of each sentence triplet. Therefore, there are three conditions in each set, and 30

exemplars of each condition. Each subject saw only one set. The order of sentences in each set are pseudo randomized.

In half of the cases, the matrix verb was 'asked'; in the other half, it was 'wondered'. The matrix subject was always a proper name, half of the cases denoting a woman, half of the cases denoting a man. The subject of the embedded clause was always a singular noun, modified by a three-word prepositional phrase. The subject was followed by the auxiliary 'had' and a participle verb. In the *whether* conditions, the direct object following the verb was either a singular noun preceded by the indefinite determiner *a* (50%), or a plural noun preceded by *some* (50%). Each sentence was completed by an adverbial expression at least three words in length.

In the *which* condition, *whether* was replaced by the direct object, with *which* replacing the *some/a*; in the *who* condition, the *which-N* phrase was replaced by *who*. In all cases, the subject NP and the filler NP (or corresponding direct object) referred to human entities.

To guarantee that the embedded verb was the place at which the *wh*-word would be assigned a thematic role, the verbs used were strongly transitive, that is, preferably took an NP complement over a PP or infinitival complement. Each verb was determined to be transitive with a Cloze probability of at least 83. (See Appendix B for details.)

Each subject was presented one of three lists. Each list was comprised of three blocks. Each block was comprised of 57 sentences. To encourage subjects to read for comprehension, a random third of the sentences were followed by a comprehension question. There were either two or three questions in each set.

1. Ms. Hooper didn't know that the smoke detectors in the hall had been tampered with. Where were the smoke detectors?
2. Kim said that the map of Italy contained some errors in the legend.
3. Emily wondered whether the performer in the concert had imitated a popstar for the audience's amusement. Who was wondering about something?
4. Angie asked which immigrants the officer at the airport had arrested for possession of drugs. Where was the officer?
5. Betsy wondered who the director of the opera had kissed after the opening performance.
6. Mr. Epstein said that the scholars at the academy had signed a petition against landmines.
7. Ms. Parker wasn't sure where the banker kept the important documents.

In each list, the ordering of the sets was pseudo-randomized.

Procedure

The subject was seated before a computer screen. Each trial began with a fixation point in the center of the screen, which lasted 500 ms. It was followed by the first word of the trial sentence. Each word appeared centered on the screen for 300 ms, followed by a blank screen for 200 ms. The screen was blank 1350 ms following the last word, which was indicated by a period following the last letter. In one-third of the trials, immediately following were a comprehension question and two possible answers, which appeared in their entirety. The presentation of a question was pseudo-randomized.

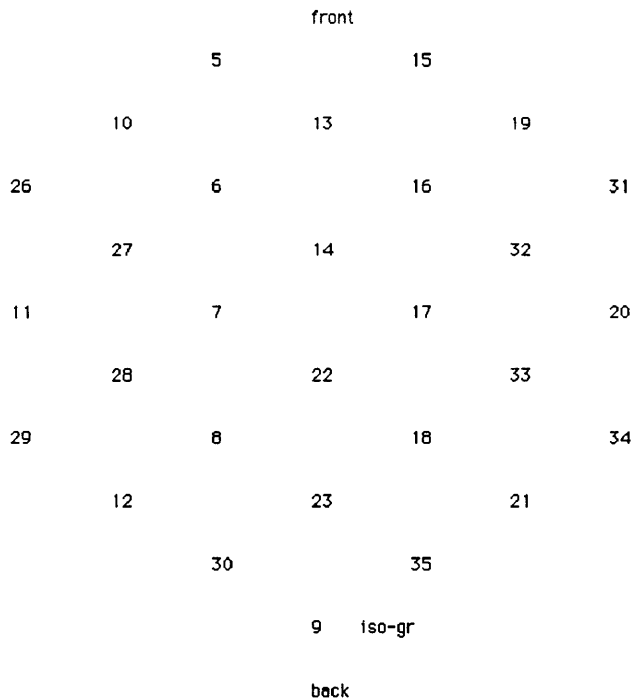
- (6) Ms. Hooper didn't know that the smoke detectors in the hall had been tampered with.
Where were the smoke detectors? living room hallway

The task was to push either the left or the right button on a button box held in the lap. The question remained on-screen until the subject responded. In this example, the answer to (6) would be the depression of the right button, since *hallway* is the rightmost of the two choices.

A ten trial practice session preceded the experimental run. The stimuli had the same structure as in the experimental run. Subjects were given feedback regarding their accuracy.

Data acquisition

A standard electrocap (Electro-Cap International) was used for a nonstandard deployment of electrode sites; the layout left the distances between each roughly equal.



Eye movements and blinks were monitored by means of an electrode beneath the left eye and one to the right of the right eye. The reference electrode was placed on the left mastoid process. A second electrode on the right mastoid was used to determine whether lateral asymmetries arose due to the use of the single reference electrode.

The impedances for the mastoid electrodes were below $2\text{k}\Omega$. Eye electrodes were below $10\text{k}\Omega$ and others were below $5\text{k}\Omega$. Electrode potentials were amplified by a SA bioamplifier amplifier with a bandpass of 0.01 to 40 Hz (6 db cutoff). The sampling rate was 200 Hz.

Data analysis

The comparisons are based on average amplitude within chosen windows. Trials during which there were eye movements and blinks were eliminated. The Geisser-Greenhouse correction was applied to effects involving more than one degree of freedom.

Results

Behavioral data:

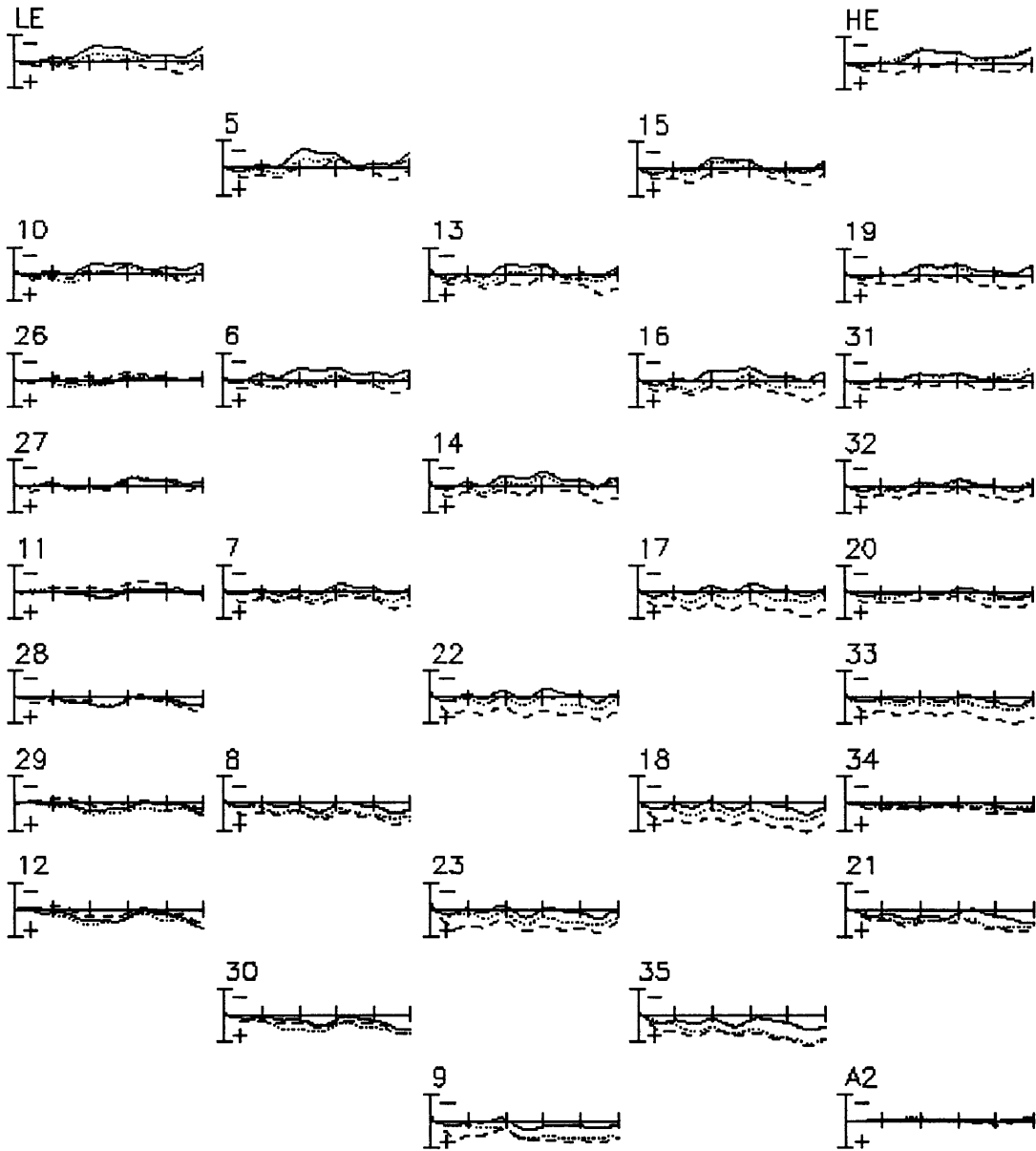
On average 5.9 (stdev 3.7) (8%) errors were made on a total of 78 comprehension questions.

ERP data

Comparisons are based on average amplitude within time windows specified below. A multivariate analysis of variance was conducted using SPSS-PC version 7 GLM procedure. Analysis for the midline channels (13, 14, 22, 23 and 9) was carried out with the within subject factors Condition (whether-which N-who) and Electrode (5 levels); Analysis for the laterals sites was conducted using the channels 5, 10, 6, 27, 8, 28, 30, 12, 15, 19, 16, 32, 18, 33, 35 and 21 and included the factors: Condition (3 levels), Hemisphere (2 levels), Anterior-Posterior (4 levels), and Laterality (2 levels). Contrasts were specified as Helmert contrast, such that *whether* was compared with the means of *which-N* and *who*, and *which-N* was compared with *who*.

We hypothesized that word level differences between the conditions should be found (a) at the words after the wh-words and (b) on the embedded verb.

ERPs for the *whether*, *who* and *which* conditions, starting at the determiner (the word following the wh-phrase) are plotted in Figure 3. The conditions did not differ substantially for word positions up to the embedded verb, save for a right and posterior positivity for the 'which' condition (e.g., site 17, 18 , & 35).

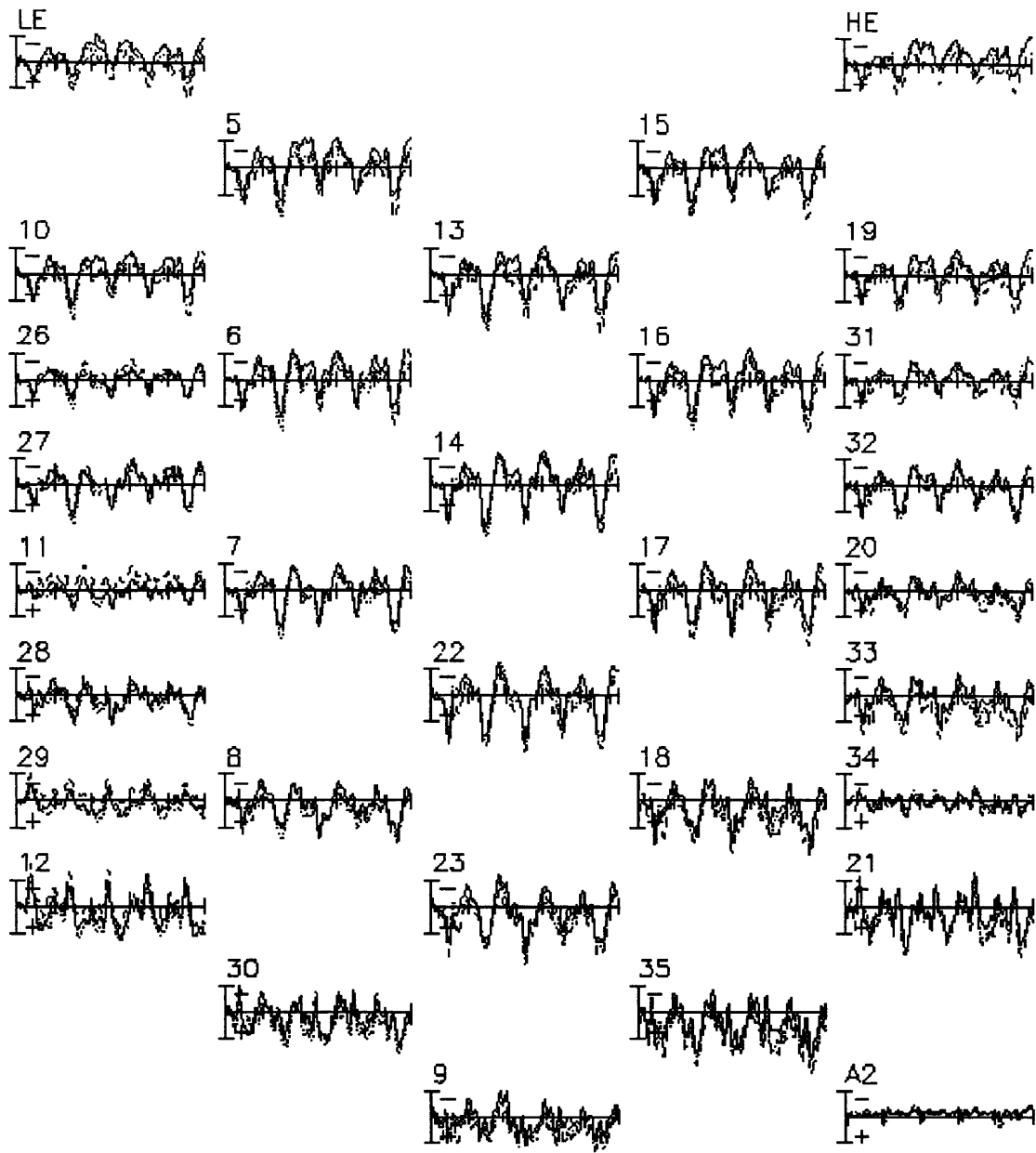


— "the" preceded by "whether"
 . . . "the" preceded by "who"
 --- "the" preceded by "which N"

Figure 3

cal bar 2.5 μ V/side, baseline 0 to 100, ticks 500 ms, filter 1 Hz

Emily wondered **whether** the performer in the concert had imitated a popstar for the audience's amusement.
 Emily wondered **who** the performer in the concert had imitated for the audience's amusement.
 Emily wondered **which popstar** the performer in the concert had imitated for the audience's amusement.



— "the" preceded by "whether"
 . . . "the" preceded by "who"
 --- "the" preceded by "which N"

Figure 4
 cal bar 2.5 μ V/side, baseline 0 to 100, ticks 500 ms, filter 20 Hz

Analyses on the word following the wh-phrase (determiner) are potentially confounded because of the different word classes preceding the determiner

(noun in the *which* conditions, vs. *who* and *whether* in the two other conditions). We therefore used the first 100 ms after onset of the determiner as a baseline. Analyses on the mean amplitude of the 300-500 interval post onset of the determiner, where a LAN effect was expected, revealed no significant difference between the conditions for midline sites. Lateral sites showed a significant interaction of Condition with Hemisphere [$F(2,27)=9.308$; $p=.001$]; Condition with Anterior-Posterior [$F(6,23)=4.096$; $p=.006$]; Condition with Laterality [$F(2,27)=3.933$; $p=.032$]; and three-way interaction of Condition with Hemisphere with Anterior-Posterior [$F(6,23)=3.732$; $p=.010$]; Condition with Hemisphere with Laterality [$F(2,27)=9.108$; $p=.001$]; and Condition with Anterior-Posterior with Laterality [$F(6,23)=3.684$; $p=.010$]. These differences were due to the *which* condition being more negative than the *who* and *whether* conditions at posterior most lateral sites in the left hemisphere, and more positive at right lateral sites.

In contrast to what has been reported in previous studies on filler-retention (Kluender and Kutas, 1993), no LAN effect is seen in the current study. The only difference is a right posterior negativity for the *which* conditions relative to the other two. This, however, may be a baseline artifact; the determiner in the *which* condition is preceded by a noun, rather than a wh-word. Open class words elicit larger (N400) negativities than closed class words. (Van Petten & Kutas, 1988).

Discussion

King & Kutas and Kluender & Kutas hypothesize that the left anterior negativity observed in their experiments is due to the retention of the filler in working memory pending later integration at the verb. The former study compared a subject relative to an object relative, and the latter compared *who*

to *that* and *if*. McKinnon and Osterhout compared *which-N* to *whether*. This last comparison shared the crucial aspect of the first two experiments, namely, a filler-gap relation compared to a sentence lacking such a structure. Yet they did not observe a LAN. Assuming that the *which-N* sentences differ from the *who* sentences syntactically and pragmatically, we attempted to replicate the disparate findings mentioned above. Specifically, we hoped to observe a LAN when comparing *who* to *whether*, but not when comparing *which-N* to *whether*. There was no difference for *who* to *whether* and a right posterior positivity for the *which-N* as compared to the *whether*. In fact, the *which-N* / *whether* comparison gave exactly opposite effects from what was predicted by our hypothesis.

This finding, along with the findings of McKinnon and Osterhout, cast doubt on the usefulness of the filler-gap hypothesis for explaining the LAN observed in the Kluender & Kutas (1993) and King & Kutas (1995) studies. While the ontology of the WH words are well-defined in linguistic theory, their salient properties with respect to on-line parsing haven't been fully explored. It is possible that *whether* is similar to *who* and *which-N* in terms of what the LAN indexes, and therefore was an inappropriate control condition.

Notice that *whether* permits strings that could otherwise not stand alone.

- (7) a. I wondered whether he had imitated a popstar or not.
- b. *He had imitated a popstar or not.

Compare this to a similar property of *who*.

- (8) a. Who did Mary like?
- b. *Did Mary like?

In this view, *who* and *whether* signal to the parser that some noncanonical string is upcoming. According to Gibson (1998), the cost of

predicting upcoming structure increases as (a) the number of predictions accumulate and (b) as new discourse items are encountered. The theoretical shift from holding items in working memory to predicting upcoming categories is potentially the answer needed to explain these null results. If the LAN is related to predicting upcoming structure, then we might expect no difference between the *who-which* comparison.

Two experiments are needed to flesh out this hypothesis. The first is a replication of this study using a control other than *whether*, one which does not make a similar prediction about upcoming structure. The second experiment needed must create a comparison in which no lexical item is demonstrably retained, but a prediction about upcoming structure is made. A LAN would be expected in both of these comparisons.

Chapter 4: Relative clause and prepositional modifiers of head nouns

Tony Harris, Ted Gibson, Phil Holcomb

The left anterior negativity found for filler-gap constructions (Kluender & Kutas, 1993; King & Kutas, 1996) was neither replicated in McKinnon & Osterhout (1995) nor in Chapter 4. The current study is a further attempt at replication with a preposition as a control condition. While some effect was observed from this comparison, it was not a LAN.

Introduction

The slow-wave LAN has come under increased scrutiny because of the failure in replicating the effect (McKinnon & Osterhout, 1995; Chapter 3). The hypothesis pursued by this experiment is that the effect is real, but that a filler-gap construction is neither necessary nor sufficient to elicit the effect.

In Chapter 3, it was suggested that the filler *who* failed to elicit a LAN because *whether* in the control condition had the same relevant properties as *who*. It was proposed that both words licensed phrases that cannot stand independently, such as "Mary liked him or not" (c.f. John wondered whether Mary liked him or not.) The current hypothesis is that this structure-licensing property is the driving force behind the appearance of the LAN.

Who-prep comparison

In the current experiment, a phrase headed by a preposition is compared to a relative clause headed by *who*.

- (1) a. The translator *who* the diplomats at the U.N. criticized responded quietly.
- b. The translator for the diplomats at the U.N. criticized the Secretary General.

The phrase "diplomats at the U.N." is expected to elicit greater negativity in (1a) than in (1b). Admittedly, these two phrases mean different things, that is, they modify *translator* in different ways semantically, but if the LAN is sensitive to differences in processing load, then there is ample reason to expect to find a strong ERP difference here. Consider Tables 1 and 2.

1 a. The translator who the diplomats at the U.N. criticized responded quietly.

A	B	C	D	E	F	G	H	I
The	translator	who	the	diplomats	at	the U.N.	criticized	responded
$M_B(0)$	*	$M_H(0)$ $M_{gap}(0)$	$M_H(0)$ $M_{gap}(0)$ $M_E(0)$	$M_H(1)$ $M_{gap}(1)$ *	$M_H(1)$ $M_{gap}(1)$ $M_G(0)$	$M_H(2)$ $M_{gap}(2)$ *	*	*
$1M(0)$	0	$2M(0)$	$3M(0)$	$2M(1)$	$2M(1)$ $1M(0)$	$2M(2)$	0	0

Table 1

b. The translator for the diplomats at the U.N. criticized the Secretary General.

A	B	C	D	E	F	G	H	I
The	translator	for	the	diplomats	at	the U.N.	criticized	the S.G.
$M_B(0)$	*	$M_D(0)$	*	*	$M_G(0)$	*	$M_I(0)$	*
$1M(0)$	0	$1M(0)$	$1M(0)$	0	$1M(0)$	0	$1M(0)$	0

Table 2

In comparing Table 1 to Table 2, there is a difference in processing load as early as column C. There is cost for predicting the gap and the verb that licenses it. Compare this to column C in Table 2. Here there is only the cost of predicting the object of the preposition. We see that the greatest difference occurs in the prepositional phrase in columns F-G: $2M(1)+M(0)$ compared to $M(0)$ and $2M(2)$ compared to 0. Thus we might expect greater negativities for the entire relative clause.

Method

Subjects. Fifteen subjects (7 male) were recruited from Tufts psychology subject pools or paid for their participation. Each participant was right-handed and had learned only English in infancy. The age range was 18 to 27.

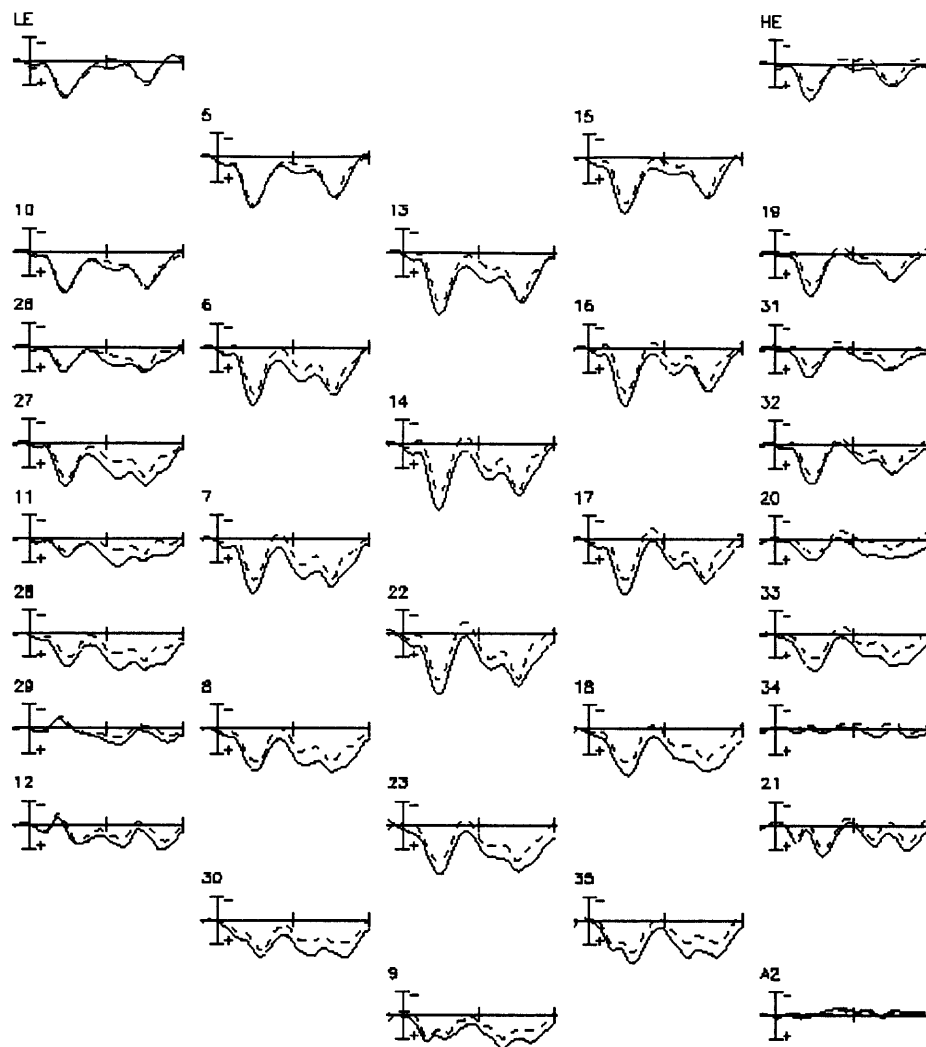
Materials. There were two sets of 100 sentences, 25 of which are experimental sentences, and 75 of which were sentences from other experiments. Each set contained one member of each sentence pair. There were 25 exemplars

of each condition. Each subject saw only one set. The sentences in each set were pseudo-randomized.

Procedure, data acquisition, and data analysis were as in the previous experiment.

Results

The embedded subject is the first point of comparison, as it is preceded by the same article “the” in both sentences. There appears to be a trend toward widespread negativity of the *who* condition relative to the preposition condition. No other effects for condition were observed.



— emb subj, -WH
 --- emb subj, +WH

Cal 2.5 $\mu\text{V}/\text{div}$ Window -100→1000 ticks 500 onset 100

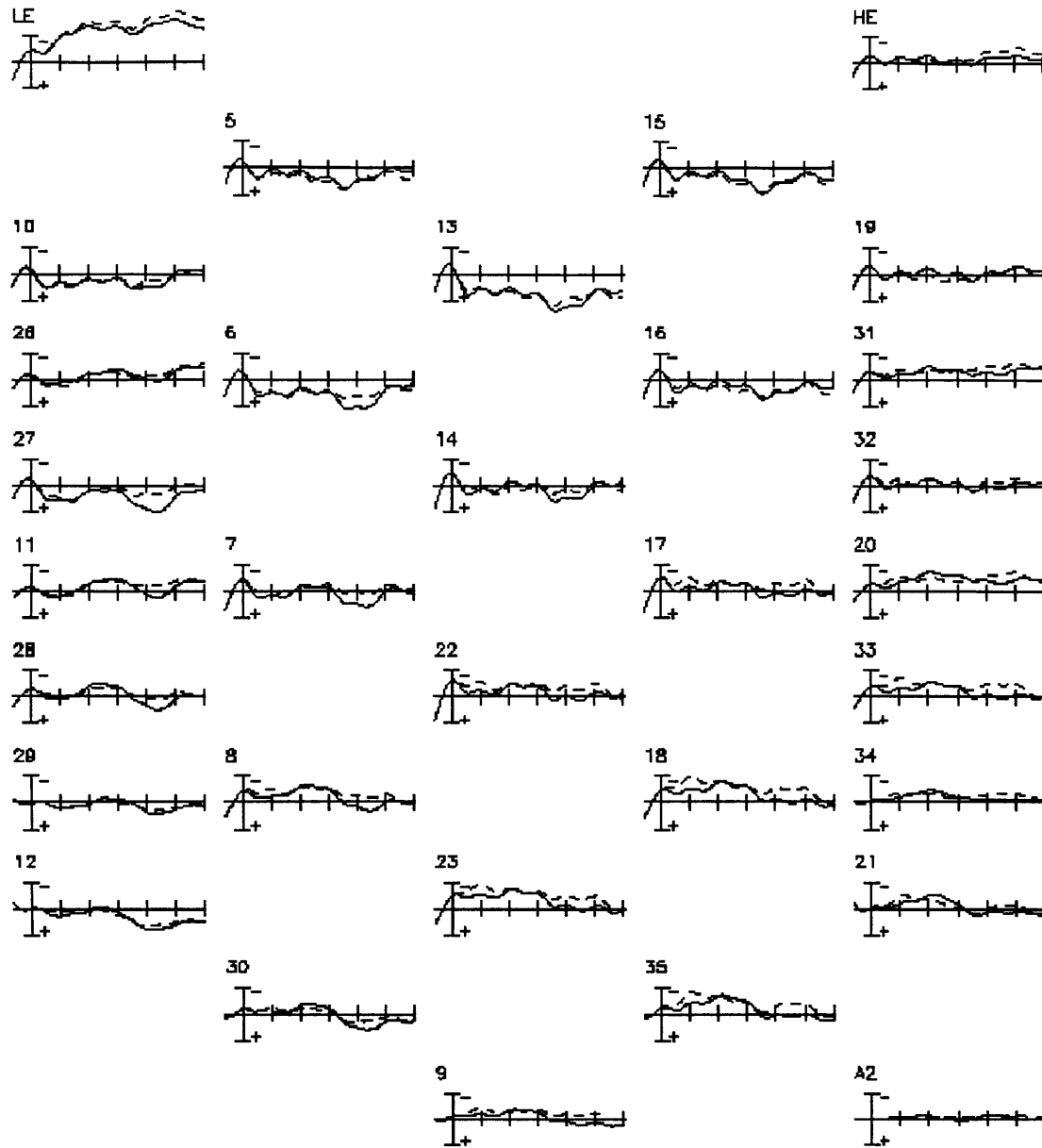
Figure1

-WH: The translator for the diplomats at the U.N. criticized the Secretary General.

+WH: The translator who the diplomats at the U.N. criticized responded quietly.

For all fifteen subjects, an ANOVA for all sites showed a significant effect for condition ($F_{(1,14)}=7.29$, $p_{LF}=.017$). As data for the top ten performers is reported in the subsequent experiment, it is noted here that they also showed a significant effect in a one-tailed test. ($F_{(1,9)}=3.61$, $p = .045$).

Interestingly, individual subjects showed variable topologies for this comparison. Very few individuals showed the distribution of differences that appears in the grand average. The grand average is therefore an amalgam of effects, not the "characteristic" effect for this comparison. There may yet be some small class of different effects that correspond to different strategies, each of which has some posterior negativity. The small sample size in this study did not make it possible to determine whether this was the case.



— matrix subject, -WH
 --- matrix subject, +WH

Cal 2.5 μ V/side Window -300-3000 Hcks 500 onset 300

Figure 2

0 mark is "translator", each tick is a word onset

-WH: The translator for the diplomats at the U.N. criticized the Secretary General.

+WH: The translator who the diplomats at the U.N. criticized responded quietly.

Figure 2 shows that there is an effect at *diplomats* and that it is not due to baseline. The small negativity following the matrix subject in this plot is not significant. Notice that no effect is observed at *for-who*. While *whom* is expected to be more negative due to condition, it is also expected to be less negative due to class. There is also no effect at the subsequent article, but there is no predicted load change from the previous epoch: there is a difference of 2M(0) at both position. The epoch for *diplomats* has the first change in load (over identical lexical items).

Discussion

Failure to elicit a LAN in the preceding study and in McKinnon & Osterhout may have been due to use of a filler-like control. Therefore, the current comparison substituted a preposition instead of a complementizer as a control. A negativity was observed at a point of diverging memory loads: expected, it was not localized to the left frontal area. Its actual distribution was not revealed by this experiment, presumably due to its low power. The fact that an effect was detected despite the low power suggests that another study with more subjects is warranted.

One possibility for the absence of the a strong left anterior distribution could be due to the fact that the prepositional phrase modifies its head in a way highly similar to the relative clause. Those similarities would result in overlying ERPs. Therefore, the differences that remain are seen in more posterior distribution seen here. However, even under this interpretation, the filler-gap hypothesis is refuted. It should be the common modification properties that subtract out and the difference due to the filler-gap construction that remains.

The last possibility is that the filler-gap construction has always been irrelevant and what we are observing in this comparison are the differences in modification properties of the preposition and the relative clause.

What is noteworthy is that some negative-going wave was observed here, in contrast to *who-whether* comparison of the previous study, for which no effect was detected. The wide variability in subjects' evoked potentials is compatible with the intuition that the relationship of the PP to the head noun is subject to greater variation in interpretation. For example, "the lawyer with the lobbyists" could refer to a situation in which a lawyer is standing near lobbyists, or one in which a lawyer has sided with some lobbyists. In this light, it is possible that again we have a comparison which is not clean enough to provide the predicted difference, but which produces some negativity nonetheless.

Chapter 5: Relative clause vs. sentential complement comparison

Tony Harris, Ted Gibson, Phil Holcomb

Abstract

The left anterior negativity found for filler-gap constructions (Kluender & Kutas, 1993; King & Kutas, 1996) was neither replicated in McKinnon & Osterhout (1995) nor in Chapter 4-5. The current study is a further attempt at replication using a sentential complement - relative clause comparison. The complementizers are the same as two used in Kluender & Kutas (1993), namely, *who* and *that*. For good comprehenders, this comparison produced a LAN.

Introduction

The ambiguous results of the *who*-prep comparison make firm conclusions difficult. The comparison in the current experiment used *who* and *that*, as Kluender & Kutas (1993) did. The verbs, however, required both an NP and CP complement. What differed was whether or not the clause following the direct object was the sentential complement or an intervening relative clause.

- (2) a. Tammy assured the plumber whom the unionists had called that her fixtures were new.
 b. Tammy assured the plumber that the unionists had called from their shop that morning.

The prediction is that the filler-gap construction in 2a will elicit a LAN with respect to 2b during the relative clause period (the underlined portion of (2)).

A	B	C	D	E	F	G	H	I
she	assured	the	plumber	whom	the	unionists	called	that
$M_B(0)$	* $M_D(0)$ $M_I(0)$	$M_D(0)$ $M_I(0)$	* $M_I(1)$	$M_G(0)$ $M_H(0)$ $M_I(1)$ $M_{gap}(0)$	$M_G(0)$ $M_H(0)$ $M_I(1)$ $M_{gap}(0)$	* $M_H(0)$ $M_I(2)$ $M_{gap}(0)$	* $M_I(3)$ *	$M_{subj}(0)$ $M_{verb}(0)$
1M(0)	2M(0)	2M(0)	1M(1)	3M(0) 1M(1)	3M(0) 1M(1)	2M(0) 1M(2)	1M(3)	2M(0)

Table 1

A	B	C	D	E	F	G	H	I
she	assured	the	plumber	that	the	unionists	called	
$M_B(0)$	* $M_D(0)$ $M_I(0)$	$M_D(0)$ $M_I(0)$	* $M_I(1)$	$M_G(0)$ $M_H(0)$ *	$M_G(0)$ $M_H(0)$	* $M_H(1)$	*	
1M(0)	2M(0)	2M(0)	1M(1)	2M(0)	2M(0)	1M(1)	0	

Table 2

Consider the first point of difference in (2), column E in Tables 1 and 2. When *whom* is encountered, three predictions are made: the relative clause verb, the object gap, and presumably the subject of the relative clause, since *whom* indicates that the verb will be transitive. In addition, there is the prediction that a sentential complement will follow. This yields a load of 3M(0)+1M(1). Compare this to the load for *that* (Table 2). The prediction for the sentential complement is dispelled, but predictions

for the complement clause verb and subject are incurred (c.f. column I, Table 1). This load of 2M(0) is considerably less than that for *whom*. The difference is same at *unionists* (column G). In Table 1, the prediction for the relative clause subject is realised and all other predictions remain, and the same is true for column G in Table 2.

Method

Subjects. Twenty-three subjects (8 male) were recruited from Tufts psychology subject pools or paid for their participation. Each participant was right-handed and had learned only English in infancy. The age range was 18 to 35 (median age 20).

Materials. There were two sets of 90 sentences, 30 of which are experimental sentences, and 60 of which were sentences from other experiments. Each set contained one member of each sentence pair. Each subject saw only one set. The sentences in each set were pseudo-randomized. Each sentence was followed by a yes/no question.

Procedure, data acquisition, data analysis were as reported in the previous experiment.

Results

As was motivated in Chapter 2, it is easiest to interpret the data from subjects who are known to have performed the task effectively. The data presented below are from the top half of subjects (80% correct or better).

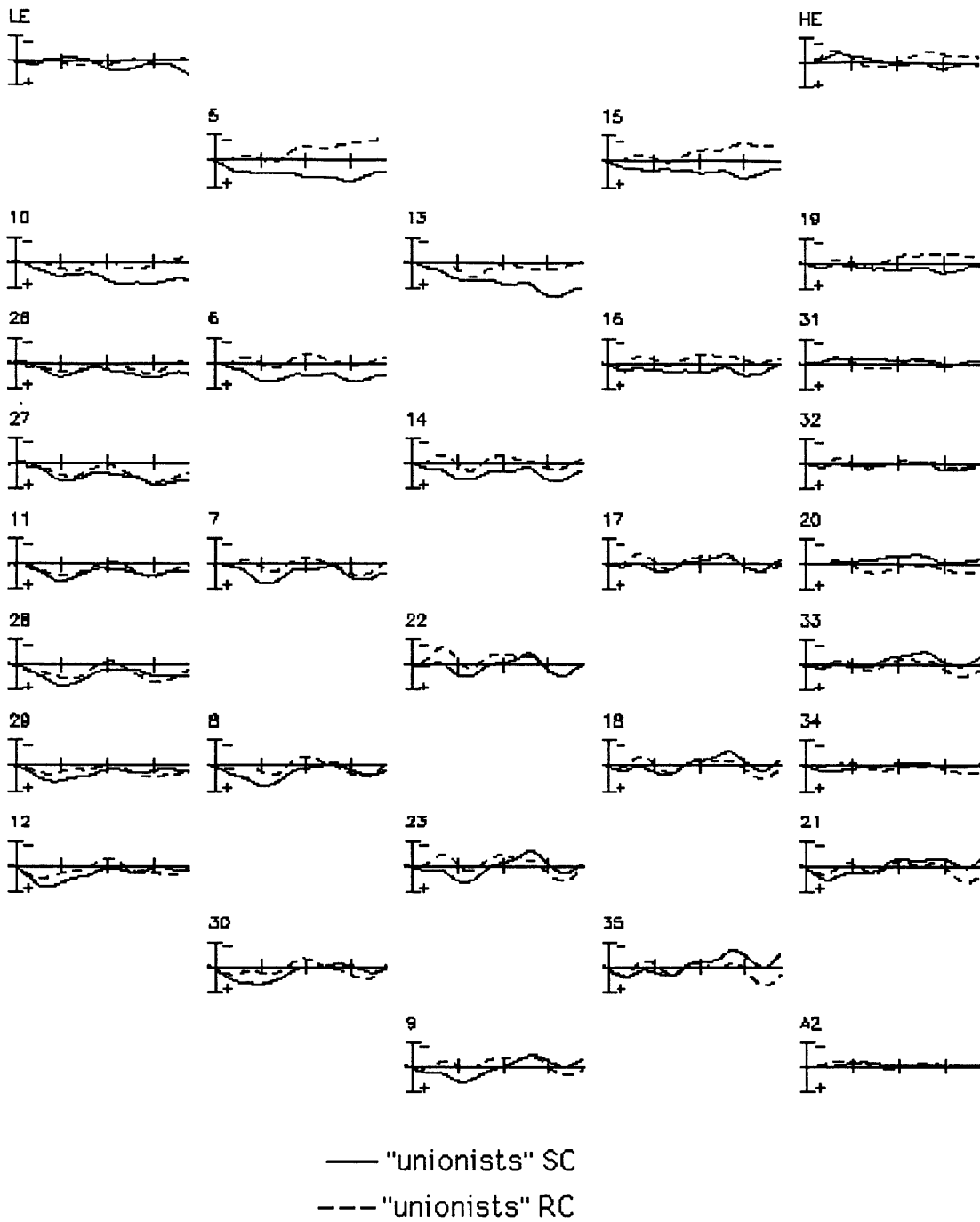
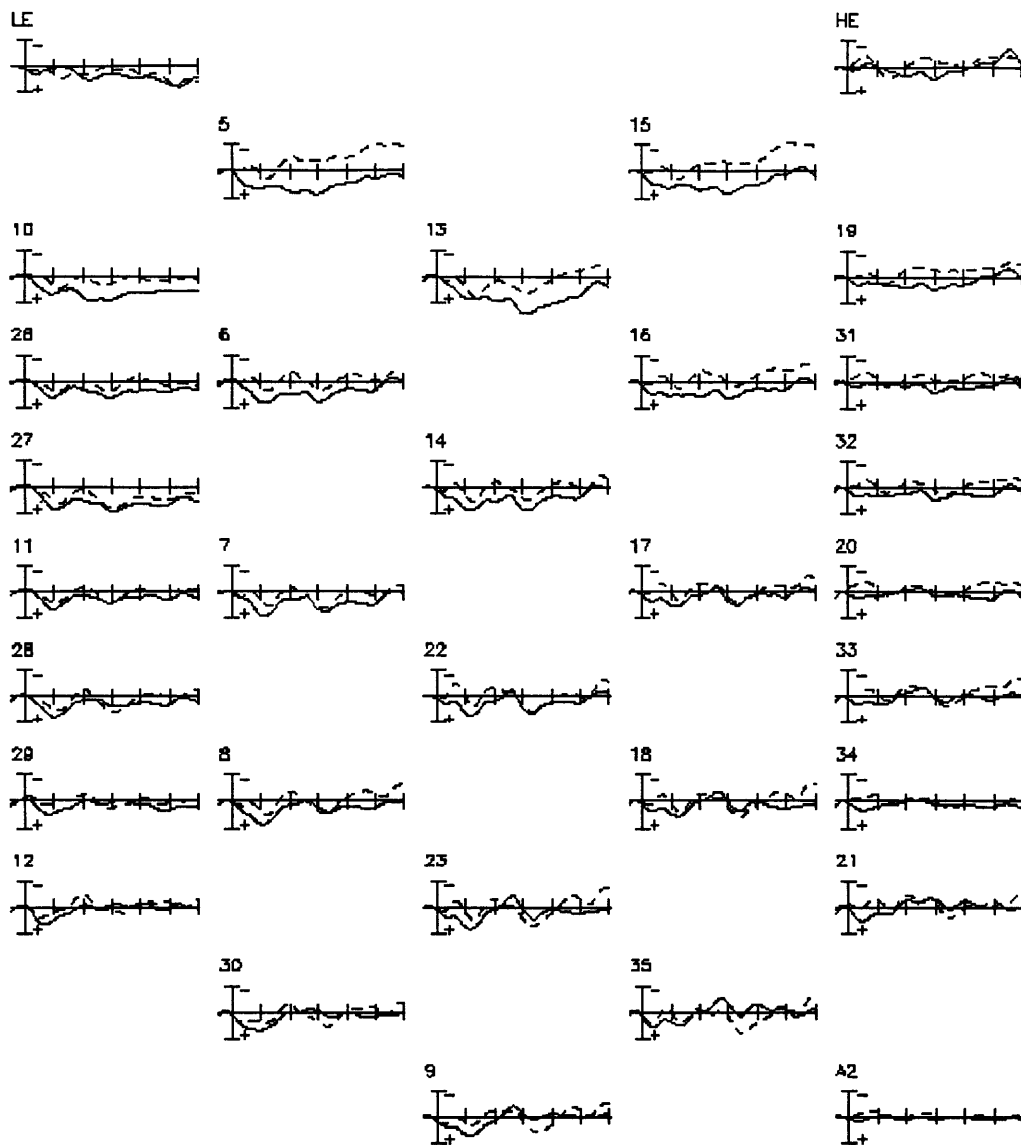


Figure 1
 top 12 subjects
 cal bar 2.5µV/side, baseline -100 to 0, ticks 650 ms, epoch -100 to 2600 ms, low pass 1 Hz

dashed line Tammy assured the plumber whom the unionists had called that her fixtures were new.
solid line Tammy assured the plumber that the unionists had called from their shop that morning.

Note that a strong left anterior negativity is present from the subject of the embedded/relative clause which persists at least for the duration of the clause. Measurements were taken at 0-2600 for the top 12 performers. Sentences which were followed by questions that were answered incorrectly were removed from analysis. The interaction of condition by site was significant in a one-tailed test ($F_{(28,308)}=2.28$, $p=.030$). The effect for condition was significant ($F_{(1,11)}=4.49$, $p=.029$) in a one-tailed test for the four left anterior sites (5,6,10,13). The effect for condition was not significant when all subjects were included. Figure 2 shows the plot for all 23 subjects.



— "unionists" SC
 --- "unionists" RC

Figure 2

all 23 subjects

cal bar $2.5\mu\text{V}/\text{side}$, baseline -100 to 0, ticks 650 ms, epoch -100 to 2600 ms, low pass 1 Hz

dashed line Tammy assured the plumber whom the unionists had called that her fixtures were new.

solid line Tammy assured the plumber that the unionists had called from their shop that morning.

The effect for the interaction was significant ($F_{(28,616)}=5.65$, $p<.001$) reflecting the difference that occurred in predominantly in left anterior sites. The test for the four left anterior sites yielded a similar pattern of results. While there was no effect for condition, there was a significant effect for the interaction. ($F_{(3,66)}=4.79$, $p=.005$)

Conclusion

The effect observed here makes it less likely that previous reports of the LAN were spurious. We are therefore encouraged to interpret the results for the who-prep comparison as likely to be real. We might speculate that the preposition had ambiguous modification properties and elicited a wide range of effects among the subjects. For example, *with* in "the lawyer with the lobbyists" can be taken to mean "allied with" or "standing with." The same variability in interpretation is not present in the comparison in this experiment. The results seen here are compatible with previous LAN studies.

The current comparison above puts us now in a better position to test the structure-licensing hypothesis outlined in the discussion of Chapter 3. This hypothesis states that the property of fillers that give rise to left anterior negativities is that they allow some argument of the verb to be missing, i.e., that it licenses a non-canonical structure. If this is indeed the relevant property, then a nonfiller which licenses some non-canonical structure will also elicit a LAN.

Chapter 6: Evoked potentials of direct object - sentential complements

Tony Harris, Ted Gibson, Phil Holcomb

Abstract

It is hypothesized in this experiment that left anterior negativities (LAN) seen in response to filler-gap constructions (Kluender & Kutas, 1993; Chapter 5) are due not to the retention of the filler over the relevant clause, but to the parser's prediction of the gap (c.f. Gibson (1998)). If making a prediction is responsible, then a prediction of something other than a gap will also elicit a LAN. In a direct object / sentential complement comparison, a LAN was observed.

Introduction

Only one of the conditions (*whether*) in Chapter 3 lacked a filler-gap structure. Both of the others (*who* & *which-N*) did have such structures, yet the comparison of the two filler-gap sentences to *whether* failed to elicit a LAN. This failure and the failure of McKinnon and Osterhout (1995) cast doubt on the filler-gap hypothesis with respect to the LAN.

Any alternative explanation must address the commonalities of the three conditions. In Chapter 3, it was hypothesized (since referred to as the structure-licensing hypothesis) that all three WH words licensed certain strings that could otherwise not stand alone. For example, *who* allows a string in which the verb is missing an argument and *which* allows a string that ends with "or not." The current hypothesis is that this licensing characteristic is what earlier LAN studies revealed.

If this hypothesis is correct, then any lexical item(s) that license additional structure will elicit a LAN, regardless of whether some lexical item must be held in working memory pending integration.

- 1a. The candidate avoided the woman who the press photographed with him on his boat.
- 1b. The candidate admitted that the woman who the press photographed was friendly.

At *woman* in (1a), no further lexical material is required to ensure the well-formedness of the sentence. At the same point in (1b), however, at least a verb (e.g. minimally, an intransitive verb like *danced*) is required to complete the sentence.

What is interesting about this comparison is that *woman* in both sentences must be held in working memory pending integration with the

embedded verb, *photographed*. The only difference at that point is that (1a) requires a verb in the complement clause.¹

Following the structure licensing hypothesis proposed here, a LAN will be observed starting from the point at which a difference in complement type is detected. In this comparison, this will be the matrix verb, as all matrix verbs were selected according to their complement biases.

A	B	C	D	E	F	G	H	I
he	avoided		the	woman	who	the press	photo'd	
M _B (0)	* M _E (0)		M _E (0)	*	M _H (0) M _{gap} (0)	M _H (1) M _{gap} (1)	* *	
1M(0)	1M(0)		1M(0)	0	2M(0)	2M(1)	0	

Table 1

A	B	C	D	E	F	G	H	I
he	admitted	that	the	woman	who	the press	photo'd	lied
M _B (0)	* M _E (0) M _I (0)	M _E (0) M _E (0) M _I (0)	M _E (0) M _E (0) M _I (0)	* * M _I (1)	M _H (0) M _{gap} (0) M _I (1)	M _H (1) M _{gap} (1) M _I (2)	* * M _I (3)	*
1M(0)	2M(0)	2M(0)	2M(0)	1M(0)	2M(0) 1M(1)	2M(1) 1M(2)	1M(3)	0

Table 2

In column B on Tables 1 and 2, we see that there is a load of 1M(0) associated with the NP complement verb (*avoided*) and 2M(0) for the sentential complement bias verb (*admitted*). This is not the optimal point for a comparison, however, because the complementizer *that* in Table 2 means all subsequent words are mismatched. At *woman*, there is a difference of 1M(0), but this is essentially the same as the load difference in the baselining epoch which precedes it. No difference is predicted to be revealed in the evoked

¹It can be argued, pretheoretically, that the matrix verb must be maintained in working memory pending integration. However, data from this experiment do not support this supposition, as will be argued in the discussion section.

potential. A detectable difference should be present at *who*, however. The load difference here is 1M(1).

Subjects. See Chapter 4

Materials. There were two sets of 100 sentences, 50 of which are experimental/control sentences, and 50 of which were sentences from another experiment. Each set contained one member of each sentence pair. Each subject saw only one set. The sentences in each set were pseudo-randomized.

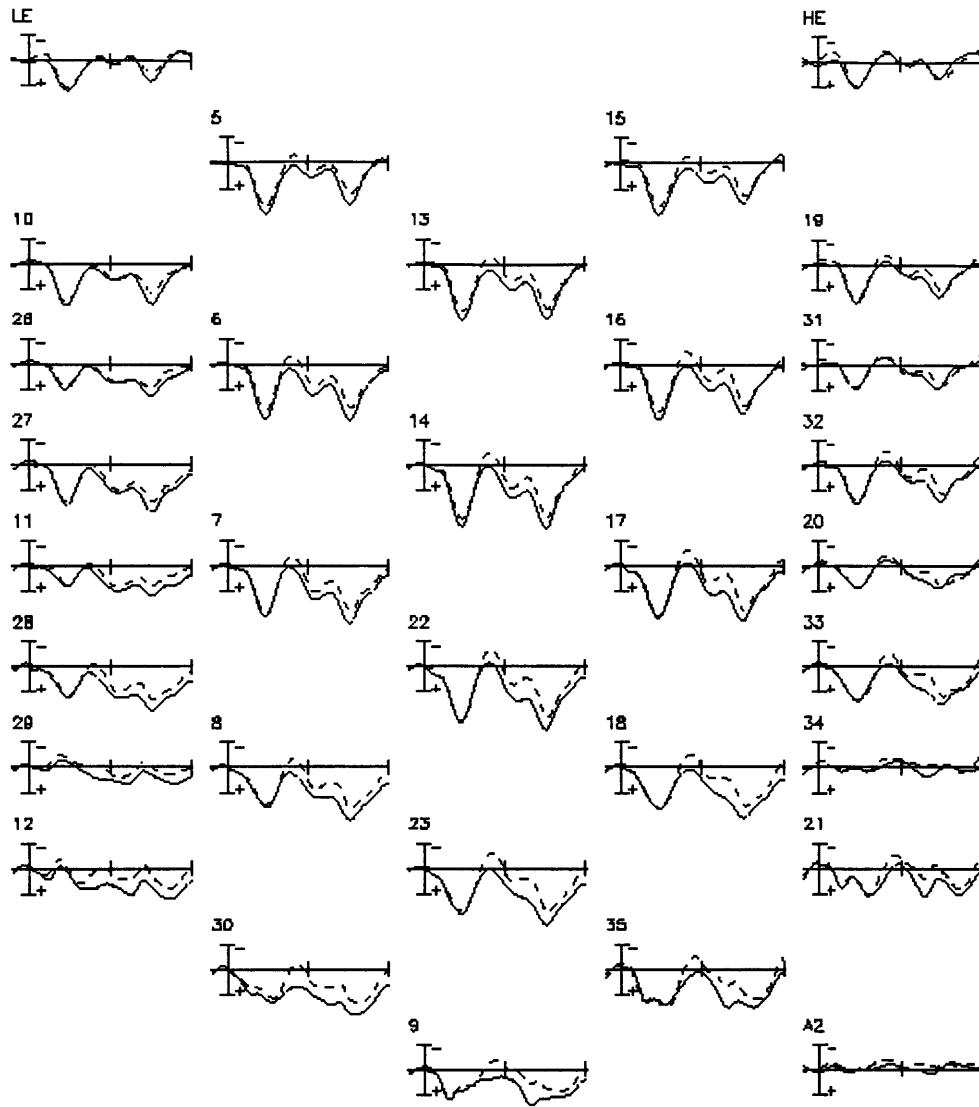
The candidate admitted that the woman who the press photographed was friendly.
The candidate avoided the woman who the press photographed with him on his boat.

Each verb was determined informally to be either biased for an NP complement or a sentential complement. The sentential complement condition always had a *that* separating the verb and the complement. The following six words were identical in each pair. Subsequent words varied.

Procedure. See Chapter 4.

Data analysis. See Chapter 5

Results.



— DO, NPcomp
 --- emb subj, CPcomp

Cal 2.5 µV/divide Window -100-1000 ticks 500 onset 100

Figure 1

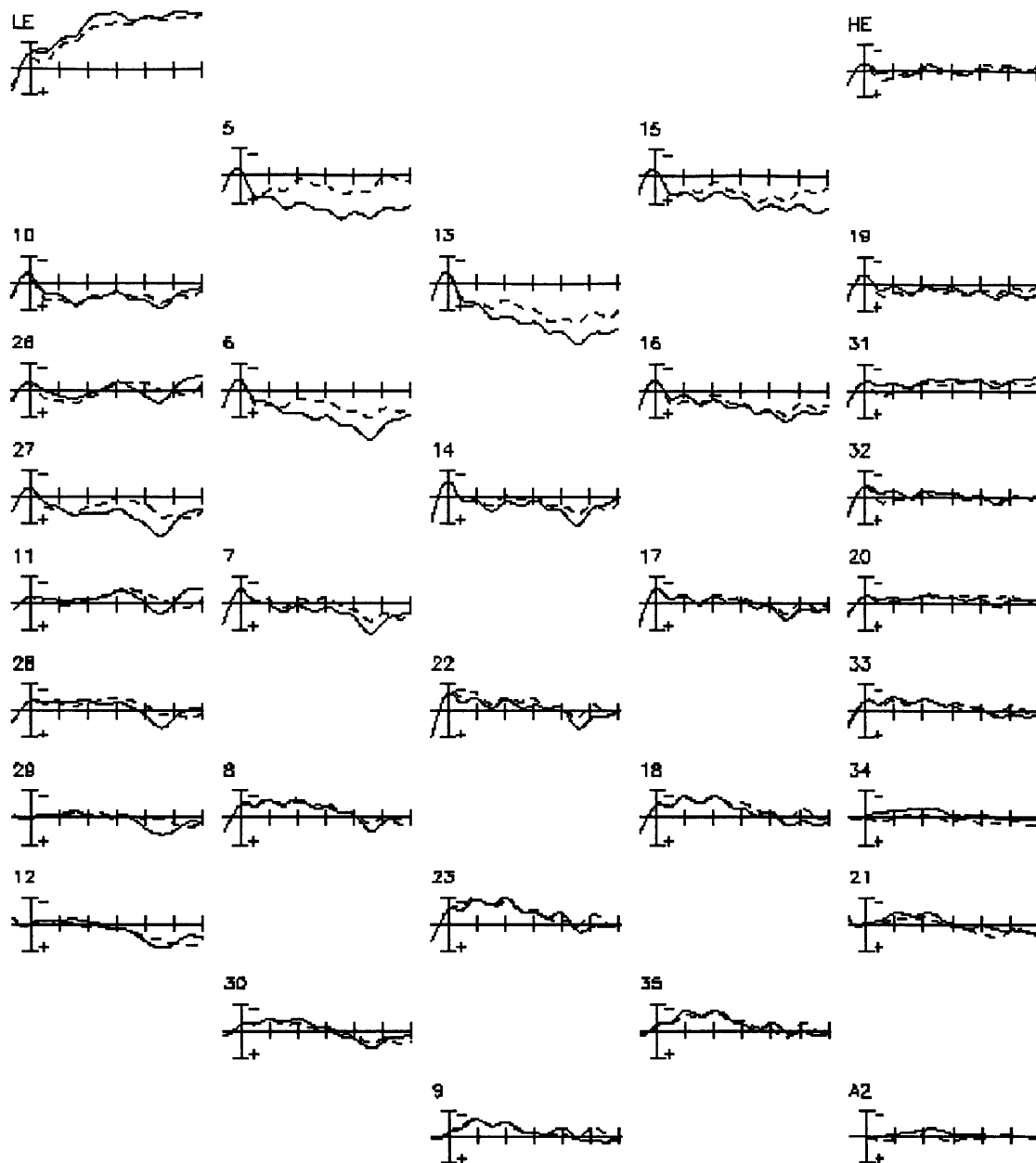
NP-CP at embedded subject/direct object, 15 subjects, -100 to 0 baseline

The candidate admitted that the woman who the press photographed was friendly.
 The candidate avoided the woman who the press photographed with him on his boat.

In order to get a fair baseline, the epoch preceding the point of measurement should contain the same word. The plot assumes that the waveforms in the preceding 100 ms are not the result of the experimental

manipulation and therefore average at $0\mu\text{V}$. If the words being read in that 100ms are different, then the assumption is false. *Woman* in this example is the first epoch that a clean comparison is possible. There appeared to be widespread (all 29 sites) negativity comparing the direct object to the embedded subject ($F_{(1,14)}=5.66$, $p=.032$). There was a significant difference in condition for the 4 midline sites ($F_{(1,14)}=4.72$, $p=.047$) and for 18 lateral sites ($F_{(1,14)}=6.16$, $p=.026$).

Notice that at *woman* there is no predicted ERP difference, due to no change in relative load. The load difference both at *the* and at *woman* is $1M(0)$. Interestingly, there is an indication that there is a voltage difference perhaps in the last portion of *woman*, but certainly in the earliest portion of *who*, too early for *who* to have been identified by the parser. This can only be due to an evoked response to *woman*, although such responses generally start at 200 ms, or there is a preexisting difference due to condition. This forces us to examine the evoked response to the matrix verb, which signals which condition the trial belongs to.



— matrix subject, NPcomp
 --- matrix subject, CPcomp

Cal 2.5 μ V/side Window -300-3000 Hzs 500 onset 300

Figure 2

Cal bar 2.5 μ V/side, baseline -300 to 3000, low pass 1 Hz, 10 subjects
 The candidate admitted that the woman who the press photographed was friendly.
 The candidate avoided the woman who the press photographed with him on his boat.

There was an effect of hemisphere ($F_{(1,14)}=11.18, p=.005$) in a 1000 ms-2000 ms time window. There was no effect of condition or interaction of condition by site for 4 midline sites or for all 29 sites. However, the difference at channels 5 and 6 (1000 ms-2000 ms) was significant in a one tailed test ($F_{(1,14)}=.3.69, p=.038$). Since the matrix verbs were chosen to be biased for either NP or CP complements, the condition of a given sentence can potentially be identified at the third word. Note however that this early difference is not predicted by our use of the Gibson (1998) model.

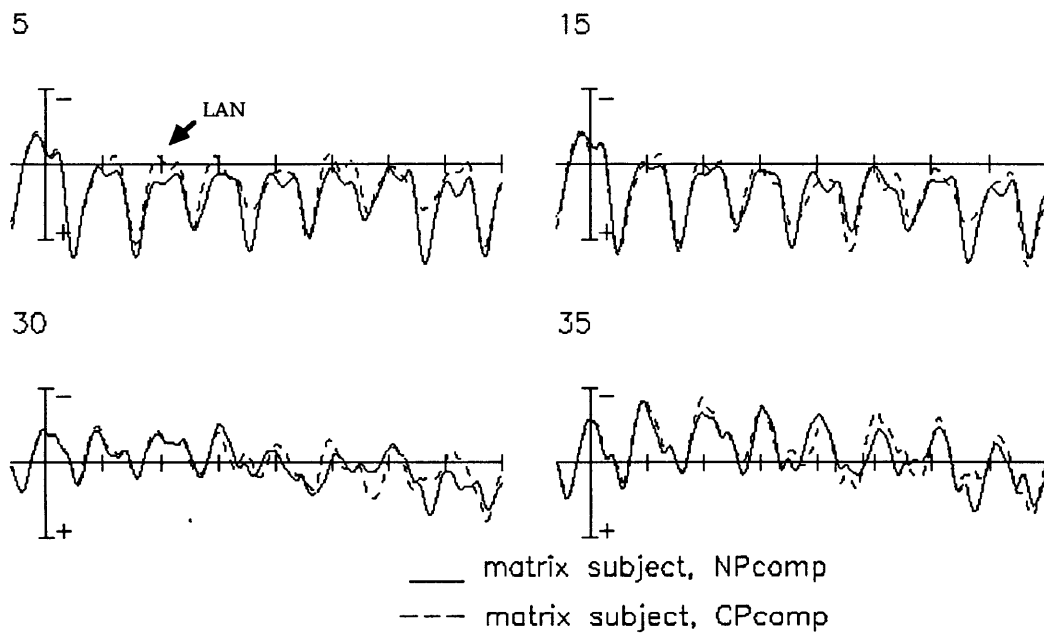


Figure 3

Cal bar $5\mu\text{V}/\text{side}$, baseline -300 to 4000, low pass 20Hz, 15 subjects
 The candidate admitted that the woman who the press photographed was friendly.
 The candidate avoided the woman who the press photographed with him on his boat.

Figure 3 shows the left and right most anterior and most posterior sites which shows the localization of the effect. (Each tic marks the onset of a word.)

Discussion

Unfortunately, the power of this study was rather low (15 subjects, 25 trials per condition). Nevertheless, a significant LAN-like effect was observed from at least the matrix verb on.

By hypothesis, predicting structure is computationally costly to the parser. This is proposed here to be the driving force behind the elicitation of left anterior negativities by filler-gap constructions. Following this hypothesis, predicting a sentential complement with respect to a direct object should also reveal a LAN. This was observed in a comparison of the matrix subjects. The highly localized LAN for the NP/S complement comparison is unlikely to be spurious, given this is exactly what was predicted. Secondly, notice the persistence of the difference in the evoked potential even when comparing open to closed-class words. Open-class words elicit more short-term posterior negativity than closed-class words (Van Petten & Kutas, 1984). At position five in the sentence, for example, *the* is compared to *woman*, and *woman* is expected to be more negative. In position six, *woman* is compared to *who*, with *woman* again expected to be more negative. The sentential complement is consistently more negative, making it unlikely that the effect is due to lexical items.

A reasonable criticism of this comparison is that the negativity seen here is due to the storage in working memory of the matrix verb pending integration with its complement, and that the predictive aspect pursued in this chapter is irrelevant. Note that the negativity arises unambiguously at the verb, the point at which complement information is first available. While latency cannot be judged from these plots (see footnote 1), a difference is unambiguously present at the matrix verb. If the verb must be placed in working memory pending integration with its complement, this operation would have had to take place in both conditions, yielding no difference in the evoked potential. If storing the verb is conducted by different operations based on complement type, then some difficulty arises in differentiating this hypothesis from the prediction hypothesis.

When comparing the embedded subject and direct object (woman), no LAN is observed, although there seems to be a negativity everywhere but the left anterior sites. This is consistent with the argument that a LAN was elicited earlier, at the matrix verb, and was baselined out for this comparison. What is left unexplained is the posterior negativity for the *who*. It is reminiscent of the negativity seen in the *who*-prep comparison in Chapter 4, however.

In summary, the Gibson (1998) definition of working memory load seems to handle the major findings of all known LAN experiments. It predicts a left anterior negativity at the matrix subject in this comparison and is at least consistent with the failure to find a difference when comparing *whether* to a filler-gap construction.

Gibson (1998) appears to be successful in predicting differences in EEG amplitude when working memory becomes burdened, but it is inconsistent with data recorded after points of integration. It predicts that the load on working memory is reduced after items in working memory are integrated into the current sentence. King and Kutas (1995) and Kluender and Kutas (1993) both show that the negativity is persistent even after points of integration. So far, there is no explanation in the literature for this persistent negativity.

Conclusion

There appeared to be a problem in the literature with regards to the limited constructions that could elicit the LAN. The filler-gap hypothesis predicted similar effects wherever a filler to a non-filler were compared, but this was not observed in the two known attempts at comparing *which* to

whether. The type of parsing predictions in Gibson (1998) seem to better explain where differences will arise and when they will not.

Conclusion

While linguistic theories have strong behavioral consequences, not all of their internal mechanisms do. A second tier of evidence is needed here to ensure that those mechanisms of a theory are realistic. In this thesis, we've seen how data from event-related potentials can be used to test aspects of theories that were hitherto not directly confirmable.

In the case of binding theory, the presence or absence of a P600 revealed whether certain constructions were constrained by syntactic processing, or were free of those constraints. Specifically, anaphors seemed to be constrained by Condition A while logophors were not affected. The pragmatic/syntactic distinction drawn by Reinhart & Reuland (1993) was developed based on data from speakers' intuitions, but those judgments themselves did not reveal that distinction. The distinction was internal to the theory. Other versions of Binding Theory do not rely on that distinction. The ERPs reported here provided first-time evidence that two different neurological systems were involved in constraining the distribution of anaphora.

While ERPs seem useful in shedding light on the domain of grammatical knowledge, they also showed promise in theories of sentence processing. Commitments to a given parse can be detected by reading time slowdowns at points where disambiguation between possible structures is made, or when items must be integrated into the correct structure. But where are those commitments incurred? With the earliest available information, or only after encountering disambiguating information?

There is also work to be done in defining what is syntactically complex, and how that interacts with working memory, in real time. What is the trade-off between the cost of maintaining items in working memory with the cost of integrating those items at some later time?

The current work does not resolve these issues, but it does suggest that the parser may be using lexical information to predict upcoming structure instead of passively holding it until the requisite structure is encountered. In the LAN replication study, we learned that comparing fillers like *who* and *which-N* to each other produced no differences, as might have been expected under a discourse-linking hypothesis. There was also no difference between clauses headed by *who* and *whether*, as might be expected under the filler-gap hypothesis. This suggests that some new explanation is needed for why LAN effects are achieved when comparing *that* to *who*.

The comparison of verbs with NP or CP complements seem to support the structure-licensing hypothesis. A LAN was observed here where none was seen in the *who-whether* comparison.

FUTURE DIRECTIONS:

There are two avenues of exploration opened by the current findings. The first involves the exploration of load as reflected in LAN amplitudes. Ruchkin et al. (1992)'s data showed an amplitude which is proportional to the number of syllables to be remembered during the retention period, but no (successful) attempt has been made at demonstrating this effect for the processing of grammatical sentences of varying difficulty. If the LAN produces amplitude changes proportional to the hypothesized load, this would provide an invaluable tool in processing theory-building.

- (1) a. Did the man at the fair help someone?
- b. Who_i did the man at the fair help t_i ?
- c. Who_j did the unionist_i who_i the man at the fair helped t_i impress t_j ?

(1) shows an increasing number of dependencies surrounding the underlined phrase. During the prepositional phrase *at the fair* in (1a), there is only one predicted category, the VP, which by hypothesis (Gibson 1998), has no cost. If there indeed is a

cost, it is at least shared in (1). In (1b), there is the filler-gap relation indexed here as *i*. In (1c), there are two such chains, indexed *i* and *j*. If the LAN indexes processing load, the amplitude for (1c) ought to be greater than that of (1b), which in turn ought to be greater than (1a).

The second avenue of exploration involves the persistence of the negativity. There is some evidence to suggest that it persists past the point of retention/prediction. In filler-gap constructions, Kluender & Kutas (1993) report a negativity after detection of the gap. On first blush, this seems counterintuitive; after integration with the verb, we expect the negativity to diminish. However, some constructions contain secondary gaps that are dependent on a shared filler.

- (2) a. Which report did you file _ before reading _ ?
b. *Which report did you file _ before you read _ ?

In cases such as (2a), whatever work being done before the first gap must continue until the second is reached. In light of this possibility, the persistent negativity makes sense.

In (2b), however, notice that no secondary gap is possible in the embedded clause. This contrast brings to mind the question of whether the LAN is sensitive to syntactic constraints, which would suggest language-specificity for the effect. If the LAN reflects the use of a general resource, there would be little reason to expect such sensitivity. The former hypothesis predicts that the LAN will not persist where a gap is syntactically impossible, namely, the adjunct clause of (1b). The latter hypothesis predicts that the effect will be subject only to decay/reactivation processes as might independently exist.

Consider (3) as a test of sensitivity to syntactic constraints.

- (3) a. Who₁ did you₂ embarrass t₁ by PRO₂ blatantly criticizing t₁ ?
b. *Who₁ did you₂ embarrass t₁ for PRO₁ blatantly criticizing t₁ / t₂ ?
c. Who₁ did you₂ embarrass t₁ for PRO₁ blatantly criticizing the government?

(3a) is the same type of parasitic gap construction as seen in (21a). Like (2a), the secondary gap can only exist in an untensed clause. In (3b), *by* is replaced with *for*, which causes the understood subject to be coreferential with the extracted item (indexed as 1 here). This is a violation of Condition C of Binding Theory, which states that R-expressions such as t_1 cannot be bound. Here it is bound by the understood subject, PRO_1 . t_2 is not possible because of lack of antecedent government by a filler. Note that (3c), which has an NP object, is acceptable. Therefore, at *for*, the parser knows that an object gap is not possible. If the cases that we have seen earlier were cases of gap prediction, then there will be decreased negativity in the epochs following the *for* than the *by*, when comparing (3a) to (3c). The two necessary control conditions are (4).

- (4) a. Did you₂ embarrass the president₁ by PRO_2 blatantly criticizing him₁ ?
b. Did you₂ embarrass the president₁ for PRO_1 blatantly criticizing the government?

Detecting a decrease would support the notion that there is working memory specific to language, but it would not imply that other faculties cannot make use of it. Failure to detect it would detract from the structure-licensing hypothesis, because there is simply no way to predict a gap after the *for* is encountered.

The interpretation of evoked potentials is far from certain at this point, however, the experiments needed in the immediate future seems clear. The power of ERP methodologies seems to be the most difficult aspect of their use: they are sensitive to a large number of factors, many of which are extraneous to the given topic of inquiry. A large amount of work remains to be done before these factors are understood well enough to allow for immediate and precise examinations of theoretical subtleties, but those examinations are indeed pending.

Appendices

Appendix A: Instructions given to subjects in Binding Experiment

You will be reading a number of sentences on a computer screen. The sentences are presented one word at a time; one word flashes on, then it flashes off. Some of the sentences have questions attached to them. The questions are only related to the action in the sentence, and who is doing it. For example, if you see a sentence, "John kissed Mary under a tree," the question would be, "who was kissed under a tree?" The question simply ensure comprehension of the sentence.

Some of the sentences will be normal sentences, and some will sound strange. Your job will be to overcome that strangeness and answer the question anyway. For example, if you saw the sentence, "Mary said John likes her," the question would be, "Who was liked?" And your answer would be...? However, you may see a sentence like, "Mary said John likes him," and the question would be, "Who was liked?" The answer would be John, because even though the sentence sounds strange, *John* is the only "him" around.

Ten practice sentences were given in the experimental situation; five agreeing (i) and five disagreeing (ii) with the matrix subject. If more than one question was answered incorrectly, the entire list was repeated.

(i) Marcie's boyfriend E-mailed her by mistake.

Who was E-mailed? Marcie / boyfriend

(ii) Debbie's data analyst corrected him after discovering a mistake.

Who was corrected? Debbie / data analyst

The sentences that you'll be reading in the experiment will not be exactly the same as the practice sentences, but the same strategy for answering the questions will apply. One thing that they have in common, however, is that you cannot figure out the answer by context, by who is most likely to be doing something. All the sentences are reversible. You may see a sentence in one form where the answer is on the left. Another person will see the same sentence in a different form where the answer is on the right.

In the last set of sentences, the difference was between him and her. In the upcoming sentences, the difference will be between himself and themselves. An example would be, John's brothers like themselves. The question would be, "Who is liked? And you'd answer...? Right. The strange version would be, John's brothers like himself. The question would be, "Who is liked? And the answer would be...? Right, because *himself* is singular and *John* is singular.

In the two possible answers, there is always one singular noun and one plural, but you won't know which is receiving the action of the sentence until you read the *himself/themselves*.

Try to answer each question as quickly as possible. You'll notice that all the questions are of the same form. This will enable you to decide on your answer as soon as you see the *himself/themselves*. Try to snap off an answer as soon as you see the question.

Appendix B: Sentence Completion Task

Rationale:

Results reported by Boland (et al), among others show that gap-filling is sensitive to the subcategorization preference of the verb. If the verb is preferably intransitive, gap-filling appears to be delayed. Similarly, if the verb allows a direct object, but also selects an infinitival complement, gap-filling can be delayed if the filler is not plausible as a direct object. In order to be sure that gap-filling takes place at the verb in the experimental materials, only verbs that were used that preferably occur with a direct object only.

Subjects

Thirty native speakers of English mainly MIT undergraduates were paid \$4 for participation.

Materials

Sixty-three sentence fragments were constructed consisting of a subject NP, "had" and a participle verb (e.g. 'The girl in the boat had seen...') In addition, 13 sentence fragments were given in which the verb was followed by an NP ('The constructor built Joanne...'). These fragments tested completion preferences to allow constructing materials for an independent experiment.

Procedure

Subjects were asked to complete the fragments with the first thing that came into their minds and were instructed not to look back to previous completions. Subjects completed the task in about 20 minutes.

Scoring

Completions were coded with respect to whether the provided verb was followed by (i) an object NP, possibly followed by an adverb or adjunct clause and (ii) any other element following the object NP.

Twenty-eight verbs were selected which were completed with only a direct object (+ possible adverbials) by at least 25 out of the 30 subjects (83%). These twenty-eight verbs were used to construct the materials for the ERP study; each verb was used three times, each time with different noun and prepositional phrases.

Appendic C: Binding stimuli

coargument, agree condition

The agencies' representative inculcated Jones and himself by accident.

The cover girls' photographer reassured Felix and himself about the lighting.

The infants' nanny dressed Dorothy and herself carefully for the outing.

The artists' patron served Brad and herself at the opening. Who was served? artists / patron

The athletes' sponsor withdrew Nichols and itself from the meet. Who was withdrawn? athletes / sponsor

The buyers' agent pleased Cummings and himself with his purchases.

The cabbies' dispatcher startled Oscar and himself with sudden radio feed-back.

The refugees' medic inoculated Jenkins and himself against dysentery. Who was inoculated? refugees / medic

The sailors' captain trusted Lieutenant Pollock and himself in the worst seas.

The boys' cousin introduced Suzie and himself at the wedding.

The sorority sisters' housekeeper calmed Mary and herself after the break-in. Who was calmed? sorority sisters / housekeeper

The children's father excused Estelle and himself from the table.

The Johnsons' butler held Smithers and himself in high regard.

The labs' overseer evaluated Kenrick and himself for accurate reporting of data. Who was evaluated? labs / overseer

The lepers' aide-worker examined Alison and herself for signs of infection.

The lions' tamer frightened Stupich and himself with the unpredictable pistol. Who was frightened? lions / tamer

The litigants' arbitrator satisfied Fleischer and himself with the final arrangement.

The gang members' mastermind disguised Hogarty and himself before the heist. Who was disguised? gang members / mastermind

The accountants' firm committed Saphier and itself to the new contract.

The schoolgirls' teacher asked Erin and herself themselves about the solution in the text book.

The sharecroppers' landowner freed Sharon and himself from manual labor.

The Benson's waiter short-changed Gordon and himself at the restaurant. Who was short-changed? Bensons / waiter

The board members' ad exec scolded Stromquist and himself for loss of market share.

The hunters' guide disoriented Payette and himself in a ravine. Who was disoriented? hunters / guide

The industrialists' spin doctor saw Nordstrom and himself as a benefit to the public.

The corpses' mortician prepared Stevens and himself for the embalming.

The insurgents' leader camouflaged Juarez and himself along the road.

The musicians' conductor worked Heinrich and himself to death before the concert.

The activists' spokesman heard Linda and himself on the radio. Who was heard? activists / spokesman

The girls' uncle treated Betty and himself to ice cream.

The design teams' director promoted Ferguson and himself to a better project.

The post-docs' advisor relieved Kim and himself of responsibility on the project.
 The twins' babysitter covered Nora and herself with a blanket. Who was covered? twins / babysitter
 The vacationers' tour guide registered Sawyer and himself at the cheapest hotel. Who was registered? vacationers / tour guide
 The contractors' supplier deceived Hudson and himself about the real costs.
 The reformers' opposition drew Stockbridge and itself into the controversy.
 The addicts' counselor employed Bob and himself everyday in busy work.
 The advertisers' PR-man sold Mr. Davidson and himself on the idea.
 The natives' chief lauded Batu and himself before his rivals. Who was lauded? natives / chief
 The pensioners' stock broker betrayed VanDorn and himself with sloppy record keeping. Who was betrayed? pensioners / stock broker
 The stuntmen's coordinator moved Lewis and himself to a better vantage point.
 The survivors' rescuer strapped McKensie and himself into the helicopter. Who was strapped? survivors / rescuer
 The proofreaders' redactor pushed Schafer and himself to the limit.
 The puppies' mother hid Ozzie and herself from the dog-catcher.
 The climbers' radio-man comforted Gail and himself after the tragic mishap.
 The conspirators' hitman sacrificed Scavito and himself during the botched mission. Who was sacrificed? hitman / conspirators
 The delegates' translator recognized Moselsky and himself as relatively unimportant.
 The swimmers' trainer exhausted Danny and himself before the big meet.
 The technicians' supervisor doubted Cartman and himself after the last mistake.
 The teenagers' dentist rattled Denise and himself after a painful mistake.
 The spys' control agent identified Weisman and himself in the photograph. Who was identified? spys / control agent
 The Stewarts' handyman limited Jeff and himself to rear-door entry during renovations.
 The employees' manager trained Tracy and himself on the job. Who was trained? employees / manager
 The ward members' nurse fooled Dr. Conley and herself with her cheerfulness.
 The women's boss exonerated Novak and himself in court. Who was exonerated? women / boss
 The playwrights' producer included Dana and himself in the cast of a running show.
 The newscasters' intern reminded Amy and himself of the new air date.
 The entrepreneurs' bank insured Computron and itself against catastrophic loss.
 The policemen's sergeant informed Finnigan and himself of new policy directives. Who was informed? policemen / sergeant
 The tenants' landlord educated Travers and himself on lease law.

 The governor's appointees injured Nelson and themselves with an untimely press leak. Who was injured? governor / appointees
 The anchorman's cameramen amused Kelly and themselves during a commercial.
 The despot's bodyguards hurried Piantes and themselves to the helipad.

The loudmouth's friends quoted Marsha and themselves for ironic effect. Who was quoted? loudmouth / friends

The manufacturer's consultants submitted Ramani and themselves to questioning.

The foundation's proponents forced Goldman and themselves into the spotlight.

The congressman's speech-writers disengaged Anderson and themselves from the fray.

The contract's bidders portrayed Uptown Architects and themselves as extremely desirable.

The senator's constituents compromised Donham and themselves over farm subsidies. Who was compromised? senator / constituents

The sorcerer's rivals changed Marek and themselves into a cloud of smoke. Who was changed? sorcerer / rivals

The crooked cop's informants implicated Pearson and themselves during the interrogation.

The defendant's lawyers described Kevin and themselves as hard-working.

The fugitive's pursuers persuaded Knapp and themselves of the futility of the chase.

The diver's teammates congratulated Rick and themselves on the discovery. Who was congratulated? diver / teammates

The editor's reporters vindicated Levenson and themselves after the sensationalism charges.

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The king's noblemen restored Hamilton and themselves to power.

The nitpicker's office-mates defended Larry and themselves against unjust criticism. Who was defended? nitpicker / office-mates

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The bear's cubs washed Miffy and themselves behind the ears. Who was washed? bear / cubs

The pilot's mechanics brow-beat Gould and themselves after the race.

The boycott's targets hurt the government and themselves with bad publicity. Who was hurt? boycott / targets

The knight's squires placed Lady Chilton and themselves on horseback.

The jeweler's salesmen cursed Kaminsky and themselves for the slow business.

The author's publishers inconvenienced Helen and themselves with the new deadline. Who was inconvenienced? author / publishers

The president's biographers praised Larsen and themselves for a job well done.

The businessman's blackmailers frustrated Pawly and themselves with the long waiting game.

The bus driver's passengers commended Jackie and themselves for their role in the wreck.

The surgeon's patients distracted Marjorie and themselves in the waiting room. Who was distracted? surgeon / patients

The mobster's henchmen maneuvered Janick and themselves into the new territory.

The groom's ushers rushed Tammy and themselves to the church.

The dictator's cronies proclaimed Ramirez and themselves as the winners of the staged elections.

The candidate's supporters cheered Rufkin and themselves after the victory.

The consortium's retailers protected Vance, Inc. and themselves from suit. Who was protected? consortium / retailers
The nation's soldiers guarded General Carthas and themselves from attack.
The princess' handmaidens anointed Anna and themselves with scented oils. Who was anointed? princess / handmaidens
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The heretic's accusers contradicted Chartrand and themselves in the mock trial. Who was contradicted? heretic / accusers
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The stranger's hosts sat Judy and themselves at the dinner table.
The city's inhabitants love Mario and themselves more than anyone else.
The workaholic's relatives outdid Jaimie and themselves in planning the trip.
The ambassador's staff personnel immersed Comerford and themselves in the new language.
The coach's worst players surprised Difabio and themselves with their performance. Who was surprised? coach / worst players
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The queen's ministers presented Lord Belmore and themselves to the Viceroy.
The programmer's coworkers teased Ron and themselves about the playboy calendar. Who was teased? programmer / coworkers
The scientist's detractors questioned Eastly and themselves after the startling finding.
The traitor's captors found Bicknell and themselves alone in an old building.
The vintner's chemists blamed Harding and themselves for the poor year. Who was blamed? vintner / chemists
The prosecutor's investigators convinced Judge Andrews and themselves beyond a doubt. Who was convinced? prosecutor / investigators
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The winner's collaborators rewarded Severin and themselves with a party. Who was rewarded? winner / collaborators
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Coargument, disagree condition

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The post-docs' advisor relieved himself of responsibility on the project.

The twins' babysitter covered herself with a blanket. Who was covered? twins / babysitter

The vacationers' tour guide registered himself at the cheapest hotel. Who was registered? vacationers / tour guide

The contractors' supplier deceived himself about the real costs.

The reformers' opposition drew itself into the controversy

The addicts' counselor employed himself everyday in busy work.

The advertisers' PR-man sold himself on the idea.

The natives' chief lauded himself before his rivals. Who was lauded? natives / chief

The pensioners' stock broker betrayed himself with sloppy record keeping. Who was betrayed? pensioners / stock broker

The stuntmen's coordinator moved himself to a better vantage point.

The survivors' rescuer strapped himself into the helicopter. Who was strapped? survivors / rescuer

The proofreaders' redactor pushed himself to the limit.

The puppies' mother hid herself from the dog-catcher.

The climbers' radio-man comforted himself after the tragic mishap.

The conspirators' hitman sacrificed himself during the botched mission. Who was sacrificed? hitman / conspirators

The delegates' translator recognized himself as relatively unimportant.

The swimmers' trainer exhausted himself before the big meet.

The technicians' supervisor doubted himself after the last mistake.

The teenagers' dentist rattled himself after a painful mistake.
The spys' control agent identified himself in the photograph. Who was identified? spys / control agent
The Stewarts' handyman limited himself to rear-door entry during renovations.
The employees' manager trained himself on the job. Who was trained? employees / manager
The ward members' nurse fooled herself with her cheerfulness.
The women's boss exonerated himself in court. Who was exonerated? women / boss
The playwrights' producer included himself in the cast of a running show.
The newscasters' intern reminded himself of the new air date.
The entrepreneurs' bank insured itself against catastrophic loss.
The policemen's sergeant informed himself of new policy directives. Who was informed? policemen / sergeant
The tenants' landlord educated himself on lease law.

The governor's appointees injured themselves with an untimely press leak. Who was injured? governor / appointees
The anchorman's cameramen amused themselves during a commercial.
The despot's bodyguards hurried themselves to the helipad.
The loudmouth's friends quoted themselves for ironic effect. Who was quoted? loudmouth / friends
The manufacturer's consultants submitted themselves to questioning.
The foundation's proponents forced themselves into the spotlight.
The congressman's speech-writers disengaged themselves from the fray.
The contract's bidders portrayed themselves as extremely desirable.
The senator's constituents compromised themselves over farm subsidies. Who was compromised? senator / constituents
The sorcerer's rivals changed themselves into a cloud of smoke. Who was changed? sorcerer / rivals
The crooked cop's informants implicated themselves during the interrogation.
The defendant's lawyers described themselves as hard-working.
The fugitive's pursuers persuaded themselves of the futility of the chase.
The diver's teammates congratulated themselves on the discovery. Who was congratulated? diver / teammates
The editor's reporters vindicated themselves after the sensationalism charges.
The executive's secretaries organized themselves for greater efficiency.
The king's noblemen restored themselves to power.
The nitpicker's office-mates defended themselves against unjust criticism. Who was defended? nitpicker / office-mates
The designer's models recommended themselves for the new project.
The bear's cubs washed themselves behind the ears. Who was washed? bear / cubs
The pilot's mechanics brow-beat themselves after the race.
The boycott's targets hurt themselves with bad publicity. Who was hurt? boycott / targets
The knight's squires placed themselves on horseback.
The jeweler's salesmen cursed themselves for the slow business.

The author's publishers inconvenienced themselves with the new deadline. Who was inconvenienced? author / publishers

The president's biographers praised themselves for a job well done.

The businessman's blackmailers frustrated themselves with the long waiting game.

The bus driver's passengers commended themselves for their role in the wreck.

The surgeon's patients distracted themselves in the waiting room. Who was distracted? surgeon / patients

The mobster's henchmen maneuvered themselves into the new territory.

The groom's ushers rushed themselves to the church.

The dictator's cronies proclaimed themselves as the winners of the staged elections.

The candidate's supporters cheered themselves after the victory.

The consortium's retailers protected themselves from suit. Who was protected? consortium / retailers

The nation's soldiers guarded themselves from attack.

The princess' handmaidens anointed themselves with scented oils. Who was anointed? princess / handmaidens

The carpenter's apprentices burdened themselves with the fate of the shop.

The heretic's accusers contradicted themselves in the mock trial. Who was contradicted? heretic / accusers

The insurrection's advocates touted themselves as the sole means of liberation.

The stranger's hosts sat themselves at the dinner table.

The city's inhabitants love themselves more than anyone else.

The workaholic's relatives outdid themselves in planning the trip.

The ambassador's staff personnel immersed themselves in the new language.

The coach's worst players surprised themselves with their performance. Who was surprised? coach / worst players

The company's investors drove themselves into bankruptcy.

The program's administrators cheated themselves out of much needed funds.

The prophet's disciples criticized themselves for minor sins. Who was criticized? prophet / disciples

The psychiatrist's colleagues villified themselves at the inquiry.

The queen's ministers presented themselves to the Viceroy.

The programmer's coworkers teased themselves about the playboy calendar. Who was teased? programmer / coworkers

The scientist's detractors questioned themselves after the startling finding.

The traitor's captors found themselves alone in an old building.

The vintner's chemists blamed themselves for the poor year. Who was blamed? vintner / chemists

The prosecutor's investigators convinced themselves beyond a doubt. Who was convinced? prosecutor / investigators

The millionaire's daughters distanced themselves from racist statements.

The winner's collaborators rewarded themselves with a party. Who was rewarded? winner / collaborators

The sharpshooter's competitors measured themselves by the strictest criteria.

The heroine's companions locked themselves in the dungeon by accident.

The mercenary's enemies judged themselves as the most dangerous element in the battle.

The environmentalist's sympathizers stationed themselves behind the barricade.

Noncoargument, disagree condition

The agencies' representative inculcated themselves by accident.

The cover girls' photographer reassured themselves about the lighting.

The infants' nanny dressed themselves carefully for the outing.

The artists' patron served themselves at the opening. Who was served? artists / patron

The athletes' sponsor withdrew themselves from the meet. Who was withdrawn?
athletes / sponsor

The buyers' agent pleased themselves with his purchases.

The cabbies' dispatcher startled themselves with sudden radio feed-back.

The refugees' medic inoculated themselves against dysentery. Who was inoculated?
refugees / medic

The sailors' captain trusted themselves in the worst seas.

The boys' cousin introduced themselves at the wedding.

The sorority sisters' housekeeper calmed themselves after the break-in. Who was
calmed? sorority sisters / housekeeper

The children's father excused themselves from the table.

The Johnsons' butler held themselves in high regard.

The labs' overseer evaluated themselves for accurate reporting of data. Who was
evaluated? labs / overseer

The lepers' aide-worker examined themselves for signs of infection.

The lions' tamer frightened themselves with the unpredictable pistol. Who was
frightened? lions / tamer

The litigants' arbitrator satisfied themselves with the final arrangement.

The gang members' mastermind disguised themselves before the heist. Who was
disguised? gang members / mastermind

The accountants' firm committed themselves to the new contract.

The schoolgirls' teacher asked themselves about the solution in the text book.

The sharecroppers' landowner freed themselves from manual labor.

The Benson's waiter short-changed themselves at the restaurant. Who was short-
changed? Bensons / waiter

The board members' ad exec scolded themselves for loss of market share.

The hunters' guide disoriented themselves in a ravine. Who was disoriented? hunters
/ guide

The industrialists' spin doctor saw themselves as a benefit to the public.

The corpses' mortician prepared themselves for the embalming.

The insurgents' leader camouflaged themselves along the road.

The musicians' conductor worked themselves to death before the concert.

The activists' spokesman heard themselves on the radio. Who was heard? activists /
spokesman

The girls' uncle treated themselves to ice cream.

The design teams' director promoted themselves to a better project.

The post-docs' advisor relieved themselves of responsibility on the project.

The twins' babysitter covered themselves with a blanket. Who was covered? twins /
babysitter

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The bear's cubs washed herself behind the ears. Who was washed? bear / cubs

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The queen's ministers presented herself to the Viceroy.
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The traitor's captors found himself alone in an old building.
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The winner's collaborators rewarded himself with a party. Who was rewarded? winner / collaborators
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The heroine's companions locked herself in the dungeon by accident.
The mercenary's enemies judged himself as the most dangerous element in the battle.
The environmentalist's sympathizers stationed himself behind the barricade.

Appendix D: Wh-prep stimuli

The chef who the restaurant in the suburbs fired later won an important award. The restaurant fired the chef true false left

The chef from the restaurant in the suburbs fired an apprentice for burning some potatoes. The restaurant fired the chef true false right

The translator who the diplomats at the U.N. criticized eventually responded in a positive way. The translator responded positively true false left

The translator for the diplomats at the U.N. criticized the Secretary General. The translator criticized the diplomats true false right

The choreographer who the dancers at the school despised switched to writing screenplays. The choreographer despised screenplays true false right

The choreographer for the dancers at the school despised modern jazz music. The dancers despised jazz true false right

The father who the girl with the freckles hugged was not allowed to visit her very often. The father visited the girl often true false right

The father of the girl with the freckles hugged her briefly when she came home. The father hugged the girl at home true false left

The waitress who the guests at the table thanked went to get their coats. The waitress thanked the guests true false right

The waitress for the guests at the table thanked them for their giant tip. The waitress thanked the guests true false left

The sculptor who the academy in the capital praised was too shy to give a speech.

The sculptor was shy true false left

The sculptor from the academy in the capital praised Picasso for the beauty of his compositions. The sculptor praised Picasso true false left

The child who the composer of the sonata cherished had died of tuberculosis. The composer died of tuberculosis true false right

The child of the composer of the sonata cherished the time with her father. The child composed the sonata true false right

The passenger who the driver of the shuttle warned eventually returned to his seat.

The driver returned to his seat true false right

The passenger near the driver of the shuttle warned him about crossing pedestrians. The driver warned the passenger true false right

The secretary who the executive at the institute ridiculed complained to the management. The secretary ridiculed the executive true false right

The secretary for the executive at the institute ridiculed the management all the time. The secretary ridiculed the executive true false right

The supervisor who the students in the classroom hated took on another job. The supervisor took another job true false left

The supervisor of the students in the classroom hated to grade papers all the time.

The supervisor hated the students true false right

The violinist who the symphony in the Netherlands wanted enjoyed her work immensely. The symphony wanted the violinist true false left

The violinist with the symphony in the Netherlands wanted more respect among her peers. The violinist wanted respect true false left

The fisherman who the workers on the dock respected decided to brave the storm.

The workers braved the storm true false right

The fisherman near the workers on the dock respected the unpredictability of the sea.

The workers respected the fisherman true false left

The innkeeper who the person in the black_hat visited was wanted by the police.

The innkeeper was wanted by the police true false left

The innkeeper near the person in the black_hat visited a mysterious traveler. The innkeeper visited a traveler true false left

The celebrity who the organizers of the convention brought entertained the guests for hours. The organizers entertained the guests true false right

The celebrity with the organizers of the convention brought notes on cue cards. The organizers brought notes true false right

The appraiser who the bank beside the museum distrusted expected more pay. The appraiser distrusted the bank true false right

The appraiser for the bank beside the museum distrusted the new clients. The appraiser distrusted the clients true false left

The advisor who the board of the directors sought had too many appointments. The directors sought the advisor true false left

The advisor of the board of the directors sought some clarifications of recent investment decisions. The advisor sought clarification true false left

The visitor who the guide of the tour disliked took pictures in forbidden areas. The visitor was in forbidden areas. true false left

The visitor near the guide of the tour disliked the other tour members. The visitor was near the guide. true false left

The doctor who the inhabitants of the village consulted was worried about a potential epidemic. The villagers consulted the doctor true false left

The doctor for the inhabitants of the village consulted an expert about his findings.

The villagers had a doctor true false left

The policeman who the precinct in the South_End sent arrested a notorious drug runner. The precinct sent a policeman true false left
The policeman from the precinct in the South_End sent a mysterious bag to the lab for inspection. The bag was sent to the precinct true false right

The butler who the resident of the castle brought on vacation refused to take time off. The resident went on vacation true false left
The butler for the resident of the castle brought a martini to the study every evening. The butler went to the study each evening true false left

The friend who the president of the corporation invited was a well-known actor in Italy. The corporation was in Italy true false right
The friend of the president of the corporation invited many actors to the party. The president invited actors true false right

The conductor who the orchestra at the opera hired took a position in Japan. question alternatives answer
The conductor of the orchestra at the opera hired a tailor to make his suits. question alternatives answer

The mediator who the players in the league chose appeared not to be neutral at all. question alternatives answer
The mediator for the players in the league chose to discuss all problems openly. question alternatives answer

The man who the journalist in the documentary decried made millions with home shopping. question alternatives answer
The man with the journalist in the documentary decried teenage drug use. question alternatives answer

The mother who the boy with the red_hair called came running towards him. question alternatives answer
The mother of the boy with the red_hair called a friend for advice. question alternatives answer

The negotiator who the hijacker of the plane requested refused to enter the cockpit. question alternatives answer
The negotiator for the hijacker of the plane requested more time to think. question alternatives answer

The caretaker who the gorilla in the cage liked broke a leg while sweeping the floor. question alternatives answer
The caretaker of the gorilla in the cage liked to hug the animal once in a while. question alternatives answer

The hair_stylist who the actress in the movie married became a very rich man. question alternatives answer

The hair_stylist for the actress in the movie married a member of the camera crew.
question alternatives answer

The advocate who the environmentalists at the factory needed argued for their cause.
question alternatives answer

The advocate for the environmentalists at the factory needed more facts to argue the case.
question alternatives answer

The obstetrician who the clinic in the city promoted was pleased about her new position.
question alternatives answer

The obstetrician from the clinic in the city promoted the nurse because of her dedication.
question alternatives answer

The employee who the leader of the government recommended was excellent at dealing with the media.
question alternatives answer

The employee of the leader of the government recommended a long campaign.
question alternatives answer

The lawyer who the witness of the crimes avoided refused to settle the case.
question alternatives answer

The lawyer for the witness of the crimes avoided confrontations outside the case.
question alternatives answer

The prisoner who the terrorist from the Middle_East threatened seemed surprisingly calm.
question alternatives answer

The prisoner of the terrorist from the Middle_East threatened to make a lot of noise.
question alternatives answer

The representative who the senator from the midwest agreed_with was closely involved in the discussions.
question alternatives answer

The representative of the senator from the midwest agreed_with the new policies.
question alternatives answer

The assistant who the plumber from the garage looked_for was working in the shop.
question alternatives answer

The assistant of the plumber from the garage looked_for the mechanic in the shop.
question alternatives answer

The agent who the athlete from the Olympics spoke_to drew up a contract proposal.
question alternatives answer

The agent for the athlete from the Olympics spoke_to the International Olympic Committee.
question alternatives answer

The administrator who the university in the United_Kingdom talked_to was flattered by the job offer.
question alternatives answer

The administrator for the university in the United_Kingdom talked_to many foreign students.
question alternatives answer

The attorney who the victim of the assault trusted stared at the suspects. question
alternatives answer

The attorney for the victim of the assault trusted the judge in the case. question
alternatives answer

The editor who the reporter from the Globe met at a party commissioned some
freelance work. question alternatives answer
The editor near the reporter from the Globe met some heads of state at the state dinner.
question alternatives answer

The woman who the salesman from the mall insulted left the store in a hurry.
question alternatives answer
The woman with the salesman from the mall insulted him by mistake. question
alternatives answer

The artist who the actor in the Broadway_hit admired was showing paintings at a
nearby gallery. question alternatives answer
The artist with the actor in the Broadway_hit admired the sets at the theater.
question alternatives answer

The chief who the tribe in the valley adored was killed by a neighboring tribe.
question alternatives answer
The chief of the tribe in the valley adored the people in the region. question
alternatives answer

The campaigner who the candidate in the election overlooked became disenchanted
with the hard work. question alternatives answer
The campaigner for the candidate in the election overlooked two major donors.
question alternatives answer

The bishop who the diocese in the Bronx revered travelled to Cuba to see the Pope.
question alternatives answer
The bishop of the diocese in the Bronx revered the cardinal who he worked for.
question alternatives answer

The prosecutor who the ringleader of the gang stared_at was not easily threatened.
question alternatives answer
The prosecutor of the ringleader of the gang stared_at the accused criminals.
question alternatives answer

The confidante who the professor at the college ignored was more careful about offering
advice again. question alternatives answer
The confidante of the professor at the college ignored the negative reports in the media.
question alternatives answer

The commissioner who the department of the interior suspended spoke out on late-night TV. question alternatives answer

The commissioner for the department of the interior suspended a senior advisor.
question alternatives answer

The foreman who the company at the hearing discredited provided damaging evidence. question alternatives answer

The foreman for the company at the hearing discredited the reports of code violations.
question alternatives answer

The outfielder who the fans in the stands cheered caught a ball facing the sun.
question alternatives answer

The outfielder near the fans in the stands cheered his teammate's fine play.
question alternatives answer

The nanny who the couple in the townhouse loved decided to take another position.
question alternatives answer

The nanny for the couple in the townhouse loved the children as her own.
question alternatives answer

Appendix E: NP/CP comparison

The racketeer swore that the evidence that the FBI presented was planted. The FBI presented evidence true false left

The racketeer disputed the evidence that the FBI presented to the police. The FBI presented evidence true false left

The candidate admitted that the woman who the press photographed was a close friend. The candidate was a close friend true false left

The candidate avoided the woman who the press photographed with him on his boat. The woman was photographed on the boat true false left

The librarian worried that the administrators who the faculty despised would reduce the budget. The librarian despised the administrators true false right
The librarian questioned the administrators who the faculty despised after many earlier selfish decisions. The librarian despised the administrators true false right

The balloonist complained that the rigging that the ground_crew prepared was shoddy. The balloonist complained about the rigging true false left
The balloonist adjusted the rigging that the ground_crew prepared before lift-off. The balloonist adjusted the rigging true false left

The geologist hoped that the surveyor who the expedition relied_on would survive the snake bite. A snake bit the geologist true false right
The geologist criticized the surveyor who the expedition relied_on for sloppy methods. The surveyor was sloppy true false left

The dissident implied that the student who the government framed would appeal. The dissident framed the student true false right
The dissident avoided the student who the government framed for pamphleting. The dissident framed the student true false right

The electrician complained that the apprentice who the unionists teased was working too slowly. The apprentice complained about being teased true false right
The electrician consoled the apprentice who the unionists teased during lunch breaks. The unionists teased the apprentice true false left

The spy reported that the admiral who the CIA followed had changed the secret code. The admiral changed the code true false left
The spy tricked the admiral who the CIA followed during the cold war. The CIA followed the admiral true false left

The counterfeiter insisted that the plates that the etchers engraved contained a mistake. The counterfeiter made a mistake true false right
The counterfeiter changed the plates that the etchers engraved on Wednesday. The etchers engraved plates Wednesday true false left

The optometrist noticed that the glasses that the athlete broke had a manufacturing defect. The athlete broke the glasses true false left
The optometrist fixed the glasses that the athlete broke during a competition. The athlete broke the glasses true false left

The chauffeur acknowledged that the motorist that the witness identified was speeding. The chauffeur was speeding true false right
The chauffeur confronted the motorist that the witness identified in a court of law. The chauffeur was identified true false right

The diver feared that the oil-rig that the drillers repaired was leaking. The diver repaired the oil-rig true false right
The diver damaged the oil-rig that the drillers repaired last Saturday. The diver repaired the oil-rig true false right

The secretary implied that the message that the lawyer dictated was too dramatic. The secretary was dramatic true false right
The secretary typed the message that the lawyer dictated from his office. The lawyer was in his office true false left

The singer decided that the lyrics that the amateur composed were worth listening to again. The singer listened to the lyrics true false left
The singer liked the lyrics that the amateur composed in his spare time. The singer composed the lyrics true false right

The judge stipulated that the defendant who the plaintiff accused had to perform community service. question alternatives answer
The judge criticized the defendant who the plaintiff accused of malicious harm. question alternatives answer

The guitarist doubted that the song that the producer recommended was innovative. question alternatives answer
The guitarist loved the song that the producer recommended because it was innovative. question alternatives answer

The general argued that the operation that the soldiers proposed was too risky. The general proposed a risky operation true false right
The general approved the operation that the soldiers proposed during the meeting. The general proposed the operation true false right

The principal regretted that the children that the teachers warned strayed onto the highway. question alternatives answer
The principal punished the children that the teachers warned for being unruly. question alternatives answer

The economist concluded that the documents that the government drafted were overly optimistic. question alternatives answer
The economist edited the documents that the government drafted in the most recent meetings. question alternatives answer

The anthropologist hypothesized that the gods that the pygmies worshipped liked to party. question alternatives answer
The anthropologist described the gods that the pygmies worshipped in the jungle. question alternatives answer

The con_man claimed that the insurance that the retirees bought covered all natural disasters. question alternatives answer
The con_man endorsed the insurance that the retirees bought from the bogus company. question alternatives answer

The inventor realized that the device that the patent_office received was defective. question alternatives answer
The inventor built the device that the patent_office received by express mail. question alternatives answer

The candymaker speculated that the shop_clerks that the retailers hired were stealing. question alternatives answer
The candymaker approved_of the shop_clerks that the retailers hired last week. question alternatives answer

The bellboy knew that the room that the guest requested was empty. question alternatives answer
The bellboy checked the room that the guest requested before his arrival. question alternatives answer

The congressman proclaimed that the bill that the opposition sponsored would increase the deficit. question alternatives answer
The congressman supported the bill that the opposition sponsored as a good will gesture. question alternatives answer

he logger believed that the trees that the environmentalists protected were dangerous. question alternatives answer
The logger cut_down the trees that the environmentalists protected from harvest. question alternatives answer

The industrialist claimed that the pollution that the EPA measured was insignificant. question alternatives answer
The industrialist produced the pollution that the EPA measured with sensitive equipment. question alternatives answer

The newscaster alleged that the policies that the mayor advanced were bad for business. question alternatives answer

The newscaster ridiculed the policies that the mayor advanced as good for business.
question alternatives answer

The parents predicted that the kidnapper who the security_guard captured would be tried in the state. question alternatives answer

The parents identified the kidnapper who the security_guard captured last night.
question alternatives answer

The captain learned that the helmsman who the crew trusted had been drunk on duty.
question alternatives answer

The captain scolded the helmsman who the crew trusted until recently. question alternatives answer

The skater asserted that the jump that the judges insisted_on was too difficult.
question alternatives answer

The skater completed the jump that the judges insisted_on at the competition.
question alternatives answer

The explorer assumed that the myth that the tribesmen described was based on fact.
question alternatives answer

The explorer challenged the myth that the tribesmen described by entering the tomb.
question alternatives answer

The trucker mentioned that the axle that the welders fixed was rattling again.
question alternatives answer

The trucker replaced the axle that the welders fixed after the accident. question alternatives answer

The vegetarian suspected that the report that the cattlemen published was biased.
question alternatives answer

The vegetarian disputed the report that the cattlemen published last week. question alternatives answer

The trespasser indicated that the sign that the proprietor posted was illegible.
question alternatives answer

The trespasser ignored the sign that the proprietor posted on the fence. question alternatives answer

The constable speculated that the delinquent who the old_man accused had fled the neighborhood. question alternatives answer

The constable chased the delinquent who the old_man accused of the crime.
question alternatives answer

The historian conceded that the manuscript that the editor reviewed was amusing.
question alternatives answer

The historian wrote the manuscript that the editor reviewed for the magazine.
question alternatives answer

The accountant suggested that the books that the auditors checked should be recalculated. question alternatives answer
The accountant amended the books that the auditors checked at a meeting last night. question alternatives answer

The programmer discovered that the program that the computer compiled was not reliable. question alternatives answer
The programmer wrote the program that the computer compiled in two minutes. question alternatives answer

The imposter confessed that the politician who the KGB kidnapped was hidden in another country. question alternatives answer
The imposter imitated the politician who the KGB kidnapped over the weekend. question alternatives answer

The hippie argued that the values that the church endorsed were out of date. question alternatives answer
The hippie rejected the values that the church endorsed at a town meeting. question alternatives answer

The missionary suggested that the rituals that the natives practiced should be adopted in western society. question alternatives answer
The missionary ridiculed the rituals that the natives practiced during the full moon. question alternatives answer

The mathematician proved that the theorem that the physicists developed could be derived. question alternatives answer
The mathematician ignored the theorem that the physicists developed at the conference. question alternatives answer

The bridesmaid hoped that the priest who the couple selected would be on time. question alternatives answer
The bridesmaid admired the priest who the couple selected for the ceremony. question alternatives answer

The babysitter thought that the toddler who the police picked_up was from the neighborhood. question alternatives answer
The babysitter recognized the toddler who the police picked_up in the neighborhood. question alternatives answer

The councilman announced that the position that the assembly supported was untenable. question alternatives answer
The councilman obscured the position that the assembly supported in the vote. question alternatives answer

The treasurer confessed that the proposals that the voters favored were ineffective.

question alternatives answer

The treasurer endorsed the proposals that the voters favored at the conference.

question alternatives answer

The chancellor explained that the movement that the racists formed was exploiting high unemployment.

question alternatives answer

The chancellor decried the movement that the racists formed in high unemployment neighborhoods.

question alternatives answer

The manager insisted that the employee who the company hired should be given her own office.

question alternatives answer

The manager disliked the employee who the company hired for the job.

question alternatives answer

The shopper conjectured that the coats that the sales_staff tagged were underpriced.

question alternatives answer

The shopper bought the coats that the sales_staff tagged in the stock room.

question alternatives answer

Appendix F: Subject/Object relative clause study

The tourist who the merchant angrily insulted tossed the money onto the counter.

The tourist insulted the merchant. true false right

The tourist who angrily insulted the merchant tossed the money onto the counter.

The tourist insulted the merchant. true false left

The prisoner who the guard openly shoved registered a complaint with the warden.

The prisoner shoved the guard. true false right

The prisoner who openly shoved the guard registered a complaint with the warden.

The prisoner shoved the guard. true false left

The poet who the novelist harshly criticized wrote the review in the literary journal.

The novelist criticized the poet. true false left

The poet who harshly criticized the novelist wrote the review in the literary journal.

The novelist criticized the poet. true false right

The musician who the composer casually consulted suggested a change of tempo.

The composer consulted the musician. true false left

The musician who casually consulted the composer suggested a change of tempo.

The composer consulted the musician. true false right

The clerk who the secretary madly adored completed the project ahead of schedule.

The clerk completed the project. true false left

The clerk who madly adored the secretary completed the project ahead of schedule.

The clerk completed the project on schedule. true false right

The singer who the actress warmly praised received a part in the new show. The actress received a part. true false right

The singer who warmly praised the actress received a part in the new show. The singer received a part. true false left

The reporter who the politician savagely attacked admitted the error after the hearing.

The reporter admitted the error. true false left

The reporter who savagely attacked the politician admitted the error after the hearing.

The politician admitted the error. true false right

The Israeli who the Egyptian critically wounded hurled a grenade at the disabled tank.

The Egyptian hurled a grenade at the tank. true false right

The Israeli who critically wounded the Egyptian hurled a grenade at the disabled tank.

The Israeli disabled the tank. true false right

The engineer who the scientist callously ridiculed tested a machine for unexpected defects. The scientist ridiculed the engineer. true false left

The engineer who callously ridiculed the scientist tested a machine for unexpected defects. The engineer ridiculed the scientist. true false right

The general who the admiral keenly respected upheld the decision to invade the island.

The admiral respected the general. true false right

The general who keenly respected the admiral upheld the decision to invade the island.

The general respected the admiral. true false left

The lecturer who the dean loudly supported spurned an invitation to address the students. The dean supported the lecturer. true false right

The lecturer who loudly supported the dean spurned an invitation to address the students. The lecturer supported the dean. true false left

The director who the producer thoroughly hated ruined the production through his spiteful behavior. The producer hated the director. true false right

The director who thoroughly hated the producer ruined the production through his spiteful behavior. The producer hated the director. true false right

The ambassador who the duchess truly admired arranged the meeting in total secrecy.

The ambassador arranged a meeting. true false left

The ambassador who truly admired the duchess arranged the meeting in total secrecy.

The ambassador arranged a meeting. true false left

The councilman who the treasurer intensely despised controlled the debate over the zoning regulations. The treasurer controlled the debate. true false right

The councilman who intensely despised the treasurer controlled the debate over the zoning regulations. The treasurer controlled the debate. true false right

The historian who the librarian politely invited planned the conference far in advance.

The historian invited the librarian. true false right

The historian who politely invited the librarian planned the conference far in advance.

The historian invited the librarian. true false left

The bandit who the thief sharply kicked stole a truck from the warehouse. The bandit kicked the thief. true false right

The bandit who sharply kicked the thief stole a truck from the warehouse. The bandit kicked the thief. true false left

The diplomat who the president pointedly ignored altered the policy without further approval. The diplomat altered the policy. true false left

The diplomat who pointedly ignored the president altered the policy without further approval. The diplomat altered the policy. true false left

The writer who the critic bluntly attacked sipped a sherry at the literary event. The writer sipped a sherry. true false left

The writer who bluntly attacked the critic sipped a sherry at the literary event. The writer sipped a sherry. true false left

The porter who the bellhop graciously praised spent the bonus on a new television.
The bellhop spent the bonus on shoes. true false right
The porter who graciously praised the bellhop spent the bonus on a new television.
The bellhop spent the bonus on shoes. true false right

The doctor who the professor actively respected prepared a report on the strange phenomenon.
The doctor respected the professor. true false right
The doctor who actively respected the professor prepared a report on the strange phenomenon.
The professor respected the doctor. true false left

The forward who the goalie excitedly kicked missed the ball near the goal. The forward kicked the goalie. true false right
The forward who excitedly kicked the goalie missed the ball near the goal. The forward missed the goal. true false left

The minister who the priest repeatedly ignored accepted an award for the treatment center. The minister accepted an award. true false left
The minister who repeatedly ignored the priest accepted an award for the treatment center. The priest accepted an award. true false right

The fireman who the cop speedily rescued sued the city over working conditions.
The fireman sued the city. true false left
The fireman who speedily rescued the cop sued the city over working conditions.
The fireman sued the city. true false left

The salesman who the executive fiercely accused denied the charge of embezzling company funds. The executive denied the charge true false right
The salesman who fiercely accused the executive denied the charge of embezzling company funds. The executive denied the charge true false right

The killer who the policeman severely injured squeezed the trigger of his revolver.
The killer was injured true false left
The killer who severely injured the policeman squeezed the trigger of his revolver.
The killer was injured true false right

The Democrat who the Republican eagerly confronted rejected the money from the interest group. The Democrat rejected the money true false left
The Democrat who eagerly confronted the Republican rejected the money from the interest group. The Democrat rejected the money true false left

The nurse who the therapist sternly questioned reported a change in the patient's condition. question alternatives answer
The nurse who sternly questioned the therapist reported a change in the patient's condition. question alternatives answer

The player who the coach quietly despised abandoned the team after another losing season. question alternatives answer

The player who quietly despised the coach abandoned the team after another losing season. question alternatives answer

The senator who the governor frequently opposed captured the nomination at the party convention. question alternatives answer

The senator who frequently opposed the governor captured the nomination at the party convention. question alternatives answer

The teacher who the principal secretly threatened demanded an investigation by the school board. question alternatives answer

The teacher who secretly threatened the principal demanded an investigation by the school board. question alternatives answer

The waiter who the busboy kindly assisted stacked the glasses near the sink. question alternatives answer

The waiter who kindly assisted the busboy stacked the glasses near the sink. question alternatives answer

The engineer who the scientist cautiously warned discovered a problem with the space probe. question alternatives answer

The engineer who cautiously warned the scientist discovered a problem with the space probe. question alternatives answer

The gambler who the gangster deeply hated buried a trunk behind the restaurant. question alternatives answer

The gambler who deeply hated the gangster buried a trunk behind the restaurant. question alternatives answer

The butler who the maid blindly loved unwrapped a box of chocolate peanuts. question alternatives answer

The butler who blindly loved the maid unwrapped a box of chocolate peanuts. question alternatives answer

The alderman who the mayor firmly supported proposed a change in the city charter. question alternatives answer

The alderman who firmly supported the mayor proposed a change in the city charter. question alternatives answer

The architect who the scholar generously invited discussed the outcome of the project. question alternatives answer

The architect who generously invited the scholar discussed the outcome of the project. question alternatives answer

The prosecutor who the detective flatly challenged produced an alibi on the spot. question alternatives answer

The prosecutor who flatly challenged the detective produced an alibi on the spot. question alternatives answer

The captain who the sergeant personally comforted folded the flag from the casket.
question alternatives answer

The captain who personally comforted the sergeant folded the flag from the casket.
question alternatives answer

The barber who the waitress patiently loved examined the ring studded with diamonds.
question alternatives answer

The barber who patiently loved the waitress examined the ring studded with diamonds.
question alternatives answer

The outlaw who the sheriff gravely injured rode a stallion around the sleepy town.
question alternatives answer

The outlaw who gravely injured the sheriff rode a stallion around the sleepy town.
question alternatives answer

The mechanic who the welder truthfully accused obtained a reward from the company.
question alternatives answer

The mechanic who truthfully accused the welder obtained a reward from the company.
question alternatives answer

The soldier who the sailor roughly pushed smashed a bottle against the bar.
question alternatives answer

The soldier who roughly pushed the sailor smashed a bottle against the bar.
question alternatives answer

The cowboy who the rancher rudely shoved pulled a pistol out of his holster.
question alternatives answer

The cowboy who rudely shoved the rancher pulled a pistol out of his holster.
question alternatives answer

The counselor who the judge stubbornly opposed invented a reason to disqualify the juror.
question alternatives answer

The counselor who stubbornly opposed the judge invented a reason to disqualify the juror.
question alternatives answer

The author who the editor constantly consulted revised the chapter slightly before publication.
question alternatives answer

The author who constantly consulted the editor revised the chapter slightly before publication.
question alternatives answer

The violinist who the pianist furiously insulted performed a movement badly during the concert.
question alternatives answer

The violinist who furiously insulted the pianist performed a movement badly during the concert.
question alternatives answer

The carpenter who the electrician helpfully advised finished the job on schedule.
question alternatives answer

The carpenter who helpfully advised the electrician finished the job on schedule.
question alternatives answer

The criminal who the officer seriously wounded retrieved a package from the sidewalk.
question alternatives answer

The criminal who seriously wounded the officer retrieved a package from the sidewalk.
question alternatives answer

The ghost who the witch bitterly threatened uttered a curse in the foul darkness.
question alternatives answer

The ghost who bitterly threatened the witch uttered a curse in the foul darkness.
question alternatives answer

The auditor who the coroner publicly questioned delayed a vacation until the
controversy ended. question alternatives answer

The auditor who publicly questioned the coroner delayed a vacation until the
controversy ended. question alternatives answer

Appendix G: sentential complement / relative clause comparison

Tammy assured the plumber whom the unionists had called that her fixtures were new. Did Tammy call some unionists? no
Tammy assured the plumber that the unionists had called from their_shop early that morning. Did Tammy call some unionists? no

Mr._Newbert informed the cabbie whom the pedestrians had shouted_at that a patrol car was following. Was the cabbie shouting? no
Mr._Newbert informed the cabbie that the pedestrians had shouted_at someone_else. Was the cabbie shouting at Mr. Newbert? no

Nola persuaded the dealer whom the buyers had loved that her work ought to_be put on consignment. Did buyers love the dealer? yes
Nola persuaded the dealer that the buyers had loved her_art. Did the dealer believe Nola was popular? yes

Clifton insisted to_the committee whom the senators had convened that the deficit must be addressed. Was the committee convened by senators? yes
Clifton insisted to_the committee that the senators had convened the_meeting on time. Did the senators address the committee? no

Ms._Doan indicated to_the council whom the activists had resisted that it ought to_continue work on the_dam. Was the council building a dam? yes
Ms._Doan indicated to_the council that the activists had resisted the_proposed dam_project. Did the peasants oppose the dam? yes

Jerry maintained to_the manager whom the interns had despised that he would not be_late again. Did interns despise the manager? yes
Jerry maintained to_the manager that the interns had despised the_project. Was the project hated? yes

Vickie told the bouncer whom the prostitutes had insulted that happy hour was starting. Did the bouncer get insulted? yes
Vickie told the bouncer that the prostitutes had insulted some_of the_patrons. Did the bouncer roam the bar? no

Edmonds implied to_the delegate whom the ambassadors had disparaged that the_talks would be troublesome. Did Martin disparage the ambassadors? no
Edmonds implied to_the delegate that the ambassadors had disparaged the_talks. Did the delegate disparage the talks? no

Mr._Pohl whispered to_the doorman whom the superintendant hired that a_female guest would_arrive soon. Did the superintendant hire a female guest? no
Mr._Pohl whispered to_the doorman that the superintendant hired a_nephew for_the midnight_shift. Did the doorman learn when the nephew worked? yes

Mr._Kelridge announced to_the students whom the proctors had identified that cheating was not tolerated. Did the students identify the proctors? no
Mr._Kelridge announced to_the students that the proctors had identified the_cheaters.
Were the cheaters caught? yes

Mr._Huntington assured the caterer whom the organizers had contracted that only 30 guests would arrive. Did he know the organizers contracted the caterer? yes
Mr._Huntington assured the caterer that the organizers had contracted only them.
Was only one caterer contracted? yes

Mr._Lipton informed the veterinarian whom the horses had liked that the race would be postponed. Did the vet like to have the race postponed? no
Mr._Lipton informed the veterinarian that the horses had liked no other vet. Did the vet race the horses? no

Ms._Carlyle notified the policeman whom the witnesses had stopped that a_burglary had occurred in_a nearby building. Did Ms. Carlyle stop the policeman? no
Ms._Carlyle notified the policeman that the witnesses had stopped a_fleeing suspect.
Did witnesses flee the policeman? no

Jill persuaded the eavesdropper whom the janitors had caught that it was better to remain silent. Did the eavesdropper repeat what he had heard? no
Jill persuaded the eavesdropper that the janitors had caught on to his_spying. Did the eavesdropper's friends spy on Jill? no

Stephanie promised the babysitter whom the children had asked_for that her services were appreciated. Did Stephanie appreciate the babysitter? yes
Stephanie promised the babysitter that the children had asked_for her in particular.
Did the children want the babysitter? yes

Nichole told the courier whom the marketers had dispatched that the package contained perishable materials. Did Nichole know what was in the package? yes
Nichole told the courier that the marketers had dispatched someone to meet him.
Did Nichole get the package from marketers? no

Joel convinced the DA whom the litigants had praised that a plea bargain was the best course of_action. Did the litigants praise the DA? yes
Joel convinced the DA that the litigants had praised his hard-line stance. Did the litigants agree with his position? yes

Ollie proclaimed to_the crowd whom the agents had watched that the_country was becoming too_liberal. Did Ollie speak in public? yes
Ollie proclaimed to_the crowd that the agents had watched their every move. Did Ollie speak in public? yes

Glenn indicated to_the stewardess whom the passengers had met that his seatbelt was broken. Did the passengers complain to the stewardesses? no
Glenn indicated to_the stewardess that the passengers had met the end of their patience. Did Glenn have a broken seatbelt? yes

Penny announced to_the carpenter whom the termites had frustrated that she was calling in a_fumigator. Did the carpenter call a fumigator? no
Penny announced to_the carpenter that the termites had frustrated her fumigator. Did the carpenter see termites in the basement? no

Dorothy mentioned to_the artisan whom the Peruvians had welcomed that she intended to_visit. Was Dorothy planning a trip? yes
Dorothy mentioned to_the artisan that the Peruvians had welcomed his_visit. Did the Peruvians like the artisan? yes

Sheila convinced the conductor whom the orchestra had applauded that he should retire. Did the conductor applaud the orchestra? no
Sheila convinced the conductor that the orchestra had applauded him spontaneously. Did the conductor applaud the orchestra? no

Henry implied to_the translator whom the summit had bored that the minister was_drunk. Was the minister bored at the summit? no
Henry implied to_the translator that the summit had bored_him senseless. Did the summit bore Henry? yes

Mr._Benton maintained to_the panel whom the church_elders had elected that his art was_not pornographic. Did the church elders elect Mr. Benton? no
Mr._Benton maintained to_the panel that the church_elders had elected him to_reinstate family_values. Did the church elders elect the panel? no

Gloria insisted to_the dentist whom the hospital had had recommended that her insurance covered all treatment. Was the dentist recommended by the hospital? yes
Gloria insisted to_the dentist that the hospital had had recommended full anesthesia. Was anesthesia recommended by the hospital? yes

Moscowitz notified the suspect whom the jury had indicted that his trial_date had_been set. Did Mosowitz notify the jury? no
Moscowitz notified the suspect that the jury had indicted some_one else. Did the Moscovitz notify the jury? no

Fletcher proclaimed to_the stock-holders whom the conglomerate had cheated that a_reorganization was_underway. Did the conglomerate cheat the stock-holders? yes
Fletcher proclaimed to_the stock_holders that the conglomerate had cheated the Securities Exchange Commission. Did the SEC notify the stock-holders? no

Mr._Eaton mentioned to_the reviewers whom the editors had chosen that the submitter was a Nobel laureate. Were the reviewers chosen by the editors? yes
Mr._Eaton mentioned to_the reviewers that the editors had chosen a Nobel laureate as his replacement. Were the editors replacing Mr._Eaton? yes

Escavito promised the generals whom the elections had ousted that there was room in_his new_cabinet. Did the elections oust Escavito? no
Escavito promised the generals that the elections had ousted all their potential enemies. Did the elections oust the generals? no

Stowell whispered to_the interrogator whom the government had sent that the mafia was in his department. Did the government send the interrogator? yes
Stowell whispered to_the interrogator that the government had sent military supplies to a dictator in Central America. Did Stowell know of the government shipment?
yes

Bibliography

- Besson, M., Kutas, M., & Van_Petten, C. (1992). An event-related potential analysis of semantic congruity and repetition effects in sentences. *Journal of Cognitive Neuroscience*, 4(2), 132-149.
- Bolinger, D. (1972). *What did John keep the car that was in? *Linguistic Inquiry*, 3, 109-114.
- Baddely & Hitch (1974) Working Memory. In *The Psychology of Learning and Motivation* (Vol. 8, pp.47-89), G.H. Bower (Ed.). San Diego, CA: Academic Press.
- Cinque, G. (1991) Types of A'-dependencies, Cambridge: MIT Press
- Chomsky, N. (1981). *Lectures in Government and Binding*. Dordrecht, The Netherlands: Foris Publications.
- Chomsky, N. (1986). *Barriers*. Cambridge: MIT Press.
- Chomsky, N. (1993). A minimalist program for linguistic theory. In *The View from Building 20: Linguistic essays in honor of Sylvan Bromberger* (pp. 1-51). Cambridge: MIT Press.
- Gibson, E. (1991) A Computational Theory of Human Linguistic Processing: Memory Limitations and Processing Breakdown. Dissertation, Carnegie Mellon University.
- Gibson, E. (1998) Linguistic complexity: Locality of syntactic dependencies. *Cognition* (in press).
- Hagoort, P., Brown, C., & Groothusen, J. (1993). The Syntactic Positive Shift as an ERP-measure of syntactic processing. *Language and Cognitive Processes*.
- Higginbotham (1980) Pronouns and bound variables, *Linguistic Inquiry*, 14, p. 395-420
- Just, M. & Carpenter, P. (1992) A Capacity Theory of Comprehension: Individual Differences in Working Memory., *Psychological Review*, 99 (1), p.122-148
- King, J., & Kutas, M. (1995). Who did what and when? Using word- and clause-level ERPs to monitor working memory usage in reading. *Journal of Cognitive Neuroscience*. 7(3) pp. 376.
- 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 Sixteenth Annual Meeting of the Berkeley*
- Kluender, R. (1992). Deriving Island Constraints. In H. Goodluck & M. Rochmont (Eds.), *Island Constraints: Theory, Acquisition, and Processing* Dordrecht: Kluwer Academic Publishers.
- Kluender, R., & Kutas, M. (1993). Subjacency as a Processing Phenomenon. *Language and Cognitive Processes*, 8(4), 573-633.
- Kluender, R., & Kutas, M. (1993). Subjacency as a Processing Phenomenon. *Language and Cognitive Processes*, 8(4), 573-633.
- Kluender, R., & Kutas., M. (1993a). Bridging the Gap: Evidence from ERPs on the Processing of Unbounded Dependencies. *Journal of Cognitive Neuroscience*, 5(2), 196-214.
- Kluender, R. Münte, T., Cowles, H., Szentkuti, A., Walenski, M., & Wieringa, B. (1998) Brain potentials to English and German questions, poster, Cognitive Neuroscience Society
- Kuno, S. (1987) Functional syntax: anaphora, discourse and empathy. Chicago: University of Chicago Press.
- Kutas, M., & Hillyard, S. (1980). Reading Senseless Sentences: Brain Potentials Reflect Semantic Incongruity. *Science*, 207, 203-205.
- Kutas, M., Lindamood, T., & Hillyard, S. (1984). Word expectancy and event-related potentials during sentence processing. In Komblum & Requin (Eds.), *Preparatory States and Processes* (pp. 217-238). Hillsdale, New Jersey: Erlbaum.

- Manzini, M. R. (1992). *Locality: A Theory and Some of its Empirical Consequences*. Cambridge: MIT Press.
- McKinnon, R., & Osterhout, L. (1996). Constraints on movement phenomena in sentence processing: Evidence from event-related potentials. *Language and Cognitive Processes*, 11:5, p. 495
- Neville, H., 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(2), 151-165.
- Osterhout, L. (1990). Event-related brain potentials elicited during sentence comprehension. Dissertation.
- Osterhout, L., & Holcomb, P. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, 31, 785-806.
- Osterhout, L., & Holcomb, P. (1993). Event-Related Potentials and Language Comprehension. In M. Rugg & M. Coles (Eds.), *Electrophysiological Studies of Human Cognition* Oxford U. Press.
- Osterhout, L., & Mobley, L. (1994). Event-related Brain Potentials elicited by failure to agree.
- Penke, M., Weyerts, H., Gross, M., Zander, E., Münte, T. & Clahsen, H. (1997) How the brain processes complex words: an ERP study of German verb inflections. *Brain Res Cogn Brain Res*. 6(1): 37-52.
- Pesetsky, D. (1987). WH in situ: Movement and unselective binding. In *The Representation of (In)definiteness*. E. Reuland and ter Meulen, A.(Eds) Cambridge:MIT Press.
- Reinhart and Reuland, (1993) Reflexivity. *Linguistic Inquiry*, 24(4), p. 657-720
- Rizzi, L. (1986). On Chain Formation. *Syntax and Semantics*, 19, 65-95.
- Rösler, F., Pütz, P., Friederici, A., & Hahne, A. (1993). Event-related brain potentials while encountering semantic and syntactic constraint violations. *Journal of Cognitive Science*, 5(3), 345-362.
- Rugg, M. (1990). Event-related brainpotentials dissociate repetition effects of high- and low- frequency words. *Memory & Cognition*, 18(4), 367-379.
- Ruchkin, D., Johnson, R., Grafman, J., Canoune, H., & Ritter, W. (1992). Distinctions and similarities among working memory processes: and event-related potential study. *Cognitive Brain Research*, 1, p. 53-66.
- Van Petten, C., & Kutas, M. (1990). Interactions Between Sentence Context and Word Frequency in Event-Related Potentials. *Memory and Cognition*, 18(4), 380-393.
- Zribi-Hertz, A. (1989) Implicit arguments, the binding theory and control. *Natural Language & Linguistic Theory*, 5:151-180.