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An electrophysiological analysis of animacy effects in the processing of object relative sentences

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Abstract

Event-related brain potentials (ERPs) were used to investigate how and when a semantic factor (animacy) affects the early analysis of a difficult syntactic structure, namely, object relative sentences. We contrasted electrophysiological and behavioral responses to two object relative types that were syntactically and lexically identical and varied only in the order of the component animate and inanimate nouns [Inanimate (Animate) vs. Animate (Inanimate)]. ERPs were recorded from 40 subjects to each word of 30 I(A) and 30 A(I) sentences that occurred randomly among a set of various other sentence types read for comprehension. ERP effects to the early noun animacy manipulation were observed beginning with the initial noun and extending past the main clause verbs. We interpret the timing and multitude of electrophysiological effects, including the N400, P600, and left-anterior negativity, as evidence that both semantic and syntactic, and perhaps other types of information, are used early during structural analysis and message-level computations as needed for comprehension.

Descriptors: Event-related potential, Animacy, Object relative clauses, Role assignment, Sentence processing, Parsing

Understanding sentences in a laboratory booth is a lightning-quick, remarkable process that involves the integration of many types of information, not to mention the engagement of a host of cognitive operations. Clearly a cognitive ability this efficient and complex requires a number of low-level operations (e.g., role assignment, retrieval from working memory, word recognition, etc.) as well as higher-order computations (e.g., relationships among clausal participants). To date, we have only a faint notion about either the psychological or the neural mechanisms that subserve understanding. Given the speed at which the analysis and integration of information at these various levels takes place, the recruitment of event-related brain potentials (ERPs) into the language domain is a potentially wise investment by investigators interested in sentence and discourse processing. Electrophysiological measures offer exquisite temporal resolution and a number of parameters in the brain's response to afford inferences about how a reader constructs the meaning of a sentence. Moreover, ERPs provide such inferences while the reader has to do little more than read, precisely the cognitive ability under investigation.

In this report, we have analyzed two sentence types that appear to differ very little. On the surface, it seems that only the order of four lexical items has been reversed in what are otherwise lexically and syntactically identical structures. Yet, this reversal reveals processing differences between the two sentence types, starting relatively early in the sentence in word-by-word reading time data (Weckerly & Kutas, 1998) and as we will show even earlier in scalp-recorded electrical brain activity.

Some Language Basics

Psycholinguists and linguists alike have identified various regularities in aspects of language, from the systematic combinations of sounds to form words to the higher-level processes that give humans the flexibility to understand metaphor and other nonliteral uses of language. All researchers agree that these different aspects and levels of linguistic input are continually analyzed and synthesized as an utterance is understood. Although theoretical approaches to the study of language vary in their definition of what each of these aspects or levels entails, we will attempt to give a basic definition of the aspects of language most often studied in sentence comprehension.

Syntax captures the hierarchical structure in language, including how words are combined into phrases and sentences. For instance, our knowledge of the syntactic rules of English tell us that "John kicked the ball" is a permissible (i.e., grammatically correct) combination of its constituent elements, whereas "John the ball kicked" is not. Syntactic analysis also specifies how elements within a structure are related to one another. Linguists and psycholinguists use the notion of grammatical role to describe the various relationships among words in a structure. In the example sentence above, "John" is the grammatical subject and "the ball" is the grammatical object. The grammatical relationships between words

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is an aspect of language forms that people use to determine who did what to whom in order to understand an utterance.

The term *semantics* refers to information about word meaning and the relationship between words and the objects, events, or concepts that they represent. The sentences "John kicked the ball" and "John knew the answer" are syntactically identical; they both consist of a subject, a verb, and an object. Yet, they clearly do not mean the same thing; they differ in their semantics. Semantic analysis is meant to capture this difference. Thematic roles describe the mapping between noun phrases in sentences ("John," "the ball," "the answer") to discourse entities, the basic units in a message level representation of a sentence. Considering thematic roles in their most basic sense, in "John kicked the ball" "John" fills the role of agent, and "the ball" fills the role of the patient. By contrast, in a semantic analysis of the sentence "John knew the answer," "John" might instead be assigned the thematic role of experiencer.

Generally speaking, the assignment of grammatical and thematic roles to sentence constituents reflects syntactic and semantic analysis, respectively. Most language theorists agree that there is no clear one-to-one mapping between grammatical and thematic roles. In fact, it is the hypothesized relationship of these levels and the extent to which they are implemented as separate systems by the brain that make for the variety of language processing models. Although researchers differ fundamentally as to exactly what roles (e.g., grammatical, thematic) are assigned and what kinds of representations they fit into (e.g., phrase structure analysis, meaning-level representation, etc.), most models have some mechanism for interpreting the basic relationship between participants in a clause.

There are other levels of linguistic description that are important in comprehending a simple sentence. The lexical level relates to information associated with single words. For example, the fact that a ball is a thing (noun) as opposed to an action (verb) and that it is round and usually made of plastic is the kind of lexical information that most language theorists believe is accessed during the construction of a sentence's meaning. On many accounts, lexical representations may contain both syntactic and semantic attributes. For example, lexical information associated with the verb "kick" might include that this string of sounds is a verb that requires two grammatical roles (a subject and an object) and two thematic roles (an agent and a patient).

Pragmatics describes regularities that determine the effective use of language in social situations. It is our knowledge of the pragmatic rules of English that allows us to understand "Do you have a watch?" as a request for the time rather than a sincere interest in whether or not one actually owns a watch. Higher-order rules or conventions of this sort also influence how we understand a single sentence, and there is wide debate as to how early in the course of a sentence pragmatic information influences comprehension processes. Nearly all who study language processing agree that comprehension involves the synthesis of syntactic, semantic, lexical, and pragmatic levels of language input.

Models of sentence processing try to account for how and when these various types of information (syntactic, semantic, pragmatic, and lexical) are combined into a sentence-level representation as comprehension takes place in real time. The essence of modular approaches is that the syntactic and semantic levels of analysis are distinct, such that analysis at one level does not influence the other (Clifton & Frazier, 1988; Ferriera & Clifton, 1986; Frazier, 1989). In some modular models, these analyses are serially ordered, whereas in others these analyses take place in parallel, but in all cases the analyses are independent (Mitchell, 1987). Grammatical roles are assigned independently of thematic roles and specific lexical attributes of words. Only under certain conditions such as the need to reanalyze an erroneous syntactic structure do the information types interact. The ease of synthesizing the output of these independent analyses or the cost of reanalysis within any level relates directly to processing difficulty.

Other theories are less restrictive as to the types of information used in syntactic analysis. In "lexical-entry driven" accounts (Trueswell, Tanenhaus, & Kello, 1993), lexical information associated with verbs is used routinely in the initial syntactic parse (i.e., syntactic analysis). Some constraint-based lexicalist approaches (MacDonald, Perlmutter, & Seidenberg, 1994; Trueswell & Tanenhaus, 1994) make use of semantic and probabilistic lexical information in addition to lexically specified syntactic information to guide the initial analysis. Least restrictive in their view of what kinds of information may guide comprehension are interactive models (Bates & MacWhinney, 1989; Marslen-Wilson & Tyler, 1980; Taraban & McClelland, 1988), wherein various types of information are said to combine continuously throughout a sentence's analysis. Under this approach, comprehension typically does not involve any abrupt backtracking, because all types of information are combined on a word-by-word basis, limited only by processing speed and resources. Thus, processing difficulty fluctuates according to the consistency of information, probabilistic tendencies associated with various forms of input, and in some cases, the demands on nonlinguistic faculties, such as working memory.

It is incumbent upon any model of sentence processing to explain why certain linguistic forms are more difficult to understand than others or why some structures take longer to process according to error, reading times, and other behavioral measurements. Processing difficulty has been examined by holding a syntactic configuration constant and varying the semantic content of key elements. It is then possible to look at the timepoint(s) of difficulty as a way to infer the time course and division of labor of the hypothesized subprocesses. Sentence processing differences often extend beyond the locus of explicit semantic manipulation. The temporal resolution in ERP measures may thus be a more sensitive measure in detecting processing differences.

Object Relatives

The syntactic structure used in this experiment, sentences containing an object relative clause, is known to be difficult to understand. Due to their unusual syntactic structure, object relatives might prove useful in gauging when different types of information are used. As opposed to most structures in English, object relatives contain a noun phrase that occurs before the verb, where standard word order rules would normally place this argument in a postverbal position. For example, object relatives (ORs) as in example (1) below are configured such that two nouns precede the verb that relates them. ORs are syntactically ambiguous up to the relative clause subject determiner "the," at which point the comprehender has enough syntactic information to know that they have encountered a relative clause. In fact, there is enough information for the reader to know that it is an object as opposed to a subject relative.

(1) The student that the dissertation baffled swore to the heavens she would never utter a complex structure again.

OR syntax forces the comprehender to make grammatical and thematic role assignments to displaced and distant arguments ("student" as subject of the main clause and object of the relative clause). OR syntax also requires rapid processing of the adjacent verbs of the main ("swore") and relative ("baffled") clauses, allowing for the possibility that role assignment processes may overlap in time. Any viable theoretical account of sentence processing must therefore not only specify what kinds of information are used in these operations, but delineate the timecourses of their use as well.

In this investigation, we examined the processing of ORs by manipulating the animacy of the nouns in the initial noun phrases. Our stimuli were constructed from two types of clauses. One clause had an animate noun as subject and an inanimate noun as grammatical object (e.g., "The editor recognized the poetry."). The other clause had the same nouns, only in opposite roles; that is, the inanimate noun took the subject role and the animate noun serves as object (e.g., "The poetry depressed the editor."). The verbal predicates in each clause were chosen such that their selectional restrictions were consistent with the animacy configurations used. Selectional restrictions refer to requirements as to what types of nouns may fill thematic roles for given verbs. For example, the verb "recognize" requires an animate noun as the agent, whereas its patient may either be animate or inanimate, as in "The editor recognized the poetry" or "The editor recognized the poet." The two clause types were combined so that one was a main clause and the other a relative clause to form two different OR structures as in the examples (2a,b) below. The initial animate and inanimate nouns for A(I) and I(A) sentences, respectively, were matched on both word length and frequency (Francis & Kucera, 1982; see Table 1).

(2a) I(A): Inanimate-Animate
The poetry that the editor recognized depressed the publisher of the struggling…

(2b) A(I): Animate-Inanimate
The editor that the poetry depressed recognized the publisher of the struggling…

Note that this experiment is not a completely balanced design, as we were concerned about exposing our volunteers to so many OR constructions that they would begin to expect them and thus alter their processing strategies. We therefore chose the two animacy configurations that we hypothesized would be most extreme. Moreover, because we manipulated only the order in which particular nouns and verbs appeared, we ensured that the observed differences (if any) could be attributed only to the interaction between semantic and/or pragmatic information inherent in the configuration of the lexical items and their syntactic structure.

In a word-by-word reading time study using these same materials, we had found that readers were in fact sensitive to noun animacy information prior to the relative clause verb (Weckerly & Kutas, 1998). Specifically, we observed a reading time advantage for sentences with an inanimate main clause subject and an animate relative clause subject (as in 2a) compared with those with the inverse animacy configuration (as in 2b). The advantage began with the relative clause subject (~20 ms) and lasted beyond the main clause verb up through its direct object.

Table 1. *Means (SD) for Word Length and Word Frequency for Initial Nouns in Relative Clause Sentence Types*

	Word length	Word frequency
Animate	8.02 (2)	45 (103)
Inanimate	7.88 (2)	36 (42)

Language-Related ERP Effects

The use of ERPs in the study of sentence comprehension is a fairly recent enterprise. The collective efforts of electrophysiological investigations of language comprehension have produced several reliable ERP patterns that may aid in understanding the inner workings of language processing. Both semantic and syntactic features of sentences have been manipulated. When these manipulations have included various linguistic violations, initially different componentry were linked to each domain. However, it is debatable whether there exists a simple one-to-one correspondence between ERP components and linguistic domains. A brief description of the most often observed ERP components found in language processing studies follows.

N400. The N400 is a posterior, slight right hemisphere negativity between 250 and 600 ms. The amplitude of the N400 component of the ERP has been found to correlate with the difficulty of integration of a word into a sentence context. Although the N400 effect is largest in response to clear semantic incongruities (Kutas & Hillyard, 1980), modulations in amplitude have been observed with expectancy and cloze probability (Kutas & Hillyard, 1984). However, the N400 response cannot be interpreted as a pure index of probability, because sentence final words semantically related to expected endings elicit less negativity even when they are anomalous and their cloze probability is zero. In general, N400 differences have been linked to the semantic expectancy of an item given a context, be it a prime in a word pair or prior words in a sentence (Kutas, 1993; Van Petten & Kutas, 1991).

P600. Late positivities have been reported in various studies of sentence comprehension with diverging interpretations of their functional significance; most recently, P600s have been linked to aspects of syntactic analysis (e.g., Friederici & Mecklinger, 1996; Hagoort, Brown, & Groothusen, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992). Whereas there is some evidence indicating that the P600 is not syntax-specific (Coulson, King, & Kutas, 1998), it does appear to be elicited at regions of processing difficulty in sentences, often engendered at a syntactic level.

Left-anterior negativity (LAN). The LAN, first described by Kluender and Kutas (1993a), is hypothesized to reflect some aspect of working memory operations. In a study of sentences containing long-distance dependencies, these investigators observed an enhanced LAN to words occurring as a working memory load was carried and also to words immediately following a sentence position where role assignments were hypothesized to take place. Working memory load to words immediately following the point at which role assignment could be completed is likely to be high, as these links must be integrated into the sentence's temporary representation in working memory (see also King & Kutas, 1995). More recently, Friederici and her colleagues (Friederici, Hahne, & Mecklinger, 1996; Friederici & Mecklinger, 1996) have offered an alternative interpretation of the LAN within a two-stage model of sentence parsing. On their account, the LAN reflects a disruption in the first stage of parsing during which an initial phrase structure is built. Thematic role assignment and syntactic reanalysis when needed are presumed to occur as a part of the second stage.

The present experiment was designed to use these ERP components to answer questions about the use of animacy information in the processing of OR sentences. Specifically, we measured various ERP effects to determine how early animacy is registered and how long animacy affects sentence processing. From such data, we can hypothesize about how animacy information may have been used to circumvent or to ease the difficult stages of processing inherent in our two types of OR structures. Moreover, we can use these data to help adjudicate between strictly modular and more interactive models of sentence comprehension.

Given our knowledge of these components and the temporal sensitivity of ERPs, we have some general expectations about when and what kinds of effects we might find as I(A) and A(I) sentences are read. We expect to find some ERP effect of animacy at the relative clause subject, given that reading time differences are evident in this sentence position. This effect may come in the form of an N400 to the unexpected, and therefore difficult to integrate, inanimate relative clause subject in A(I) sentences. Moreover, there is a frequency difference between object relatives containing animate versus inanimate heads that we believe will lead to different expectancies in the two OR conditions. Specifically, in I(A) but not A(I) configured sentences, readers may take advantage of the higher probability that inanimate nouns head object as opposed to subject relatives (Fox & Thompson, 1990). It has been noted that given the fragment, "the book (inanimate noun) that . . . ," readers can expect that nearly 80% of the time the fragment will be completed with an OR structure ("the book that the boy bought . . .") as opposed to a subject relative structure ("the book that contained the passage . . ."). If the parser is indeed sensitive to such distributional statistics (a nonsyntactic factor) at this stage of processing, then there is further support in I(A) sentences for the initial inanimate noun to be assigned as object, the role that it actually plays in the relative clause. In addition, these statistics provide clues as to what type of relative clause the reader is most likely to face (object as opposed to subject relative). No such strong tendencies are associated with relative clauses with animate heads.

We also predict LAN effects at locations in the A(I) sentences where demands on working memory are high, such as at the verbs and perhaps at the complementizer. In an electrophysiological study with materials similar to ours, King and Kutas (1995) found a greater LAN to main clause verbs of object as compared with subject relative structures, although verbs in both sentence types generated larger LANs than for verbs in unembedded sentences. We might also find greater late positive activity (of the P600-type) for the later words of the sentence such as the verbs and beyond where the unnaturalness or infrequency of the OR construction at a discourse level is noticeable. Discourse-level analysis refers to the higher-order message level analysis of a sentence. We hypothesize that one result of our animacy manipulation will be that I(A) sentences are more natural and sensible, whereas A(I) sentences describe events that are not as natural. For example, "the editor that the poetry depressed" is grammatically correct, yet English speakers do not typically describe an animate noun in terms of the actions of an inanimate noun. This difference in naturalness may be reflected in greater late positivity in A(I) words. All in all, we expect to find electrophysiological evidence of a difference between A(I) and I(A) sentences as early as the initial main clause subject and as late as the main clause direct object.

Our predictions are based on a lexicalist-interactionist view of sentence processing. If we observe differences between I(A) and A(I) sentences prior to the relative clause verb, this observation will be taken as support for models of language comprehension that include a role for probabilistic information in the initial stages of parsing and allow interaction among different information types. Modular models that claim that syntactic analysis precedes semantic analysis would not predict such an early difference, because noun animacy carries no strictly syntactic information.

Methods

Subjects

Forty UCSD students (21 women) between 18 and 27 years of age participated in the experiment, receiving $5.00 an hour. Thirty-eight were right-handed (17 with immediate left-handed family members) and two were left-handed. All were native English speakers with no history of reading difficulties or neurological disorders.

Materials

Participants read a total of 350 sentences, of which 60 were the critical object relatives (30 of each type). The remaining 290 filler sentences included a variety of structures, 90 of which ended with a semantically incongruous word.

Two stimulus lists were constructed out of 60 pairs of OR sentences. Each list contained 30 sentences with the I(A) animacy configuration and 30 with the A(I) animacy configuration. Each list contained the same lexical items, but the OR conditions in which they occurred were reversed. Each participant saw only one of the two lists of OR sentences.

Comprehension questions followed 42% of the sentences. Probes to OR structures were designed to test peoples' comprehension for both the relative and main clause verbs. "True" questions tested comprehension of the relative clause verb by presenting the simple transitive sentence form of the relative clause relation. "False" questions queried subject/object relationships of the main clause. Examples of the critical sentences and comprehension probes appear in Table 2.

Questions to the remainder of the sentences tested prepositional phrases, noun phrases, and verb phrases. True and false probes occurred in roughly equal numbers.

Experimental Procedure

All 350 sentences were presented one word at a time in the center of a CRT (cathode ray tube) as each individual's electroencephalogram (EEG) was being recorded. Words were flashed for a duration of 200 ms with stimulus-onset asynchrony of 500 ms. Participants were instructed to read the sentences for comprehension, knowing that they were to be queried after a subset of them. The question appeared in its entirety in the center of the screen 1,500 ms after the onset of the sentence final word. Participants responded by pressing one of two buttons held in either hand (the

Table 2. *Sample Critical Sentences and Associated Comprehension Probes*

A(I) The novelist that the movie inspired praised the director for staying true to the complicated ending.
T: The movie inspired the novelist.
F: The novelist praised the movie.

I(A) The movie that the novelist praised inspired the director to stay true to the complicated ending.
T: The novelist praised the movie.
F: The movie inspired the novelist.

Note: A(I) = animate (inanimate); I(A) = inanimate (animate); T = true; F = false.

assignment of buttons to hands was counterbalanced across participants). Trials without comprehension probes were followed by the instruction "Press either button to continue." There was a total of 6.8 s between experimental sentences (including the time for responding to the comprehension questions).

EEG Recording Parameters

ERPs were recorded from 26 geodesically arranged electrodes on an electrode cap and from electrodes over both mastoid processes. Electrodes placed at the outer canthi and under both eyes were used to detect eye movements and blinks. All recordings were made online with reference to an electrode at the left mastoid and re-referenced offline to an average of the activity over the left and right mastoids.

The EEG was digitized online at a sampling rate of 250 Hz and stored for analysis on an optical disk. Amplifiers were set with half-amplitude cutoffs of 0.01 Hz and 100 Hz (time constant (TC) = ~8 s). Epochs with blinks, eye-movements, and amplifier blocking were either rejected offline before averaging (approximately 16% of all trials) or corrected using an adaptive filtering algorithm. Artifact-free EEG was averaged over individual words with the 100 ms preceding word onset serving as a baseline.

Results

Comprehension Questions

Participants showed no reliable difference in their ability to answer comprehension probes following A(I) versus I(A) sentences, $t(1,84) = .106$, $p < .751$. As in the reading time study with these materials (Weckerly & Kutas, 1998), comprehension of questions based on ORs was significantly worse than of those based on the unembedded filler sentences of approximately equal length (see Table 3).

As previous results have revealed substantial individual variation in ERP analyses as a function of sentence comprehension (King & Kutas, 1995), we also analyzed our data from this standpoint. The distribution of scores on comprehension probes was bimodal with 15 subjects scoring 75% or above whereas the other 25 scored below 70%. High comprehenders were thus defined as individuals who scored more than 75% correct in answering probes to OR sentences, whereas low comprehenders comprised those who scored below 75%. With this clear cutoff value, we could look at the "best case scenario" in processing OR structures while still giving us enough high comprehenders (15) to yield reliable results should group differences exist.

High comprehenders were not only equally accurate in answering questions about A(I) and I(A) sentences (approximately 79%), they were also not reliably better on the unembedded filler sentences of equal length (81%). The remaining 25 people in the low comprehender group also did not show any reliable difference between A(I) and I(A) sentences, but they made more errors on questions from ORs (55%) than from the filler sentences of equal length (71%).

Table 3. *Percentage Correct Response to Comprehension Probes for Various Sentence Types*

Group/sentence type	Correct response
All subjects (N = 40)	
Animate (inanimate)	65%
Inanimate (animate)	67%
Other sentence types	76%
High Comprehenders (n = 15)	
Animate (inanimate)	79%
Inanimate (animate)	79%
Other sentence types	81%
Low comprehenders (n = 25)	
Animate (inanimate)	53%
Inanimate (animate)	56%
Other sentence types	71%

ERP Data

All measurements were made relative to the average activity 100 ms immediately preceding the word of interest. ERPs to words were measured for activity within the typical latency bands for LAN (200–500 ms), N400 (300–600 ms), and P600 (500–700 ms). Mean amplitudes were submitted to a four-way repeated-measures analysis of variance (ANOVA) with within-subject variables of OR type (2 levels), anterior-posterior electrode (11 levels), hemisphere (2 levels), and participants ($N = 40$). For all the results reported, the Huynh–Feldt correction was applied where sphericity assumptions were violated; in these cases the uncorrected degrees of freedom are reported with the corrected probability levels. A summary of the ANOVA results is provided in Table 4. Separate analyses also were conducted on the data for high and low comprehenders. ERPs as a function of comprehension group are reported only when statistical differences were observed.

First word (initial main clause subject determiner). As expected, we found no reliable ERP differences between the two OR types at the sentence initial main clause subject determiner (the).

Second word (initial main clause subject). The second word in each OR sentence was a noun that served as the subject of the main clause and eventually as the object of the relative clause; it was inanimate in the I(A) sentences (poetry) and animate in the A(I) sentences (editor). This difference in animacy was evident relatively early in the ERP (Figure 1), with ERPs to inanimate nouns being significantly more negative than those to animate nouns between 200 and 500 ms postword onset, mean amplitude, $F(1,39) = 5.32$, $p < .026$. There was an ERP animacy effect in both low and high comprehenders. Although no statistical tests were conducted, the distribution of the animacy effect seemed to vary with comprehension skill; to the eyeball, the distribution has a frontocentral maximum in the low comprehenders and a more posterior maximum, reminiscent of the N400, in the higher comprehenders (Figure 2).

Collapsed across the initial noun of experimental filler sentences (Figure 1), there was a reliable main effect of animacy, $F(1,39) = 13.43$, $p < .001$, as well as significant interactions with anterior-posterior electrode site, and a three-way interaction between sentence type, hemisphere, and anterior-posterior, $F(10,390) = 3.91$, $p < .002$, $\epsilon = 0.64$. Inanimate nouns elicited greater negativity from 200 to 500 ms.

Third word (complementizer). The third word in each OR sentence was the complementizer (that). On the whole, the ERP to this word was different as a function of the animacy of the first noun. The ERP to the complementizer was more negative between 200 and 700 ms when the first noun was animate as in A(I) sentences than when it was inanimate as in I(A) sentences, from 200 to

Table 4. *ANOVA Results for Various ERP Measures Taken on Individual Words Throughout the Course of the Critical Sentence Types*

Sentence type/word position	Interaction	F	p
Main clause initial nouns I(A) vs. A(I) *poetry* vs. *editor* (200–500 ms)	C	$F(1,39) = 5.32$	$p < .026$
Main clause initial noun with fillers *animate* vs. *inanimate* (200–500 ms)	C C × H × E	$F(1,39) = 13.43$ $F(10,390) = 4.09$	$p < .001$ $p < .019$
Complementizer I(A) vs. A(I) *that* vs. *that* (400–700 ms)	C C × E	$F(1,39) = 7.73$ $F(10,390) = 4.40$	$p < .008$ $p < .006$
Relative clause determiner I(A) vs. A(I) *the* vs. *the* (300–600 ms)	C	$F(1,39) = .33$	$p < .569$
Relative clause subject, Grand I(A) vs. A(I) *editor* vs. *poetry* (300–600 ms)	C	$F(1,39) = 2.44$	$p < .126$
Relative clause subject, High comp. I(A) vs. A(I) *editor* vs. *poetry* (300–600 ms)	C × E	$F(10,140) = 4.73$	$p < .015$
Relative clause verb I(A) vs. A(I) *recognized* vs. *depressed* (400–700 ms)	C × E	$F(10,390) = 5.43$	$p < .005$
Main clause verb I(A) vs. A(I) *depressed* vs. *recognized* (200–500 ms)	C × H C × E C × H × E	$F(1,39) = 10.92$ $F(10,390) = 6.79$ $F(10,390) = 3.25$	$p < .002$ $p < .001$ $p < .0043$
Main clause verb I(A) vs. A(I) *depressed* vs. *recognized* (400–700 ms)	C × E C × H × E	$F(10,390) = 4.95$ $F(10,390) = 4.15$	$p < .000$ $p < .000$
Main clause direct object determiner, Grand I(A) vs. A(I) *the* vs. *the* (300–600 ms)	C	$F(1,39) = .61$	$p < .440$
Main clause direct object determiner, High comp. I(A) vs. A(I) *the* vs. *the* (300–600 ms)	C C × E	$F(1,14) = 4.65$ $F(10,140) = 4.70$	$p < .049$ $p < .002$
Main clause direct object noun, I(A) vs. A(I) *publisher* vs. *publisher* (400–700 ms)	C × H C × E	$F(1,39) = 16.35$ $F(10,390) = 2.38$	$p < .001$ $p < .098$

Note: C = condition; H = hemisphere; E = electrode.

500 ms, OR type, $F(1,39) = 4.98$, $p < .031$; OR type by anterior-posterior, $F(10,390) = 3.21$, $p < .045$, $\epsilon = 0.23$; 400–700 ms, main effect of OR type, $F(10,390) = 7.73$, $p < .008$; OR type by anterior-posterior, $F(10,390) = 4.40$, $p < .006$, $\epsilon = 0.25$ (see Figure 3).

Fourth word (relative clause determiner). ERPs to "the" in this position did not differ.

Fifth word (relative clause subject noun). The fifth word in each OR sentence was the second noun in this sentence; it served as the subject of the relative clause. Across all the participants there was a nonsignificant trend for the ERP to be more negative between 300 and 600 ms for the inanimate second nouns of A(I) sentences than for the animate second nouns of I(A) sentences, $F(1,39) = 2.44$, $p < .126$. This difference was reliable when the analysis was restricted to high comprehenders, OR type by anterior-posterior, $F(10,140) = 4.73$, $p < .015$, $\epsilon = 0.33$ (see Figure 4).

Sixth word (relative clause verb). The sixth word in the sentence was the first verb in the sentence; it served as the relative clause verb. The ERP to the relative clause verb in the A(I) sentences was characterized by a greater positivity between 400 and 700 ms at posterior recording sites compared with the relative clause verb in I(A) sentences, sentence type by anterior-posterior electrode, $F(10,390) = 5.43$, $p < .005$, $\epsilon = 0.23$ (see left column, Figure 5).

Seventh word (main clause verb). The seventh word in each OR sentence was the second verb in the sentence; it served as the main clause verb. The ERPs to the main clause verbs in A(I) sentences showed both a LAN effect and a P600 relative to those in I(A) sentences (Figure 5). In other words, between 200 and 500 ms, the response to main clause verbs in A(I) sentences was more negative than to those in I(A) sentences, OR type × Hemisphere, $F(1,39) = 10.92$, $p < .002$; OR type × Anterior-posterior, $F(10,390) = 6.79$, $p < .001$, $\epsilon = 0.22$; OR type × Hemisphere × Anterior-posterior, $F(10,390) = 3.25$, $p < .004$, $\epsilon = 0.63$; this effect was more pronounced in good comprehenders (see Figure 6). On average, between 400 and 700 ms, the response to main clause verbs in A(I) sentences was more positive than to those in I(A) sentences, OR type × Hemisphere, $F(1,39) = 15.05$, $p < .001$; OR type × Anterior-posterior, $F(10,390) = 4.75$, $p < .003$, $\epsilon = 0.26$; OR type × Hemisphere × Anterior-posterior, $F(10,390) = 4.15$, $p < .001$, $\epsilon = 0.69$; this effect was more pronounced in the poor comprehenders (see Figure 6).

Eighth word: Main clause direct object determiner. From this word position throughout the remainder of the sentence, the two object relative sentence types were lexically identical. Specifically, the eighth word in the sentence was a definite article ("the") which served as the determiner for the direct object in the main clause. Across all the participants, there was no reliable difference in the ERPs to these in I(A) vs A(I) sentences, OR type, $F(1,39) = .61$, $p < .440$, OR type × Anterior-posterior, $F(10,390) = 1.94$, $p <$

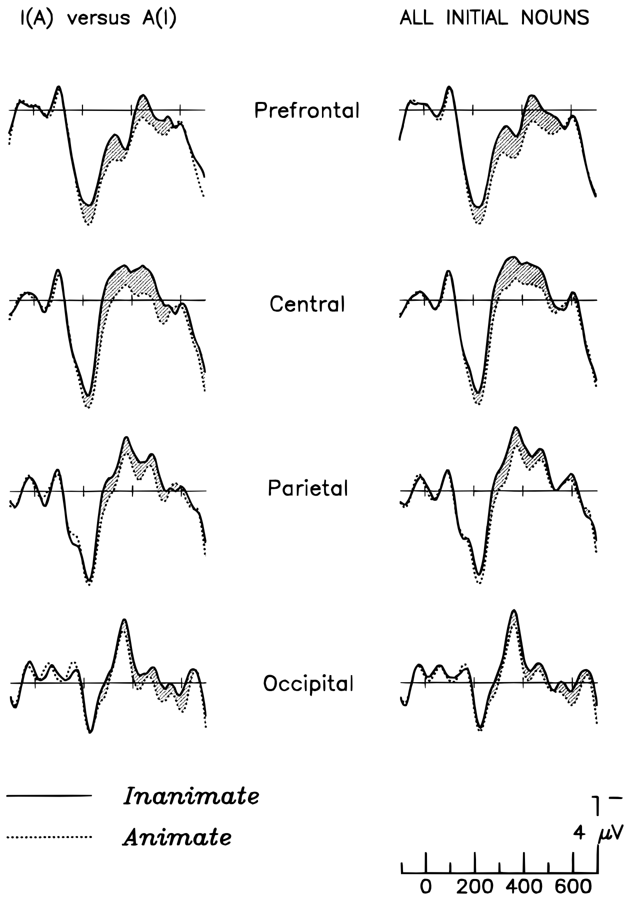

Figure 1. Grand-average event-related potentials (ERPs) ($N = 40$) to animate (solid line) and inanimate sentence initial nouns from four midline locations from the front to the back of the head. ERPs in the lefthand column are from the two critical object relative sentence types, whereas those in the righthand column also include responses to sentence initial nouns from all other sentences in the experiment. Shaded is the animacy effect.

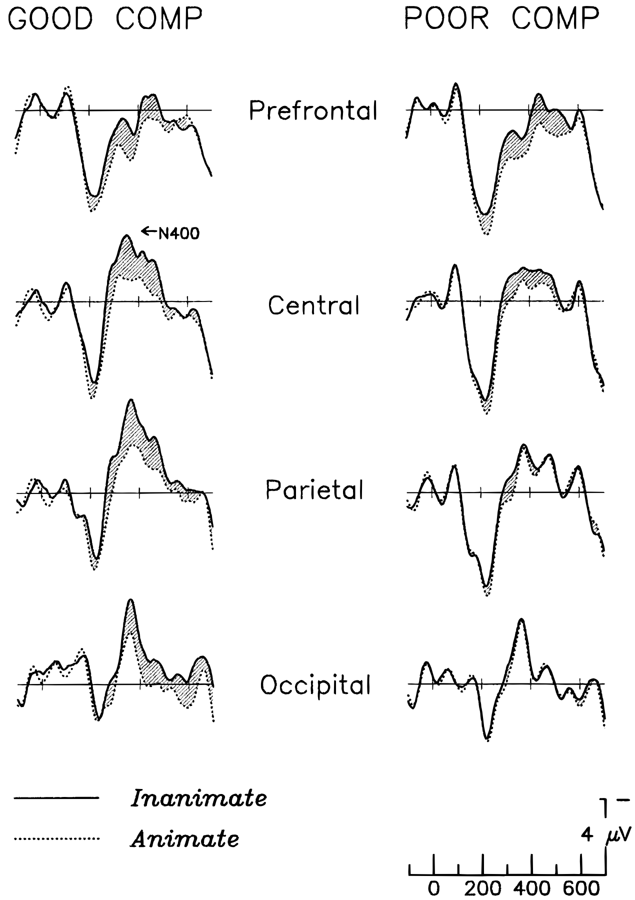

Figure 2. Grand-average event-related potentials (ERPs) to all animate (solid line) and inanimate sentence initial nouns from four midline locations from the front to the back of the head divided according to comprehension performance. The data from 15 good comprehenders are on the left and those from the 25 poor comprehenders are on the right. Shaded is the animacy effect.

.149, $\epsilon = 0.22$. However, high comprehenders did show greater negativity from 300 to 600 ms over posterior sites to these determiners in A(I) sentences, main effect of OR type, $F(1,14) = 4.65$, $p < .049$; OR type × Anterior posterior, $F(10,140) = 4.70$, $p < .002$, $\epsilon = 0.37$.

Ninth word: Main clause direct object noun The ninth word in the sentence was a noun that served as the direct object of the main clause. Across all participants, the ERP to this noun produced greater positivity between 400 and 700 ms in the A(I) compared with I(A) sentences; this difference was more pronounced over the left than right hemisphere and over frontal than posterior sites, OR type × Hemisphere, $F(1,39) = 16.35$; OR type × Anterior-posterior, $F(10,390) = 2.38$, $p < .098$, $\epsilon = 0.22$.

Discussion

In this experiment, we manipulated the animacy of the nouns that served as the relative and main clause subjects in OR sentences to determine whether or not this manipulation would have any effect on the processing of the various words within such constructions. We found that the manipulation did have an effect, and did so early in a sentence. The main clause nouns in the I(A) and A(I) sentences differed only in animacy; they were matched on average length and frequency. Thus, the ERP difference we observed between them was at minimum a sign that animacy (a semantic attribute) was noted. Because Kounios and Holcomb (1992) also found different ERP patterns for concrete compared with abstract nouns, the brain may be sensitive to broad semantic features of words independent of context. On the other hand, ERP differences here may reflect the reader's surprise at encountering an inanimate noun in the grammatical subject position of the sentence, when subjects are typically animate.

In English, the first noun is often the subject of the sentence; thus, it is highly likely that readers temporarily assign it as such. The high correlation between noun animacy and sentential subject (Bates & MacWhinney, 1982; Bock, 1986; Li & Thompson, 1976) provides statistical support for making this assignment initially. Accordingly within the OR sentences, initial animate nouns as in A(I) sentences may be more activated or more easily integrated as sentence subjects than the inanimate nouns as in the I(A) condition would be, and this might be what is reflected in the ERP difference.

Finally, the ERP animacy effect at the main clause noun may or may not reflect the use of the animacy information in the

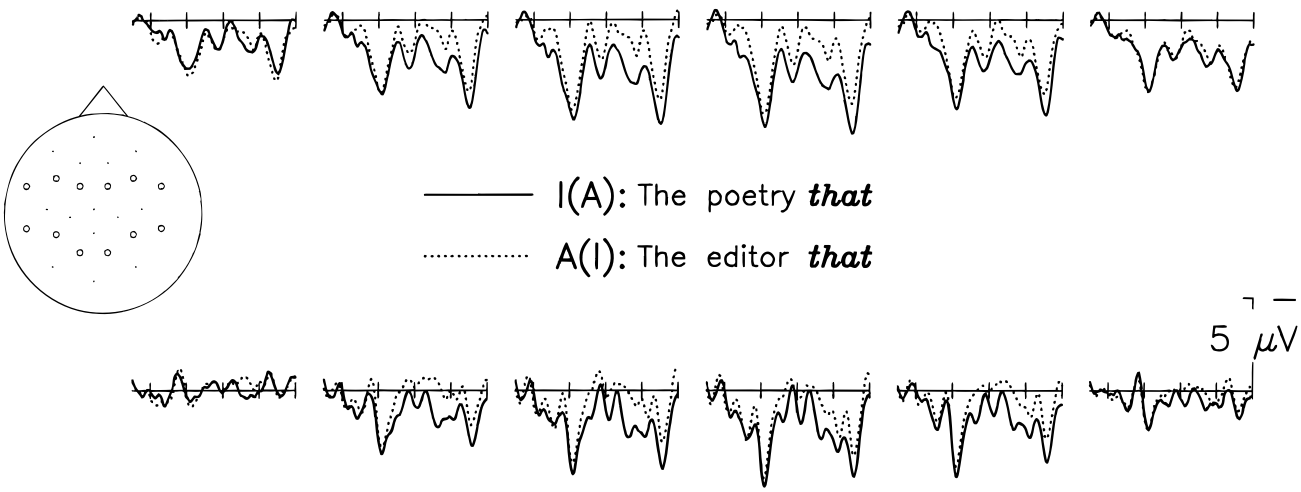

Figure 3. Grand-average event-related potentials (ERPs) ($N = 40$) to the complementizer ("that") following an inanimate noun as in I(A) sentences (solid line) versus an animate noun as in A(I) sentences (dotted line) shown for lateral, medial, and midline locations going from the left to right side along a coronal line over central (top row) and another over more posterior sites (bottom row) of the head. The schematic head shows all the recording sites; those in the larger open circles are the positions for which waveforms are drawn. Tick marks are at 0, 200, 400, 600, and 800 ms postword onset.

assignment of grammatical roles (i.e., determining the subject), although we believe that it does. Nonetheless, this ERP effect is unequivocal evidence that noun animacy is registered at this point.

There is continued evidence for the immediate use of animacy information in the response to the complementizer "that." Specifically, we observed greater negativity in the ERP to "that" in A(I) versus I(A) sentences. This ERP effect might also reflect differential expectancies generated at this point in the sentence, for example, the complementizer "that" might be less expected when an animate as opposed to an inanimate noun serves as main clause subject.

Animate nouns, being prototypically "good" subjects (and agents), are likely to be predicated by all types of verbs (transitive, action, stative, etc.). Inanimate nouns, on the other hand, being less "agentive" and used less often as subjects, are more likely to be followed by a stative (e.g. "remain," "seems") as opposed to some sort of action verb (e.g., "hit," "build," "drive," etc.). Moreover, of their occurrences in the sentence initial position, inanimate nouns might function more often as the head of a relative clause. In the I(A) case, following an initial inanimate noun, readers thus may expect a stative verb or a complementizer that heralds an upcoming relative clause; there may be no singular strong expectancy generated. In contrast, based on word order and noun animacy, the expectancy in A(I) sentences is for a verb. Encountering the complementizer in A(I) sentences would violate this expectancy. Readers also may take advantage of the higher probability that inanimate nouns head object as opposed to subject relatives (Fox & Thompson, 1990) in processing I(A) sentences. No such tendencies are associated with relative clauses with animate heads.

The two nouns serving as relative clause subjects in the I(A) and A(I) sentences also differed in their animacy. Thus, any ERP difference at this point could reflect this difference, some prior effect of the previous noun's animacy, or both. The presence of a clear N400 to the inanimate noun in the A(I) sentences for the high comprehenders may indicate that this word was unexpected. Low comprehenders do not show any reliable differential N400 activity to the two OR types at this point, although their responses in both OR types do show greater N400 activity than those to the second noun in unembedded sentences. This finding may signify that low comprehenders experience more difficulty integrating the relative clause nouns into the ongoing representation of the OR sentence than in integrating nouns in an unembedded sentence, although their expectancies may not be as specific. It could be argued, however, that low comprehenders have no expectations and simply await the next word, which happens to be an inanimate noun in the A(I) sentences, and only then deal with its processing. But the question then remains what it is about this inanimate noun that elicits a larger N400 in high comprehenders.

After processing the relative clause determiner ("The poetry that the . . ."), readers could have strong expectations for the lexical category (i.e., noun, verb) of the upcoming item based on syntactic, semantic, and pragmatic information. For both I(A) and A(I) sentences, we think readers would expect the next item to be either an adjective or a noun, the grammatical subject of the relative clause, and animate. Under these assumptions, readers do not come across the relative clause noun and then begin to look for its grammatical role. Rather, they have estimated the syntactic structure from lexical items encountered thus far, allotted a slot for a noun, and expect the lexical properties of the next word to conform to the grammatical subject role. Readers could also have strong expectations about the animacy of the upcoming noun based on statistical tendencies at the clausal and structural levels and the discourse use of OR structures. There is no compiled evidence that addresses the animacy distributions of subjects in object relative clauses. However, we believe an inquiry of this kind would show that animate nouns are more likely than inanimate nouns to be grammatical subjects of the relative clause, regardless of the animacy of the previous head noun.

Animate relative clause subjects are more plausible pragmatically and more consistent with the discourse use of object relatives than are inanimate relative clause subjects. Typically, relative clauses are used to introduce a new noun into a discourse by "grounding" it, or tying it to the actions of an already established discourse

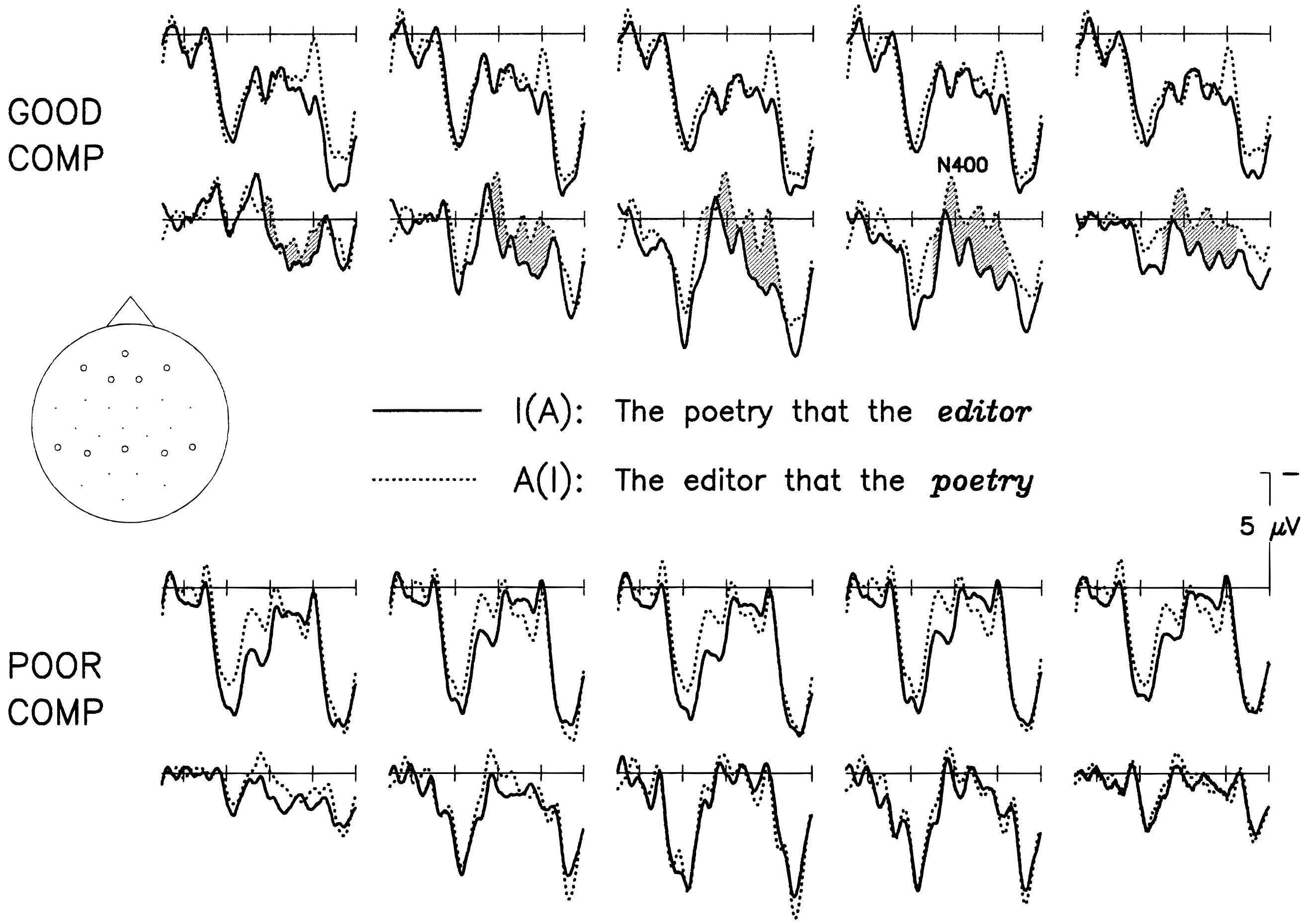

Figure 4. Grand-average event-related potentials (ERPs) to the noun serving as the subject of the relative clause for good ($n = 15$) and poor ($n = 25$) comprehenders. Waveforms are shown for lateral, medial, and midline locations along a coronal line going from the left to the right over the front (top row of ERPs in each case, marked at front of schematic head by open circles) and another over the back of the head (bottom row of ERPs in each case, marked at back of schematic head by open circles). Tick marks are at 0, 200, 400, 600, and 800 ms postword onset. Shaded is the N400 effect on the relative clause subject.

participant. Consistent with the animacy-subject correlation, people tend to talk about the world in terms of the actions of other people. This is especially so when the purpose of the clause is to "identify" the head noun. For this reason, readers are less likely to find an inanimate noun in a relative clause subject position. But in our A(I) sentences, readers did encounter an inanimate subject in the relative clause, which we propose they had difficulties integrating as the subject. Both the violation of the semantic and pragmatic level expectancies and the increased difficulty in integration are likely to elicit N400 activity.

The account of the N400 effect in high comprehenders described above assumes word-by-word integration and interaction among different information types. Interactive parsing models with these characteristics would thus explain the ERP effects in terms of difficulty of integration, and we venture to guess, difficulty of integration at the semantic level. Because in any simultaneous-yet-separate view of syntactic and semantic processing, syntactic analysis would yield identical output for our two OR types, processing differences between them would have to be attributed to nonsyntactic (semantic, pragmatic) levels of analysis as well. Crucially, this view would entail that thematic roles (semantic roles) be assigned prior to a verb and without access to syntactic structure. But according to many parsing theories of both the modular and interactive persuasions, thematic roles are associated with verbs; that is, nouns in a sentence fill the thematic slots offered by the verb. Moreover, role assignment, grammatical or thematic, depends on properties of the verb. At this point in the sentence, however, no verb has been encountered. It thus behooves such models to account for the ERP difference within a semantic and/or pragmatic level without recourse to the verb.

Yet another pattern of ERP effects is evident at the relative and main clause verbs. We believe this pattern suggests that although the readers are not particularly surprised by the lexical items, they do experience substantial working memory and processing load differences at these locations. The ERPs to both verbs in A(I) sentences are characterized by greater P600 activity between 400 and 700 ms than to those in I(A) sentences. P600 activity of this type is generally linked to more difficult processing and/or reanalysis as a consequence of various manipulations or violations of structural aspects of sentences (for a review see Osterhout & Holcomb, 1995). Importantly, our sentences contained no structural or grammatical violations. This finding is consistent with the position that the P600 is not observed exclusively under conditions of syntactic irregularity.

In materials similar to ours, Mecklinger, Schriefers, Steinhauer, and Friederici (1995) reported that past participles in German object relative structures were associated with a larger positive component (P345) than those in subject relatives. They used noun number combinations such that the clause final past participle adjudicated between a subject or object relative reading. Because a large positivity was observed even when lexical items biased an object relative reading, Mecklinger et al. concluded that semantic information was not consulted in disambiguating syntactic structure and the observed positivity was linked to a violation at the syntactic level of analysis. In subsequent investigations, Friederici and colleagues have maintained that a LAN effect indexes the first pass of parsing where phrase structure is computed, whereas the P600 reflects disruption at the second-stage of parsing where thematic role assignment (semantic analysis) and/or reanalysis is undertaken. With this view of parsing, we would expect to see no LAN distinguishing ERPs to the relative clause verbs in I(A) versus A(I) sentences, which are syntactically well formed and differ only in the configuration of semantic information. Yet, we observed both a LAN effect and a P600 to the main clause verb in well-formed A(I) sentences.

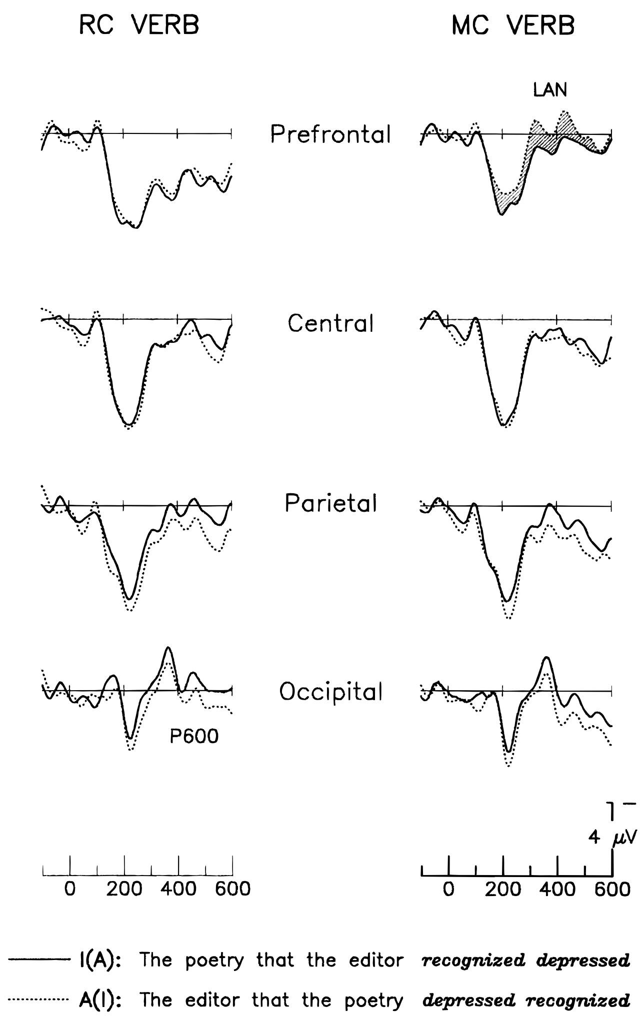

Figure 5. Comparison of the grand-average event-related potentials ($N = 40$) to the relative and main clause verbs in the inanimate (animate) [I(A)] versus animate (inanimate) [A(I)] sentence conditions at four midline electrode sites from the front to the back of the head. Shaded is the left-anterior negativity effect on the main clause verb.

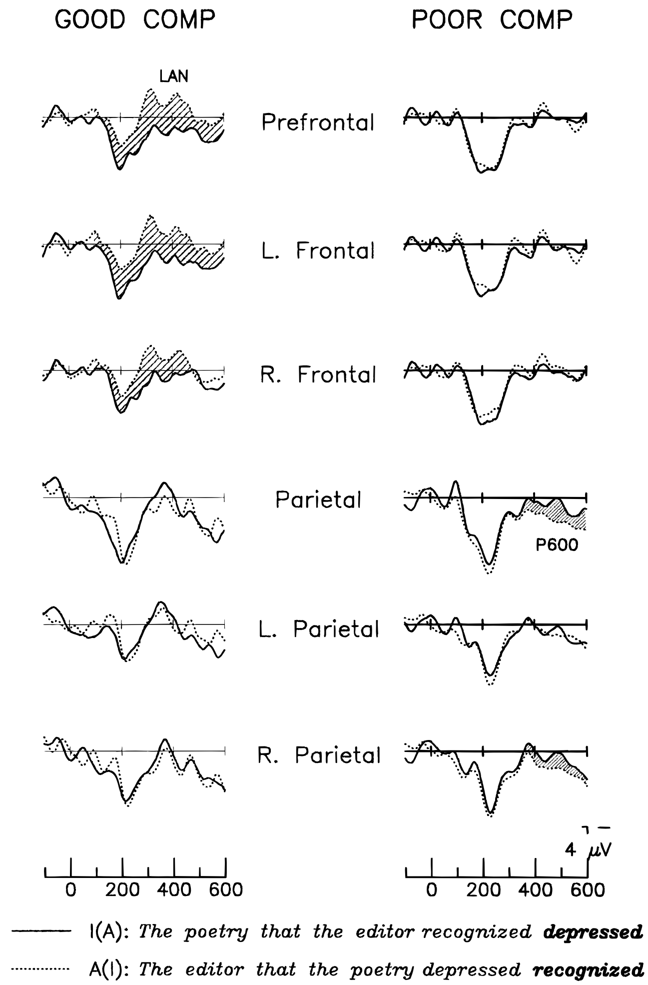

Figure 6. Comparison of the grand-average event-related potentials to the main clause verbs in good ($n = 15$) and poor ($n = 25$) comprehenders at three frontal and three posterior electrode sites. Shaded is the left-anterior negativity effect on the main clause verb in good comprehenders and the P600 effect on the main clause verb in poorer comprehenders.

We suggest that it is the relative inconsistency between semantic and syntactic information in A(I) sentences that gives rise to some difficulty in inferring grammatical structure. When readers encounter the relative clause verb in these OR sentences, they have all the information necessary to complete role assignments for the relative clause. We hypothesize that role assignments in the I(A) relative clause are far easier than in the A(I)s, because the I(A) semantic, syntactic, and pragmatic cues all point to the human relative clause noun as grammatical subject and the inanimate first noun as object. The late positivity at the relative clause verb of A(I) sentences thus may signal this difficulty in processing resulting from the discrepancy in information types.

Due to the difficult syntax of OR constructions, we might contend that relative clause role assignments often extend into processing of the main clause verb, perhaps in proportion to the difficulty of the relative clause role assignments. In fact, the main clause verb of an OR sentence is usually the locus of the greatest behavioral effects. The late positivity to A(I) main clause verbs thus may be related to this continued difficulty of relative clause assignment combined with additional processing difficulties imposed by a juxtaposed main clause verb, where comprehenders are faced with main clause role assignments. We expect the animacy configuration in A(I) relative clauses to continue to impede processing during the back-to-back occurrence of the relative and main clause verbs, despite the fact that an animate noun is in the grammatical subject position of the main clause.

This configuration may also lead to differences in working memory demands. As expected, this difference was manifested in a LAN effect—a larger negativity between 200 and 500 ms with a focus around frontal regions of the left hemisphere to the main clause verbs in A(I) sentences. The LAN has been described in investigations of sentences with embedding as an index of working memory load (e.g., King & Kutas, 1995; Kluender & Kutas, 1993a, 1993b). Its presence in our data is consistent with the hypothesis that the LAN is not just a marker of embedding per se but rather of memory load associated with the embeddings.

To complete the relative clause role assignments in A(I) sentences, readers must keep information about both nouns and role assignments in the relative clause active in working memory up through the main clause verb. By contrast, the greater consistency of semantic and syntactic information in I(A) sentences allows for more efficient integration of relative clause role assignments and therefore less of a memory load. In other words, because role assignments are more readily resolved in I(A) sentences, information pertinent to nouns, especially the relative clause noun, and regarding relative clause role assignments can be released, thereby freeing up working memory resources for main clause assignments.

Conclusions

The goal of this investigation was to track the use of animacy information in the processing of a very difficult syntactic structure, the object relative. We kept lexical information in two OR conditions constant and varied only the ordering of the constituent nouns and verbs. We know from a reading time study with these same materials that this simple reversal has a significant impact on how efficiently I(A) and A(I) are processed. We first witnessed animacy's impact on the reading times at the relative clause subject, five words into the sentence. Using ERPs, we uncovered evidence of animacy's effect much earlier at the main clause subject, the second word in the sentence. The temporal precision of ERPs has thus offered us a view that noun animacy is registered almost as soon as it is available, challenging us to clarify what is behind this registration.

Looking at ERPs not only demonstrated the immediacy of animacy's effect, but also the duration of its impact in words subsequent to the sentence subject. We also saw these effects with reading times as the dependent measure, but using ERPs, we observed at least three qualitatively different types of effects at different points in the sentence. These independent fluctuations in ERP measures thus may reflect the signature of various subprocesses that were heretofore undifferentiable given only reaction time data.

In summary, we conclude that animacy matters both early and late in the processing of OR sentences, in the processing of nouns and verbs, for low level operations (e.g., role assignments and retrieval from working memory) and for higher-order message-level computations. We believe that the timing of the various animacy effects, in particular, the fact that they occur early in the sentence and at multiple locations even before any verbs, suggests that syntactic, semantic, and perhaps other types of information interact early and continuously to influence the incremental formation of a sentence-level representation.

As in most studies of sentence comprehension, a single manipulation results in the simultaneous alteration of information at other levels. Hence, it is difficult to change semantics without also changing pragmatics somewhat. Ultimately, all language theorists believe that the information obtained from syntactic and semantic features of input interacts, at the very least in some final synthesis of all levels of language dimensions, perhaps as the brink of understanding is reached. If major philosophies of sentence interpretation are distinguished primarily by the immediacy with which sources interact, then the temporal precision and multi-dimensional nature of ERPs is a powerful tool. We now have the capacity to monitor comprehension word-by-word. The onus is upon theorists to spell out what *would* constitute evidence for the interaction (or lack thereof) of syntactic and semantic information or operationalize the nature of "separate but simultaneous" processing into testable predictions. Only then will the potential of ERPs as a window to watch understanding in real-time be unlocked.

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