BRAIN AND LANGUAGE **61,** 169–182 (1998)
ARTICLE NO. BL971917

Gap-Filling and End-of-Sentence Effects in Real-Time Language Processing: Implications for Modeling Sentence Comprehension in Aphasia

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We present an on-line study showing different sources of lexical activation during sentence comprehension, distinguishing in this respect between reflexive syntactic and less temporarily constrained nonsyntactic sources. Specifically, we show that both the syntactic process of gap filling and a nonsyntactic end-of-sentence effect can be measurable in real time and can be temporally separated. The distinction between activation sources provides a new perspective on real-time sentence comprehension in aphasia and accounts for the disparate results reported in the literature.

INTRODUCTION

The purpose of the present work is to chart the temporal pattern of lexical activation and reactivation during the course of sentence comprehension. In particular, our aim is to disentangle syntactic versus nonsyntactic sources of this pattern. In this connection, and in what follows, we discuss the 'reflexive' syntactic process of gap filling and a nonsyntactic wrap-up effect likely linked to discourse-level processing. We then present seemingly contradictory observations drawn from studies of aphasia—a line of research that has important implications when considering how specific brain regions are involved in language processing. To forecast, we will show that the disparate results can be accounted for in light of the above-mentioned distinction between syntactic and nonsyntactic processing mechanisms. We present an experiment that supports our argument by showing that these two sources of

The research reported in this paper was supported by NIH Grants AG 10496 and DC 0081.
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0093-934X/98 $25.00

lexical activation are measurable in real time and can be temporally separated.

Linguistic and Processing Considerations

In a canonical sentence in English, a direct object follows a transitive verb. In many cases, however, this order is not upheld; that is, often, the direct object precedes the verb as in the following sentence:

The girl that the boy chases is tall.

Even so, we immediately and effortlessly intuit the relation between the two. In the above sentence we know automatically that ''the girl'' is the direct object of the verb ''chases.''

Our capacity to account tacitly for a verb's arguments even without the cue of word order is formally articulated in, among other places, Chomsky's theory of government and binding (1981). On this account, objects of transitive verbs appear as the verb's complement and directly follow it at a level of representation called deep structure. If the object of the verb is not phonetically realized at this position in surface structure, it has moved to a different place in the syntactic tree. Positioning of arguments at deep structure is not lost completely, however, since the moved constituent leaves behind a type of empty category called a trace in the position from which it moved. So in the surface structure of the object relative sentence above, a trace fills the position after the verb and is coindexed with the moved constituent ''the girl'' (as shown by the subscript i):

The $girl_i$ that the boy chases (t_i) is tall.

The position in the sentence represented by the trace also has real-time processing consequences. We refer here to gap filling, the demonstration that not only are moved lexical items activated when first encountered in the string, but they are again activated—or reactivated at the gap or trace coindexed with the moved constituent (Hickok, Canseco-Gonzalez, Zurif, & Grimshaw, 1992; Love & Swinney, 1996; Nicol & Osterhout, 1989, cited in Nicol, 1988; Nicol & Swinney, 1989; Swinney, Ford, Frauenfelder, & Bresnan, 1987; Swinney & Osterhout, 1990; Tanenhaus, Boland, Garnsey, & Carlson, 1989; Tanenhaus, Carlson, & Seindenberg, 1985; Tanenhaus, Stowe, & Carlson, 1989; Zurif, Swinney, Prather, Wingfield, & Brownell, 1995).

To explain in more detail how a gap activates the semantics of a moved argument, we describe the experimental paradigm used. Activation is typically measured by semantic priming, which refers to a facilitation of processing; it is observed when a target word is processed faster when immediately preceded by a semantic associate of the word as opposed to when preceded by an unrelated lexical item (Meyer, Schvaneveldt & Ruddy, 1975; Neely, 1997).

A method that has been particularly useful in discovering when words are activated during the course of a sentence is cross-modal lexical priming (CMLP) (Swinney, Onifer, Prather, & Hirshkowitz, 1979). In this paradigm, sentences are presented auditorily at a normal speaking rate, and at some point during each sentence, a lexical decision is made about a probe visually displayed on a screen. With respect to gap filling, a priming effect at the gap site means that the moved constituent has been reactivated at the gap to serve as a prime for a semantically associated word. In effect, the moved constituent appears to be activated twice in the sentence—once when first encountered and again at the gap indexed by the trace to which it is syntactically linked.

End-of-String Effects

In addition to syntactically driven reactivation, some researchers claim that reactivation may also occur at the end of the sentence as a nonsyntactic wrap-up effect. In particular, in the context of single-sentence presentations, it can be taken to reflect a task-specific strategy whereby a subject tries to connect the probe to the sentence's meaning—a strategy that implicates *semantics* but is of no relevance at all to normal *syntactic* operations.[1]

Yet even though a wrap-up effect seems to be widely accepted in the literature, for whatever reason (Fodor, Ni, Crain, & Shankweiler, 1996; Swinney & Zurif, 1995; Simpson, 1994; Blumstein et al., 1998), the data that support this notion are scanty and in fact, difficult to separate from reactivation effects due to syntactic operations.

Accordingly, we sought to discover whether indeed the two sources of reactivation—wrap-up and gap filling—could be distinguished. We were particularly impelled to explore this matter in the hope of resolving some apparently contradictory findings from aphasia research—some claims about gap filling based on results that may be confounded with end-of-sentence wrap-up effects.

Gap Filling in Aphasia

In two separate experiments (Zurif et al., 1993; Swinney et al., 1996) we have discovered that the brain region implicated in Wernicke's aphasia is not crucially involved in the syntactic operation of recognizing and filling gaps in real time: Wernicke's patients recognize and fill gaps in the normal time frame. Lesions to this region, rather, seem to effect later, likely semantic, phases of comprehension (Swinney & Zurif, 1995; Shapiro et al., 1993).

By contrast, the brain region associated with Broca's aphasia *does* appear to be necessary for the operation of gap filling. In both our experiments,

[1] Possibly, when sentences are linked in normal conversation, this wrap-up effect serves to make arguments available for immediately following discourse segments.

Broca's aphasics were unable to form dependency relations at the gap in real time—whether for object relative sentence constructions that they had difficulty understanding, or even for subject relative constructions that they comprehend easily.

These data on Broca's aphasia form a bridge: on the one side, they connect to independent observations of primary lexical activation problems apart from sentence processing (e.g. Milberg et al., 1995)—particularly to the observation of slower-than-normal lexical activation (Prather, 1994; Prather et al., 1992) sufficient to adversely affect fast-acting syntactic reflexes but not slower-developing and longer-lasting semantic operations. On the other side, the gap-filling data connect to off-line comprehension patterns: the data suggest that since Broca's aphasics do not have the processing resources necessary to reactivate lexical information to form dependency relations normally, they cannot provide the syntactic basis for thematic assignment to moved constituents essential to comprehension. Presumably, therefore, they rely abnormally on nongrammatical strategies to achieve such mapping—strategies that sometimes work and sometime do not (Grodzinsky, 1990).

Moreover, the data from our two gap-filling experiments can be viewed along with recent PET and ERP findings. PET data by Stromswold et al. (1996) provide evidence for increased blood flow in Broca's area when comprehending complex syntactic structures. Research by Friederici and Mecklinger (1996) on event-related brain potentials reveals two separate stages of processing in different brain regions, one early syntactic-building stage in the left anterior region where Broca's area is located, and a later interpretation-and-reanalysis stage located in the centro-parietal region. In sum, these results all emphasize the crucial role of the brain region associated with Broca's aphasia in initial stages of syntactic processing.

However, Blumstein et al. report quite the opposite pattern of reactivation from the above-mentioned experiments (Zurif et al., 1993; Swinney et al., 1996). Specifically Blumstein et al. showed gap filling for Broca's aphasic patients but not for Wernicke's aphasics. This discrepancy warrants close examination.

Blumstein et al. suggest that different experimental paradigms might be at the root of the opposing results. Unlike the cross-modal paradigm we used, Blumstein et al. presented not only the sentence, but also the probe in the auditory modality. And they claim that this single modality of presentation avoids the changing attentional demands required in the CMLP paradigm. Perhaps the demands are not the same in the two tasks; but in our view, there is an attentional shift from sentence to probe whatever the probe's modality. Indeed it is plausible to suppose that the attentional demands are *greater* in the single-modality task—that a finer discrimination is required when the shift of focus from the sentence to the probe has to be within the same modality, and that this taxes the attention more than in the cross-modal paradigm.

To our minds, a more compelling possibility for the disparate results is that *their data are not reflecting gap filling.* In their first experiment, two of the four sentence constructions contained gaps at the end of the sentence; so, half of the stimulus items in this experiment may have conflated gap-filling and end-of-sentence wrap-up effects.

This is an especially viable possibility given that, as we have noted earlier, automatic lexical activation in Broca's aphasic patients seems to have a slower-than-normal rise time. And since end-of-sentence processing (implicating discourse and semantic levels) is likely to be less temporally restrained than within-sentence gap-filling, it may reasonably be supposed that Broca's patients are more capable of sentence-final checking than of filling temporally evanescent gaps.

Moreover, just these factors could be expected to limit reactivation in Wernicke's aphasic subjects. Given their comprehension difficulties and in particular their inability to activate argument structure in the normal fashion (Shapiro, 1990), one would expect that it is at the end of the sentence where they would show difficulties filling gaps; namely, their syntactic reflexes would be obscured by semantic obtrusions at this sentence-final position.

But in this first experiment, neither Broca's nor Wernicke's aphasic patients provided enough data for a separate analysis of gap positioning, and so the considerations we have raised remain inconclusive.

Not so however for Blumstein et al.'s second experiment. In this second study, *all* the gaps were at sentence-final position, and therefore all were confounded with wrap-up effects. The situation is even more suspect given the fact that young normals in this second experiment showed end-of-sentence priming *even with control sentences that did not have sentence final gaps.*[2] Blumstein et al. raise the possibility that they may have been tapping into residual priming, and not strictly speaking 'reactivation' of the antecedent. But they argue against this possibility by maintaining that there were too many words between the antecedent and the gap to allow such residual priming.

We agree with Blumstein et al. that the priming was not likely a result of residual activation given the seven syllables between the antecedent and the gap/end-of-sentence position, but we disagree that what they detected was gap filling, especially since the control sentences yielded sentence-final priming even though they contained no gaps.

Indeed for Broca's aphasic patients, the end-of-sentence effect might not have been related to normal processing—whether gap-filling *or* discourse implicated checking. In view of their possibly incomplete syntactic representations, they may have simply adopted a task-specific strategy whereby they

[2] Pilot data for control sentences seem to have been drawn from a population of young adults; in the actual experiment, however, there is no indication that the Broca's aphasics were tested on these control sentences.

tried to integrate the semantics of the probe into the sentence by making the probe the next word in the sentence—a strategy far removed from normal sentence comprehension. The fact that the probe and the sentence were in the same modality makes this an even stronger possibility. (See Love and Swinney, 1995, for an extensive discussion of this type of experimental artifact).

To this point, a handful of arguments have been built up around the concept of the end-of-sentence wrap-up effect. As discussed above, however not much empirical evidence supports this phenomenon. And it is with the intention of seeking such evidence that we have undertaken the present study; that is, we set out to discover whether or not a nonsyntactic wrap-up effect exists apart from the ephemeral syntactic processing inherent in gap filling. To this end, we conducted an experiment using sentences in which the gap was far removed from sentence-final position.

METHODS

Subjects. Twelve elderly neurologically intact subjects participated in the experiment. Their ages ranged from 65 to 80 years with a mean age of 74. All of the participants had normal or corrected-to-normal vision and hearing, and none had any history of neurological injury or disease. All were native speakers of English with an average of 13.5 years of education.

Materials. The stimulus materials consisted of 120 auditorily presented sentences. Of these, 48 were experimental subject relative constructions of the sort, ''The gymnast loved the professor from the northwestern city who complained about the bad coffee.''[3] For each subject relative, the gap occurred exactly five words after the antecedent so that an overload of memory capacity associated with six or more words between the antecedent and gap for elderly subjects (Zurif et al., 1995) would not interfere with reactivation patterns.

To tap into the temporal pattern of antecedent reactivation we used a cross-modal lexical priming paradigm (Swinney, Onifer, Prather, & Hirshkowitz, 1979). Sentences were presented auditorily to the subjects, and at some point during the sentence, a visual letter string appeared on a computer screen. Priming effects were assessed by comparing reaction times to probes that were semantically related to the moved constituent with reaction times to unrelated probes.

To this end, each experimental sentence was paired with two words to be used as visual probes for the examination of priming. The related probe was a close semantic associate to the antecedent. Its selection was determined by both published data of normal adults (Jenkins, 1970; Keppel & Strand, 1970; Postman, 1970) and data obtained within our lab: college-age and elderly adults gave first associates to a list of words that were incorporated as antecedents in the experimental sentences. A control probe was matched to each related probe in frequency (Kučera and Francis, 1976), number of syllables, and *a priori* average reaction time as determined by a study of baseline lexical decisions for words in list form. So for the subject relative

[3] Technically, it is the wh-element ''who'' which moves from subject position [Spec of VP] to [Spec of C] assuming the VP-internal subject hypothesis (Burton & Grimshaw, 1992; Kitagawa, 1986; Koopman & Sportiche, 1988). The wh-element forms a syntactic chain in which ''who'' is linked to its trace in subject position within the VP. Even though movement of this sort is considered string-vacuous since the transformation does not reorder the constituents in the string of words, evidence of such movement is supported with cross-linguistic data (Clements, McCloskey, Maling, & Zaenen, 1983).

example above, the related probe ''teacher'' is a semantic associate of the antecedent ''professor,'' and this related word is matched up with the control probe ''cattle.''

In order to test where semantic activation of the antecedent occurred in the sentence, a probe appeared at one of four different sites as indicated by the superscript positions:

> The gymnast loved the professor$_i$ •^{1} from the northwestern •^{2} city who$_i$ •^{3} (t$_i$) complained about the bad coffee.•^{4}

Site 1 is directly after the antecedent; site 2 is at a pregap position, 800 ms after the antecedent; site 3 is at the gap; and site 4 is at the end of the sentence. We looked for priming immediately after the antecedent as one baseline, to determine whether the probes were sensitive enough to measure semantic activation. The pregap position at site 2 served as another baseline allowing us to monitor how quickly priming waned with time and to gauge residual activation. Probe sites at the gap and end-of-sentence were, of course, intended to measure possible reactivation patterns stemming from two separate sources, syntactic (position 3) and nonsyntactic (position 4).

To ensure that related words were not better continuations of the sentence than were control words at each probe position (and facilitate priming effects), 12 adult subjects rated how well each probe word continued the sentence on a scale from 1 (bad continuation) to 5 (good continuation). Planned comparisons of mean rating scores for related and control probes at each site revealed a significant preference for the related probes only at position 2 (pregap) where no effect of priming was anticipated (Position 1, $F(1, 11) = .335$, $p = .574$; Position 2, $F(1, 11) = 10.351$, $p = .008$; Position 3, $F(1, 11) = .482$, $p = .502$; Position 4, $F(1, 11) = .593$, $p = .457$).

Randomly placed among the experimental sentences were 52 filler sentences matched in length and structure, but with some variation in the positioning of the relative clause. Each filler sentence was paired either with a real-word letter string that bore no relation to the sentence or with a nonword probe that obeyed phonetic rules of English. To prevent the unlikely occurrence of subjects anticipating the exact probe positions in the experimental set, the probe site for filler sentences varied; some occurred early on, some roughly in the middle, and others near the end of the sentence.

Apparatus and stimulus construction. The sentences were recorded by a female native English speaker and read at a normal rate of speech. Each of the sentences was initially recorded into a soundfile on a Macintosh IIci computer using AudioMedia II sound editing software (Digidesign). Sentences were read into a unidirectional, low-impedance microphone and fed into a Gemini pre-amp mixer. From here the sentences were digitized on the computer and saved on a single channel in a soundfile. For each sentence, a tone of 1000 Hz with a duration of 100 ms was placed in a predetermined position on a second channel. The sentences and their respective tones were then transferred to a stereo cassette tape with precisely 5 s of silence between each sentence.

The tape was played back on a Sharp RD771AV Diapilot Cassette Recorder. The sentences were played in stereo over a set of headphones, while the tones were read off the second channel and were thus inaudible to the subjects. These tones triggered both a tone decoder and a software-accessible Metrobyte CIM05 clock card in the PCIII IBM compatible computer. Using the RTLAB V9.0 software program, the tone signaled the decoder to visually display a letter-string probe on a Zenith 287 video monitor and simultaneously initiated the timing mechanism of the clock card. Reaction times measured how many milliseconds it took for the subject to depress either of two buttons on a button box that was also connected to the clock card via the computer.

Design. Four tapes were prepared, each with the same sentences in the same random order, but with varying probe sites for the experimental sentences. For example, in tape 1, the probe for experimental sentence 1 was visually displayed immediately after the antecedent; in tape 2, the probe appeared at the pregap site; in tape 3, it appeared at the gap; and in tape 4, it appeared at the end of the sentence. Each probe site was represented in one-fourth of the experimental sentences for any given tape.

Subjects were tested in two sessions. They heard the same tape during both sessions, but responded to different probes. To this end, two lists of probes were compiled, one which appeared during the first session and the other during the second. Each probe list consisted of 48 experimental probes, 12 filler real-word probes, and 60 nonwords. Of the experimental probes, 24 were related probes and 24 were control. Related and control probes were equally distributed across probe sites 1 through 4. For instance, the related probes for list 1 were matched with six sentences that triggered a probe at site 1, six at site 2, six at site 3, and six at site 4; and likewise for the control probes. The second probe list contained the member of the pair not appearing in the first list. So for example, if a subject saw an experimental probe at a particular position in a given sentence, during the next session, the subject would see the matched control at that position for the same sentence. In this way, each subject served as his or her own control.

Procedure. Each subject was tested individually over two sessions with one month between the sessions to minimize—if not eliminate—any effects caused by overexposure to the auditorily presented stimuli. For each session, the subject was introduced first to a lexical decision task and second to a cross-modal lexical decision task in a practice session before the actual experimental stimuli were presented.

Before the practice session, it was explained to subjects that they would see a string of letters appear on the computer screen in front of them and would have to make a lexical decision about this letter string. Subjects were familiarized with the response keys and asked to press the ‘‘yes’’ button if they thought the letter string presented was a real English word and to press the ‘‘no’’ button if they thought the letter string was a nonword. They were encouraged to respond as quickly but as accurately as possible. Feedback on response latency, averaged across five trials, was presented to the subjects during the task so that subjects could gauge how fast they were responding and monitor themselves if responses slowed during the course of testing. After subjects mastered the lexical decision task, they were given a set of headphones and asked to listen carefully to each auditorily presented sentence. The subjects also watched the computer screen and at some point during each sentence, a letter string flashed up on the screen. Subjects were instructed to decide whether the letter string formed a real English word or a nonword as quickly as they could, but with as few mistakes as possible.

After these practice sessions, the actual experiment began. To encourage subjects to attend to the auditory stimuli, 14 multiple-choice questions regarding the content of the most recently presented sentence were asked at random intervals during testing. Reaction time feedback averaged across 40 trials was presented to the subjects during the experiment.

RESULTS

Only correctly identified probe words were considered in the statistical analysis. Reaction times which were more than 3 standard deviations above or below the subject’s overall mean per condition were also screened out. Since subjects served as their own control, both data points for a matched pair were discarded if one or the other points of the pair was screened out. The reaction times that were omitted constitute 3% of all the scores combined. Table 1 charts the overall reaction times for each probe site using screened data.

Based on the hypothesis that priming effects are structurally governed or are related to effects induced by phrasal boundaries, we carried out planned comparisons separately for each probe site; that is, comparisons were per-

TABLE 1
Mean Reaction Times (ms) for Control and Related Probes

	Probe type		
Probe site in sentence	Control	Related	Difference
At antecedent	806	753	$\Delta = 53$[a]
Pregap	751	752	$\Delta = -1$
Gap	802	740	$\Delta = 62$[a]
End-of-sentence	742	709	$\Delta = 33$[a]

[a] $p < .05$ (paired comparisons).

formed for related and control probes (examining for priming) at the antecedent, site 1; separately at the pregap position, site 2; at the gap, site 3; and at the end of the sentence, site 4. The results of the planned comparisons reveal that there was significant priming for the related probes at the antecedent ($F(1, 11) = 6.336$, $p = .029$), at the gap ($F(1, 11) = 8.187$, $p = .015$), and at the end of the sentence ($F(1, 11) = 5.372$, $p = .041$), but not at the pregap site ($F(1, 11) = .004$, $p = .951$).

DISCUSSION

The results show that priming occurred immediately following the antecedent, at the gap site, and also importantly at the end of the sentence. Priming was not, however, observed at the pregap position, 800 ms downstream from the antecedent and before the gap. The absence of priming at the pregap position illustrates that activation of the antecedent did not occur everywhere in the sentence and that the experimental paradigm allowed us to measure where sentence structure did induce reactivation. Furthermore, a noneffect at the pregap site shows that priming at the gap was not some remnant of an already-activated semantic network, but rather reflected reactivation of the antecedent.

As predicted, results indicate that there is an end-of-sentence effect distinct from the reactivation of the antecedent observed at the gap position. For several reasons, we conclude that this end-of-sentence effect reflected reactivation (and not residual activation). First, the average distance between the gap and the end of the sentence was slightly greater than the distance between the antecedent and the gap, and as we know from the pregap results this distance allowed for the priming effect to diminish. Second, it is reasonable to assume that the activation of the semantic network is no greater at the gap than at the word itself and thus would not initiate a priming effect that would decay significantly slower.

The important element to extract from this experiment is that the end-of-sentence wrap-up effect can be measured in real time and is seen to be distinct from syntactically governed gap filling. First we point out that the article of faith regarding the existence of the end-of-sentence wrap-up effect, which has been upheld in the literature, is now supported empirically. To be sure, it is a phenomenon not well understood. It may, for example, reflect a general integration of information to help the listener draw from general knowledge and construct meaning from the utterance. Or, it may be a component of a processing mechanism which checks the well-formedness of the sentence to ensure that all arguments in the construction have been represented correctly. Or, it may even be a task specific strategy of no relevance at all to sentence comprehension.

Regardless of its function, however, we now have strong evidence for the presence of a distinct end-of-sentence wrap-up effect in sentence processing, and its confirmation provides an important perspective on the conflicting data in aphasia. Specifically, our data suggest that Blumstein et al.'s claimed demonstration of gap filling in Broca's aphasia is, at best, confounded with a nonsyntactic form of reactivation. In fact, our data suggest an even more likely scenario—that Blumstein et al.'s finding is entirely driven by a nonsyntactic wrap-up procedure. We opt for this latter possibility because of the slower-than-normal lexical activation pattern shown by Broca's aphasic patients, a pattern that would more likely accommodate a putatively less constrained wrap-up or checking procedure than an evanescent syntactic reflex. This, along with off-line comprehension patterns of Broca's aphasic patients, in addition to ERP and PET findings, compels us to maintain that the brain region associated with Broca's aphasia is crucially involved in the real-time syntactic processing of gaps.

APPENDIX

Materials	Related probe	Control probe
1. The postman saw the **barber** from the business district who enjoyed playing chess.	hair	cent
2. The foreman scolded the **hound** at the construction site who had started to eat the men's lunches.	dog	press
3. The student wrote to the **lawyer** from the downtown office who had argued a case in front of the Supreme Court.	judge	frog
4. The child waved to the **priest** standing on the corner who had lost all his money in Las Vegas.	church	field
5. The bachelor was related to the **general** from the foreign legion who had received many medals.	army	chicken
6. The musician resembled the **coach** from the high school who ran 5 miles a day.	team	bear
7. The hat check girl winked at the **clown** with the baggy pants who had won the talent contest.	circus	cradle
8. The man liked the **tailor** with the British accent who claimed to know the queen.[4]	clothes	weight

[4] Eight of the 48 experimental sentences contained PRO.

Materials	Related probe	Control probe
9. The nurse accompanied the **sailor** with the red Mercedes who loved auctions.	boat	camp
10. The man joked with the **pilots** from the infamous company who were out of work due to long strikes.	planes	stick
11. The editor picked the **secretary** from the employment agency who promised to start on Monday.	typewriter	ornament
12. The agent telephoned the **artist** from the small town who loved to play with finger paints.	paint	wire
13. The woman telephoned the **speaker** from the community college who was late for the 12:00 engagement.	microphone	monument
14. The boy befriended the **jockey** with the fancy outfit who wrote a bestselling book.	horse	peer
15. The heiress missed the **jeweler** from the department store who had moved to the Midwest to start his own business.	diamond	puzzle
16. The child noticed the **prisoner** with the Hawaiian shirt who had been convicted of the crime.	jail	soap
17. The gymnast loved the **professor** from the northwestern city who complained about the bad coffee.	teacher	cattle
18. The landlord greeted the **waiter** from the popular spot who sang tenor with the local choir.	service	country
19. The article quoted the **astronaut** with the large family who hoped to run for office.	space	stage
20. The parents hired the **magician** with the handlebar mustache who had performed a one-man-show on Broadway.	trick	bunch
21. The naturalist distrusted the **mayor** with the snake phobia who refused to visit the zoo.	city	water
22. The attorney trusted the **addict** from the community clinic who wrote long letters to his grandmother.	drug	lock
23. The athlete proposed to the **gardener** with the dirty fingernails who had started a successful business.	plant	blood
24. The pawnbroker argued with the **customer** with the mink coat who made an unrealistic offer.	client	anchor
25. The chemist telephoned the **chef** at the fancy hotel who was in the middle of chopping onions.	cook	fly
26. The disk jockey disliked the **maid** from the penthouse apartment who laughed at the dirty jokes.	servant	insect
27. The fireman ran towards the **millionaire** with the cumbersome package who was escaping from the flaming building.	money	study
28. The rock star responded to the **reporter** from the women's magazine who was taping the entire conversation.	writer	livestock
29. The accountant thanked the **nun** in the train station who pointed out the way to the museum.	monk	bull
30. The woman avoided the **golfer** at the national tournament who had a notoriously wild swing.	club	neck
31. The fisherman chose the **dentist** with all the magazines who prescribed lots of pain killers.	teeth	moon
32. The janitor yelled at the **actor** in the cloth bathrobe who sat in the wet paint.	play	town
33. The candidate smiled to the **audience** in the crowded hall who were stunned by his nasty remark.	crowd	fish

Materials	Related probe	Control probe
34. The woman sang to the **baby** with the blond hair who lay sleeping under the blanket.	child	class
35. The ranger scolded the **campers** from the Audobon Society who had forgotten flashlights and matches.	tent	scars
36. The medic thanked the **captain** from the regional headquarters who brought candybars to the men.	leader	sheep
37. The girlscout watched the **cat** with large yellow spots who was sitting patiently beside the fish tank.	kitten	tenant
38. The clerk welcomed the **guests** at the ritzy hotel who were planning to stay for a week.	visitors	butterfly
39. The leopard chased the **guide** with the heavy equipment who encouraged the group to run.	travel	measure
40. The trainer sold the **horse** with the wavy mane who was terribly afraid of thunder.	cow	slave
41. The pilgrims feared the **Indians** from the scary forest who had unfamiliar customs.	tribe	pig
42. Santa Claus greeted the **kids** at the shopping mall who had waited in line for hours.	children	elephant
43. The scientist observed the **monkey** on the African coast who swung from tree to tree.	thief	ape
44. The patrolman stopped the **motorist** on the California freeway who was exceeding the speed limit.	driver	speaker
45. The townspeople loved the **prince** with the curly hair who brought peace and harmony to the kingdom.	duke	goat
46. The child watched the **tiger** behind the metal bars who was anxiously awaiting his feeding hour.	lion	priest
47. The salesman badgered the **wife** from the local suburbs who was tending her sick children.	husband	police
48. The reviewer panned the **comedian** with the long nails who told long stories about her childhood.	laughter	patience

REFERENCES

Blumstein, S., Byma, G., Kurowski, K., Hourihan, J., Brown, T., & Hutchinson, A. 1998. On-line processing of filler-gap constructions in aphasia. *Brain and Language,* **61,** 149–168.

Burton, S., & Grimshaw, J. 1992. Coordination and VP-internal subjects. *Linguistic Inquiry,* **23,** 305–313.

Chomsky, N. 1981. *Lectures on government and binding.* Dordrecht: Foris.

Clements, G., McCloskey, J., Maling, J., & Zaenen, A. 1983. String-vacuous rule application. *Linguistic Inquiry,* **14,** 1–17.

Fodor, J. D., Ni, W., Crain, S., & Shankweiler, D. 1996. Tasks and timing in the perception of linguistic anomaly. *Journal of Psycholinguistic Research,* **25,** 25–57.

Friederici, A., & Mecklinger, A. 1996. Syntactic parsing as revealed brain responses: First-pass and second-pass parsing processes. *Journal of Psycholinguistic Research,* **25,** 157–176.

Grodzinsky, Y. 1990. *Theoretical perspectives on language deficits.* Cambridge, MA: MIT Press.

Hickok, G., Canseco-Gonzalez, E., Zurif, E., & Grimshaw, J., 1992. Modularity in locating wh-gaps. *Journal of Psycholinguistic Research,* **21,** 545–561.

Jenkins, J. J. 1970. The 1952 Minnesota word association norms. In L. Postman & G. Keppel (Eds.). *Norms of word associations.* New York: Academic Press.

Keppel, G., & Strand, B. Z. 1970. Free-association responses to the primary responses and other responses selected from the Palermo-Jenkins norms. In L. Postman & G. Keppel (Eds.). *Norms of word associations.* New York: Academic Press.

Kitagawa, Y. 1986. *Subjects in Japanese and English.* Unpublished doctoral dissertation. University of Massachusetts, Amherst, MA.

Koopman, H., & Sportiche, D. 1988. Subjects. Unpublished manuscript, University of California, Los Angeles.

Kučera, J., & Frances, W. N. 1976. *Computational analysis of present-day American English.* Providence, RI: Brown Univ. Press.

Love, T., & Swinney, D. 1996. Coreference processing and levels of analysis in object-relative constructions: Demonstration of antecedent reactivation with the cross-modal priming paradigm. *Journal of Psycholinguistic Research,* **25,** 5–24.

Meyer, D., Schvaneveldt, R., & Ruddy, M. 1975. Loci of contextual effects on visual word recognition. In P. Rabbit & S. Dornic (Eds.). *Attention and performance,* Vol. V. New York: Academic Press.

Milberg, W., Blumstein, S., Katz, D., Gershberg, F., & Brown, T. 1995. Semantic facilitation in aphasia: Effects of time and expectancy. *Journal of Cognitive Neuroscience,* **7,** 33–50.

Neely, J. H. 1977. Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General,* **106,** 226–254.

Nicol, J. 1988. *Coreference processing during sentence comprehension.* Doctoral dissertation, Massachusetts Institute of Technology.

Nicol, J., & Osterhout, L. 1988. *Reactivating antecedents of empty categories during parsing.* Unpublished manuscript.

Nicol, J., & Swinney, D. 1989. The role of structure in coreference assignment during sentence comprehension. *Journal of Psycholinguistic Research,* **18,** 5–19.

Postman, L. 1970. The California norms: Association as a function of word frequency. In L. Postman & G. Keppel (Eds.). *Norms of word association.* New York: Academic Press.

Prather, P. A. 1994. The time course of lexical activation in fluent and nonfluent aphasia. *Linguistic and Cognitive Neuroscience,* 128–144.

Prather, P., Zurif, E., Stern, C., & Rosen, T. J. 1992. Slowed lexical access in nonfluent aphasia: A case study. *Brain and Language,* **43,** 336–348.

Shapiro, L., & Levine, B. 1990. Verb processing during sentence comprehension in aphasia. *Brain and Language,* **38,** 21–47.

Shapiro, L., Gordon, B., Hack, N., & Killackey, J. 1993. Verb-argument structure processing in complex sentences in Broca's and Wernicke's aphasia. *Brain and Language,* **45,** 423–447.

Simpson, G. B. 1994. Context and the processing of ambiguous words. In M. A. Gernsbacher (Ed.). *Handbook of Psycholinguistics* (pp. 359–374). San Diego: Academic Press.

Stromswold, K., Caplan, D., Alpert, N., & Rauch, S. 1996. Localization of syntactic comprehension by positron emission tomography. *Brain and Language,* **52,** 452–473.

Swinney, D., Ford, M., Frauenfelder, U., & Bresnan, J. 1987. *The time course of coindexation during sentence comprehension.* Paper presented at the Psychonomic Society Meeting, Seattle.

Swinney, D., Onifer, W., Prather, P., & Hirshkowitz, M. 1979. Semantic facilitation across sensory modalities in the processing of individual words and sentences. *Memory & Cognition,* **7,** 159–165.

Swinney, D., & Osterhout, L. 1990. Inference generation during auditory language comprehension. In A. Graesser & G. Bower (Eds.). *Inferences and text comprehension.* San Diego: Academic Press.

Swinney, D., & Zurif, E. 1995. Syntactic processing in aphasia. *Brain and Language,* **50,** 225–239.

Swinney, D., Zurif, E., Prather, P., & Love, T. 1996. Neurological distribution of processing resources underlying language comprehension. *Journal of Cognitive Neuroscience,* **8,** 174–184.

Tanenhaus, M. K., Boland, J., Garnsey, S. M., & Carlson, G. N. 1989. Lexical structure in parsing long-distance dependencies. *Journal of Psycholinguistic Research,* **18,** 37–50.

Tanenhaus, M., Carlson, G., & Seidenberg, M. 1985. Do listeners compute linguistic representations? In A. Zwicky, L. Kartunnen, & D. Dowty (Eds.). *Natural language parsing: Psycholinguistic, theoretical, and computational perspectives.* London and New York: Cambridge Univ. Press.

Tanenhaus, M. K., Stowe, L. A. & Carlson, G. 1989. The interaction of lexical expectation and pragmatics in parsing filler–gap constructions. In *Proceedings of the Seventh Annual Cognitive Science Society Meeting* (pp. 361–365).

Zurif, E., Swinney, D., Prather, P., Wingfield, A., & Brownell, H. 1995. The allocation of memory resources during sentence comprehension: Evidence from the elderly. *Journal of Psycholinguistic Research,* **24,** 165–182.