An eye-movement-contingent probe paradigm

GRETCHEN KAMBE, SUSAN A. DUFFY, CHARLES CLIFTON, JR., and KEITH RAYNER
University of Massachusetts, Amherst, Massachusetts

A new eye-movement-contingent probe task is presented in which readers' eye movements are monitored as they read sentences and respond to a probe word; the timing of the display of the probe word is dependent on fixation of a target word. The present study examined semantic priming effects. The target word was either related (*doctor*) or unrelated (*lawyer*) to the probe word (*nurse*), and the probe appeared 120, 250, 500, or 750 msec after the reader first fixated on the target word. When the probe word appeared (in the location of the target word), the rest of the sentence disappeared until the participant named the probe word. Then the sentence reappeared, and the participant continued reading the sentence. Naming times to the probe word were recorded, as was sentence reading time and the eye movement behavior relative to the onset of the probe word. Priming effects were observed, since probe reaction time to related probes was faster than that to unrelated probes. Ways in which this paradigm can be used to study various issues in language processing are discussed.

In this article, we introduce an eye-movement-contingent probe paradigm that can be used to study the representation that has been encoded during reading. Probe tasks have been widely used to examine a number of issues related to language processing and discourse representations, including (but not limited to) (1) lexical ambiguity resolution, (2) anaphor resolution, (3) inference generation, (4) syntactic parsing, and (5) time course issues related to language comprehension. Probe tasks are generally used to directly examine active concepts during reading, and both cross-modality and within-modality paradigms have been used. In the probe task, a single probe word is presented at some point during comprehension. The participant must respond in some way to the probe word (the typical response is lexical decision, naming, or old/new judgment), and response time is typically the dependent variable. In the critical conditions, the probe word is usually presented at a point in comprehension at which the experimenter hypothesizes that a particular concept will be activated by the comprehension process being studied; this concept will prime the probe word and speed processing on that word.

The probe technique was initially developed in the auditory domain, under the label of cross-modal priming. With this technique, participants listen to a sentence or a text while looking at a video monitor. At critical points

during listening comprehension, a string of letters appears on the monitor, and the participants are asked to respond to (e.g., make a lexical decision to or name) the probe word. Response time is facilitated when the probe word appears immediately after the listener has heard a priming word. The technique has been especially useful in investigating the comprehension of ambiguous words (Onifer & Swinney, 1981; Seidenberg, Tanenhaus, Leiman, & Bienkowski, 1982; Swinney, 1979). Swinney found that probes related to both the intended and the unintended meanings of an ambiguous word were primed when the ambiguous word was preceded by disambiguating context and the probe was presented immediately after the ambiguous word. He also found that if the probe was delayed by several hundred milliseconds, only the intended meaning was primed. Thus, it became clear that it is critical to be able to vary the stimulus onset asynchrony (SOA) between the priming word and the probe word to obtain a complete view of real-time processing. This technique has also been used to investigate sense selection for unambiguous words (Moss & Marslen-Wilson, 1993; Tabossi, 1988; Williams, 1988), comprehension of idioms (Cacciari & Tabossi, 1988), anaphor resolution (MacDonald & MacWhinney, 1990), and the effects of paragraph contexts on the comprehension of unambiguous words (Hess, Foss, & Carroll, 1995).

In cross-modal priming, the critical sentences are presented auditorily; thus, this technique allows the study of *spoken* language comprehension. Within the comprehension literature, however, much of the research has been based on procedures in which participants read rather than listen to texts. Thus, within the field, attempts have been made to adapt this method to *written* language comprehension. Two characteristics of cross-modal priming make it especially useful for studying comprehension: First, the experimenter can present the probe word anywhere in the discourse and, thus, has control

This research was supported by Grants HD17246, HD26765, and HD18708 from the National Institutes of Health. K.R. was also supported by a Research Scientist Award from the National Institute of Mental Health (MH01255) and by a Leverhulme Professorship at the University of Durham (U.K.). We thank Ken Forster and Wayne Murray for their very helpful comments on a prior version of the article. The authors are sad to note that Susan Duffy died on February 14, 2002. Correspondence concerning this article should be sent to G. Kambe, Department of Psychology, University of Nevada, 4505 Maryland Parkway, Box 455030, Las Vegas, NV 89154-5030 (e-mail: gkambe@unlv.edu).

over the SOA between the prime and the probe (control that was so important in the study of ambiguous words), and second, the text is presented in a normal way so that the participant is engaged in normal comprehension processes. These characteristics have been difficult to replicate in a reading version of the probe task. The early probe tasks within the reading comprehension literature (e.g., McKoon & Ratcliff, 1980; O'Brien, Duffy, & Myers, 1986) were participant-paced. Texts were presented one line at a time; participants pressed a key to display the next line, and the probe word followed a particular target line. Although the reading processes were fairly normal (the reader had control over when and where the eyes moved), the disadvantage of this technique was that the experimenter had no control over the delay between the priming word and the probe (and it was not possible to have an "immediate" condition with no delay). In later adaptations of the technique (e.g., Duffy, Henderson, & Morris, 1989; Kintsch & Mross, 1985; Millis & Graesser, 1994; Till, Mross, & Kintsch, 1988), experimenters sought to gain control over SOA by controlling the timing of the presentation of the text. In one experimenter-paced probe task, the critical sentences are presented one word at a time on the video monitor, using a rapid serial visual presentation (RSVP) followed by a probe word that is marked, in some way (i.e., the probe is presented in a different letter case or the probe word is surrounded by asterisks), as the word to which the participant must respond. This technique has the advantage of allowing the experimenter to insert the probe word anywhere in the discourse and to control the delay between the priming word and the probe word (by controlling how long the priming word appears on the screen and how long after its disappearance the probe word appears). Additional variations on the probe RSVP task include presenting the words for varying amounts of time, depending on length (e.g., Gernsbacher, 1989), presenting full sentences for a varying amount of time, depending on length (e.g., Langston, Kramer, & Glenberg, 1998), and presenting the words serially across the screen, rather than in one central position, and allowing the words to cumulate, rather than erasing each word when its successor appears (Dell, McKoon, & Ratcliff, 1983; Greene, McKoon, & Ratcliff, 1992; McKoon & Ratcliff, 1989).

The drawback of all of these experimenter-paced visual presentation probe techniques, however, is that the presentation of the sentences to be read in these experiments is not ecologically natural with respect to normal reading. In the cross-modal technique, participants hear auditory language as it is normally presented. In contrast, in the experimenter-paced visual presentation probe techniques as currently implemented, participants are not seeing text as it is normally presented, and hence, they are not reading normally. In this case, normal reading specifically refers to written language comprehension in which the entire text is available for processing (so that readers may spend as much time as desired on a particular word while moving forward or backward through the

text at will), as opposed to reading that is controlled by the experimenter (RSVP) or buttonpressing, which fails to allow the reader's eyes to move naturally through the text.

A technique that has been widely used to examine on-line components of reading because it allows normal reading of text has been the recording of readers' eye movements (Rayner, 1998). Thus, the entire text is presented at the onset of a trial, and readers are able to move through the text (both forward and backward) as they choose. However, recording eye movements does not allow the experimenter to directly determine what concept is active at a particular point in time. Although cross-modal priming techniques have been useful in determining what concepts are activated during spoken language comprehension, the purpose of the present experiment was to find a way to determine what concepts are currently being activated during written language comprehension. In order to address this issue more directly, we combined features of eye movement recording and probe tasks in an eye-movement-contingent probe paradigm. Not only does eye movement recording allow data collection during normal reading, it also provides an on-line record of where the eye is currently fixated. This then allows the experimenter to control the precise location and timing of presentation of the probe word with respect to the text that is being comprehended. Although this task may not be any more natural than other probe paradigms, in the sense that reading is still being disrupted, the task attempts to approximate normal reading behavior by exposing the reader to the entire text, thus allowing for normal eye movements (so that readers have control over how much time they can spend on each word in the text) during reading. Nonetheless, since the probe is contingent on the location of the eye, the interval between reading a word and presenting the probe is tightly controlled.

In this new paradigm, readers read sentences while their eye movements were recorded. At a particular point during reading, the current sentence disappeared, and a probe word appeared on the video monitor, which they had to name. After the naming response had been made, the entire sentence reappeared, and the reader completed reading the sentence. To ensure that the readers were processing the entire sentence for meaning, comprehension questions about the sentence were asked after the reader had pushed a button to terminate the display. The comprehension questions typically required the reader to process the complete sentence (including information presented before and after the target word) in order to answer the question correctly. This was to minimize strategies that depended on ignoring the sentence content in favor of responding quickly to the probe word. To validate the technique, we sought to replicate the finding that processing of a given target word (e.g., *nurse*) is facilitated when it is preceded by a related word (e.g., *doctor*), as compared with an unrelated word (e.g., *lawyer*; see, e.g., Meyer & Schvaneveldt, 1971). Thus, partici-

pants read sentences containing target words that were related or unrelated to the probe word.

METHOD

Participants

Twenty-four members of the University of Massachusetts community either received course credit or were paid \$5 to participate in the experiment. Either they had normal uncorrected vision, or they wore soft contact lenses.

Apparatus and Procedure

Eye movements were monitored by a Fourward Technologies Dual Purkinje Eyetracker (Generation 5). The eyetracker, which has a spatial resolution of 10 min of arc, was interfaced to a 486 computer, which in turn was interfaced to a NEC video monitor. Viewing was binocular, but only the position of the right eye was monitored. The brightness of the video monitor was adjusted to a comfortable level for each participant and was held constant throughout the experiment. The eye position was sampled every millisecond by the eyetracker. The probe appeared 120, 250, 500, or 750 msec following the onset of the first fixation on the target word in the sentence. Accurate timing of the presentation was achieved by using a vertical sweep frequency of 200 Hz, so that the largest possible timing error was 5 msec. Half of the participants received probes with delays of 120 or 500 msec, and the other half had delays of 250 or 750 msec. When the probe came on, the sentence disappeared, and the participants named the probe word as quickly as possible. The probe word always appeared in the location of the target word. A microphone (which was also interfaced with the computer) was placed directly in front of the participant and was used to record naming times. Once the participant named the probe word, it disappeared, and the entire sentence reappeared. The participants' eye movements were recorded throughout the entire trial. Figure 1 illustrates the procedure.

A chinrest and a forehead rest were used to minimize head movements during the experiment.¹ When the participants first arrived for the experiment, their task was explained to them, and then the eyetracker was calibrated to the participant. This involved the participant's looking at a series of calibration targets. The calibration was then checked by asking the participants to fixate on a series of boxes. During this calibration check, a red dot that moved in synchrony with the eyes was examined to make sure that when the participants looked at a given calibration box, the dot was superimposed on the calibration box. The calibration check was completed prior to each trial.

Materials

The participants read 24 experimental sentences and 24 filler items (which also contained probe words). All of the items were simple one-line sentences (with no more than 75 character spaces). Each experimental sentence contained a target word that was either related (*doctor*) or unrelated (*lawyer*) to the probe word (*nurse*). Target words varied in their location within the sentence. However, at least two words preceded and followed each target word. For a given participant, half of the sentences contained a target word that was related to the probe word, and half contained a target word that was unrelated. The related target words were determined by the University of South Florida word association, rhyme, and word fragment norms (Nelson, McEvoy, & Schreiber, 1994). The degree to which the related target word was associated with the probe word ranged from .379 to .885 (average = .687). The unrelated target word was not associated to the probe word. The target words were all matched on word length and frequency. Table 1 shows example sentences.

RESULTS

The probe response time was analyzed as a function of whether the probe was related or unrelated to the target word and as a function of the delay. In addition, we also analyzed the sentence reading time and certain relevant eye movement characteristics.

Probe Response Times

Table 2 shows the probe response times. Since half of the participants received probes with delays of 120 and 500 msec from the onset of a fixation on the target word (and the other half received delays of 250 and 750 msec), the data were analyzed in a 2 (delay group) $\times$ 2 (delay interval: short vs. long) $\times$ 2 (target type: related vs. unrelated) analysis of variance (ANOVA), with delay group as a between-subjects manipulation and the other two factors as within-subjects manipulations.

The ANOVA revealed that participants in the 120/500-msec probe conditions responded faster (660 msec) than those in the 250/750-msec probe conditions [769 msec; $F_1(1,22) = 9.42$, $MS_e = 30,446$, $p < .01$; $F_2(1,46) = 58.55$, $MS_e = 6,934$, $p < .001$]. Likewise, across the two delay

Figure 1. An example of the eye-movement-contingent probe paradigm in the 500-msec delay condition. The top line shows the sentence in which *doctor* is the target word. The plus signs indicate the participant's eye fixations. Five hundred milliseconds after the target word is fixated, the sentence disappears, and the probe word is displayed in the location of the target word. The participant's eyes then move back to the target word location, and the participant names the probe word. Once the probe word is named, it disappears (line 3), and the participant continues reading the sentence.

Table 1
Example Stimuli
(Target Word Underlined, Probe Word in Italics)

Janice went to the famous (<u>doctor</u> / <i>lawyer</i>) yesterday because she needed his help. Probe: <i>nurse</i>
Mary was so hungry she ate the moldy (<u>bread</u> / <i>apple</i>) as a snack before leaving. Probe: <i>butter</i>
Artie threw (<u>mud</u> / <i>ice</i>) at his best friend during the mock battle. Probe: <i>dirt</i>

groups, there was a tendency for reaction times to be faster to short probe delays (120 and 250 msec) than to long probe delays [500 and 750 msec; $F_1(1,22) = 8.17$, $MS_e = 2,350$, $p < .01$; $F_2(1,46) = 2.62$, $MS_e = 7,345$, $p < .12$]. This effect reflects the fact that as delay increased, the eyes were more likely to have moved to a later position in the sentence (see below). In those cases, a time-consuming regression was required to fixate the probe word. More important, as also can be seen in Table 2, reaction times were shorter to related probes than to unrelated probes [$F_1(1,22) = 51.41$, $MS_e = 2,793$, $p < .001$; $F_2(1,46) = 44.94$, $MS_e = 6,601$, $p < .001$]. Although there was no difference between related and unrelated probes at the 120-msec probe delay, none of the interactions approached significance.² Post hoc tests revealed that the priming effect (the difference between related and unrelated probes) was significant at all other probe delays ($p < .01$). Thus, in this eye-movement–contingent probe paradigm, the basic finding that semantically related probes are responded to faster than unrelated probes was replicated.

Sentence Reading Time

Table 3 shows the average time that it took readers to read the sentences (not including probe display and probe reaction times). An ANOVA of these data revealed that there was a tendency for the participants who received the 120/500-msec probe delays to read the sentences faster than those with the 250/750-msec probe delays [$F_1(1,22) = 4.52$, $MS_e = 134,315$, $p < .05$; $F_2(1,46) = 2.09$, $MS_e = 517,827$, $p = .16$]. Basically, then, the participants with the 120/500-msec probe delays responded faster overall to the probes and also read the sentences faster than did the other group of participants. We suspect that this difference reflects little else other than the fact that the former group of participants have faster reaction times (and also faster reading times) than the latter group and that there is nothing particularly special about the 120/500-msec probes, in comparison with the 250/750-msec probes. Finally, sentence reading times were longer (by 159 msec) when the probe word was not related to the target word [$F_1(1,22) = 19.87$, $MS_e = 104,958$, $p < .001$; $F_2(1,46) = 15.85$, $MS_e = 302,220$, $p < .001$]. Readers found it easier to read sentences with related probes than those with unrelated probes. Most likely, this was due to the fact that the unrelated probes

introduced concepts that were inconsistent with the meaning of the sentence. This information had to be processed and rejected as irrelevant to the overall meaning of the sentence.

Eye Movements Back to the Probe Word Location

Because the probe word appeared in the same position on the screen as did the target word, on some trials the eyes had moved on to a later position in the sentence before the probe appeared. In those cases, the eyes had to move back to the probe word in order to respond to it. Table 4 shows the percentage of trials on which the eyes moved back to the probe word location as a function of probe delay. As is clear from the table, when the probe delay was short (120 msec), the reader's eyes were typically (73% of the time) in the location of the probe word when it came on. However, and not surprisingly, as the delay of the probe onset increased, the probability that the eyes were not at the target location when the probe appeared increased, as did the probability of readers' moving their eyes to the probe location. We also computed the average saccade size distance between the location of the eyes when the probe first appeared and the actual probe word location; this distance was 1.69, 5.81, 9.03, and 15.86 letter spaces for the 120-, 250-, 500-, and 750-msec probe delays, respectively. Critically, when the delay resulting from the eye movement was subtracted from the probe response times, the difference between related and unrelated probe reaction times remained.³

DISCUSSION

In this article, we have introduced a new paradigm that combines aspects of experiments using eye movement recording procedures and experiments using probe reaction time. Using this eye-movement–contingent probe paradigm, we were able to successfully replicate the priming effect found between related words: Naming times to the probe were facilitated across all but possibly the shortest probe delays when the target word was related to the prime word. The pattern of eye movements indicated that if the probe word appeared after the eyes had moved away from the target location, the reader returned to that location. This occurred 27% of the time for the 120-msec probe delay condition and 91% of the time for the 750-msec delay. The distance that the eyes moved was dependent on the duration of the delay. However, the distance between the eyes and the probe word had no significant effect on the amount of facilitation.

Table 2
Probe (Naming) Reaction Times (in Milliseconds)

Probe Type	Delay			
	120	250	500	750
Related	621	712	686	794
Unrelated	621	748	710	821
Difference	0	36	24	27

Table 3
Total Sentence Reading Time (in Milliseconds)

Probe Type	Delay			
	120	250	500	750
Related	3,407	3,244	3,571	3,731
Unrelated	3,499	3,531	3,681	3,877

The orderly pattern of results serves to validate the new technique, providing evidence that response time to the probe word is sensitive to currently activated concepts.⁴

The probe paradigm allows a researcher to present a probe contingent upon where the eye is currently fixated and, thus, to determine what concepts are activated when a reader first processes some particular information. The advantage of this technique is that reading comprehension can proceed normally, at the reader's own pace, while allowing precise control over the placement and timing of the probe word. The possibility of normal reading behavior is especially important when one wants to present full paragraphs as stimuli; it feels very awkward to read a long paragraph under experimenter-paced visual presentation procedures. This awkwardness may change the comprehension processes in critical ways. We are at a point now in the study of comprehension processes where it is important to be able to present fairly lengthy texts so that we can look at the effects of more distant context on the processing of current information. For example, a number of lines of research now focus on the time course of activation of concepts from earlier in a text, including the activation of antecedents for pronouns (e.g., Greene, Gerrig, McKoon, & Ratcliff, 1994), activation of information associated with a particular character in a text (e.g., Albrecht & O'Brien, 1993; O'Brien, Rizzella, Albrecht, & Halleran, 1998), and activation of goal information (e.g., Albrecht & Myers, 1995; Lutz & Radvansky, 1997).

In addition, the technique provides a complement to current eye movement studies. Although eye movement data have been used successfully to examine a number of issues related to language processing (see Rayner, 1998), direct measures of the extent to which a given concept is activated are not available from eye fixation times (and hence, inferences must be made about levels of activation). For example, a series of studies of the comprehension of ambiguous words (Duffy, Morris, & Rayner, 1988; Kambe, Rayner, & Duffy, 2001; Rayner, Pacht, &

Duffy, 1994) used fixation duration data to make inferences about which meanings were activated. The present technique can be used to provide a more direct assessment of meaning activation for the various meanings of an ambiguous word and of how this activation is modulated by both meaning frequency and strength of contextual bias. Although further exploration of the technique is necessary, we suspect that it can be used to examine a wide range of issues related not only to lexical ambiguity resolution, but also to language comprehension in general.

REFERENCES

- ALBRECHT, J. E., & MYERS, J. L. (1995). Role of context in accessing distant information during reading. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **21**, 1459-1468.
- ALBRECHT, J. E., & O'BRIEN, E. J. (1993). Updating a mental model: Maintaining both local and global coherence. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 1061-1070.
- CACCIARI, C., & TABOSSI, P. (1988). The comprehension of idioms. *Journal of Memory & Language*, **2**, 668-683.
- DELL, G. S., MCKOON, G., & RATCLIFF, R. (1983). The activation of antecedent information during the processing of anaphoric reference in reading. *Journal of Verbal Learning & Verbal Behavior*, **22**, 121-132.
- DUFFY, S. A., HENDERSON, J., & MORRIS, R. (1989). The semantic facilitation of lexical access during sentence processing. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 791-801.
- DUFFY, S. A., MORRIS, R. K., & RAYNER, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory & Language*, **27**, 429-446.
- GERNSBACHER, M. A. (1989). Mechanisms that improve referential access. *Cognition*, **32**, 99-156.
- GREENE, S. B., GERRIG, R. J., MCKOON, G., & RATCLIFF, R. (1994). Unheralded pronouns and management by common ground. *Journal of Memory & Language*, **33**, 511-526.
- GREENE, S. B., MCKOON, G., & RATCLIFF, R. (1992). Pronoun resolution and discourse models. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 266-283.
- HESS, D. J., FOSS, D. J., & CARROLL, P. (1995). Effects of global and local context on lexical processing during language comprehension. *Journal of Experimental Psychology: General*, **124**, 62-82.
- KAMBE, G., RAYNER, K., & DUFFY, S. A. (2001). Global context effects on processing lexically ambiguous words: Evidence from eye fixations. *Memory & Cognition*, **29**, 363-372.
- KINTSCH, W., & MROSS, E. F. (1985). Context effects in word identification. *Journal of Memory & Language*, **24**, 336-349.
- LANGSTON, W., KRAMER, D. C., & GLENBERG, A. M. (1998). The representation of space in mental models derived from text. *Memory & Cognition*, **26**, 247-262.
- LUTZ, M. F., & RADVANSKY, G. (1997). The fate of completed goal information in narrative comprehension. *Journal of Memory & Language*, **36**, 293-310.
- MACDONALD, M. C., & MACWHINNEY, B. (1990). Measuring inhibi-

Table 4
Percentage of Trials on Which the Readers
Moved Their Eyes (Regressed) to the Target Word Location,
With the Average Number of Character Spaces the Eyes Moved

Probe Type	Delay (msec)							
	120		250		500		750	
	%	No.	%	No.	%	No.	%	No.
Related	27	1.67	68	6.07	83	9.67	85	15.21
Unrelated	27	1.71	64	5.56	79	8.40	96	16.51

- tion and facilitation from pronouns. *Journal of Memory & Language*, **29**, 469-492.
- McKoon, G., & Ratcliff, R. (1980). The comprehension processes and memory structures involved in anaphoric reference. *Journal of Verbal Learning & Verbal Behavior*, **19**, 668-682.
- McKoon, G., & Ratcliff, R. (1989). Semantic associations and elaborative inferences. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **15**, 326-338.
- Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology*, **90**, 227-234.
- Millis, K. K., & Graesser, A. C. (1994). The time-course of constructing knowledge-based inferences for scientific texts. *Journal of Memory & Language*, **33**, 583-599.
- Moss, H. E., & Marslen-Wilson, W. D. (1993). Access to word meanings during spoken language comprehension: Effects of sentential semantic context. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **19**, 1254-1276.
- Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (1994). *The University of South Florida word association, rhyme and word frequency norms*. Unpublished manuscript.
- O'Brien, E. J., Duffy, S. A., & Myers, J. L. (1986). Anaphoric inference during reading. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **12**, 346-352.
- O'Brien, E. J., Rizzella, M. L., Albrecht, J. E., & Halleran, J. G. (1998). Updating a situation model: A memory-based text processing view. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **24**, 1200-1210.
- Onifer, W., & Swinney, D. A. (1981). Accessing lexical ambiguities during sentence comprehension: Effects of frequency of meaning and contextual bias. *Memory & Cognition*, **9**, 225-236.
- Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, **124**, 372-422.
- Rayner, K., Pacht, J. M., & Duffy, S. A. (1994). Effects of prior encounter and global discourse bias on the processing of lexically ambiguous words: Evidence from eye fixations. *Journal of Memory & Language*, **33**, 527-544.
- Seidenberg, M. S., Tanenhaus, M. K., Leiman, J. M., & Binkowski, M. (1982). Automatic access of the meaning of ambiguous words in context: Some limitations of knowledge-based processing. *Cognitive Psychology*, **14**, 489-537.
- Swinney, D. A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning & Verbal Behavior*, **18**, 645-659.
- Tabossi, P. (1988). Effects of context on the immediate interpretation of unambiguous nouns. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **14**, 153-162.
- Till, R. E., Mross, E. F., & Kintsch, W. (1988). Time course of priming for associate and inference words in a discourse context. *Memory & Cognition*, **16**, 283-298.
- Williams, J. N. (1988). Constraints upon semantic activation during sentence comprehension. *Language & Cognitive Processes*, **3**, 165-206.

NOTES

1. Monitoring eye movements with a Dual Purkinje eyetracker requires care to ensure that the system is able to accurately record the location of the eye and its subsequent movements. Typically, a bite bar is used to stabilize the participant's head (to unconfound head and eye movements) during an experiment. This was not possible in the present experiment because of the voiced responses. As a result, we used a combination of a chin- and a headrest. Then we had the participants practice making voiced responses while (1) not moving their head away from the chin/headrest, and (2) keeping as still as possible to avoid disrupting the tracking. An extensive practice session containing the same consonant/vowel sounds as the probe words in the experiment was performed before the participants began the experiment. The participants completed the experiment only after they were able to make voiced responses without disrupting tracking (only 1 individual did the practice session a second time). Of course, head-mounted eyetrackers that record head and eye movements can also be used in the probe paradigm described here, and we have successfully used an SR-Eyelink tracker in this paradigm.

2. In addition to the experiment reported here, we conducted two other probe delay experiments. In the first experiment, with 20 highly experienced eye-tracking participants (typically, members of our laboratory) and no filler trials, we obtained strong priming effects (ranging between 21 and 55 msec) across the SOA range used in the experiment reported here. In this study, there was a 36-msec priming effect at the 120-msec probe delay. In the second experiment, with 32 unpracticed undergraduate students as participants and 30 nonprobe filler trials (in which no probe ever appeared), we obtained a pattern very similar to that reported here across the same SOA range (although the overall priming effects were somewhat attenuated). In this study, there was a nonsignificant 6-msec priming effect at the 120-msec probe delay.

3. We had two reasons for varying and analyzing probe delay: (1) to determine what the appropriate delay would be to maximize the odds of the readers' eyes still being on the target word when the probe word appeared and (2) to determine how often and how far the readers' eyes would have to travel to return to the probe word. We originally thought that we would have a larger problem with individuals finishing the sentence before the probe word appeared at the longest (750 msec) probe delay. We also did not expect the readers to regress 1-2 character spaces at the shorter delay (since the information was typically already within the fovea). Unsurprisingly, the longer the delay, the further the readers' eyes typically were from the target word (occasionally, the reader had already regressed to an earlier point in the sentence and were thus fairly close to the target word location when the probe appeared).

4. Wayne Murray pointed out that, at the longer probe delays, the concept may no longer be active. Instead, the movement of the readers' eyes back to the prime location may reactivate the concept.

(Manuscript received September 26, 2001;
revision accepted for publication April 22, 2002.)