Psychology and Aging

Eye Movements of Older and Younger Readers When Reading Disappearing Text

Keith Rayner, Jinmian Yang, Monica S. Castelhano, and Simon P. Liversedge

Online First Publication, December 13, 2010. doi: 10.1037/a0021279

Psychology and Aging

0882-7974/10/$12.00 DOI: 10.1037/a0021279

Eye Movements of Older and Younger Readers When Reading Disappearing Text

Keith Rayner
University of California, San Diego

Jinmian Yang
University of Massachusetts, Amherst

Monica S. Castelhano
Queen's University

Simon P. Liversedge
University of Southampton

Older and younger readers read sentences in which target words were masked 40 to 60 ms after fixation onset. Masking only the target word caused more disruption than did masking each word in the sentence, and this effect was stronger for the younger readers than for the older readers. Although older readers had longer eye fixations than did younger readers, the results indicated that the masking effect was comparable for the 2 groups. However, for both groups, how long the eyes remained in place was strongly influenced by the frequency of the fixated word (even though it had been rapidly replaced by the mask and was no longer there when the eyes did move). This is compelling evidence that for both older and younger readers, cognitive/lexical processing has a very strong influence on when the eyes move in reading.

Keywords: disappearing text, eye movements, older and younger readers

Older readers tend to make more (Kemper & McDowd, 2006; Kemper & Liu, 2007; Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Castelhano, & Yang, 2009, 2010; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006) and longer eye fixations (Kliegl et al., 2004; Rayner, Reichle, et al., 2006; Rayner et al., 2009; Stine-Morrow et al., 2010) during reading than do younger readers. It has also been demonstrated that older readers make longer saccades and skip words more frequently than do younger readers (Laubrock, Kliegl, & Engbert, 2006; Rayner, Reichle, et al., 2006; Rayner et al., 2009). This results in them making more regressions to skipped words than do younger readers. Finally, older readers have a slightly smaller and less asymmetric perceptual span than do younger readers (Rayner et al., 2009), and on some fixations they obtain slightly less preview benefit from the word to the right of fixation than do younger readers (Rayner et al., 2010). All of these factors result in older adults reading more slowly than do younger readers (Hartley, Stojack, Mushaney, Annon, & Lee, 1994; Stine-Morrow, Miller, & Hertzog, 2006). Indeed, Rayner, Reichle, et al. (2006; Rayner et al., 2009) suggested that older readers adopt a riskier reading strategy in which they guess[1] what the next word is more often than do younger readers to partially compensate for their slower processing of text.

Although older readers might adopt a somewhat different reading strategy than do younger readers, it is important to note that they do show word frequency and word predictability effects. Thus, as with younger readers, older readers look longer at low-frequency words than at high-frequency words and they look longer at low-predictable words than at high-predictable words (Laubrock et al., 2006; Rayner, Reichle, et al., 2006). Indeed, frequency and predictability effects both tend to be larger in older readers than in younger readers.

Given that older readers read more slowly than do younger readers and also adopt somewhat different reading strategies than younger readers to partially compensate for their slower reading, an interesting question is whether their slower reading and longer eye fixations occur because it takes them longer to encode the fixated words. A direct way to test this question is to use the *disappearing text paradigm* (Blythe, Liversedge, Joseph, White, & Rayner, 2009; Ishida & Ikeda, 1989; Liversedge et al., 2004; Rayner, Inhoff, Morrison, Slowiaczek, &

Keith Rayner, Department of Psychology, University of California, San Diego, La Jolla; Jinmian Yang, Department of Psychology, University of Massachusetts, Amherst; Monica S. Castelhano, Department of Psychology, Queen's University; and Simon P. Liversedge, Department of Psychology, University of Southampton.

This research was supported by Grant HD26765 from the National Institutes of Health and by a grant from the Microsoft Corporation to Keith Rayner. Grants from the World University Network enabled Monica S. Castelhano and Simon P. Liversedge to visit the University of California, San Diego, when this article was written. We thank Phil Allen, Reinhold Kliegl, Ulrich Mayr, and an anonymous reviewer for very helpful comments on a prior version of this article.

Correspondence concerning this article should be addressed to Keith Rayner, Department of Psychology, University of California, San Diego, San Diego, CA 92093. E-mail: krayner@ucsd.edu

[1] The term *guess the next word* as used here and elsewhere in this article is not meant to imply any type of conscious strategy on the part of the reader. Rather, the processing system is unconsciously engaging a strategy of skipping words on the basis of partial visual information about the skipped word.

Bertera, 1981; Rayner, Liversedge, & White, 2006; Rayner, Liversedge, White, & Vergilino-Perez, 2003), in which text is masked or simply disappears at a certain point on each fixation. A striking result from this paradigm is that reading proceeds quite normally if the reader gets to see the text for 50–60 ms before it disappears or the mask appears.[2] This does not mean that words can be identified in 50–60 ms, but it does mean that readers are able to encode all of the visual information that they need from the text in this time frame. What is more interesting perhaps is that how long the eyes remain in place is very much influenced by the frequency of the fixated word (Blythe et al., 2009; Liversedge et al., 2004; Rayner, Liversedge, et al., 2003; Rayner, Liversedge, et al., 2006): if the word is low frequency, the eyes remain in place longer than if it is a high-frequency word even when the text has been masked or disappears. This is very striking evidence in support of the idea that lexical processing strongly influences when to move our eyes during reading and is the process that drives the eyes through the text.

In the experiment reported here we extended current findings on the basis of the disappearing text paradigm in relation to two important questions. First, we assessed whether the period required for successfully encoding words in the disappearing text paradigm varies with age. That is, are there differences between older and younger readers in how long the text has to be available from fixation onset before the mask appears in order for reading to remain undisrupted? Thus, in one condition, in line with prior disappearing text experiments, each fixated word in a sentence was masked after a different time period (40, 50, or 60 ms). We assumed that if older readers needed longer to encode the fixated words, they would show more disruption in all disappearing text conditions than would the younger readers, and this would be especially pronounced in the shorter mask conditions.

In order to address a second theoretical question, we also included a condition in which only a designated target word in the sentence was masked after the appropriate interval (again, 40, 50, or 60 ms). By comparing reading behavior when a single word was masked (when fixated) with reading behavior when every word of the sentence was masked (when fixated), we could assess the ease with which older and younger readers adapted to unusual presentation conditions that occurred regularly, and over an extended period, in relation to those that occurred for short-lived periods at irregular positions within a sentence. Such comparisons allowed us to directly test the claim advocated by Rayner, Pollatsek, and Reichle (2003), that when a mask appears at quasi-random places during reading, it causes more disruption (because the subjects do not know which word will be masked) than when the mask appears consistently as each word is fixated during reading. On the assumption that adaptation declines with age, we also anticipated that flexibility in dealing with the disappearing text stimuli may be reduced in the older adults in relation to the younger adults.

Finally, the inclusion of the single-word disappearing-text condition also allowed us to assess another aspect of ongoing processing, namely, how sensitive older and younger readers are to a short-lived perturbation of the text. In relation to this question, we were keen to assess whether, in hand with less-flexible adaptation to extended periods of unusual presentation conditions, there was reduced sensitivity to short-term perturbations in older readers in comparison with younger readers.

General Method

Subjects

Thirty-two young adults who were students at the University of Massachusetts at Amherst participated in the experiment; they averaged 21.8 years of age (range = 18 years to 28 years). In addition, 32 older adults from the community participated in the experiment; they averaged 72.3 years of age (range = 65 years to 89 years). The groups did not differ in number of years of schooling (15.5 years for the younger readers and 15.6 years for the older readers). The young adults had either normal or corrected-to-normal vision. All of the older adults[3] had corrected 20/20 vision for reading, and they wore their glasses during the experiment. All of the older readers reported that they spent quite a bit of time each day reading newspapers and books. Half of the subjects in the older and younger groups read the target sentences in a condition in which each of the fixated words was masked (*sentence masked condition*), and the other half read the sentences in a condition in which only the target word in each sentence was masked (*target word masked condition*).

Apparatus

Sentences were presented on a 22-inch (approximately 55 cm) ViewSonic VX924 LCD monitor attached to a Pentium 166-MHZ computer interfaced with an SR Research Ltd. EyeLink 1000 eye-tracking system, with high spatial resolution and a sampling rate of 1000 Hz (1-ms sampling resolution). Although viewing was binocular, only the right eye was tracked. The sentences were presented on a single line with lowercase letters (except when capitals were appropriate). The letters were black on a white background. Subjects were seated 63 cm from the monitor, and three characters equaled 1 degree of visual angle. Custom-built software ensured that the mask (*X*s replacing the letters in the fixated word) appeared at the designated point in each fixation.

Materials and Design

Sixty-four pairs of high-frequency and low-frequency target words were embedded in neutral sentence frames; 40 word pairs (and sentences) from Juhasz, Liversedge, White, and Rayner

[2] The patterns of eye movements that are observed do not differ regardless of whether the text is masked or disappears (Rayner, Liversedge, et al., 2006).

[3] The older participants were part of a large group of volunteers in the Amherst, Massachusetts, area who serve as a control group for comparison with Alzheimer's patients in an ongoing study. None of them reported any vision problems (other than needing glasses for reading); they all self-reported that they had corrected 20/20 vision. Prior to the experiment, the older readers completed the Shipley Institute of Living Scale test (Zachary, 2006) to evaluate their vocabulary and abstraction skills. Those who read when each of the words of the sentence was masked had an average score on the test of 67 (out of 80, with a range from 48 to 79), and those who read the sentences when only the target word was masked had an average score of 69.4 (with a range from 61 to 79).

(2006) were used, and 24 additional pairs (and appropriate sentence frames) were created. The pairs of high- and low-frequency words were matched on word length, and ranged between 6 and 10 characters ($M = 7.14$). The 64 high-frequency words had an average frequency of 159 words per million, and the 64 low-frequency words had an average frequency of 3 words per million (Baayen, Piepenbrock, & Gulikers, 1995). The average predictability of the target words, determined by a close rating in which the target word had to be guessed on the basis of the preceding context, was very low (averaging under 2% for both the high- and low-frequency words). The following sentences are examples for the pair of words *history* and *zoology*:

1a. Beth wanted to study history/zoology at a college in Canada.

1b. My mother said that a degree in history/zoology would be very helpful.

In total, subjects read 128 sentences averaging 10 words in length (range = 8 to 14).

In the sentence masked condition (see Figure 1), each fixated word in the sentence was masked after the designated interval (40, 50, or 60 ms); in the control no-mask condition, the sentence appeared normally. In the target word masked condition, only the target word was masked after the designated interval (again 40, 50, or 60 ms, or with no mask). In both conditions, once the fixated word was masked, it did not reappear until the reader fixated on another word (i.e., an immediate refixation on the word did not result in it reappearing). Subjects in the sentence masked condition read 128 sentences, and those in the word masked condition read the same128 sentences (in each case, 32 sentences with 40-, 50-, and 60-ms mask onsets, and 32 normal sentences). The sentences were presented in a 14-point fixed-width font (Courier New). Each subject read any given target word or sentence frame only once, and the assignment of target words to sentence frames and different conditions was counterbalanced across subjects. Whether a single target word was masked or all the words in the sentence were masked was blocked across subjects. However, within each block, the mask onset was randomized across sentences so that subjects could not predict from trial to trial whether masking would or would not occur, and if it did, how quickly mask onset would occur.

Sentence Masked condition:

```
Fixation 3:
Beth wanted to study history at a college in Canada.
Beth wanted to XXXXX history at a college in Canada.
                 *

Fixation 4:
Beth wanted to study history at a college in Canada.
Beth wanted to study XXXXXXX at a college in Canada.
                        *

Fixation 5:
Beth wanted to study history at a college in Canada.
Beth wanted to study history XX a college in Canada.
                              *
```

Target Masked condition:

Fixation 4:

```
Beth wanted to study history at a college in Canada.
Beth wanted to study XXXXXXX at a college in Canada.
                        *
```

Figure 1. Examples of the disappearing text paradigm when each successively fixated word in the sentence was masked in turn, and when only the target word was masked. The asterisk represents the position of the fixation. In the sentence masked condition, each word that the reader fixated was masked. The panel shows the third, fourth, and fifth fixations on the sentence only. The fourth fixation was on the target word (*history*). In the target-word masked condition, only the target word was masked. In the high-frequency version of the sentence the target word was *history*, and in the low-frequency version, the target word was *zoology*.

Procedure

When subjects first arrived for the experiment, some background information was obtained from them concerning their level of education, their reading habits, and general visual function. Then the eye-tracking system was calibrated; this typically took about 5 min. Calibration accuracy was determined by asking subjects to sequentially fixate on three fixation points that were presented in the position in which the sentence would subsequently appear. The validity of the calibration was checked prior to the presentation of each sentence by asking subjects to fixate on a fixation marker. If an accurate fixation occurred on the fixation marker, the next trial occurred; if the fixation was not accurate, the subject was recalibrated (which typically took less than a minute). Subjects read sentences that appeared one at a time on the video monitor. They were asked to read each sentence silently for comprehension, and they were told that they would be asked questions about the sentences. Yes–no questions appeared on the monitor following one half of the sentences and were related to the meaning of the sentence. Subjects responded by choosing one of two alternatives via a button press.

Results and Discussion

As per Rayner, Reichle, et al. (2006), there was no difference in comprehension accuracy between the two groups: Older readers answered the comprehension questions correctly 89% of the time in comparison with 90% for the younger readers. Approximately 5% of the data were lost because of blinks and track losses (with no differences across the mask onset conditions). Fixations less than 80 ms or more than 800 ms were excluded from the analyses (these were included in the 5% data loss). A number of standard eye movement measures were examined for the target words (Liversedge & Findlay, 2000; Rayner, 1998, 2009). As per Rayner, Liversedge, et al. (2003, 2006), global measures of processing were also examined when each word was masked. However, global analyses are not meaningful when only the target word is masked.[4] Thus, results are reported first in terms of global measures for the condition in which each fixated word in the sentence was masked. These global analyses are followed by local analyses for the target word when the entire sentence was masked and then by local analyses for the target word when only the target word was masked. Finally, analyses directly comparing the target word data under the two disappearing text conditions are reported.

Global Analyses

When each word in the sentence was masked, reading was slowed by the onset of the mask for both the older and younger readers, but the masking effect was much stronger for the older readers than for the younger readers. A series of 2 (age: older and younger) $\times$ 4 (mask onset: no mask, 60 ms, 50 ms, 40 ms) analyses of variance (ANOVAs) were carried out on the global measures (shown in Table 1). An analysis of the sentence reading time yielded main effects of age, $F(1, 30) = 13.82$, $p < .01$, with older adults taking longer overall than younger adults to read the sentences, and mask onset, $F(3, 90) = 51.55$, $p < .001$. Pairwise comparisons between each mask onset condition indicated that all conditions differed significantly from each other (ps $< .05$), and shorter mask onsets produced longer reading times. There was also an interaction between age and mask onset, $F(3, 90) = 16.68$, $p < .001$, which was largely due to the fact that the difference between the no-mask condition and the mask conditions was almost five times larger for the older readers than for the younger readers (ps $< .01$). Indeed, when we removed the no-mask condition from the analyses and conducted a 2 (age: older and younger) $\times$ 3 (mask onset: 60 ms, 50 ms, 40 ms) ANOVA, we found main effects of age, $F(1, 30) = 15.68$, $p < .001$, and mask onset, $F(2, 60) = 18.12$, $p < .001$, but no interaction between the two variables, $F(2, 60) = 1.37$, $p > .2$. Pairwise comparisons of the mask onset effect conditions indicated that all conditions differed significantly from one another with shorter mask onsets producing longer reading times—40 ms versus 50 ms, $t(31) = 2.81$, $p < .01$; 40 ms versus 60 ms, $t(31) = 6.14$, $p < .001$; and 50 ms versus 60 ms, $t(31) = 3.09$, $p < .01$. Thus, the mask onset variable had a comparable influence on sentence reading times for older and younger readers.

There are four striking aspects of the sentence reading time data. First, older readers read much more slowly than did the younger readers. Indeed, the reading rates, when converted to words per minute (wpm), for the older and younger readers were 187 and 271 wpm, respectively, in the no-mask control condition. The reading rate for the older readers was thus about a third slower than that for the younger readers (see also Hartley et al., 1994, who found similar rate decrements for older readers in two of the three indices of reading speed they reported). Second, the older readers were much more disrupted overall by the mask onset than were the younger readers. Third, the more immediate the mask onset, the more disruptive to processing it was. Fourth, and perhaps most important, for the sentence reading times the magnitude of the disruption associated with each mask onset was similar in older and younger adults, even though, overall, reading times were much longer in older adults than in younger adults.

The average fixation duration yielded only a main effect of mask onset, $F(3, 90) = 19.43$, $p < .001$, with all mask onsets resulting in longer fixation durations than the no-mask condition (ps $< .01$). The age effect and its interaction with mask onset were not significant, Fs < 1. In the ANOVA excluding the no-mask condition, the main effects of mask onset and age, and the interaction between them, were not significant: for mask onset, $F(2, 60) = 1.67$, $p = .20$, for age, $F(1, 30) < 1$, $p > .4$, and interaction, $F(2, 60) = 1.92$, $p = .16$. The number of fixations yielded main effects of mask onset, $F(3, 90) = 41.23$, $p < .001$, and age, $F(1, 30) = 17.31$, $p < .001$, and an interaction between the two, $F(3, 90) = 16.09$, $p < .001$. As with the sentence reading time data, we carried out an ANOVA excluding the no-mask condition, and consistent with the sentence reading time, we found main effects of age, $F(1, 30) = 18.87$, $p < .001$, and of mask onset, $F(2, 60) = 15.15$, $p < .001$. Once again, without the no-mask condition included, the interaction was not significant ($F < 1$). Pairwise comparisons of the mask onset effect condition indicated that all conditions differed significantly from one another with shorter mask onsets producing more fixations—40 ms versus 50 ms, $t(31) = 2.51$, $p < .05$; 40 ms versus 60 ms, $t(31) = 5.44$, $p < .001$; and 50 ms versus 60 ms, $t(31) = 3.06$, $p < .01$. Thus, the effects observed for number of fixations were very similar to those for the sentence reading time data.

Consistent with prior reports (Laubrock et al., 2006; Rayner, Reichle, et al., 2006; Rayner et al., 2009), an analysis of the saccade length data revealed that older readers' saccades were longer than those of younger readers,[5] $F(1, 30) = 7.58$, $p < .01$. Finally, we examined the number of regressions subjects made when they read the sentences. This analysis produced main effects of mask onset, $F(3, 90) = 4.74$, $p < .005$, and a marginal effect of age, $F(1, 30) = 3.29$, $p = .08$, but no interaction between the two ($F < 1$). Pairwise comparisons showed that the 40-ms versus 50-ms difference, and the 50-ms versus 60-ms difference were not reliable (ts < 1.5, ps $> .05$), whereas the 40-ms versus 60-ms difference was reliable, $t(31) = 2.15$, $p < .05$.

In summary, the sentence reading times—as well as the average fixation duration data, the saccade length data, and the regression data—indicate that older adults were making long

[4] Although it is not meaningful to analyze the global data from the condition in which only the target word was masked, it is meaningful to analyze the global data from the counterpart control condition in which it did not disappear. However, for data when only the target word was masked, it is instructive that the average saccade length was longer for the older readers (11.0 letters) than for the younger readers (9.2 letters), and overall reading time in the no-mask condition was longer for the older readers (2807 ms) than for the younger readers (2499 ms; all effects were significant, ps $< .05$). However, the effect observed for the sentence reading time data only amounted to a 12% increase in reading rate in comparison with the 31% difference between the two groups in the control no-mask condition when each word was masked. It is clear that masking every word in the sentence was much more disruptive overall to reading than was masking a single word, and that the increased disruption was itself much greater for older adults than for younger adults. This pattern of effects is important in relation to other aspects of the data that we discuss in more detail in later sections of this article.

[5] With respect to saccade lengths, the appropriate metric is letters (and is so reported in Table 1) rather than visual angle, because the distance the eyes traverse from one saccade to the next is determined by letters rather than by visual angle as long as the text is of normal size (Morrison & Rayner, 1981).

Table 1
Mean Sentence Reading Time, Average Fixation Duration, Average Saccade Length, Number of Fixations per Sentence, and Number of Regressions per Sentence in the Experimental Conditions When the Whole Sentence Was Masked for the Older and Young Readers

Measure	No mask	60 ms	50 ms	40 ms
Sentence reading time				
Older	3524 (1770)	5181 (2486)	5482 (2367)	5766 (2652)
Young	2438 (469)	2766 (566)	2965 (641)	3099 (678)
Average fixation duration				
Older	241 (38)	255 (29)	259 (33)	261 (36)
Young	237 (24)	252 (24)	250 (21)	252 (21)
Average saccade length				
Older	11.0 (2.5)	12.0 (2.6)	11.5 (2.7)	11.9 (2.9)
Young	9.2 (2.2)	9.6 (2.0)	9.4 (1.9)	9.8 (1.8)
Number of fixations				
Older	14.3 (5.3)	19.8 (8.5)	20.7 (7.9)	21.6 (8.3)
Young	10.3 (1.4)	10.9 (1.7)	11.8 (1.9)	12.2 (2.1)
Number of regressions				
Older	2.7 (1.4)	2.8 (1.4)	3.1 (1.5)	3.2 (1.6)
Young	1.9 (1.4)	2.0 (1.4)	2.0 (1.4)	2.2 (1.7)

Note. Sentence reading time and average fixation duration are in milliseconds; for average saccade length the values are number of letter spaces. Standard deviations are given in parentheses.

saccades along with many fixations to read and then reread the sentences. Taken together, the global measures suggest that older readers may have adopted a somewhat "risky" reading strategy (particularly under the disappearing text conditions), whereby they made long fixations and long saccades, often skipping over words and then making regressions and additional fixations in order to reinspect text after initially reading it. The younger readers appear far less likely to adopt a similar risky reading strategy.

Local Analyses

In the sections that follow, we report local analyses of a number of different eye movement measures for the sentence masked condition and the target word masked condition. We view the global analyses just reported as the most diagnostic of the effects of age and mask onset. Of course, as was noted earlier, it is meaningless to do global analyses when only a single target word was masked, so the local analyses allow direct comparison between the single-word and whole-sentence mask conditions. However, there were considerable individual differences, both in terms of the measures themselves and in terms of how subjects reacted to the mask onset. This results in cases in which effects are significant across items, but not subjects, particularly for the main effect of age. Note, however, that the global analyses we just discussed demonstrate very clearly that there is a major effect of age in the paradigm, and the local analyses supplement these findings, providing finer-grain detail as to how the manipulations influenced subjects in both age groups.

A series of 2 (age) × 2 (frequency) × 4 (mask onset) ANOVAs based on subject ($F1$) and item ($F2$) variability were carried out on selected eye movement measures associated with the target word. Frequency and mask onset were manipulated within subjects. In both sets of local analyses, whenever we obtained a reliable interaction of mask with another variable, we also carried out counterpart ANOVAs in which the mask onset variable included just three levels relating to only the 40-, 50-, and 60-ms onsets. These analyses were conducted to assess the extent to which the no-mask condition contributed to the reliability of the interaction. Our rationale was that we were primarily interested in determining the extent to which increasing the duration of the encoding period prior to masking from 40 to 60 ms resulted in differences in eye movement behavior. For this reason, in both sets of local analyses below, we report only interactions when they were reliable in both of the ANOVAs.

The following standard measures (Liversedge & Findlay, 2000; Rayner, 1998, 2009) are reported (and are presented in Tables 2 and 3): first fixation duration (the duration of the first fixation on the word), gaze duration (the sum of all forward fixations on the word prior to an eye movement to another word), and total time (the sum of all fixations on a word). Although the first two measures reflect immediate on-line processing (Rayner, 1998, 2009), total time provides information about general difficulty associated with reading. In addition, total number of fixations on the target word and number of regressions into the target word[6] were examined. Because the target words were at least six letters long, they were rarely skipped. Skipping rate ranged between 5% and 7% and did not differ across conditions; therefore, we do not discuss skipping rate further. Data from the condition in which each word in the sentence was masked (see Table 2) is reported first, followed by data from the condition in which only the target word was masked (see Table 3).

Sentence Masked Condition

First fixation duration and gaze duration. Consistent with prior research, there was a robust frequency effect, with high-frequency words fixated for less time than low-frequency words: For first fixation duration, the frequency effect was 22 ms, $F1(1, 30) = 37.35$, $p < .001$, $F2(1, 96) = 47.01$, $p < .001$; for gaze

[6] We also examined regressions leaving the target word and found that there were no differences.

Table 2
First Fixation Duration, Single Fixation Duration, Gaze Duration, and Total Time on the Target Word for the Different Conditions and Age Groups When the Entire Sentence Was Masked

	No mask		60 ms		50 ms		40 ms	
Masked sentence	High	Low	High	Low	High	Low	High	Low
First fix duration (ms)								
Older	244 (61)	274 (55)	264 (66)	279 (68)	263 (55)	285 (55)	256 (38)	268 (51)
Younger	228 (26)	261 (41)	248 (34)	263 (51)	246 (38)	270 (46)	243 (32)	265 (47)
Single fixation (ms)								
Older	253 (72)	292 (65)	267 (72)	281 (71)	268 (66)	291 (66)	262 (50)	277 (64)
Younger	235 (26)	271 (44)	247 (38)	268 (50)	249 (42)	260 (39)	246 (35)	256 (52)
Gaze duration (ms)								
Older	278 (121)	355 (174)	290 (101)	334 (118)	301 (136)	331 (93)	313 (166)	334 (147)
Younger	260 (26)	301 (55)	266 (49)	303 (65)	269 (60)	316 (69)	284 (58)	299 (67)
Total time (ms)								
Older	475 (272)	604 (349)	723 (399)	898 (430)	733 (322)	975 (491)	866 (380)	936 (428)
Younger	325 (74)	378 (126)	361 (91)	492 (127)	386 (125)	551 (159)	448 (99)	563 (224)
Number of fixations								
Older	1.8 (0.7)	2.2 (0.9)	2.6 (1.2)	3.0 (1.1)	2.6 (1.0)	3.2 (1.2)	3.0 (1.0)	3.3 (1.4)
Younger	1.4 (0.3)	1.5 (0.4)	1.4 (0.3)	1.8 (0.4)	1.5 (0.3)	2.0 (0.4)	1.7 (0.4)	2.0 (0.6)
Regressions (%)								
Older	23.4 (15.9)	28.5 (11.6)	26.5 (15.0)	38.3 (14.2)	25.5 (18.1)	37.5 (17.4)	32.6 (12.5)	33.9 (16.2)
Younger	13.4 (10.3)	18.1 (10.1)	19.2 (12.0)	31.5 (12.3)	21.5 (11.8)	35.1 (15.2)	27.0 (14.7)	32.9 (14.5)

Note. Number of fixations per target word and regressions into the target word are also presented. Standard deviations are given in parentheses.

duration, the frequency effect was 39 ms, $F1(1, 30) = 44.29$, $p < .001$, $F2(1, 96) = 34.69$, $p < .001$. Clearly, the ease with which a word could be lexically identified had a significant influence on how long subjects fixated the target word regardless of whether it was or was not masked. Although the main effect of mask onset was significant by subjects for first fixation duration, $F1(3, 90) = 2.75$, $p < .05$, $F2(3, 288) = 1.94$, $p = .12$, it was not significant for gaze duration ($ps > .6$). Although first fixation duration and gaze duration tended to be longer for older readers than for younger readers (mean first fixation duration = 267 ms for older readers and 253 ms for younger readers; mean gaze duration = 317 ms for the older readers and 287 ms for the younger readers), the differences between the two groups were significant only by items, but not by subjects ($ps > .3$): for first fixation duration, $F2(1, 96) = 19.21$, $p < .001$; for gaze duration, $F2(1, 96) = 22.0$, $p < .001$.

Table 3
First Fixation Duration, Single Fixation Duration, Gaze Duration, and Total Time on the Target Word for the Different Conditions and Age Groups When Only the Target Word Was Masked

	No mask		60 ms		50 ms		40 ms	
Masked target word	High	Low	High	Low	High	Low	High	Low
First fix duration (ms)								
Older	234 (50)	254 (42)	270 (50)	276 (55)	264 (50)	288 (58)	260 (37)	273 (39)
Younger	218 (41)	248 (39)	275 (53)	310 (60)	282 (54)	308 (64)	293 (63)	322 (67)
Single fixation (ms)								
Older	248 (69)	270 (66)	286 (83)	297 (86)	277 (74)	299 (83)	271 (57)	299 (84)
Younger	221 (41)	261 (50)	282 (57)	324 (77)	286 (52)	324 (75)	302 (71)	342 (83)
Gaze duration (ms)								
Older	277 (95)	313 (125)	309 (83)	326 (87)	314 (91)	377 (141)	317 (97)	345 (74)
Younger	253 (55)	307 (79)	338 (95)	377 (98)	343 (91)	412 (115)	359 (109)	396 (102)
Total time (ms)								
Older	375 (129)	486 (226)	553 (170)	594 (223)	591 (239)	690 (253)	607 (249)	673 (189)
Younger	317 (138)	390 (151)	511 (236)	615 (275)	512 (212)	690 (288)	589 (264)	658 (299)
Number of fixations								
Older	1.5 (0.5)	1.8 (0.6)	2.0 (0.6)	2.1 (0.7)	2.1 (0.8)	2.3 (0.7)	2.1 (0.8)	2.4 (0.7)
Younger	1.4 (0.3)	1.6 (0.5)	1.8 (0.7)	2.0 (0.8)	1.8 (0.6)	2.5 (0.9)	2.0 (0.7)	2.3 (1.0)
Regressions (%)								
Older	21.0 (15.8)	29.9 (19.1)	44.9 (19.9)	40.6 (19.9)	43.4 (20.2)	46.7 (20.1)	45.5 (23.9)	50.2 (22.8)
Younger	12.6 (11.4)	16.3 (15.5)	34.2 (22.6)	39.5 (22.2)	28.7 (20.4)	42.7 (23.6)	34.9 (22.8)	41.6 (24.9)

Note. Number of fixations per target word and regressions into the target word are also presented. Standard deviations are given in parentheses.

Overall, the first fixation and gaze duration results show clearly that frequency was affected when subjects initiated a saccade to leave the target word, indicating a direct relationship between ongoing cognitive processing and eye movement control during reading. The age effect suggests that older readers take longer to read words than do younger readers, and although the effect of mask for first fixation duration was not reliable in the items analyses, the numerical pattern showed that initial fixations were similar for 60- and 50-ms mask onsets, and slightly shorter for 40-ms onsets. Furthermore, the lack of interactive effects indicates that the mask onset delay did not modulate the influences of age or frequency. Thus, it appears that the effects we observed held for older and younger readers alike.

Total time. Total time is a comparatively late measure of processing, providing information about general difficulty of processing. For this measure we obtained main effects of frequency, $F1(1, 30) = 38.34$, $p < .001$, $F2(1, 123) = 47.07$, $p < .001$; of age, $F1(1, 30) = 13.93$, $p < .001$, $F2(1, 123) = 415.57$, $p < .001$; and of mask onset, $F1(3, 90) = 36.80$, $p < .001$, $F2(3, 369) = 42.39$, $p < .001$. Total times on the target word were longer for low-frequency words ($M = 675$ ms) than for high-frequency words ($M = 540$ ms), and longer for older readers ($M = 776$ ms) than for younger readers ($M = 438$ ms). These effects are unsurprising, but do show that our manipulation of frequency was effective, and once again demonstrate that older readers take longer to process words than do younger readers. The mask onset effects are more interesting. Here we obtained a clear and systematic pattern such that total times were shortest in the no-mask condition ($M = 446$ ms), somewhat longer in the 60-ms onset condition ($M = 619$ ms), longer in the 50-ms mask onset condition ($M = 661$ ms), and longest in the 40-ms mask onset condition ($M = 703$ ms). Thus, the total time data clearly show that overall masking did disrupt processing of the target word, and furthermore, that disruptive effect increased the shorter the onset delay. Finally, consistent with the first fixation and gaze duration data, the lack of reliable interactions indicates that these effects held for older and younger readers alike.

Number of fixations. Similar to the total time data, the three main effects were highly significant: frequency, $F1(1, 30) = 37.94$, $p < .001$, $F2(1, 125) = 33.33$, $p < .001$; age, $F1(1, 30) = 18.45$, $p < .001$, $F2\ (1,125) = 463.85$, $p < .001$; and mask onset, $F1(3, 90) = 32.49$, $p < .001$, $F2(3, 375) = 40.13$, $p < .001$. Readers made more fixations for low-frequency words ($M = 2.4$) than for high-frequency words ($M = 2.0$). Clearly, less-frequent words were more difficult to process than were more-frequent words. Older readers ($M = 2.7$) made more fixations than did younger readers ($M = 1.7$), consistent with the view that older readers took longer to process the target word than did younger readers. Also, as with the total reading times, the pattern of effects for mask onset showed fewest fixations in the no-mask condition ($M = 1.7$), and increased disruption with shorter mask onsets (60 ms = 1.9, 50 ms = 2.3, and 40 ms = 2.5). Again, the failure to obtain reliable interactions indicates that effects were comparable for older and younger readers.

Regressions in. The main effects of frequency and mask onset were highly significant: frequency, $F1(1, 30) = 32.40$, $p < .001$, $F2(1, 125) = 21.36$, $p < .001$ (high frequency = 23.8%, low frequency = 32%); mask onset, $F1(3, 90) = 7.73$, $p < .001$, $F2(3, 375) = 12.22$, $p < .001$ (no mask = 20.1%, 60-ms mask = 29.1%, 50-ms mask = 29.9%, and 40-ms mask = 31.6%). Once again, target word frequency affected eye movements such that readers regressed to reread the target word more often when it was low than high frequency, and the effect of masking the target was disruptive, with increased revisits for shorter mask onsets. The effect of age was only significant by items, $F1(1, 30) = 2.62$, $p = .12$, $F2(1, 125) = 15.33$, $p < .001$, but the numerical pattern was similar to that observed in previous measures with more regressions to the target word for older than for younger readers. Finally, the regressions measure was the only one to show any reliable interactive effect. For this measure, we found a Frequency × Mask Onset interaction, $F1(3, 90) = 3.38$, $p < .05$, $F2(3, 375) = 2.84$, $p < .05$ (and note that this interaction maintained in the analysis with the no-mask condition removed). The interactive pattern was somewhat curious. For both high- and low-frequency words, there was a substantial increase in regressions to the target word in all of the mask conditions in relation to the no-mask condition (and this was greater for low- than for high-frequency targets). Also, for the high-frequency words, regressions increased by a small amount from 60- to 50-ms mask onsets, and then quite substantially from 50- to 40-ms mask onsets. In contrast, for the low-frequency words, there was a modest increase in regressions between the 60-ms and the 50-ms mask onset conditions; however, for the 40-ms mask onset condition, in fact the percentage of regressions to the target word actually fell to a level below that for the 60-ms onset condition. It is not entirely clear what to make of this pattern of effects, and it is perhaps worth noting again that the regression in measure was the only measure to show an interactive pattern. Perhaps the most noteworthy aspects of the results are that there was always a disruptive effect of masking regardless of the onset, and for all but one of the data points, as the mask onset was reduced, the percentage of regressions increased regardless of frequency.

Target Word Masked Condition

First fixation duration and gaze duration. Similar to the case in which the entire sentence was masked, there was a robust frequency effect: For first fixation duration the effect was 23 ms, $F1(1, 30) = 33.27$, $p < .001$, $F2(1, 110) = 16.58$, $p < .001$; for gaze duration, it was 43 ms, $F1(1, 30) = 62.69$, $p < .001$, $F2(1, 110) = 28.23$, $p < .001$. The main effect of age was only significant by items: for first fixation duration, $F1(1, 30) = 1.16$, $p > .2$, $F2(1, 110) = 38.72$, $p < .001$; for gaze duration, $F1 < 1$, $F2(1, 110) = 17.12$, $p < .001$. In addition, there was a highly significant mask onset effect for first fixation duration, $F1(3, 90) = 35.65$, $p < .001$, $F2(3, 330) = 42.46$, $p < .001$; and for gaze duration, $F1(3, 90) = 27.01$, $p < .001$, $F2(3, 330) = 28.23$, $p < .001$, due to the fact that all mask onsets yielded much longer fixation times than did the no-mask condition (ps $< .01$). Furthermore, there was only very modest change in the magnitude of the disruption observed for each of the different mask onsets, with slightly shorter first fixation and gaze durations on the target word for 60-ms mask onsets in relation to the 50- and 40-ms mask onsets. Thus, the pattern of effects observed for the single-word masking condition was somewhat different from that observed when all of the words in the sentence were masked (given that in the sentence-masked condition, fixations were slightly shorter for the 40-ms mask onset condition than for the other two conditions).

The Age × Mask Onset interaction was significant for the first fixation duration analyses, $F1(3, 90) = 7.40$, $p < .001$, $F2(3, 330) = 9.91$, $p < .001$ (and note that this interaction was reliable by items, and marginal, $p = .07$, in the subjects analysis with the no-mask condition removed). The mask onset conditions yielded much larger disruption for the younger readers than for the older readers. This is an interesting effect, because it seems to suggest that the older readers were less sensitive to a sudden mask onset for just one word within the sentence. In contrast, it appears that the younger readers were sensitive to this sudden change, and furthermore, their reading was immediately disrupted by it. Finally, there was a marginally significant Age × Frequency interaction in first fixation duration, $F1(1, 30) = 3.39$, $p = .076$, $F2(1, 110) = 3.40$, $p = .068$ (this interaction was also marginal in the analysis with the no-mask condition removed). This interaction arose owing to the frequency effect being larger for the younger readers than for the older readers.

Total time. The main effects of frequency, $F1(1, 30) = 41.36$, $p < .001$, $F2(1, 111) = 19.40$, $p < .001$, and of mask onset, $F1(3, 90) = 37.46$, $p < .001$, $F2(3, 333) = 55.44$, $p < .001$, were robust, again indicating that low-frequency words took longer to read than did high-frequency words, and that unmasked words ($M = 392$ ms) were read more quickly than were masked words (60-ms mask = 568 ms, 50-ms mask = 621 ms, and 40-ms mask = 632 ms), and that as the mask onset decreased, total reading times for the target word increased. We also obtained a main effect of age that was marginal by items, and not reliable by subjects $F1(1, 30) < 1$, $p > .6$, $F2(1, 111) = 3.73$, $p = .056$; as before, numerically, older readers had longer total reading times than did the younger readers (571 ms vs. 535 ms on the target word).

Number of fixations. There were main effects of frequency, $F1(1, 30) = 34.39$, $p < .001$, $F2(1, 117) = 23.46$, $p < .001$, with more fixations on low-frequency words than on high-frequency words. There was once again a robust effect of mask onset, $F1(3, 90) = 25.29$, $p < .001$, $F2(3, 351) = 31.66$, $p < .001$, with all the mask conditions (60-ms mask = 2.0, 50-ms mask = 2.2, and 40-ms mask = 2.2) producing more fixations than did the no-mask conditions (1.6). Note also that the number of fixations on the target word increased as the mask onset decreased from 60 ms down to both 50 ms and 40 ms. Finally, on average, older readers made more fixations ($M = 2.0$) on the target word than did younger readers ($M = 1.9$), though this effect was significant only by items, $F1 < 1$, $F2(1, 117) = 4.00$, $p < .05$.

Regressions in. Finally, we examined the percentage of regressions back to the target word. We obtained significant main effects of frequency, $F1(1, 30) = 11.67$, $p < .001$, $F2(1, 125) = 6.79$, $p < .05$, and of mask onset, $F1(3, 90) = 29.50$, $p < .001$, $F2(3, 375) = 46.88$, $p < .001$. Consistent with all the measures so far, low-frequency words were more difficult to process than were high-frequency words. Also, masking the target word was disruptive, such that readers made more regressions under masked conditions than under the no-mask condition. Furthermore, there was a steady increase in the percentage of regressions to the target word as the mask onset decreased from 60 to 40 ms. As with the number of fixations measure, the effect of age was significant by items, $F1(1, 30) = 2.17$, $p = .15$, $F2\ (1, 125) = 17.32$, $p < .001$, and numerically at least, the older readers ($M = 40.3\%$) made more regressions to the target word than did the younger readers ($M = 31.3\%$).

Overall, the total reading times, the number of fixations, and the percentage of regressions back to the target word all showed a very clear and consistent pattern of effects. Broadly, all of the measures reflect the fact that older readers take longer to process words than do younger readers, that low-frequency words were harder to process than were high-frequency words (regardless of how old the readers were), that masking caused disruption to reading, and that shorter mask onsets caused more disruption than did more delayed mask onsets.

Comparison of Sentence Masked and Target Word Masked Conditions

In order to better understand the target word results under the two masking conditions, a series of 2 (mask condition: full sentence masked vs. target word masked) × (2 (age) × 2 (frequency) × 4 (mask onset) ANOVAs—with mask condition and age as between-subjects variables and with frequency and mask onset within subject variables—were carried out on the data discussed above. Note that, as before, wherever necessary, we also carried out ANOVAs with the no-mask condition excluded to establish that any interactive effects across the conditions of the mask onset variable were not exclusively driven by differences between the no-mask and the different-mask onset conditions. We only report interactions for which both sets of analyses were reliable or marginal. Obviously, the relevant aspect of these analyses concerns the main effect of mask condition and the extent to which it interacted with the other variables, and therefore, only those effects will be reported and discussed.

First fixation duration and gaze duration. The main effect of mask condition was significant only by items: For first fixation duration, $F1(1, 60) = 1.54$, $p > .2$, $F2(1, 85) = 25.91$, $p < .001$; for gaze duration, $F1(1, 60) = 2.10$, $p = .15$, $F2(1, 85) = 39.81$, $p < .001$ (and in the analyses excluding the no-mask condition, the effect was not reliable by subjects for first fixation duration, $p = .09$, or for gaze duration, $p > .1$, but was by items, both ps $< .001$). Likewise, the Age × Mask Condition interaction was significant only in the items analysis: For first fixation duration, $F1(1, 60) = 2.01$, $p > .1$, $F2(1, 85) = 42.48$, $p < .001$; and for gaze duration, $F1(1, 60) = 1.62$, $p > .2$, $F2(1, 85) = 33.14$, $p < .01$ (and in the analyses excluding the no-mask condition, for both first fixation duration and gaze duration, the effect was not reliable by subjects, both ps $= .09$, but was by items, both ps $< .001$). The nature of this interaction was that the younger readers' first fixations and gaze durations were affected to a greater degree when the target word was masked than when the whole sentence was masked, but this was not the case for older readers, who were equally affected in the two conditions. We noted this effect earlier in the target word analyses, and we believe that these analyses reinforce the view that the older readers are not as sensitive to a sudden change to a single word within the sentence as are the younger readers.

Total time. Again, the main effect of mask condition was significant only in the item analysis, $F1 < 1$, $F2(1, 109) = 19.71$, $p < .001$ (for the analyses excluding the no-mask condition, the effect was not reliable by subjects, $p > .3$, but was by items, $p < .001$). There was a significant Mask Condition × Age interaction, $F1(1, 60) = 7.10$, $p < .05$, $F2(1, 109) = 165.65$, $p < .001$ (also reliable in the analyses excluding the no-mask condition, $ps < .01$), such that older readers showed greater disruption when the whole sentence was masked, but younger readers showed greater disruption when only the target word was masked. Once again, this effect is consistent with the suggestion that older readers are less sensitive to single-word changes in a sentence than are younger readers. No other interactions were significant.

Number of fixations. Similar to the total time data, the effect of mask condition was significant by items but not by subjects, $F1(1, 60) = 1.39$, $p > .2$, $F2(1, 116) = 21.80$, $p < .001$ (again, for the analyses excluding the no-mask condition, this was true also: subjects, $p > .2$; items, $p < .001$). There was a significant Mask Condition $\times$ Age interaction, $F1(1, 60) = 8.31$, $p < .01$, $F2(1, 116) = 187.13$, $p < .001$ (again reliable in the analyses excluding the no-mask condition, $ps < .01$). This interaction occurred because the older readers made more fixations than did the younger readers, and this effect was more pronounced when the whole sentence was masked than when only the target word was masked. Once again, this result is consistent with those reported above.

Regressions in. Finally, the only remaining reliable effect was the main effect of mask condition, $F1(1, 60) = 6.09$, $p < .05$, $F2(1, 116) = 59.67$, $p < .001$ (and again, this was also reliable in the analyses with the no-mask condition excluded, $ps < .01$), such that there were more regressions to the target word when it alone was masked than when every word in the sentence was masked. Again, this effect is very similar to those reported for the other measures.

General Discussion

The results from the present experiment replicate a number of prior findings from research using the disappearing text paradigm, but also provide further information about the eye movements of older readers (in comparison with those of younger readers) and properties of the disappearing text paradigm. With respect to the disappearing text paradigm, the results from the condition in which the entire sentence was masked are generally consistent with prior research (Blythe et al., 2009; Ishida & Ikeda, 1989; Liversedge et al., 2004; Rayner et al., 1981; Rayner, Liversedge, et al., 2003, 2006) in suggesting that younger readers can read fairly well when they see words for 60 ms before they are masked. In the present experiment, however, younger readers did read more effectively in the no-mask control condition than when a mask appeared after 60 ms. Specifically, when each word in the sentence was masked,[7] reading was 12% slower for the younger readers when the mask onset was at 60 ms than in the control condition; the decrement was 18% and 21% when the mask onset was 50 and 40 ms, respectively. Why reading was not quite as good in the 60-ms mask onset condition in the present experiment as in prior experiments for the younger readers is likely due to the fact that in the present experiment, mask onset was random across trials, whereas in all prior experiments mask onset was blocked. It seems likely that blocking in the prior research would cause readers to adapt their reading behavior according to when the mask would onset to a far greater degree than would be possible in the randomized situation here. Despite this, we take the data from the present experiment as being generally consistent with the view that younger readers can read fairly well when they see the text for 60 ms before mask onset.[8]

For the older readers, all of the mask onsets caused relatively greater slowdowns in reading in comparison with those for the younger readers. The decrement for the older readers amounted to 32%, 36%, and 39% in the 60-, 50-, and 40-ms onset conditions, respectively, in comparison with the no-mask control condition. However, and importantly, given the lack of an interaction between age and mask onset, we conclude that the effect of the mask onset is comparable in older and younger readers.

Another finding from the present experiment, which holds across the younger and older readers and both masking conditions, is that how long the eyes remained on a word was strongly influenced by the frequency of the fixated word. The size of the frequency effect for younger readers was 26 ms in first fixation duration and 37 ms in gaze duration (collapsed across the control and experimental conditions), whereas the size of the frequency effect for older readers was 18 ms in first fixation and 40 ms in gaze duration (again, collapsed across conditions). This finding replicates a number of prior studies (Blythe et al., 2009; Liversedge et al., 2004; Rayner, Liversedge, et al., 2003, 2006) and provides further evidence that cognitive/linguistic processing strongly influences when the eyes move during reading. The results would also appear to indicate that there are no appreciable age differences in word-frequency effects for first fixation and gaze duration. However, Rayner, Reichle, et al. (2006) found that older readers showed a larger frequency effect than did younger readers, so further research is needed on this issue.

An interesting new finding from the present experiment is that the condition in which only the target word was masked caused more disruption than when every fixated word was masked. We take this finding as being consistent with the view advocated by Rayner, Pollatsek, & Reichle (2003) that when a mask appears at quasi-random places during reading, it causes more disruption (because the subjects do not know which word will be masked) than when the mask appears consistently on each fixation in reading. This finding is also consistent with the view that the oculomotor control system is extremely flexible, being able to adapt to unusual presentation conditions rapidly and effectively.

A final aspect of the data that is related to this point, and requires consideration, is that when just the target word was masked, it was more disruptive for the younger readers than for the older readers. At least to some extent, this result may be considered counterintuitive, in that greater disruption may have been expected for the older readers than for the younger readers (and indeed, for all of the other experimental manipulations, this was the case). We interpret this finding as reflecting differential sensitivity (and responsiveness in terms of disruption to eye movements) in younger readers than in older readers. Thus, we believe that this difference reflects a reduced sensitivity to a change associated with a single disappearing word in older readers than in younger readers. A consequence of such reduced sensitivity is less disruption to processing due to the short-term, localized manipulation. Note also that the suggestion that older readers are less

[7] An accurate estimate of the amount of slowdown in overall sentence reading time when only the target word was masked is not possible.

[8] Blythe et al. (2009) demonstrated that under some situations, reading is fairly normal with mask onsets as short as 40 ms (though clearly in the present experiment, there was slowdown with such short onsets).

sensitive and responsive to a one-off disappearing text manipulation is consistent with our finding that the whole-sentence disappearing text manipulation was much more disruptive to them than to the younger readers. Clearly, the younger readers were able to modify their reading behavior much more effectively when the disappearing text manipulation occurred repeatedly for every word in the sentence than when just the target word was masked.

Although older readers read more slowly than do younger readers and engage in a more risky reading strategy, the present results also clearly document that for older readers, as with younger readers, how long the eyes remain in place is strongly influenced by the frequency of the fixated word (even when it is no longer there after 40–60 ms). As we noted above, this is very compelling evidence that cognitive/linguistic processing strongly influences when the eyes move during reading in both older and younger readers, and reinforces our view of the centrality of language processing to oculomotor control during reading

References

Baayen, R. H., Piepenbrock, R., & Gulikers, L. (1995). *The CELEX lexical data base (CD-Rom).* Philadelphia: University of Pennsylvania, Linguistic Data Consortium.

Blythe, H. I., Liversedge, S. P., Joseph, H. S. L. L., White, S. J., & Rayner, K. (2009). Visual information capture during fixations in reading for children and adults. *Vision Research, 49,* 1583–1591. doi:10.1016/j.visres.2009.03.015

Hartley, J. T., Stojack, C. C., Mushaney, T. J., Annon, T. A. K., & Lee, D. W. (1994). Reading speed and prose memory in older and younger adults. *Psychology and Aging, 9,* 216–223. doi:10.1037/0882-7974.9.2.216

Ishida, T., & Ikeda, M. (1989). Temporal properties of information extraction in reading studied by a text-mask replacement technique. *Journal of the Optical Society A: Optics and Image Science, 6,* 1624–1632. doi:10.1364/JOSAA.6.001624

Juhasz, B. J., Liversedge, S. P., White, S. J., & Rayner, K. (2006). Binocular coordination of the eyes during reading: Word frequency and case alternation affect fixation duration but not fixation disparity. *Quarterly Journal of Experimental Psychology, 59,* 1614–1625. doi:10.1080/17470210500497722

Kemper, S., & Liu, C.-J. (2007). Eye movements of young and older adults during reading. *Psychology and Aging, 22,* 84–93. doi:10.1037/0882-7974.22.1.84

Kemper, S., & McDowd, J. (2006). Eye movements of young and older adults while reading with distraction. *Psychology and Aging, 21,* 32–39. doi:10.1037/0882-7974.21.1.32

Kliegl, R., Grabner, E., Rolfs, M., & Engbert, R. (2004). Length, frequency, and predictability effects of words on eye movements in reading. *European Journal of Cognitive Psychology, 16,* 262–284. doi:10.1080/09541440340000213

Laubrock, J., Kliegl, R., & Engbet, R. (2006). SWIFT explorations of age differences in eye movements during reading. *Neuroscience and Biobehavioral Reviews, 30,* 872–884. doi:10.1016/j.neubiorev.2006.06.013

Liversedge, S. P., & Findlay, J. M. (2000). Saccadic eye movements and cognition. *Trends in Cognitive Sciences, 4,* 6–14. doi:10.1016/S1364-6613(99)01418-7

Liversedge, S. P., Rayner, K., White, S. J., Vergilino-Perez, D., Findlay, J. M., & Kentridge, R. W. (2004). Eye movements when reading disappearing text: Is there a gap effect in reading? *Vision Research, 44,* 1013–1024. doi:10.1016/j.visres.2003.12.002

Morrison, R. E., & Rayner, K. (1981). Saccade size in reading depends upon character spaces and not visual angle. *Perception & Psychophysics, 30,* 395–396.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372–422. doi:10.1037/0033-2909.124.3.372

Rayner, K. (2009). The thirty-fifth Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology, 62,* 1457–1506. doi:10.1080/17470210902816461

Rayner, K., Castelhano, M. S., & Yang, J. (2009). Eye movements and the perceptual span in older and younger readers. *Psychology and Aging, 24,* 755–760. doi:10.1037/a0014300

Rayner, K., Castelhano, M. S., & Yang, J. (2010). Preview benefit during eye fixations in reading for older and younger readers. *Psychology and Aging, 25,* 714–718.

Rayner, K., Inhoff, A. W., Morrison, R. E., Slowiaczek, M. L., & Bertera, J. H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 167–179. doi:10.1037/0096-1523.7.1.167

Rayner, K., Liversedge, S. P., & White, S. J. (2006). Eye movements when reading disappearing text: The importance of the word to the right of fixation. *Vision Research, 46,* 310–323. doi:10.1016/j.visres.2005.06.018

Rayner, K., Liversedge, S. P., White, S. J., & Vergilino-Perez, D. (2003). Reading disappearing text: Cognitive control of eye movements. *Psychological Science, 14,* 385–389. doi:10.1111/1467-9280.24483

Rayner, K., Pollatsek, A., & Reichle, E. D. (2003). Eye movements in reading: Models and data. *Behavioral and Brain Sciences, 26,* 507–526. doi:10.1017/S0140525X03520106

Rayner, K., Reichle, E. D., Stroud, M. J., Williams, C. C., & Pollatsek, A. (2006). The effect of word frequency, word predictability, and font difficulty on the eye movements of young and older readers. *Psychology and Aging, 21,* 448–465. doi:10.1037/0882-7974.21.3.448

Stine-Morrow, E. A. L., Miller, L. M. S., & Herzog, C. (2006). Aging and self-regulated language processing. *Psychological Bulletin, 132,* 582–606. doi:10.1037/0033-2909.132.4.582

Stine-Morrow, E. A. L., Shake, M. C., Miles, J. R., Lee, K., Gao, X., & McConkie, G. (2010). Pay now or pay later: Aging and the role of boundary salience in self-regulation of conceptual integration in sentence processing. *Psychology and Aging, 25,* 168–176. doi:10.1037/a0018127

Zachary, R. A. (2006). *Shipley Insitute of Living Scale.* Los Angeles, CA: WPS.

Received November 12, 2009
Revision received August 16, 2010
Accepted August 20, 2010 ■