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Eye Movements and the Perceptual Span in Older and Younger Readers

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The size of the perceptual span (or the span of effective vision) in older readers was examined with the moving window paradigm (G. W. McConkie & K. Rayner, 1975). Two experiments demonstrated that older readers have a smaller and more symmetric span than that of younger readers. These 2 characteristics (smaller and more symmetric span) of older readers may be a consequence of their less efficient processing of nonfoveal information, which results in a riskier reading strategy.

Keywords: perceptual span, eye movements, older and younger readers

It is well known that older adults tend to read more slowly than younger readers (Stine-Morrow, Miller, & Hertzog, 2006). As a result, their eye fixations are typically longer than those of younger readers (Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006), and they make more fixations and more regressions (backward movements in the text) than younger readers (Kemper, Crow, & Kemtes, 2004; Kemper & Liu, 2007; Kemper & McDowd, 2006; Kliegl et al., 2004; Rayner et al., 2006). It is interesting that older readers also make longer saccades than younger readers, and they skip target words more frequently, which results in them making more regressions to the target words (Laubrock, Kliegl, & Engbert, 2006; Rayner et al., 2006). Rayner et al. (2006) suggested that this was due to older readers adopting a riskier reading strategy in which they guessed what the next word was more often than younger readers to partially compensate for their slower processing of text.[1]

An interesting, but unresolved, issue concerning older readers relates to the size of the *perceptual span* (or the region of effective vision) during reading. In this article, we focus on this issue and the extent to which older readers might differ from younger readers in how much information they acquire during an eye fixation. It is well known that older adults process nonfoveal information less effectively than younger adults (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler, Bennett, & Mamelak, 2000). Does this translate into a smaller perceptual span for older than younger readers?

Prior research with the gaze-contingent moving window paradigm (McConkie & Rayner, 1975; Rayner & Bertera, 1979) has established that for skilled young adult readers, the span of effective vision extends from 3 or 4 letters to the left of fixation to 14 or 15 letter spaces to the right of fixation. In general, this means that readers do not obtain useful information from more than two words to the right of fixation (Rayner, 1986; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981; Rayner, Well, Pollatsek, & Bertera, 1982). In the moving window paradigm, how much information a reader can process on each fixation is controlled. For example, in a one-word window condition, the word that is currently fixated is normal, but all letters in the other words are replaced by *X*s or random letters. However, when the eyes move and the reader fixates a new word, that word is now normal and all letters in the previously fixated word are replaced by *X*s or random letters (see Figure 1). Thus, this paradigm is like a slide show in which there is a new slide on each fixation (tailored to the fixation location). When the window is larger than the fixated word (and provided that letters, as opposed to *X*s, are outside of the window), readers are generally not aware of the window.

The logic of the paradigm is that if all that was encoded on a fixation was the fixated word, then readers would read normally with a one-word window. However, reading rate in the one-word window condition is about 60% of normal for skilled college-age readers (Rayner et al., 1982). In a two-word window condition (in which the window contains the fixated word and the word to the right), reading rate is about 90% of normal, and in a three-word window condition (the window contains the fixated word and the two words to the right), reading rate is normal. Thus, the perceptual span (or the region from which readers extract useful information) appears to consist of roughly three words (the fixated word and two to the right). Research (see Rayner, 1998) has

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[1] The phrase *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.

Normal Sentence:

```
Kevin reached for Miranda's armband when she moved away from him.
```

1W Window:

```
Kevin xxxxxxx xxx xxxxxxxxx xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
  *
Xxxxx reached xxx xxxxxxxxx xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
         *
Xxxxx xxxxxxx xxx Miranda's xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
                     *
```

W+R2 Window:

```
Kevin reached for xxxxxxxxx xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
  *
Xxxxx reached for Miranda's xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
         *
Xxxxx xxxxxxx xxx Miranda's armband when xxx xxxxx xxxx xxxx xxx.
                     *
```

W+L1 Window:

```
Kevin xxxxxxx xxx xxxxxxxxx xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
  *
Kevin reached xxx xxxxxxxxx xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
         *
Xxxxx xxxxxxx for Miranda's xxxxxxx xxxx xxx xxxxx xxxx xxxx xxx.
                     *
```

Figure 1. Examples of the 1W and W + R2 moving window conditions in Experiment 1 and the W + L1 window condition in Experiment 2. The spaces between words were preserved, and all letters outside of the window were replaced with *X*s. The asterisk represents the location of the fixation. W = word; R2 = two words to the right; L1 = one word to the left.

established that different types of information are obtained within the perceptual span. Information used for word identification is obtained from a region extending to about seven or eight character spaces to the right of fixation. Beyond the word identification region, more gross types of information about letter shapes and word length information are acquired.

In the experiments reported here, we used the moving window paradigm to examine whether the size of the perceptual span is smaller for older readers than younger readers. There are a couple of reasons why older readers may have a smaller perceptual span than younger readers. First, as noted earlier, older participants process nonfoveal information less effectively than younger adults (Ball et al., 1988; Sekuler et al., 2000). This might translate into older adults processing information over a smaller region than younger readers. Second, prior research has demonstrated that beginning readers (Häikiö, Bertram, Hyönä, & Niemi, in press; Rayner, 1986) and dyslexic readers (Rayner, Murphy, Henderson, & Pollatsek, 1989) read more slowly and with smaller spans than more skilled readers. It is has also been demonstrated that difficulty encoding the fixated word leads to smaller spans (Henderson & Ferreira, 1990; Rayner, 1986; White, Rayner, & Liversedge, 2005). Given that older readers read more slowly than college-age readers (Laubrock et al., 2006; Rayner et al., 2006) and may have more difficulty encoding fixated words, their perceptual span might be smaller than that of younger skilled readers.

General Method

Participants

Twenty-four young adults who were students at the University of Massachusetts at Amherst participated in Experiment 1, and 14 participated in Experiment 2; those in Experiment 1 averaged 22.8 years of age (range = 19–28 years), and those in Experiment 2 averaged 20.8 years of age (range = 18–23 years). In addition, 24 older adults from the community participated in Experiment 1, and 10 participated in Experiment 2; those in Experiment 1 averaged 73.1 years of age (range = 65–89 years), and those in Experiment 2 averaged 71.5 years of age (range = 65–81 years). The groups did not differ in number of years of schooling (15.25 years for the young and 15.5 years for the older readers in Experiment 1 and 15.8 years for the young and 15.7 years for the older readers in Experiment 2). The young adults had either normal or corrected-to-normal vision. All of the older adults had corrected 20/20 vision for reading, and they wore their glasses during the experiment.[2] All of them reported that they spent quite a bit of time each day reading newspapers and books.

Apparatus

Sentences were presented on a 22-in. (about 55 cm) ViewSonic VX924 LCD monitor attached to a Pentium 166 MHZ computer interfaced with an SR Research 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 where capitals were appropriate). The letters were black on a white background. Participants were seated 63 cm from the monitor, and three characters equaled 1° of visual angle. Custom built software ensured that the window moved in synchrony with the eyes, and the display changes were accomplished within 6–12 ms.

Materials

In Experiment 1, 80 sentences averaging 11 words in length (range = 8–16) were read. Participants read 20 sentences in each condition, and across participants each sentence was shown in every experimental condition. In Experiment 2, there were 30 sentences, which were similar to those in Experiment 1. There were 15 sentences in each condition, and the order of presentation was counterbalanced.

Procedure

When participants first arrived for an experiment, some background information was obtained. Then, the eye-movement system was calibrated; this typically took about 5 min. Calibration accuracy was determined by asking participants to sequentially fixate on three fixation points that appeared where the sentence would subsequently appear. The validity of the calibration was checked

[2] The older participants were part of a large group of volunteers in the Amherst 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). Prior to the experiment, the older readers completed the Shipley Institute of Living Scale (Zachary, 2006) test to evaluate their vocabulary and abstraction skills. Those in Experiment 1 had an average score on the test of 67 (out of 80, with a range from 48 to 79), whereas those in Experiment 2 had an average score of 69 (with a range from 61 to 79). These scores demonstrate that the older readers had intact cognitive abilities.

prior to each sentence by asking participants to fixate on a fixation marker. If their eyes were on the fixation marker, the next trial occurred; if they were not, the participant was recalibrated (which typically took less than 1 min). Participants read sentences that appeared one at a time on the video monitor. They were asked to read each sentence silently for comprehension. They were told that they would be asked questions about the sentences; questions were asked following one half of the sentences and were about the meaning of the sentences.

Experiment 1

In Experiment 1, the gaze-contingent moving window paradigm was used to determine the size of the perceptual span for older and younger readers (see Figure 1). The window comprised either one word (the fixated word, 1W condition), two words (the fixated word and the word to the right of fixation, W + R1 condition), or three words (the fixated word plus the two words to the right of fixation, W + R2 condition); in all conditions, the letters of all words outside of the window were replaced by *X*s. In addition, a control no-window condition was included in which the sentence was presented normally without any window restriction. On the basis of prior research (Rayner, 1986; Rayner et al., 1981, 1982), we expected that the younger readers would be slowed considerably by the 1W condition, would be only moderately slowed by W + R1 condition, and would not be disrupted by the W + R2 condition. The central question we addressed in Experiment 1 was whether older readers would show a data pattern similar to that of the younger readers or whether they would reach asymptote in reading performance with a smaller window than the younger readers.

Results

As per Rayner 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 compared with 90% for the younger readers. The means were analyzed with 2 (group: older vs. younger readers) × 4 (window size: 1W, W + R1, W + R2, control) analyses of variance (ANOVAs). The most informative measure in moving window experiments (McConkie & Rayner, 1975; Rayner & Bertera, 1979) is sentence reading time. However, the data for average fixation duration, forward saccade length, regressive saccade length, total number of fixations, and number of regressions as a function of window size are also informative and reported later (see also Table 1).[3]

For total sentence reading time, there were significant main effects of window size, $F(3, 138) = 121.93$, $p < .001$, and group, $F(1, 46) = 5.47$, $p < .05$, as well as a significant interaction, $F(3, 138) = 4.32$, $p < .01$.[4] Younger readers took 3,107 ms to read the sentences, whereas it took the older readers 3,853 ms to read them. Consistent with prior research with word-based moving windows (Rayner et al., 1982), for both groups, the 1W window slowed reading (a 40% slowdown for the older readers and a 36% slowdown for the younger readers). For the younger readers, and again consistent with Rayner et al. (1982), there was no significant difference between the W + R2 condition and the no-window control condition, and there was a slight increase in reading time ($p < .05$) for the W + R1 condition compared with the control condition. However, for the older readers, there was no difference between the W + R2 and W + R1 conditions, but both yielded longer reading times than the no-window control condition ($ps < .01$).

Similar data patterns were apparent in fixation duration with a main effect of window size, $F(3, 138) = 33.37$, $p < .001$, a marginal main effect of group, $F(1, 46) = 3.67$, $p = .062$, and a significant interaction, $F(3, 138) = 3.29$, $p < .05$. Similar data patterns were also found in the total number of fixations and number of regressions, where all three effects were significant: For total number of fixations, $F(3, 138) = 71.86$, $p < .001$, for window size; $F(1, 46) = 8.21$, $p < .01$, for group; and $F(3, 138) = 11.41$, $p < .001$, for the interaction. For number of regressions, $F(3, 138) = 4.16$, $p < .05$, for window size; $F(1, 46) = 25.03$, $p < .001$, for group; and $F(3, 138) = 4.72$, $p < .05$, for the interaction. For forward saccade length, no significant group effect was observed, $F(1, 46) = 1.5$, $p > .1$, but there was a significant window size effect, $F(3, 138) = 40.18$, $p < .01$, and a significant interaction, $F(3, 138) = 12.69$, $p < .01$. Further tests showed a significant difference between older and younger adults for the 1W condition only, $t(46) = 2.6$, $p < .05$, all other $ts(46) < 1.6$, $p > .1$. For regressive saccade length, there was a significant group effect, $F(1, 46) = 24.82$, $p < .01$, a marginal effect of window size, $F(3, 138) = 2.53$, $p = .06$, and a significant interaction, $F(3, 138) = 5.49$, $p < .001$. Further contrasts revealed that there was a significant difference between older and younger adults in all window conditions, $ts(46) = 2.65$ to 5.74, $ps < .01$, with larger mean differences for the restricting window conditions than the control no-window condition.

Discussion

The data for the young readers provide a clear replication of prior work (Häikiö et al., in press; Rayner, 1986; Rayner et al., 1982) in showing that the perceptual span extends roughly two words to the right of fixation. Given that there were spaces between the words in the present moving window situation, this would translate into roughly 14 or 15 characters to the right of fixation (given an average word length of 5.1 characters per word in the sentences). It is also noteworthy that for the younger readers, there was no significant reading time difference between the W + R2 condition and the no-window control condition; this is quite consistent with prior research (see Rayner et al., 1982). However, the older readers showed a different pattern in that there was no difference between the W + R1 and W + R2 conditions, but they both were significantly longer than the control condition.

What exactly do these results mean? First, it appears that the perceptual span to the right of fixation is somewhat smaller for older readers than younger readers. That is, older readers showed no difference between the W + R1 and W + R2 conditions, suggesting that they did not obtain useful word or letter informa-

[3] With respect to saccade lengths, the appropriate metric is letter spaces rather than visual angle because the distance that the eyes traverse from one saccade to the next is determined by letters rather than visual angle as long as the text is of normal size (Morrison & Rayner, 1981).

[4] For both experiments, ANOVAs on the logarithmic transformation of the reading time and fixation duration data were carried out, and the pattern of significant results was identical to those reported in the article.

Table 1
Means for the Conditions in Experiment 1 and Experiment 2 for Older and Younger Readers

Measure	Experiment 1 window size								Experiment 2 window size			
	1W		W + R1		W + R2		No window		1W		W + L1	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Sentence reading time												
Old	4,592	1,344	3,784	1,346	3,746	1,401	3,288	1,283	4,169	777	3,565	740
Young	3,821	1,110	2,945	815	2,846	809	2,815	772	2,765	510	2,553	441
Fixation duration												
Old	280	44	268	42	267	41	256	50	253	25	246	22
Young	273	28	244	25	245	23	234	26	252	30	245	31
Forward saccade length												
Old	7.77	1.62	7.95	1.50	7.88	1.35	8.26	1.53	8.03	1.51	8.16	1.73
Young	6.71	1.17	7.33	1.20	7.74	1.25	8.18	1.45	6.72	0.96	6.91	0.90
Regressive saccade length												
Old	9.18	3.32	8.70	3.33	9.37	3.19	8.79	2.68	10.47	2.93	11.16	4.29
Young	4.77	2.39	4.77	2.89	4.47	2.70	6.34	3.65	6.48	3.98	7.32	4.47
Total no. of fixations												
Old	15.34	3.62	13.06	3.84	13.34	3.90	11.90	3.56	15.15	3.16	13.26	2.86
Young	12.08	2.95	10.55	2.38	10.23	2.50	10.55	2.20	10.49	2.15	9.66	1.48
No. of regressions												
Old	2.52	0.78	2.31	0.86	2.28	0.59	2.19	0.64	4.20	1.40	3.36	1.53
Young	1.38	0.90	1.10	0.73	1.14	0.80	1.52	0.73	1.83	0.72	1.51	0.52

Note. In Experiment 1, the window comprised either one word (the fixated word, 1W condition), two words (the fixated word and the word to the right of fixation, W + R1 condition), or three words (the fixated word plus the two words to the right of fixation, W + R2 condition). In Experiment 2, the 1W condition was the same as the 1W condition in Experiment 1. In the left word condition (W + L1), the currently fixated word and the word to the left were both present on each fixation.

tion beyond the word to the right of fixation (though they undoubtedly did obtain information about spaces between words beyond this). Second, what is more surprising is the fairly large difference between the no-window control condition, on the one hand, and the W + R1 and W + R2 conditions, on the other. This suggests that older readers might utilize more information to the left of fixation than younger readers. That is, given that we allowed readers to see only letters to the left of fixation from within the currently fixated word, we may have restricted information that they typically utilize on a fixation.

Other aspects of the data are also consistent with results reported by Rayner et al. (2006). Specifically, in the 1W condition, older readers moved their eyes further than the young readers. As per Rayner et al. (2006), we suspect this is because older readers are more likely to guess what is coming next than are younger readers. Hence, with the smallest window, they moved their eyes further forward than young readers. Consistent with prior reports (Laubrock et al., 2006; Rayner et al., 2006), older readers also had longer average fixation durations and made more fixations than young readers.

Experiment 2

In Experiment 2, the gaze-contingent moving window paradigm was used to determine whether older readers utilize more information to the left of fixation than younger readers. There were two different conditions. In the 1W condition, all letters in words to the left of fixation were replaced with *X*s; this condition was the same as the 1W condition in Experiment 1. In the left word condition (W + L1), the currently fixated word and the word to the left were both present on each fixation, with all other letters replaced by *X*s.

Results

Again, the two groups did not differ in comprehension accuracy: Older readers answered the comprehension questions correctly 93% of the time, and the younger readers answered them correctly 91% of the time. Means were analyzed with a 2 (group: older vs. younger readers) × 2 (window size: 1W, W + L1) ANOVA. As is obvious in Table 1, both the older and younger readers read faster (with less variability across readers) in the 1W condition in this experiment compared with Experiment 1. However, the results were quite clear.

As in Experiment 1, it took the older readers longer (3,867 ms) to read the sentences than the younger readers (2,659 ms), $F(1, 22) = 24.27$, $p < .001$. The 1W condition resulted in longer reading times (3,467 ms) than the W + L1 condition (3,059 ms), $F(1, 22) = 51.02$, $p < .001$. More critically, the interaction, $F(1, 22) = 11.83$, $p < .01$, was due to the relatively small difference in reading time between the two conditions for the younger readers (212 ms) together with the much larger difference between the two conditions for the older readers (604 ms).

The total number of fixations and regressions measures yielded results identical to those for the data on sentence reading time: For number of fixations, $F(1, 22) = 18.45$, $p < .001$, for the main effect of group; $F(1, 22) = 32.45$, $p < .001$, for the effect of window size; and $F(1, 22) = 5.04$, $p < .05$, for the interaction. For number of regressions, $F(1, 22) = 24.74$, $p < .001$, for the effect of group; $F(1, 22) = 30.95$, $p < .001$, for the effect of window size; and $F(1, 22) = 6.25$, $p < .01$, for the interaction. The fixation duration measure yielded an effect only of window size, $F(1, 22) = 10.18$, $p < .01$, with longer fixations (253 ms) in the 1W condition than in the W + L1 condition (246 ms). The forward saccade length data yielded a main effect of group, $F(1, 22) = 6.26$, $p < .05$, with older readers having larger saccades (8.1 characters) than younger readers (6.8), but yielded no effect of window size, $F(1, 22) = 2.39$, $p > .1$, and no significant interaction ($F < 1$). The same pattern was observed for regressive saccade length: group, $F(1, 22) = 6.55$, $p < .05$, window size, $F(1, 22) = 1.38$, $p > .2$, interaction ($F < 1$).

Discussion

Experiment 2 yielded a very clear result: Older readers have a less asymmetric perceptual span in comparison to the younger readers. Specifically, whereas the difference between the 1W and W + L1 condition was fairly small for the younger readers, it was much more sizeable for the older readers. Thus, when information to the right of fixation was restricted, the older readers found reading easier when the word to the left of fixation was present than when it was not present.

General Discussion

The results reported here indicate that older readers have a smaller and less asymmetric (or more symmetric) perceptual span than younger readers. Specifically, older readers appear to acquire useful word and letter information from a smaller region to the right of fixation than younger readers; older readers obtain information from the currently fixated word and the word to the right of fixation, whereas the younger readers acquire information from the currently fixated word and two words to the right of fixation. Further, whereas younger readers read quite normally when only letters from the fixated word were present on a fixation, older readers were slowed down and reading was more effective when the word to the left of fixation was also available on a fixation.

Given that our results suggest that older readers have a less asymmetric span than younger readers, it is interesting to note that in attempting to account for the eye-movement data of older readers in the context of the SWIFT (saccade-generation with inhibition by foveal targets) model, Laubrock et al. (2006) reported that the parameter-estimating algorithm used to find optimal model parameter values suggested that older readers have a smaller and more asymmetric perceptual span than younger readers. On the other hand, in simulating older readers' eye-movement data in the context of the E–Z reader model, Rayner et al. (2006) assumed that older readers' reduced visual acuity led to a smaller perceptual span and that older readers adopted a riskier reading strategy in which they guessed the next word more often.[5] The data from the present experiments are more consistent with the assumptions made by Rayner et al. than those by Laubrock et al.

It is interesting to speculate about why the perceptual span is both smaller and less asymmetric for older readers than younger readers. These two characteristics of older readers may be a consequence of (a) their slower processing of foveal information and (b) their less efficient processing of nonfoveal information resulting in a riskier reading strategy. Such a riskier reading strategy would lead to longer saccades, more skips of words, and more regressions. Given that older readers do not process information to the right of fixation as effectively as younger readers, older readers apparently need more information available to the left of fixation to offset the limitations in processing information to the right of fixation.

Alternatively, it may be that older readers had a harder time adapting to the moving window conditions than younger adults.[6] Specifically, older readers may have had a harder time ignoring the *X*s that were outside of the window (particularly to the left of fixation) and may have suffered from oculomotor capture by the onset of the *X*s after forward saccades. The fact that regressive saccades tended to be much larger for older readers than for younger readers may be consistent with this possibility. We thus created a saccade matrix to determine where regressions were launched and where they went. Not surprisingly, for both young and older readers, the majority of regressions went to the immediately preceding word. The biggest difference between the younger and older readers (and the basis for the larger regressive saccade length in older readers) was that from midway through the sentence, older readers were more likely than young readers to make a regression back to the beginning of the sentence. Although there may be some merit in the notion of oculomotor capture, we suspect that, overall, the results are more consistent with the view that older readers adopt a riskier reading strategy than younger readers to offset their slower foveal processing and less efficient nonfoveal processing.

[5] Again, as per the notion of guessing, the phrase *riskier reading strategy* is not intended to mean that a conscious strategy was used.

[6] We thank Reinhold Kliegl for suggesting this possibility.

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