

# The Effect of Letter Spacing on Reading Speed in Central and Peripheral Vision

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**PURPOSE.** Crowding, the adverse spatial interaction due to proximity of adjacent letters, has been suggested as an explanation for slow reading in peripheral vision. The purpose of this study was to examine whether reading speed can be improved in normal peripheral vision by increasing the letter spacing. Also tested was whether letter spacing imposes a different limit on reading speed of small versus large print.

**METHODS.** Six normal observers read aloud single, short sentences presented on a computer monitor, one word at a time, by rapid serial visual presentation (RSVP). Reading speeds were calculated based on the RSVP exposure durations yielding 80% correctly read words. Letters were rendered in Courier, a fixed-width font. Testing was conducted at the fovea, 5° and 10° in the inferior visual field. The critical print size (CPS) was first determined for each observer by measuring reading speeds for four print sizes, using the standard letter spacing (center-to-center separation of adjacent letters; standard Courier spacing: 1.16 times the width of the lowercase x). Text was then presented at 0.8x or 1.5x CPS, and reading speed was measured for five letter spacings, ranging from 0.5 times to 2 times the standard spacing.

**RESULTS.** As expected, reading speed was highest at the fovea, decreased with eccentricity, and was faster for the larger print size. At all eccentricities and for both print sizes, reading speed increased with letter spacing, up to a *critical letter spacing*, and then either remained constant at the same reading speed or decreased slightly for larger letter spacings. The value of the critical letter spacing was very close to the standard letter spacing and did not depend on eccentricity or print size.

**CONCLUSIONS.** Increased letter spacing beyond the standard size, which presumably decreases the adverse effect of crowding, does not lead to an increase in reading speed in central or peripheral vision. (*Invest Ophthalmol Vis Sci.* 2002;43:1270-1276)

Reading is difficult and slow for many patients with low vision, especially those whose central retina is damaged, and thus they are obligated to use the peripheral retina. The leading cause of visual impairment in developed countries is age-related macular degeneration,<sup>1,2</sup> which is also the leading cause of central vision loss. Because reading difficulty is the most common clinical complaint, and retaining the ability to read is the primary goal of patients with age-related macular degeneration seeking visual rehabilitation,<sup>2-4</sup> the understand-

ing of why reading is slower in the peripheral visual field is of utmost importance to the visual rehabilitation of these patients.

Recent studies have shown that even when character size is not a limiting factor<sup>5,6</sup> and when oculomotor demands are minimized with *rapid serial visual presentation* (RSVP), reading is still slower in peripheral than central vision.<sup>5-7</sup> Given current knowledge about the differences in properties between central and peripheral vision, one viable hypothesis for slow reading in peripheral vision is the enhanced crowding in peripheral vision. *Crowding* refers to the decreased visibility of a visual target in the presence of nearby objects.<sup>8</sup> A closely related phenomenon, *contour interaction*, refers to the effect of proximal contours, such as bars or edges, on the resolution of a single target.<sup>9</sup> Because our interest is in reading, which involves characters rather than simple contours, we use the term crowding, instead of contour interaction, to refer to the spatial interaction between characters. Crowding among individual letters has been suggested as a major factor contributing to slow reading in peripheral vision, because even when targets are scaled in size, the spatial extent<sup>5,10,11</sup> and intensity<sup>10,12</sup> of the interaction are still greater in peripheral than central vision.

If crowding among individual letters is indeed an important contributor to slow reading in peripheral vision, then the obvious solution to improve reading speed in peripheral vision is to eliminate or minimize crowding of letters in text. Considering that the magnitude of crowding decreases with increased separation between adjacent characters,<sup>13,14</sup> a simple way to minimize crowding in text is to increase the spacing between adjacent characters.

Indeed, increased letter spacing has been shown to improve letter-recognition accuracy and word-recognition speed. Bouma<sup>13</sup> found that the performance for identifying a peripherally presented letter flanked by adjacent letters could be as accurate as that for identifying unflanked letters, as long as the adjacent letters were separated by a distance equaling half the retinal eccentricity. Townsend et al.<sup>15</sup> also showed an improvement in the accuracy of identifying a letter embedded in a string of multiple letters, when a blank space was inserted adjacent to the target letter. With respect to word recognition, Whittaker et al.<sup>16</sup> found that the speed for recognizing common four-letter words at 10° eccentricity is increased by a factor of approximately 1.5, for a letter spacing that is four times larger than the default spacing. This benefit of increased letter spacing was not found in foveal vision, however. Using the RSVP paradigm, Latham and Whitaker<sup>5</sup> showed that word recognition speed for strings of three-letter words increases with letter spacing, in the fovea and the periphery (up to 10° eccentricity) alike. Averaged across their two subjects, the improvement in word-recognition speed was approximately 10% with large-letter spacing. Using the Times Roman font, a proportional-width font, Arditi et al.<sup>17</sup> also showed an improvement in RSVP reading speed when the letter-to-letter spacing is fixed at the same width as the letter W, instead of having a width that is proportional to individual letter width. The improvement was a factor of 2 to 3 in the fovea and 1.5 to 2 at 2° eccentricity.

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On the basis of these previous studies, there is enough evidence to suggest that reading speed may benefit from increased letter spacing, probably more so in peripheral than central vision. The purpose of this study, therefore, was to examine the effect of letter spacing on reading speed in normal peripheral vision. Although the measurements were collected from observers with normal vision, it is likely that our findings identify limitations on the reading performance that could also affect people with central visual field defects. In addition, the results of the present study provide a normal standard with which data from patients with central field defects can be compared.

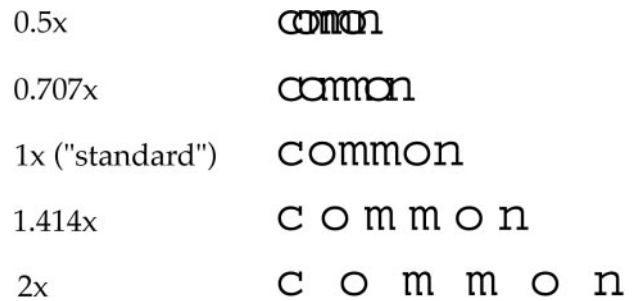
In this study, we asked the question of whether reading speed in peripheral vision can be improved with increased letter spacing, which presumably decreases crowding among individual letters. In general, reading speed should improve with letter spacing, up to the *critical spacing*, at which reading speed reaches its maximum. Further increase in letter spacing may cause a decrease in reading speed, probably because of the destruction of word-form information,<sup>18</sup> or a decrease in the number of characters that can be recognized at a glance.<sup>19</sup> Note that these two factors, together with crowding, may represent factors that codetermine reading speed at any given letter spacing. We will return to the significance of this possibility in the Discussion section. The data of Whittaker et al.<sup>16</sup> suggest that the standard letter spacing that is used in most printed materials is likely to be optimal for supporting maximum reading speed in the fovea, but it may not be large enough to support maximum reading speed in normal peripheral vision. Our hypothesis, the *non-optimal-spacing* hypothesis, predicts that the critical spacing increases in peripheral vision.

To examine the non-optimal-spacing hypothesis, we measured RSVP reading speeds for a range of letter spacings at several retinal eccentricities. We used the RSVP paradigm to minimize the need to make eye movements during reading. At each eccentricity, we constructed plots of reading speed versus letter spacing, from which the critical letter spacing was derived. By comparing the shape of these reading-speed versus letter-spacing plots and the value of critical letter spacing across eccentricities, we could test the non-optimal-spacing hypothesis. Because crowding is reported to be a near-resolution effect,<sup>17</sup> we also tested the effect of letter size on crowding by using two print sizes: one above the critical print size (CPS) for reading—that is, when print size is not a limiting factor of the maximum reading speed—and one slightly below the critical print size, at which crowding is presumably stronger.

## METHODS

### Stimuli

Oral reading speed was measured using single sentences. On each trial, a single sentence was chosen randomly from a pool of 2630 sentences. Each sentence contained between 8 and 14 words (mean,  $11 \pm 1.7$ ). All the words used were from the 5000 most frequently used words in written English, according to word-frequency tables derived from the British National Corpus.<sup>20</sup> None of the observers read any sentence more than once. Sentences used were identical with those used in Chung et al.<sup>6</sup> They were presented using the RSVP paradigm, in which words of a sentence are presented sequentially, one word at a time, left-justified on the display for a fixed-exposure duration. Words were rendered in Courier, a fixed-width font, and were presented as high-contrast (~90%), black letters on a white background of 45 candelas [ $\text{cd}/\text{m}^2$ ]. A fixed-width font, instead of the more common proportional-width fonts, was used, because it was easier to manipulate and specify the letter spacing using the fixed-width font. The text stimuli were



**FIGURE 1.** Samples of the word “common” as rendered in the five letter spacings used in the study. The values of the five letter spacings are given in the *left* column.

generated and presented using a workstation (SGI O2 Silicon Graphics, Inc., Mountain View, CA) and a color graphics display monitor (refresh rate, 75 Hz; model GDM-17E21; Sony, Tokyo, Japan). The temporal dynamics of the computer and the monitor were verified with a photo-detector and an oscilloscope.

### Psychophysical Methods

We defined the criterion reading speed as the speed that corresponds to 80% reading accuracy. The psychophysical methods for estimating reading speeds were identical with those used in Chung et al.<sup>6</sup> In brief, we determined the number of words read correctly as a function of RSVP word-exposure duration. A word was scored as read correctly as long as the observer said the word correctly, irrespective of its word order within the sentence. For each testing condition, we used the method of constant stimuli to present sentences randomly at six word-exposure durations that spanned a range of approximately 1 log unit. Each condition was tested twice, in separate blocks of trials. Eighteen sentences were tested in each block, three for each duration. When pooled across the two blocks of trials, six sentences were tested for each duration, with the total number of words read ranging from 52 to 78 (mean,  $65.9 \pm 4.2$ ). We then fit each set of data using a cumulative Gaussian curve to construct a psychometric function. To obtain the criterion reading speed, we derived from the best-fitting psychometric function the exposure duration that yields 80% of the words read correctly, and then converted the duration into speed according to the following equation:

$$\text{Reading speed (wpm)} = \frac{60}{\text{RSVP word-exposure duration (sec)}}$$

where wpm means words per minute.

### Experimental Design

The three main factors of interest in this study were: letter spacing, eccentricity, and print size.

We defined letter spacing as the center-to-center separation between adjacent letters, and normalized it to the standard spacing. On the workstation, the standard spacing for the Courier font is 1.16 times the width of the lowercase letter x, for a wide range of x-widths tested. Five letter spacings were examined for each combination of eccentricity and print size: 0.5, 0.707, 1, 1.414, and 2 times the standard spacing. Because the standard spacing is proportional to the letter size, the same level of letter spacing has a smaller physical magnitude (in millimeters) when presented in the fovea than when presented in the periphery. Figure 1 shows samples of the word “common,” as rendered in these five spacings. Note that at the smallest spacing (0.5x), there was some overlapping between adjacent letters. We scaled our letter spacings to the letter size, because for a variety of spatial tasks, peripheral vision can be considered a scaled representation of central vision.<sup>21,22</sup> Thus, it would be interesting to know whether reading

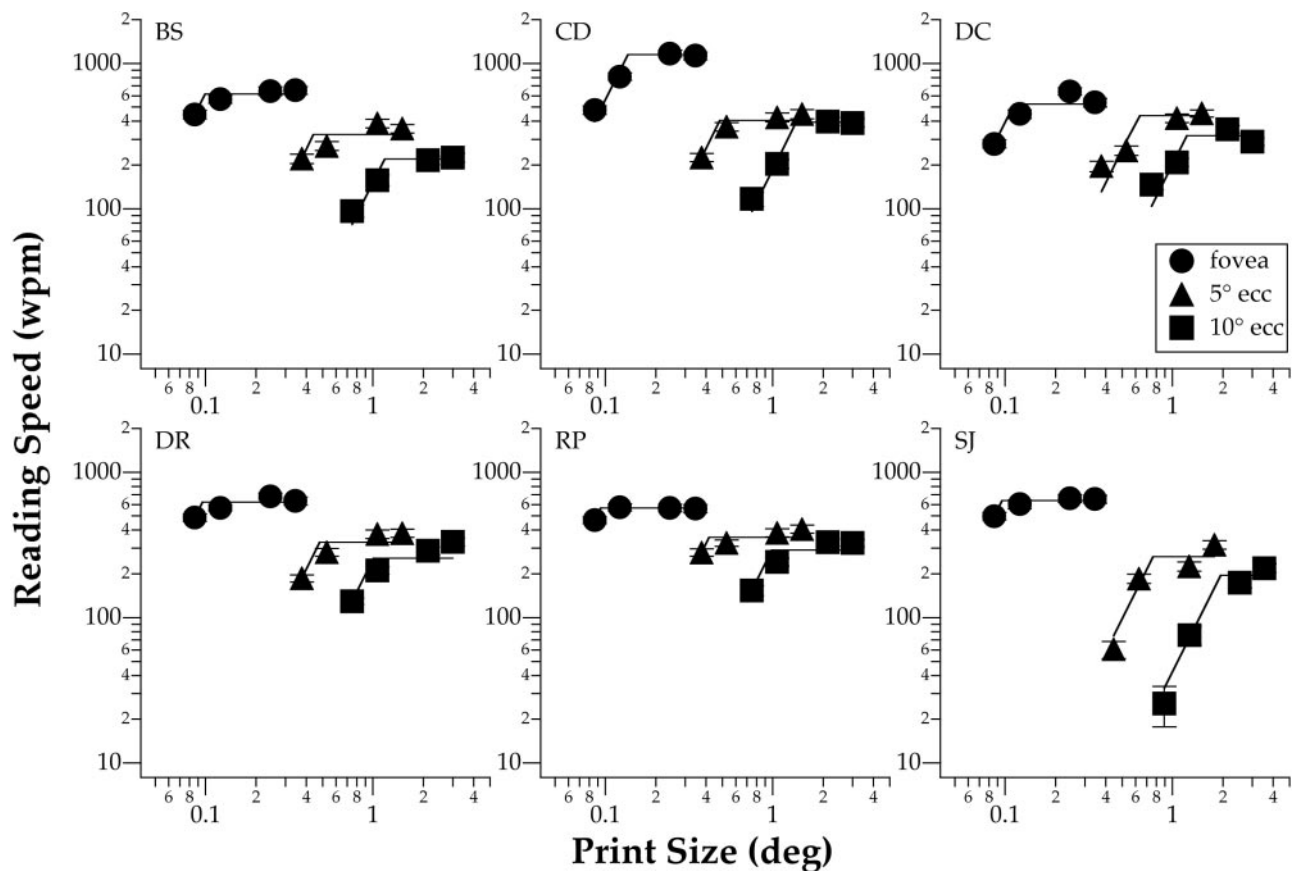


FIGURE 2. Reading speed (in words per minute; wpm) is plotted as a function of print size (in degrees) for the six observers at three eccentricities. The *straight lines* through the data points represent the two-line fits for estimating the CPS.

follows the same pattern of results, once the stimulus parameters (letter size and spacing) are scaled in peripheral vision.

The three retinal eccentricities tested were 0° (foveal), 5°, and 10° in the inferior visual field. Observers were allowed to look directly at the words on the display during foveal testing. For peripheral testing, observers were instructed to fixate along a thin, horizontal red line above the text, at a vertical distance (measured from the center of the lowercase letters) equivalent to the designated eccentricity. Viewing distances were 200, 40, and 30 cm for 0°, 5°, and 10° eccentricities, respectively. Different physical letter sizes (in millimeters) were used at these three distances to produce the desired letter sizes in degrees.

We tested two print sizes, both normalized to the CPS for reading: 0.8 and 1.5 times the CPS. To determine the CPS for each observer and at each eccentricity, we first measured RSVP reading speed for four print sizes at each eccentricity. The text used had the standard spacing. The four print sizes were chosen to span a range of 0.7 log units, similar to the range of print sizes tested in Chung et al.<sup>6</sup> Then, we fit each dataset using a two-line fit (on log-log axes), where the intersection of the two lines represents the CPS. The slope of the first line was constrained to 2.32 (on log-log axes), based on the empirical finding that the slope of the first line did not vary systematically with eccentricity and averaged 2.32 across all the curve fits.<sup>6</sup> The slope of the second line was constrained to zero. The CPS was then used to determine the physical print sizes (0.8 and 1.5 times the CPS) used in the main experiment.

In the main experiment, we examined the interplay of letter spacing, eccentricity, and print size on RSVP reading speed. Each observer attended two sessions for this part of the study, one for each print size. Three observers were tested with the smaller print size at the first session (0.8x CPS) and the larger print size (1.5x CPS) at the second session. The remaining three observers were tested in reverse order of

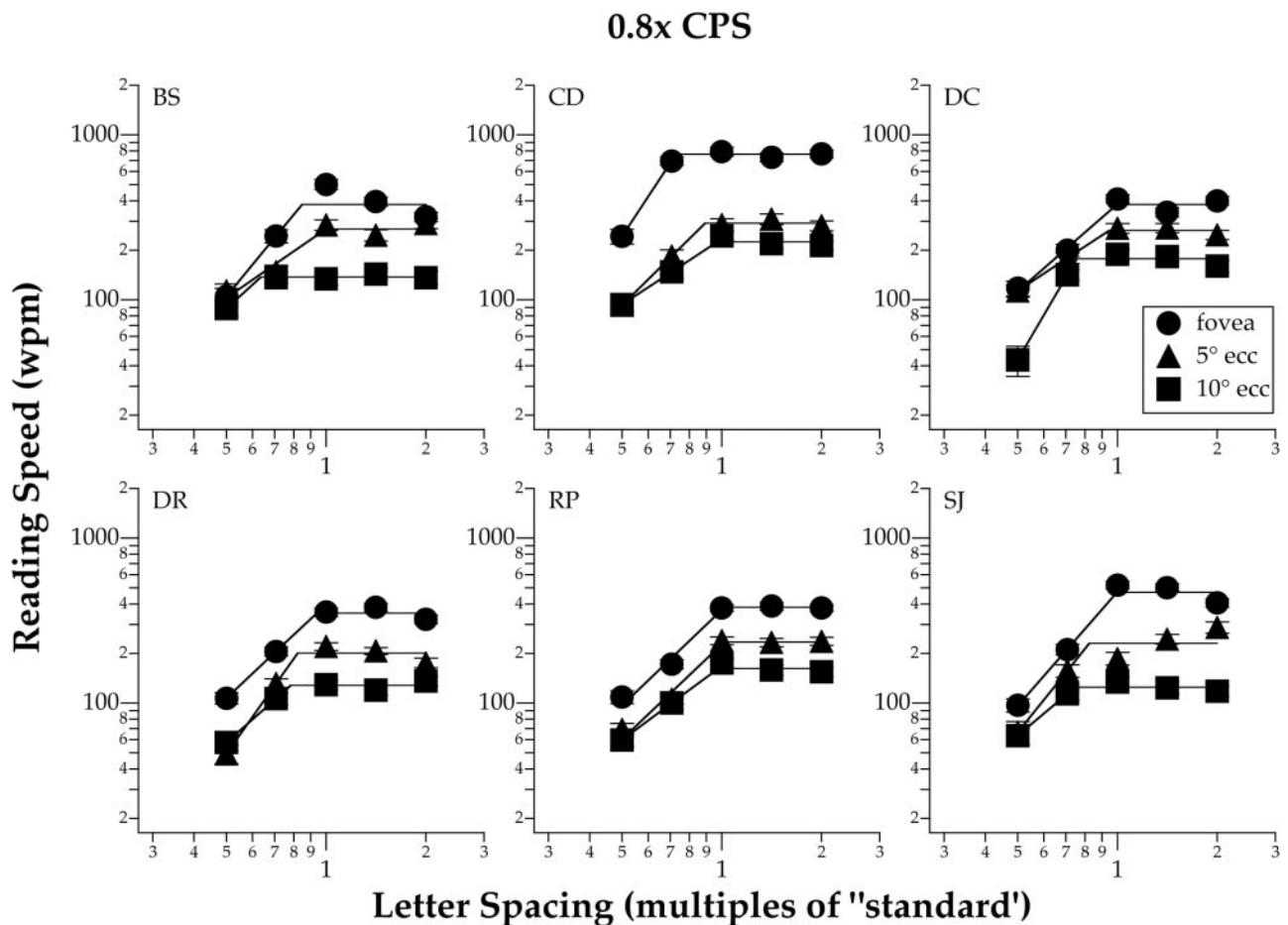
print size. In the first half of each session, 15 conditions (three eccentricities at five letter spacings) were tested. The three eccentricities were tested in an order that was unique for each observer, but that was counterbalanced across all observers. The five letter spacings for each eccentricity were tested in the same set, in a random order. These 15 conditions were repeated, in reverse sequence, in the second half of the session.

### Observers

Six native English speakers with normal vision aged between 20 and 28 participated in the study. All had (corrected) acuity of 20/15 or better in both eyes and were either emmetropic or wore contact lenses to correct for refractive errors. This study followed the tenets of the Declaration of Helsinki, and the protocol was approved by the Institutional Review Board at Indiana University. Written informed consent was obtained from each observer after the procedures of the experiment were explained and before the commencement of data collection. Only one of the observers (DR) had prior experience in reading in peripheral vision or reading with the RSVP paradigm. Regardless of whether the observer had prior experience, the first two experimental sessions were used for practice. Data from these practice sessions are not included in this report.

### RESULTS

Reading speed is plotted as a function of letter size for the three eccentricities and for each observer in Figure 2. To estimate the CPS, the two-line fit (described in the Methods section) was used to fit each dataset. The intersection of the two lines represents the estimated CPS. Averaged across the six



**FIGURE 3.** Reading speed (wpm) is plotted as a function of letter spacing (multiples of standard spacing) for the six observers at three eccentricities. Print size was 0.8x CPS, derived for each observer separately (see Fig. 2). Error bars (typically smaller than the symbol size) are  $\pm 1$  SEM. The *straight lines* through the data points represent the two-line fits for estimating the critical letter spacing.

observers, the mean CPS was  $0.11 \pm 0.02^\circ$  (SD) at the fovea (range,  $0.09$ – $0.14^\circ$ ),  $0.53 \pm 0.13^\circ$  at  $5^\circ$  eccentricity (range,  $0.41$ – $0.76^\circ$ ), and  $1.28 \pm 0.35^\circ$  at  $10^\circ$  eccentricity (range,  $0.99$ – $1.93^\circ$ ). These values are, in general, smaller than those reported in Chung et al.,<sup>6</sup> in which a different font was used (Times Roman). Previously, Mansfield et al.<sup>23</sup> showed a 15% reduction in the CPS with the Courier-Bold font, when compared with the Times Roman font in the fovea. Our estimates of the CPS at the fovea were more than 15% smaller than the average foveal CPS of Chung et al.<sup>6</sup> The greater difference in CPS between the Courier and Times Roman fonts could be due to individual observer differences and differences between the Courier-Bold and Courier fonts.

Data from the main experiment are summarized in Figures 3 (0.8x CPS) and 4 (1.5x CPS), where reading speed is plotted as a function of letter spacing for the three eccentricities. Each panel presents data for one observer. As expected, reading speeds were the highest when measured at the fovea, and decreased progressively with increased eccentricity (repeated-measures ANOVA:  $F_{(2,10)} = 94.2$ , Geisser-Greenhouse adjusted  $P < 0.0001$ ). Also, reading speeds were higher for 1.5x CPS than for 0.8x CPS (repeated-measures ANOVA:  $F_{(1,5)} = 227.9$ ,  $P < 0.0001$ ). At all eccentricities and for both print sizes, reading speed increased with letter spacing, up to a normalized spacing of approximately 1x (i.e., the standard spacing) and then either remained constant at the same reading speed, or decreased slightly with larger letter spacings (repeated-measures ANOVA for the effect of letter spacing:  $F_{(4,20)} = 260.0$ , Geisser-Greenhouse adjusted  $P < 0.0001$ ).

observers ANOVA for the effect of letter spacing:  $F_{(4,20)} = 260.0$ , Geisser-Greenhouse adjusted  $P < 0.0001$ ).

To quantify whether critical letter spacing increases in peripheral vision, we fit each set of reading speed versus letter-spacing data with a two-line fit (on log-log axes). The slope of the second line was constrained as zero, whereas the slope of the first line was free to vary. The presumption of the two-line fit is that reading speed increases with letter spacing up to a critical letter spacing, beyond which reading speed becomes independent of letter spacing (at least up to the largest spacing we tested in this study). We are aware that some of the datasets actually show a decrease in reading speed with large letter spacing(s), and because we included data for all five letter spacings in the curve-fitting, the two-line fit may have underestimated the critical letter spacing. However, Figures 3 and 4 show that the decrease in reading speed at large letter spacings did not seem to occur more consistently at any particular eccentricity. Moreover, results from the repeated-measures ANOVA using the contrast function confirmed that the average reading speed obtained at the largest letter spacing (2x) did not differ from that at 1x letter spacing ( $F_{(1,5)} = 6.55$ ,  $P = 0.051$ ), thus justifying the use of the two-line fit.

The two-line fits given in Figures 3 and 4 show that there were no systematic changes in critical letter spacing with eccentricity. Across all conditions tested, the critical letter spacing averaged  $0.85 \pm 0.14$  (SD) and did not depend on eccentricity (repeated-measures ANOVA:  $F_{(2,10)} = 2.56$ , Geis-

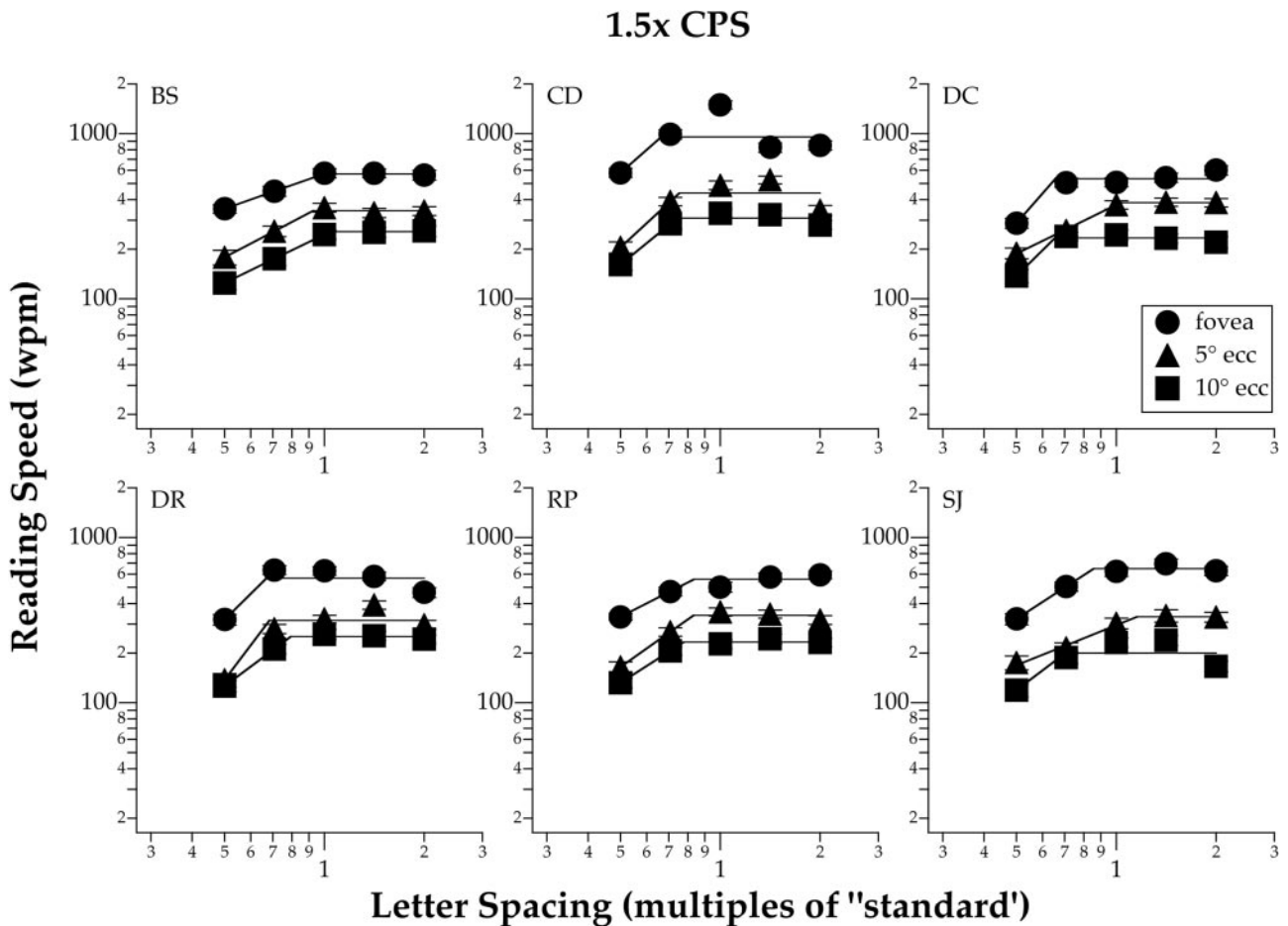


FIGURE 4. Reading speed (wpm) is plotted as a function of letter spacing as in Figure 3, with the exception that the print size was 1.5x CPS.

ser-Greenhouse adjusted  $P = 0.148$ ) or print size (repeated-measures ANOVA:  $F_{(1,5)} = 1.23, P = 0.318$ ). These findings suggest that as long as the letter spacing scales with respect to print size, then the optimal letter spacing that supports maximum reading speed is similar in the fovea and the periphery.

The group-averaged data for reading speed as a function of letter spacing are shown in Figure 5. According to our hypothesis, which predicts that the critical spacing increases in peripheral vision, we expected an interaction effect between letter spacing and eccentricity on reading speed. However, this

interaction effect was found to be insignificant (repeated-measures ANOVA:  $F_{(8,40)} = 2.23$ , Geisser-Greenhouse adjusted  $P = 0.126$ ), a confirmation that the critical spacing does not differ in the fovea and the periphery.

Similar to the interaction between letter spacing and eccentricity, almost all the other combinations of interaction between and among the three main factors are insignificant, with the exception of the interaction between print size and letter spacing. As can be seen in Figure 5, the roll-off of reading speed at small letter spacings was faster with the smaller print size,

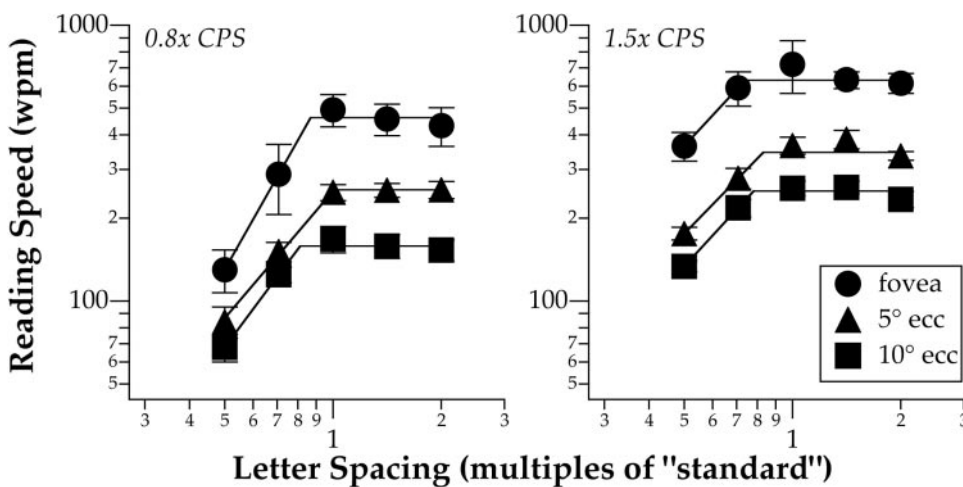


FIGURE 5. Group average data showing how reading speed changes as a function of letter spacing, for the three eccentricities and two print sizes. Error bars are  $\pm 1$  SEM. The straight lines through the data points represent the two-line fits for estimating the critical letter spacing.

suggesting that smaller letter spacings impose a stronger adverse effect on reading speed for the small print size (0.8x CPS) than the large print size (1.5x CPS). This finding is consistent with the notion that crowding is a near-resolution effect. In absolute terms, the adjacent contours are closer together for the smaller than the larger print size.

## DISCUSSION

Contrary to the prediction of the non-optimal-spacing hypothesis, by measuring reading speed as a function of letter spacing at three retinal eccentricities, we showed that the critical letter spacing did not increase with eccentricity. Instead, it appeared to be invariant with eccentricity (at least up to 10°), as long as the critical letter spacing was specified with respect to the standard spacing or the letter size. In other words, reading in peripheral vision did not benefit from increased letter spacing beyond the standard value.

Do our data provide sufficient evidence to refute the crowding explanation for slow reading in peripheral vision? Perhaps not. By increasing the letter spacing, it is likely that there is less crowding among letters.<sup>13,14</sup> However, the increased letter spacing also leads to at least two other effects that could slow down reading. First, word-shape or word-form information<sup>18</sup> is disrupted. Therefore, observers cannot use the word-form information to assist them in identifying words, and thus reading slows down. Second, the increased letter spacing may lead to a decrease in the number of letters that can be recognized at a glance—the visual span. Because the visual span has been shown to be an important factor limiting reading speed,<sup>19</sup> if fewer letters are contained in the visual span due to increased letter spacing, then reading slows down. The presence of one or both of these effects may counteract the beneficial effect of decreased crowding among letters, resulting in no overall benefit of increased letter spacing.

Previously, Chung and Mansfield<sup>24</sup> attempted to minimize the effect of crowding in text without increasing the physical word lengths. Based on the data of Kooi et al.,<sup>25</sup> who showed that crowding is reduced when the target letter and its neighboring letters are of different contrast polarities, Chung and Mansfield<sup>24</sup> hypothesized that reading mixed-polarity text would alleviate the crowding among adjacent characters and thus lead to a faster reading speed in peripheral vision. Contrary to their prediction, reading speeds obtained with uniform-polarity and mixed-polarity text were remarkably similar. Conceivably, words made up of mixed-polarity characters also lose their word-form information. Therefore, the beneficial effect of minimizing crowding using mixed-polarity text could have been counteracted by the detrimental effect of a disruption of word shape.

Our finding that reading speed does not benefit from increased letter spacing beyond the standard value seems to be at odds with the two earlier studies that show an increase in word recognition speed with increased letter spacing beyond the standard spacing.<sup>5,16</sup> In both of these studies, the words used as stimuli were uppercase, unrelated words. These words were all either three or four letters long.<sup>5,16</sup> The use of uppercase letters does not provide much word-form information,<sup>18</sup> therefore, the increased letter spacing does not make word recognition more difficult. Also, because of the short word lengths, all the words should fit well within the visual span, even with the additional letter spacing. Latham and Whitaker<sup>5</sup> found an improvement in word recognition speed when the edge-to-edge letter spacing equaled one letter width, compared with a letter spacing equaling only one fifth of a letter width. For their three-letter words, the total extent of each word at the large letter spacing is approximately five letter widths. Legge et al.<sup>19</sup>

showed that the visual span at 10° eccentricity, for an 80% accuracy (the accuracy we adopted in the present study) and a presentation duration of 300 ms (comparable to the RSVP reading speed at 10° eccentricity), is approximately 5.5 letters wide. Because the three-letter words used by Latham and Whitaker<sup>5</sup> are smaller than the visual span, the size of the visual span was probably not a limiting factor in their study. Whitaker et al.<sup>16</sup> also measured speeds for recognizing words of four uppercase letters. They found that at 10° eccentricity, word recognition becomes slower when the edge-to-edge letter spacing increases beyond a spacing equivalent to 0.6 to 0.8 letter heights. This finding is consistent with the prediction based on the limit imposed by the visual span.

Arditi et al.<sup>17</sup> found an improvement in reading speed at the fovea and at 2° eccentricity, when the Times Roman font was rendered as a fixed-width font by increasing the letter spacing between adjacent letters, compared with the original Times Roman font rendered as a proportional-width font. However, this improvement was found only with the small letter size (approximately 0.165° at the fovea and 0.33° at 2° eccentricity). When compared with the averaged CPSs reported by Chung et al.,<sup>6</sup> who also used Times Roman font, the small letter sizes used by Arditi et al.<sup>17</sup> correspond to approximately 0.94x CPS at the fovea and approximately 0.7x to 0.8x CPS at 2° eccentricity (only an estimate at 2° eccentricity, because Chung et al.<sup>6</sup> provided data at 2.5° eccentricity only). These letter sizes were not very different from the small letter size (0.8x CPS) used in the present study. Although Arditi et al.<sup>17</sup> did not provide the dimensions of the letter spacing, judging from the illustrations in their Figure 1,<sup>17</sup> the letter spacing in the proportional-width condition is likely to be close to the 0.707x letter spacing used in the present study, and their fixed-width condition should be equivalent to our 1x letter spacing. Our data showed that reading speed is higher for 1x than for 0.707x letter spacing, and more so for the smaller (0.8x CPS) than the larger (1.5x CPS) print size, which may explain why Arditi et al. found an improvement in reading speed with increased spacing only with the small letter size.

The smallest letter spacing that we used was much smaller than any letter spacing that has been examined in the literature for word reading.<sup>5,16,17</sup> At this small spacing, some of the features of individual characters overlapped one another, and thus may cause masking of overlapped features or inappropriate grouping or segmentation of letter features. Both pattern masking and inappropriate grouping would impede letter and word recognition, causing reading to slow down. However, the use of such a small letter spacing allows us to study the real limit of letter spacing on reading speed. Considering the overlapping features at this small letter spacing, the reading speeds attained by our observers were quite remarkable.

A few caveats should be kept in mind while evaluating our interpretation. First, our findings, obtained in young adults with healthy retinas, may not directly apply to people with central field loss whose retinas may be compromised by disease processes and who may in fact have more practice using the peripheral retina. Second, to test the peripheral retinas of our normal-sighted observers, inevitably we have to provide them a fixation target. The impact of this “divided-attention” task (fixating a red line while reading text presented below it) on peripheral reading speed is unknown, but casual comments from many observers suggested that fixating the red line became quite a natural task after some practice and did not seem to require much active attention. Third, earlier studies<sup>5,6</sup> have demonstrated that the fovea benefits more from contextual cues than the periphery. Our scoring scheme, which did not take word order into account, may have imposed a different limitation on the measured performance in the fovea versus the periphery. Fourth, that peripheral vision does not benefit

much from contextual cues may be an indication that peripheral reading is limited by a "plateau" effect. If we could remove this effect, then reading speed in peripheral vision might increase with letter spacing and reach a maximum reading speed comparable with that of the fovea. In that case, the critical letter spacing would have occurred at a larger spacing. However, this would work only if we assume that the factors causing the plateau effect operate only at the maximum reading speed. We do not yet know of the exact factors that cause the plateau effect, but one possibility is the visual span, which has already been shown to be a bottleneck on reading speed.<sup>19</sup>

Our attempt to use a simple text manipulation to minimize crowding in the hope of increasing reading speed in peripheral vision failed. Nevertheless, our results suggest that future attempts to minimize crowding in text may have to meet the challenges of developing techniques or methods that do not disrupt the characteristics of words, such as word form or word length, while retaining the properties of real-life reading.

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