ALIGNMENT OF DYNAMIC TEXT CAN AFFECT READING RATES IN PATIENTS WITH CENTRAL SCOTOMA

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INTRODUCTION

Age-Related Macular Degeneration (ARMD) is a common disease among the elderly, affecting about 10 percent of the U.S. population over age 65. The result of ARMD is central visual field loss due to a dense scotoma. Many patients have bilateral central field loss, leading to a binocular volume scotoma (Arditi, 1988) that typically interferes with near vision, but not navigation (Lovie-Kitchin, Farmer, and Bowman, 1982). Under these conditions, most patients spontaneously develop a Preferred Retinal Locus (PRL) in each eye (Timberlake, Mainster, Pelli, Augliere, Essock, and Arend, 1986; Whittaker, Budd, and Cummings, 1988). The PRL is the location on the retina that is consistently used for examining objects or scenes of interest, much as the fovea is used in normal vision. In ARMD the PRL is typically located just outside the margin of the central scotoma. A substantial portion of the visual field adjacent to the PRL may not be visible because it falls into the scotoma.

Reading with a PRL adjacent to a central scotoma may be problematic. One way that a central scotoma may interfere with reading is related to the programming and execution of eye movements. In normally-sighted observers, the rate at which eye movements can be programmed and executed is one of the primary factors limiting reading rate (Potter, 1984). Some patients with bilateral central scotomas have difficulty with eye movements because their oculomotor system continues to move the fovea to items of interest[1] (Whit and Bedell, 1990). The patient is then forced to execute a second eye movement to move the image from the nonfunctioning fovea to the PRL. In conjunction with the limited acuity of the retinal periphery, which may require multiple fixations to examine something closely, this pattern of two-for-one eye movements will produce a significant reduction in reading rate. Even if the patient is able to move the PRL toward the item of interest without attempting foveation, the eye movement is likely to be both slow and inaccurate. Two studies (White and Bedell, 1990; Whittaker, Cummings, and Swieson, 1991) have found saccade latencies to be 100-200 ms longer for observers with central field loss frequently fall short of the target (White and Bedell, 1990; Whittaker and Cummings, 1986), thus requiring additional «catch-up» saccades. These data suggest that the need for eye movements slows reading rates more for patients with central field loss than for normally-sighted readers.

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[1] This may be the result of residual vision at the middle of the scotoma (Timberlake et al., 1987).

The types of reading aids used by the visually impaired make an understanding of eye movements in these patients even more important. In order to compensate for their reduced acuity, these patients require substantial magnification to read. Optical hand and stand magnifiers of sufficient power limit the number of characters visible, which has been shown to limit reading rates (Fine et al., 1996), and force the reader to manually scan across the text, which requires coordination of hand and eye movements. Closed-circuit televisions (CCTVs) allow a greater field of view, but share with the magnifiers the problems of physically navigating through the text; users have particular difficulty finding the beginning of the next line, which is often out of the field of view at the end of the current line. The next generation of electronic reading aids, including the Horizon system (Mentor O&O, Norwell, MA, USA), solves the navigation problem by presenting the text dynamically. Text is moved into the field of view under the control of the display device itself, so no page navigation on the part of the reader is required. The eye movements required by dynamic displays are also likely to be different from those made during everyday reading from a page of text.

We have been testing a number of dynamic display formats with an eye toward improving the new electronic reading aids. Two dynamic display formats have been used in earlier research and are described elsewhere: Rapid Serial Visual Presentation (RSVP; Potter, 1984; Rubin and Turano, 1992, 1994; Fine and Peli, 1995) and Horizontal Scroll (HSCROLL; Legge et al., 1985 a & b; Buettner, Krischer, and Meissen, 1986; Fine and Peli, 1995, this volume). Briefly, in RSVP, each word is shown on the screen for a specified duration before it is removed and replaced with the next word in the same location. This format allows extremely high reading rates for normally sighted observer, but Fine and Peli (1995) found that low-vision observers with central field loss could read faster using HSCROLL. In HSCROLL the entire text is concatenated into one long line, which is then scrolled horizontally across the screen at a specified rate. Whittaker, Rhodes, and Cummings (1993) have shown that the OKN-like pattern of eye movements induced by a horizontal scroll display (see Whittaker, Rhodes, and Cummings, 1993 for patients with CFL; Legge, Pelli, Rubin, and Schleske, 1985 for normally-sighted observers) entrains the eye, potentially helping to compensate for the difficulty these patients have in programming eye movements.

The HSCROLL display format may be especially helpful to patients whose PRLs are directly above or below their scotomas. Peli (1986), in reviewing the literature, noted that smooth pursuit using an eccentric retinal location was only possible when the direction of motion was orthogonal to the line on the retina connecting the fovea to the eccentric location used for viewing. When the direction of motion was parallel to the retinal line, saccadic pursuit resulted (Zeevi and Peli, 1984). When a patient whose PRL is above or below the scotoma reads horizontally scrolled text, the movement of the text (and, presumably, the eyes) is orthohonal to the line connecting the fovea and the PRL, allowing smooth pursuit. Furthermore, this arrangement permits the reader to keep the scotoma above or below the line of text as it scrolls across the screen.

Guez, Gargasson, Rigaudiere, and O'Regan (1993) have reported that in most cases of ARMD with central field loss the PRL lies to the side of the scotoma, rather than above or below it. Combined with Peli's analysis, this suggests that for these patients the horizontal scroll display may actually exacerbate their eye movement difficulties, since it forces them to make eye movements along the same axis as the retinal line connecting the fovea and the PRL. Furthermore, for a patient with a PRL lateral to the scotoma, a horizontally scrolled display format forces the letters on one side of fixation into the scotoma. For these patients a vertical scroll may be more appropriate. In the display format used in this study, called VSCROLL, the text is scrolled vertically from the bottom to the top of the screen, one word on each line, much like the credits at the end of a movie. Before testing the prediction that a vertical scroll display will be better than a horizontal scroll for patients with lateral PRLs (Peli's, 1986), the interaction between text alignment and scotoma location relative to the PRL must be understood in order to optimize the presentation of the VSCROLL display. This study explores the effect of alignment on reading rate, while at the same time comparing the VSCROLL display to RSVP, which shares with VSCROLL the one-word-at-a-time format but does not require eye movements between words.

Using RSVP an VSCROLL displays, we have studied one attribute of dynamic text-the alignment of the text on the screen-which could affect the pattern of eye movements during reading. Text was presented in one of three alignments, which are similar to the justification switches in word processing programs. In the LEFT alignment condition the beginning of each word is lined up against the left hand edge of the screen, and the end of each word forms a ragged margin somewhere to the right. In the CENTER alignment condition each word is centered in the horizontal dimension of the screen, so that both, the left and right edges, are ragged. In the RIGHT alignment condition the end of each word is adjacent to the right edge of the screen, and the left margin formed by the beginning of the words is ragged. (See text in Figure 1.)

HOW MIGHT ALIGNMENT AFFECT READING RATE?

We expected text alignment to have a systematic effect on reading rate, based on three assumptions. First, readers will try to land their eyes in the same relative position in each word. Second, they will choose the position of the eyes to minimize the obstruction by the scotoma of letters adjacent to the PRL. Third, we assume that the number and extent of horizontal eye movements between and within words needed in each alignment will determine reading rate. These assumptions allow us to predict an ordering of reading rates based on alignment and PRL position, as described below. Figure 1 illustrate the rationales for our predictions, which are identical for the VSCROLL and RSVP formats.

Envision a patient whose PRL is to the right of the scotoma in the visual field (Figure 1a). In subsequent panels of Figure 1 the position of the PRL is illustrated for each word (small dot), while the position of the scotoma is shown only for the instant the patient is reading the word «what» in the three panels on the diagonal. As the patient is reading, suppose first that he tries to land his eyes near the beginning of each word. For clarity we have shown the PRL landing between the first and second letter of each word, though in reality its position is probably more variable. The top panel of Figure 1b shows him reading text in the LEFT alignment condition. The patient need not make horizontal eye movements to keep his PRL near the beginning of each word as he reads. In the top panel of Figure 1c, our patient is reading CENTERed text. To land near the beginning of each word, his eyes must move back and forth horizontally as he progresses through the text. The top panel of Figure 1d illustrates the situation when the text is RIGHT aligned. Here our hypothetical patient must make large horizontal eye movements to move from the beginning of a short word to the beginning of a long one. These horizontal distances are likely to be covered in several eye movements by patients who have both low acuity and difficulty in programming eye movements, resulting in slower reading rates.

The second and third rows of Figure 1 illustrate how the position of the PRL within a word might interact with alignment to affect reading. In the second row of panels, the reader's eyes land near the center of each word. Now the CENTER alignment condition requires no horizontal eye movements, and the RIGHT and LEFT conditions require eye movements of equal sizes. In the third row of panels, the reader's eyes land near the end of each word. Now the RIGHT alignment condition requires no horizontal eye movements, the CENTER condition requires relatively small eye movements, and the LEFT condition requires the same large eye movements as in the RIGHT condition when the reader was fixating the beginning of the word. In short, each of the alignment conditions can require no eye movements providing that the reader chooses an advantageous eye position within a word. (In fact, this is what we expect the normally-sighted observers to do.) However, low-vision observers must also consider the position of their scotoma. In the upper left panel of Figure 1 (LEFT alignment requiring no eye movements) the scotoma is on the left side, obscuring very little of the text surrounding the letter being fixated. In the center panel and the bottom right panel (showing the conditions under which the CENTER and RIGHT alignments require no eye movements) the scotoma obstructs more of the letters adjacent to the letter being fixated because fixation occurs farther from the beginning of each word. If the identity of the obscured letter cannot be determined from context, one or more eye movements will be required to examine them, thus slowing the reading rate.

Assuming that the reader's eyes maintain a consistent landing position within words, then based on these considerations of the number and extent of eye movements required to view each display and the obstruction of text by the scotoma, we predicted that our hypothetical observer, and others whose PRLs are to the right of their scotomas in the visual field, would read fastest with LEFT alignment, slowest with RIGHT alignment, and at an intermediate speed when the text was centered. Parallel logic allows us to predict that for an observer whose PRL is to the left of the scotoma, RIGHT alignment should produce the highest reading rates, followed by centered text, with LEFT alignment being the slowest. (A scotoma with a left-side PRL will obstruct the least text when the observer is fixating near the end of a word.) For an observer whose PRL is below[2] the scotoma, we predict the same effect of alignment (if any) as found in the normally-sighted observers, since the amount of text obscured by the scotoma will not depend on alignment.

We did not expect the reading rates of normally sighted observers (or patients with PRLs below their scotomas) to be affected by alignment for the following reasons. Rubin and Turano (1994) have shown that normally-sighted observers read from an RSVP display without making eye movements. An earlier study (Fine and Peli, 1995), using centered RSVP text otherwise identical to that used here, showed that normally sighted observers in the same age group studied here were able to read at rates sufficiently fast to preclude the possibility that they were making intra-word eye movements. Therefore, normally sighted observers must be able to take in even the longest word in a single glimpse, so no horizontal intra-word eye movements are to be expected in VSCROLL either. The vertical eye movements expected to be induced by the upward movement of the VSCROLL text will be the same in all alignment conditions, so overall there should be no effect of alignment on the reading rates of normally sighted observers.

We measured reading rates for observers with central scotoma and age-matched normally sighted observers for all three alignments in the RSVP and VSCROLL displays, and some observers' eye movements were videotaped to directly evaluate our assumptions. The results showed no systematic ordering of reading rates by alignment was found for RSVP, but not for VSCROLL. The videotaped eye movements reveal that our assumptions about the pattern of eye movements adopted by normally sighted observers and patients with central field loss whose PRLs were below their scotomas are essentially correct.

METHODS

Observers

Observers were recruited from the patient population of Schepens Retina Associates. All were 55 years of age or older. Observer with normal vision (n = 13) had acuity of 6/12 (20/40)

[2] We have yet to observe a patient whose PRL is above his or her scotoma, but the prediction is the same as in the case where the PRL is below the scotoma.

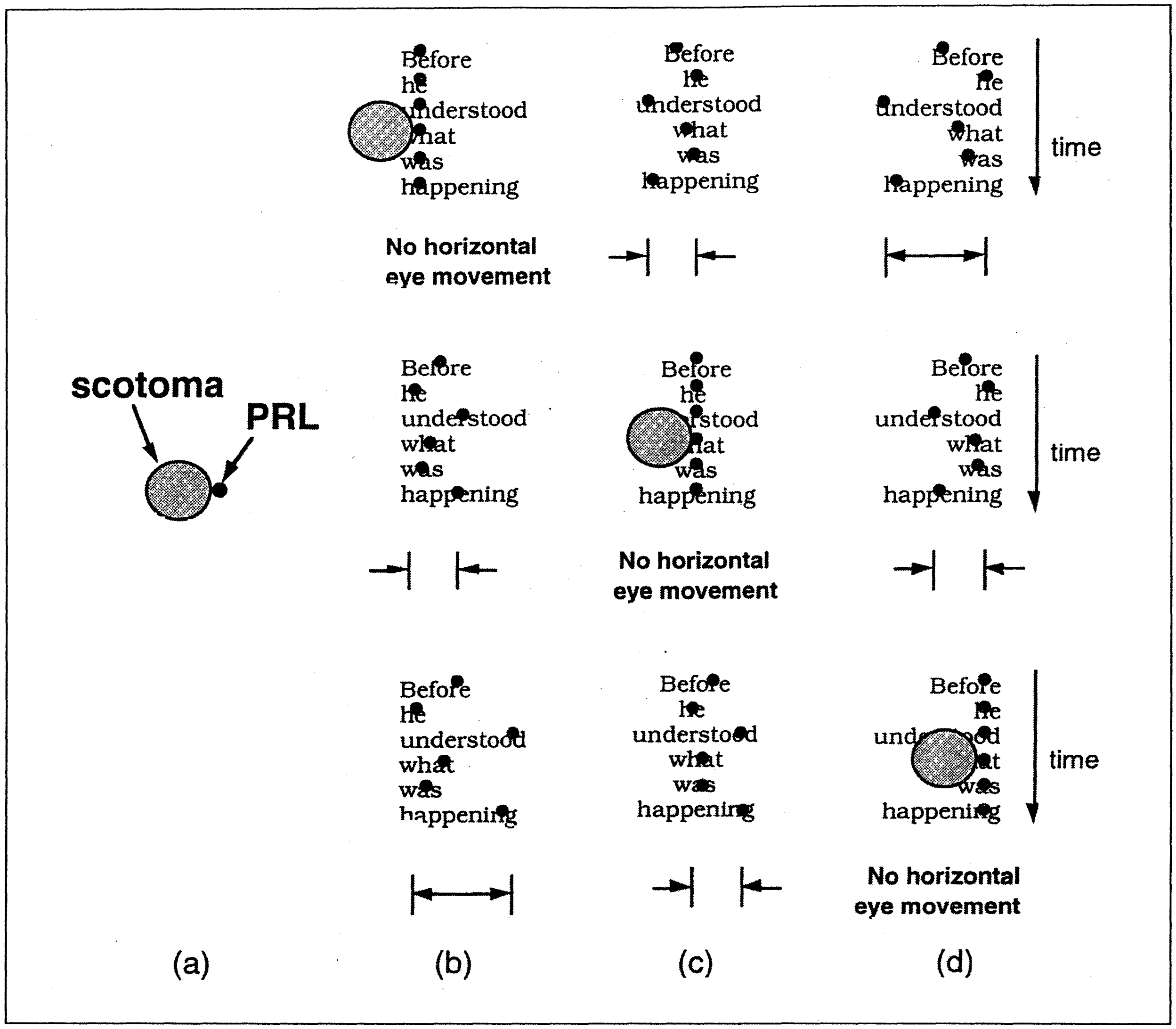

Figure 1. (a) relationship of PRL location to scotoma in the visual field. The point in the visual field corresponding to the fovea is somewhere inside the blind spot generated by the scotoma, (b) PRL with scotoma navigating LEFT aligned text. The position of the PRL is illustrated for each word (small dot), while the position of the scotoma is shown only for the instant the patient is reading the word «what». The PRL could land in a consistent position near the beginning (top panel) middle (center panel) or end (bottom panel) of each word, (c) same for CENTERed text, (d) same for RIGHT aligned text. The arrows beneath each panel indicate the extent of horizontal eye movements necessary to maintain a consistent eye position from word to word. Notice that the scotoma in the top left panel obscures the least amount of text of all the cases where are no horizontal eye movements expected, leading to the prediction that the LEFT alignment condition will produce the highest reading rate for this patient.

or better in at least one eye. The low-vision observers (n = 32) either had bilateral central field loss (according to their medical records) or had central field loss in one eye and, by their own report, did not use the other eye for form perception due to some other defect. We also set an acuity criterion of 6/30 (20/100) or worse (max. 6/240 [20/800]) in both yes (mean and median 6/60 [20/200]). Acuity was measured in each eye using a B-VAT II (Mentor O&O, Norwell, MA, USA).

For some analyses, the low-vision observers were segregated based on the location of their PRL relative to their scotoma in their dominant eye (the eye with highest acuity, which always agreed with patient's perception of which eye they used most for reading). There were five patients whose PRLs were below their scotomas, five whose PRLs were to the right of their scotomas, and six whose PRLs were to the left of their scotomas[3]. The balance of the low-vision patients either had a PRL diagonally located with respect to the scotoma or an undetermined PRL location; these patients were included in the analysis of the low-vision group as a whole but excluded from the analyses based on PRL position.

PRL location

Observers were examined by one of the authors (EP), an optometrist, to determine what portion of the retina they used to view a small spot and/or a crosshair projected on the retina with a direct ophthalmoscope. Where possible, these results were compared with the PRL location implied by the clinical scotoma map (Timberlake et al., 1986; also see Labianca and Peli, this volume) available in the patient's chart. In only a few cases did the two estimates of PRL location differ, and in all of those cases the chart information was several years old. For the purpose of analysis we used the results of the optometrist's evaluation.

Equipment

Text was presented on a Sony television monitor (actual screen size 41 x 56 cm [16 x 22 in]) driven by a modified Horizon Low-Vision Magnifier. The modified Horizon system presents text dynamically in one of several formats. It allows the experimenter to control the magnification and rate of text presentation directly. We kept magnification constant throughout the experiment to avoid varying the maximum number of letters visible on the screen. Magnification was chosen so that an average of 13 proportionally-spaced characters would fit across the width of the screen, and 3.5 lines would fit on its height. For our observers, this magnification resulted in letter heights ranging from 1.5 degrees (for normally sighted observers) to 10 degrees of visual angle, depending on seating distance. Seating distance ranged from 0.3 m to 2 m (see *Procedure*); observers wore whatever correction they would normally use for viewing TV from that distance.

Stimuli

The stimuli were sentences taken from the MNRead corpus (Legge, Ross, and Luebker, 1989). In the original corpus the sentences were designed to have exactly 55 characters, including spaces, and to be at approximately a sixth grade reading level. A few sentences were modified to make them more readable.

Reading rate measurements

Observers read (or had read to them) and signed an informed consent form before the experiment began. They were then seated at a comfortable viewing distance from the Horizon monitor with the restriction that the letters on the screen be at least four times (4x) the size of letters at their acuity limit, the size sufficient to obtain maximal reading rates by normal and low-vision observers (Legge, 1991; but see also Fine and Peli, this volume). A few practice sentences were presented. Some low-vision patients were unable to read at the 4x distance and moved even closer to the screen to complete the study. All observers began with a presentation rate of 160 words-per-minute (wpm, VSCROLL), or 150 wpm (RSVP)[4]. Thereafter, the observer

[3] This distribution of PRL location was not the subject of our study, but it is quite different from that found by Guez et al. (1993). They reported that 24 of 36 eyes tested had PRLs to the left of scotoma in the visual field.

[4] For low-vision observers, whose reading rates in this study varied from person to person by as much as a factor of 20, the practice sentences also allowed for an initial adjustment of the presentation rate.

read aloud as each sentence was presented. Presentation rate was adjusted in a staircase procedure (Fine and Peli, 1995) based on whether the observer was able to read the sentence. A sentence was considered incorect if two or more words were missed, judged by the experimenter listening to the observer and marking a fair copy of the sentence. The step size and the presentation rate were decreased after each sentence that was read incorrectly, until the smallest step size was reached. Threshold reading rate was defined to be one step slower than the presentation rate at which two consecutive sentences wre read incorrectly. For normally-sighted observers reading RSVP, the sentence would sometimes be presented much more quickly than the observer could read aloud. In these cases the observer continued to speak after the sentence was over. No observer reported any difficulty in remembering these short sentences, and none was evident in the data.

The orders os display format (VSCROLL or RSVP) and alignment (LEFT, CENTER, or RIGHT) were counterbalanced across observers. Observers completed all three alignments in one display format before beginning the other[5].

Eye movement measurements

To test our assumptions about the pattern of eye movements generated by the various alignments we videotaped some observers' eye movements as they read. After first measuring their reading rates as above, we asked them to read silently paragraph selected from fourth and fifth grade reading primers (*Multiple Skills* Series E3 and D1, respectively). Alignment and/or display format was changed between paragraphs. The paragraphs were presented at half the maximum reading rate measured using sentences, because (unlike the maximum rate) it is a rate at which one would be comfortable reading for extended periods.

Eye movements were recorded with an ISCAN remote infrared eye tracker (Burlington, MA, USA), which computes the position of the observer's gaze to an accuracy of 1 degree based on the positions of the center of the pupil and the corneal reflection. One of the ISCAN's outputs is a video signal representing the stimulus screen (the text) with the position of the observer's gaze indicated by a superimposed dot. This signal was videotaped for later analysis.

RESULTS

Normally sighted observers

For the 12 normally sighted subjects who completed both the RSVP and VSCROLL reading tasks, a 2 (display format) x 3 (alignment) ANOVA indicated a significant effect of display format (RSVP: 345±19[6] wpm; VSCROLL 272±12 wpm; $F(1,11) = 25.9$, $p < .001$), but no effect of alignment, nor an interaction between these variables [both F's < 1.4, p's > 0.2][7]. That we found no effect of alignment is consistent with our expectation that normally sighted observers will make few within word eye movements while reading from these dynamic displays. Faster

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[5] A few subjects were unable to complete both RSVP and VSCROLL measurements in the time allotted. In those cases we completed one set of measurements and attempted to schedule the other set for another day. If we were unable to eventually collect data for both RSVP and VSCROLL, that patient's data were excluded from the statistical tests for alignment and display format, but they were included in the group mean reading rates.

[6] Standard error of the mean.

[7] Reading rates for the LEFT, CENTER and RIGHT alignments were 357±32, 360±43, 318±22 for RSVP; 268±21, 272±20, 275±23 for VSCROLL.

reading rates for the RSVP format are consistent with earlier reports that have found that RSVP is read more quickly than other computer-generated display formats (Rubin and Turano, 1992, compared RSVP to a static page format; Fine and Peli, 1995, compared RSVP to a horizontal scroll format).

Low-vision observers

For the 23 observers who completed all alignment conditions in both display formats, there was a main effect of display format [$F(1,22) = 8.3$, $p = .008$; RSVP 101±10 wpm, VSCROLL 123±9 wpm], but no effect of alignment, and no interaction [both F's < 1.3, p's > 0.3] [8]. This is consistent with the findings of the normally-sighted observers, but does not take into account the position of the PRL relative to scotoma.

The small group of observers with PRLs below their scotomas (n = 5) showed a similar pattern of results to the normally sighted readers (see Fig. 2). That is, there was a marginally significant effect of display format [$F(1,3) = 5.9$, $p = 0.09$; RSVP 69±12 wpm, VSCROLL 122±14 wpm], but no main effect of alignment, nor an interaction between these two variables [both F's < 2.5, p's > 0.15] (see Fig. 2). Interestingly, these patients (as did the patients with PRLs lateral to scotoma) read somewhat faster from the VSCROLL than the RSVP display.

To test our hypothesis that readers with PRLs lateral to their scotomas wil show different patterns of reading rates for the three alignments depending on whether PRL is to the left or right, we calculated a 2 (PRL position: n = 6 right, 5 left) x 2 (display format) x 3 (alignment) ANOVA (see Fig. 2). While there was no interaction between PRL position and alignment [$F(2.18) < 1.0$, n.s.], there was a marginally-significant three-way interaction between PRL position, display format, and alignment [$F(2,18) = 2.7$, $p = 0.09$]. Inspection of Fig. 2 shows that this interaction is due to differences in reading rates for the two PRL positions and three alignments only when reading RSVP [9].

The fact that we find the expected effect of alignment on RSVP reading rates, but not on VSCROLL reading rates, may be due to the reader's ability to preview the length of the upcoming word from the VSCROLL display. In VSCROLL, the word following the one being fixated is potentially visible if the current word is at least one line above the bottom of the screen. This advance knowledge of (at least) the length of the upcoming word may allow the reader to move to the next word using a diagonal eye movement, thus placing fixation in an advantageous position. In RSVP there is little [10] advance knowledge of the upcoming text, so the best eye movement strategy is the one optimized by alignment and described in Figure 1.

EYE MOVEMENTS

We videotaped the eye movement patterns of three normally-sighted observers (one young, two over 55 years) and two low-vision observers (both with PRL below the scotoma). The eye movement patterns of normally-sighted observers were straightforward. In the RSVP format

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[8] Reading rates for the LEFT, CENTER and RIGHT alignments were 95±15, 104±19, 103±17 for RSVP; 120±14, 126±16, 122±15 for VSCROLL.

[9] This was confirmed by separate 2 (PRL position) x 3 (alignment) ANOVAs for both display formats. For RSVP the interaction just failed to reach significance [$F(2,18) = 3.3$, $p = 0.058$]. For VSCROLL, there was no interaction [$F(2,18) < 1.0$, n.s.].

[10] The length of an upcoming word is probably constrained somewhat by context.

no horizontal eye movements were observed, consistent with Rubin and Turano's (1994) report for a young normally-sighted observer. The absolute horizontal position of the eye did vary with the alignment condition. When the text was CENTERed the eye was positioned in the center of the screen, by definition in the middle of each word. When the text was aligned with the RIGHT or the LEFT of the screen, the eye was positioned 2-3 characters from the margin of the screen (this situation is illustrated in Figure 3). For LEFT aligned text, the eye was near the left edge of the screen (near the beginning of most words), while for RIGHT aligned text, the eye was near the right edge of the screen (near the end of the words). We found a similar pattern for VSCROLL text, although in this format there was an occasional eye movement toward the other end of a long word, probably because even the normal observers take advantage of the opportunity to preview upcoming text and plan an optimal eye movement. In addition, the vertical motion in the VSCROLL condition resulted in smooth upwards eye movements, resulting in a down-beat nystagmus-like pattern of smooth upwards movement and fast downwards saccades similar to what has been observed during reading of horizontally scrolled text (Whittaker, Rhodes, and Cummings, 1993; Legge, Pelli, Rubin, and Schleske, 1985).

For the two observers with PRLs below their central scotomas, initial eye movement into each word were to one end of the word when the text was justified to the side of the screen, or to the center when the text was CENTERed, similar to the eye position maintained by normally-sighted readers. In contrast to normally-sighted observers, however, these low-vision observers made numerous additional eye movements within words, often approaching a letter-by-letter pattern (Figure 3d). Interestingly, these eye movements were frequently regressive, moving backwards toward the beginning of a word. These within word eye movements occurred in both RSVP and VSCROLL and in all alignment conditions. While perhaps not sufficient to explain the vasty slower reading rates of these observers relative to age-matched, normally sighted controls, these intra-word eye movements are likely to account for a large portion of the difference in reading rates.

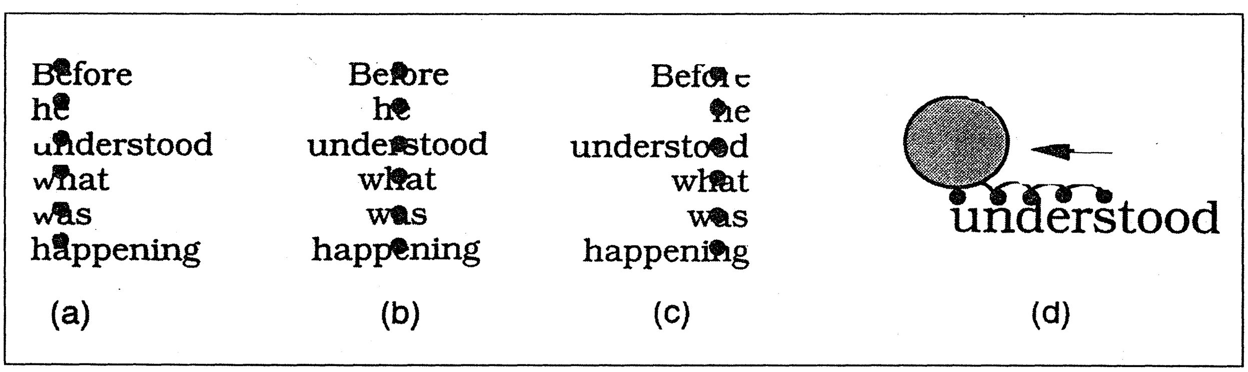

Figure 2. RSVP and VSCRLL reading rates. The expected interaction between PRL location and alignment for patients with lateral (left or right) PRLs is evident in the left panel (RSVP) and absent in the right panel. The error bars represent the standard error of the mean.

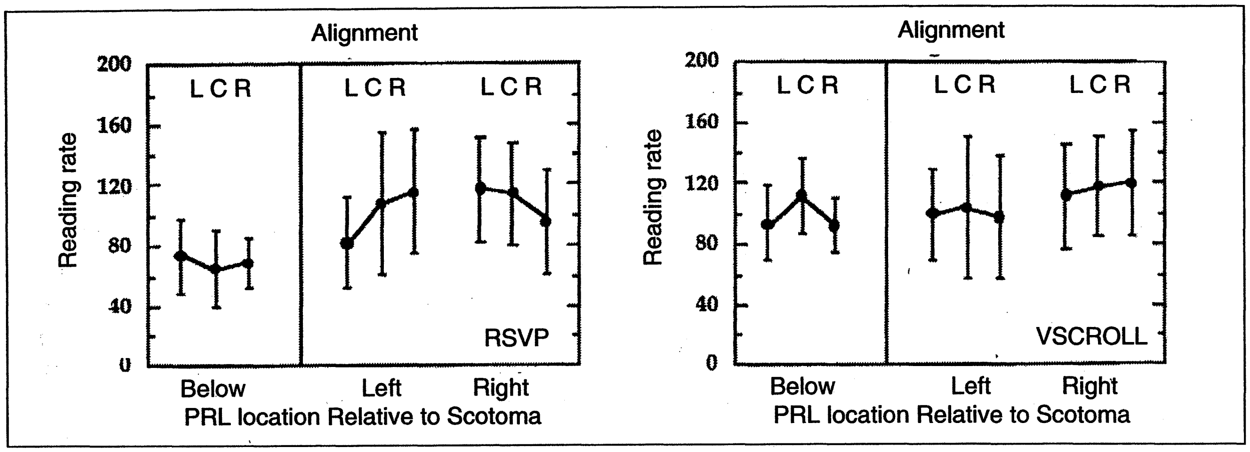

Figure 3. The pattern of eye movements of normally sighted observers during reading of VSCROLL and RSVP. (a) When text was aligned with the LEFT of the screen, the eye landed near the beginning of each word, keeping a nearly constant distance from the edge of the screen. (b) When text was CENTERed, the eye rode the center of the screen. (c) When text was aligned with the RIGHT edge of the screen, the eye landed near the end of each word. (d) Low-vision observers' initial eye position within a word followed the same pattern as in (a), (b), and (c), but in addition they made extensive intra-word eye movements, sometimes even to the point of fixating on each letter. In this example of CENTERed text, the PRL first lands near the middle of the word, then moves backward toward the beginning.

CONCLUSIONS

Consideration of eye movements is helpful in understanding the behavior of low-vision observers reading from dynamic displays. This study has demonstrated that text alignment can affect eye movements for both low-vision patients with central field loss and for normally-sighted observers. For patients with lateral PRLs text alignment affects reading rate with the RSVP display, but not the VSCROLL display, possibly because the latter format allows preview of upcoming text and therefore word-by-word optimization of the initial eye movement into a word. For all low vision observers VSCROLL was read faster than RSVP. As has been previously argued for horizontally scrolled text (Whittaker, Rhodes, & Cummings, 1993), the vertical motion of the VSCROLL display may serve to entrain the eyes' motion. The preview of upcoming text and the entrainments of eye movements will lead to fast reading rates.

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