COMPUTER DISPLAY OF DYNAMIC TEXT

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INTRODUCTION

For many people with low vision, regaining the ability to read fluently is a primary goal of their rehabilitation. Until recently, the reading aids available to them were limited to optical magnifiers. While magnification is critical for readers with impaired vision, it is often not sufficient, and the format of a standard page layout may limit reading rates. Eye movements alone consume more than 20% of reading time for normally-sighted readers and are even more time consuming for readers with central field loss (CFL). Reading is made even more difficult and time consuming when eye movements must be coordinated with the movement of the magnifier across the page. Even on a computer, where hand and eye movement coordination is not necessarily, a static page display is often impractical when the text is appropriately magnified. Figure 1 shows three views of a page-like display. At the left is a single sentence shown with 12 pt type. The middle panel of the figure shows the portio of this same sentence that can be displayed when the text is magnified 2x (24 pt), and the right panel shows what happens with 4x (48 pt) magnification. As the magnification is increased, less and less of the text can be displayed at any one time. Thus, even with the small amount of magnification shown there, a page-like display is no longer possible.

One fo the primary advantages of computer-based text displays is that they can be programmed to present the text in almost any format. By manipulating the format to reduce or eliminate the need for eye movements, especially the return sweep, reading rates for patients with CFL, for whom eye movements during reading are especially problematic (McMahon *et al.,* 1991) should increase. This is particularly important given that median reading rates for patients with CFL for static page displays have been reported to be as slow as 25 words per minute (wpm); (Legge) (1991).

We have chosen to focus our efforts on two dynamic text displays, both of which present text continuously to the reader: rapid serial visual presentation (RSVP) and a horizontally scrolling display. The left side of Fig. 2 shows several succesive screens of an RSVP display. With RSVP, each word is presented individually at the same place on the computer monitor, and, with normal vision, no eye movements are required to read from this display (Rubin & Turano, 1994; Potter, 1984). RSVP has been used for many years in reading research, and was suggested as a possible reading aid for visually-impaired readers as early as 1983 (Potter).

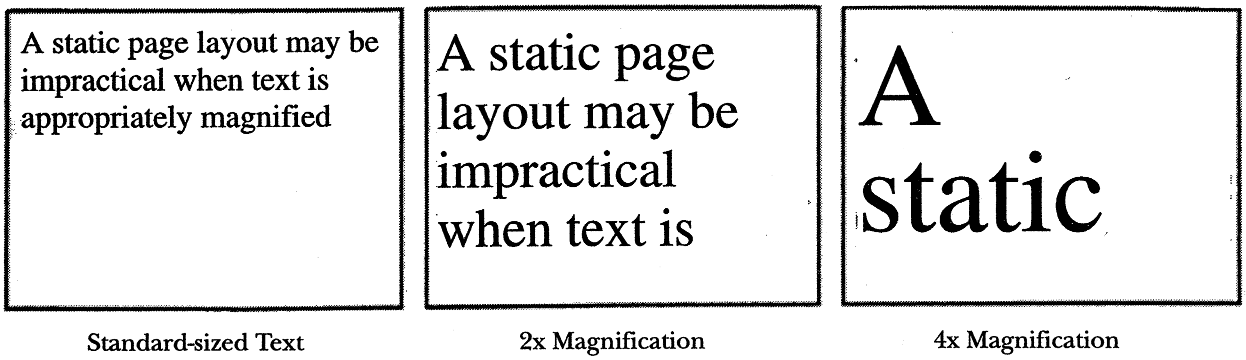

Figure 1. The effects of magnification on a static page layout presented on a computer monitor

The scroll display presents text so that the visual images are similar to what is seen through a magnifier or a CCTV panned across a line of text. This is shown on the right side of Fig. 2. The text enters from the right edge and travels across the face of the magnifier (or television screen for the computer display) until it disappears at the left edge. Using a computer, the scroll display eliminate both, the need to move the magnifier across the page and the return sweep from the end of one line to the beginning of the next. This return sweep is particularly time consuming, even for normally-sighted readers not using a magnifier. In fact, the eye movement required for the return sweep alone takes up to 10% of total reading time (Buettner *et. al.,* 1986; Rayner, 1978) and is often inaccurrate (Just & Carpenter, 1980).

We have studied several important issues with regard to these displays. In all of our studies, we asked visually-impaired and normaly-sighted, age-matched controls to read single sentences out loud while varying display parameters. We increased the display rate in discrete steps until the observer could no longer read without error. This presentation rate was then converted to words per minute (wpm) and used to compare performance with regard to the variables in question.

READING FROM RSVP AND SCROLL DISPLAYS

We first compared reading rates between the RSVP and scroll displays. Figure 3 shows reading rates by display format for three groups of readers: those with normal vision (acuity 20/40 [6/12] or better); and visually-impaired readers (acuity 20/50 - 20/600 [6/15 - 6/180]; Mdn = 20/145) with no document CFL and with documented CFL. Only those reader with normal acuity (20/40 [6/12] or better) showed any difference in reading rates between the two displays. While we had expected readers with normal vision to read faster from the RSVP display because no eye movements are required, we had also expected that visually-impaired readers would read faster from this display because no eye movements are needed between words.

Rubin and Turano (1994) showed that readers with CFL do make eye movements within words when reading from the RSVP display, and their increase in reading rate relative to a static page display was smaller than for normally-sighted or visually-impaired readers with no CFL. However, the relative increases in reading rate Rubin and Turano showed for visually-impaired readers (about 80%) was far greater than the 15% increase Legge *et al.* (1989) found when they compared reading from a page of a text and a scroll display in a similar patient population. In addition, visually-impaired readers with no CFL in Rubin and Turano's study read with RSVP about 200% faster than with a static page display. While there was a slight trend in the direction of faster reading with RSVP for our small sample of visually-impaired readers with no CFL (n = 10), it was far less than for the normally-sighted readers and did not approach statistical significance.

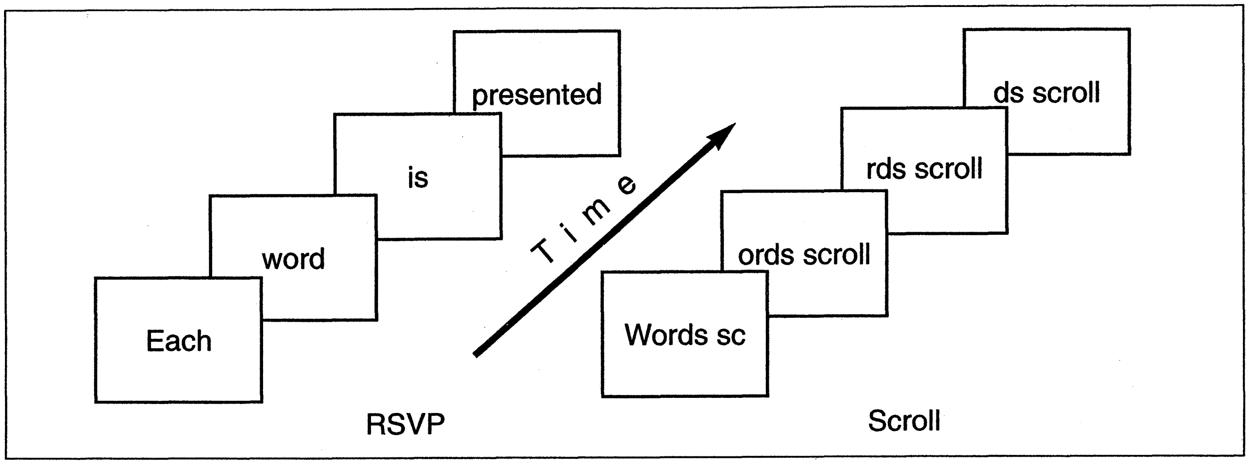

Figure 2. Successive screen presentations for the RSVP and scroll displays. With RSVP, the words are presented at the center of the screen. With the scroll display, the motion is continuous and does not take letter-by-letter jumps as depicted here.

THE EFFECTS OF VARYING THE WINDOW SIZE OF THE SCROLL DISPLAY

Our initial finding of no difference in reading rate between the two displays (Fine & Peli, 1995), especially among patients with CFL, lead us to further investigate how these patients read from the two displays. In the study just described, we varied seating distance (instead of physical character size) to change retinal character size so that the same number of letters would be available when reading from the scroll display under all conditions. There is a great deal of evidence that under normal reading conditions about 17 letters surrounding fixation (4 to the left, the remainder to the right for English readers) must be visible for maximal reading performance to be attained (see Rayner & Pollatsek, 1989). We used a character size that allowed for about 13 (proportionally-spaced) letters to be simultaneously visible. Legge *et al.* (1985a, b) reported that only about 5 (fixed-width) letters are necessary for maximal reading rates from the scroll display for both normally-sighted and visually-impaired observers. And, at least for normally-sighted readers, this is independent of character size (Legge *et al.*, 1985a). Thus, the 13 letter-display we used was no likely to limit reading rates. However, if, as Legge *et. al.*'s data suggest, far fewer letters are needed to read from the scroll display, then much larger letters could be presented without compromising reading rates. This is not true of the RSVP display, because at least one complete word must be visible during each frame of the display. While we have shown that reading rates for the scroll display tend to decrease as character size increases (Fine *et al.*, 1966a; see below), larger letters would benefit readers with more severe visual impairments who cannot read at any rate with the smaller letters.

We tested the relationship between the number of characters visible (called window size) and reading rates for the scroll display for characters of approximately the same size as those used in the experiment just described (see Fine & Peli, 1996a for a more complete description of the data currently under discussion). Visually-impaired observers (n = 12) read with windows ranging from 3 to 12 letters (smaller windows were also presented, but many visually-impaired readers were unable to read with so few letters visible). The resulting data (including those subjects who were able to read with the small windows) are shown in Fig. 4. The average window size from which these readers were able to attain their maximal reading rates was 10 letters. As a group, there was a gradual increase in reading rates up to a window size of about 7, where rates began to level off. Both of these values are substantially larger than those reported by Legge *et al.* (1985b; see their Fig. 7). Our average reading rates were faster than those reported by Legge *et al.* (149 wpm for our study versus 100 wpm from the data of Legge *et al.* Table 2). While we see no statistically significant correlation between window size and maximal reading rate in our small sample, the trend suggests that faster reading rates may require larger windows (r = 0.35).

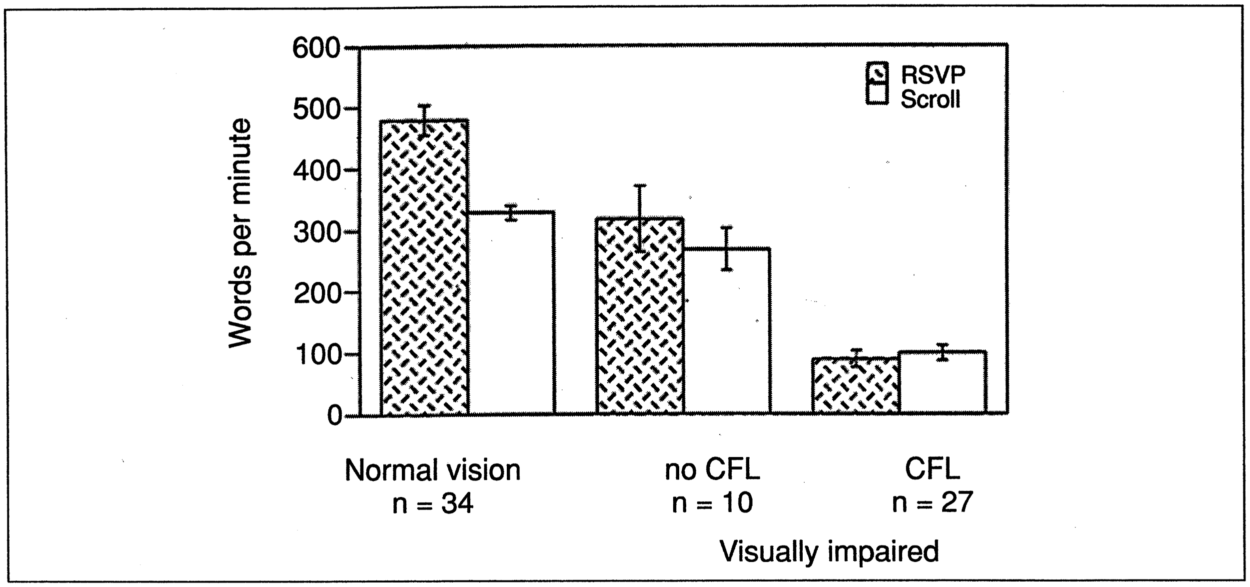

Figure 3. Reading rates (wpm) from the RSVP (hatched bars) and scroll displays for normally-sighted and visually-impaired readers (error bars are SEM). Only the group with normal vision showed any difference in reading rates from the two displays. As expected, they read faster from the RSVP display. We were surprised to find no difference in reading rate for the visually-impaired group. (Data from Fine, 1995; experiments 1, 2, and 4).

These data confirm that a much smaller window is sufficient to read scrolled text than is necessary to read from a standard, static-page display (about 17 characters for normally-sighted readers). However, at least for the readers in our study (Fine & Peli, 1996a) a window slightly larger than the average word length (5 letters) is necessary to attain maximal reading rates, and for most subjects, a window displaying about two words was required (10 letters). Thus, while somewhat larger letters may benefit reader with more severe acuity losses, they may also limit their reading rates because fewer of the letters could be simultaneously visible.

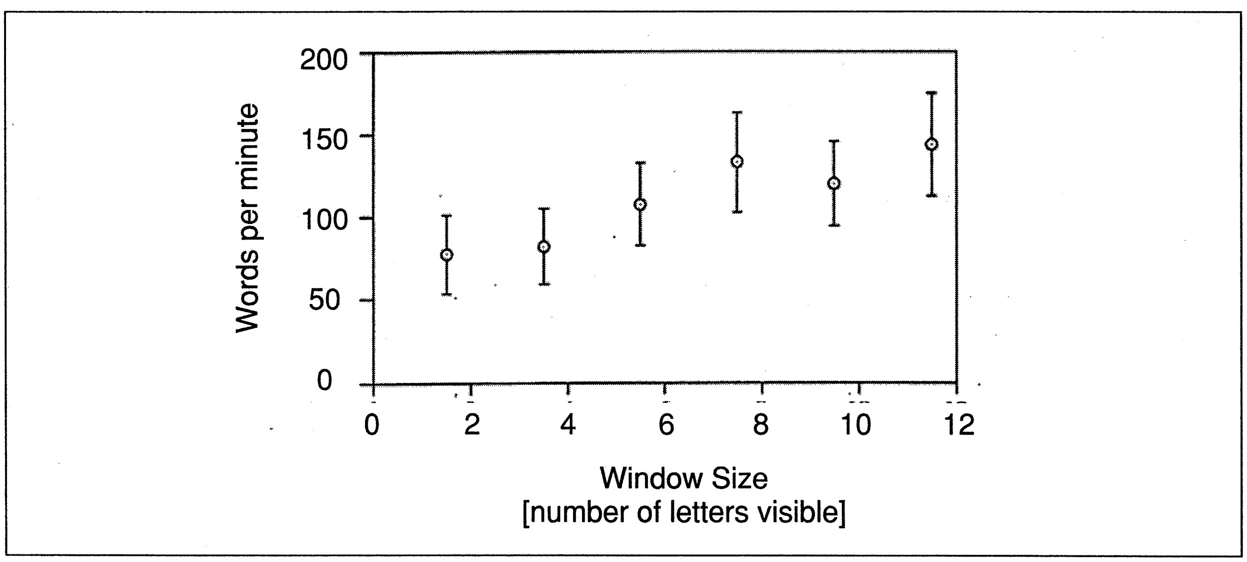

Figure 4. Mean reading rates in wpm by window size for visually-impaired readers (error bars are SEM). The data for each window size represented are averaged from two groups of subjects one of which read with an odd number of letters visible (e.g. 3) and the other with an even number visible (e.g. 4). Reading rates begin to level-off with a window of about 7 letters. The first data point on the left represents only those subjects who could read with such a small window (n = 6).

THE EFFECTS OF ACUITY RESEVE AND CHARACTER SIZE ON READING RATES

Earlier research (see. e.g. Legge *et al.*, 1985b) has shown that among visually-impaired readers, reading rates for scrolled text increase sharply with character size and asymptote at a character size of about 5x the readers' acuity threshold. (The ratio of text character size to threshold character size has been called acuity reserve [AR; Whittaker & Lovie-Kitchin, 1993].) Rubin and Turano (1994) found a fairly flat character size by reading rate function for visually-impaired observers reading RSVP. Because of this, they defined the critical character size as the size at which a reader was able to attain 90% of his/her maximum rate. Across subjects, the average critical character size corresponded to an AR of about 4. In our prior studies (Fine & Peli, 1995; 1996b) we changed the seating position of each subject so that AR would be at least 4, but the same size was used for reading from both displays.

As AR increases for any given reader, so too does the physical character size. For normally-sighted readers, the primary advantage of RSVP is that no eye movements are necessary to read. However, Rubin and Turano have shown that readers with CFL make eye movements when reading from the RSVP display, and these eye movements contribute to the smaller advantage found for RSVP in this group of readers. It is reasonable to assume that as the text characters become larger, visually-impaired readers will have to make more eye movements to see the entire letter string that makes up a word. For example, when reading with 5 deg letters (about 5x acuity threshold for a reader with 20/250 [6/75] acuity), an average 5-letter word would span 25 deg of visual angle. The average character size for visually-impaired readers in our prior experiments (Fine & Peli, 1995; 1996b) was 4.4 deg, corresponding to an average AR of 6.2. These fairly large characters may have reduced the potential benefits of the RSVP display.

To test this hypothesis, we asked visually impaired readers (acuity 20/60-20/200 [6/18-6/60]; n = 20) to read from the RSVP and scroll displays using 5 different text sizes defined in relation to their acuity. Specifically, they read with text that was 2, 4, 6, 8, and 10x their acuity threshold. If the larger characters reduce the relative benefit of RSVP, then RSVP should be read faster for the smaller characters (ARs of 2 and 4), and at about the same rate for intermediate letter sizes (Ars of 6 and 8). For the largest AR, we would predict that RSVP would be read more slowly than the scroll display.

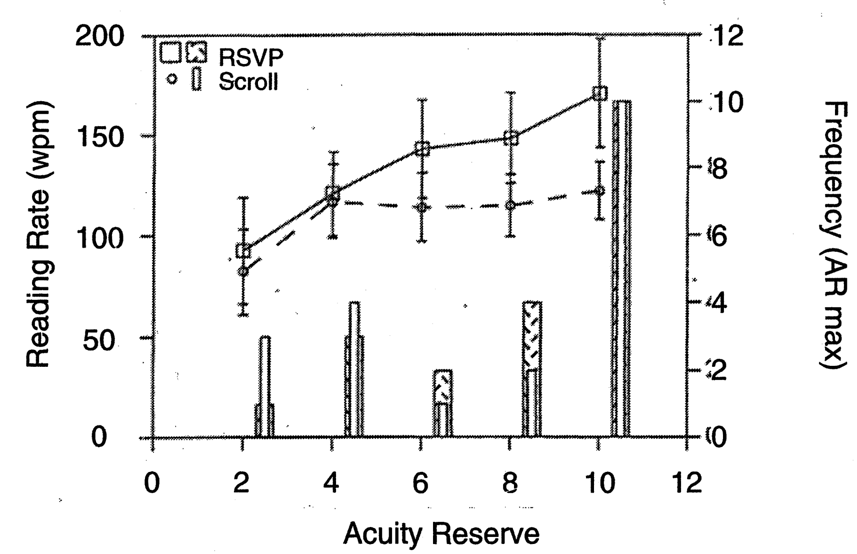

Figure 5. Reading rates by display format and acuity reserve, and number of subjects for whom a given AR produced maximal reading rates. The squares and hatched bars are RSVP; circles and open bars are scroll. The data points represent reading rates in wpm for the RSVP and scroll displays at the 5 ARs. The bars, off-set slightly from the ARs at the bottom of the graph, are frequency counts representing the ARs for which maximal reading rates were attained for each display format.

Our data do not support this hypothesis (Fig. 5). In fact, reading rates for RSVP continued to increase as AR increased. When we look at the grouped data for the scroll display, reading rates asymptote with an AR of about 4. This replicates previous findings (Legge *et. al.,* 1985b). However, even for the scroll display, most of the subjects read fastest with the largest characters. Interestingly, when we looked at the AR that produced maximal reading rates for each subject in each display condition, they were not significantly correlated [$r = 0.31$, $p = 0.19$]. That is, for many subjects, different character sizes were required to obtain maximal reading rates for the two displays, and there was no consistent trend in this requirement (6 readers required larger characters for scroll, 7 for RSVP, and 7 read at their maximal rates with the same sized characters from both displays). When we looked at reading rates for the two displays at each subjects' optimal character size (the size with which they read fastest), RSVP was read faster [$t(19) = 3.0$, $p < .008$].

These findings are quite surprising given the presumed role of eye movements in limiting RSVP reading rates. The average character size for which subjects attained their maximal reading rates was about 3.4 deg for RSVP and 3.2 deg for scroll. These are actually smaller than the letters for which we found no difference in reading rates in our previous studies (4.4 deg). Thus, it remains possible that had we continued to increase the character size, we would have seen the reading rates for RSVP decrease.

Rubin & Turano (1994) reported that as critical character size increased, reading rates decreased for visually-impaired observers reading RSVP. For our subjects, we found no relationship between optimal character size and reading rate for the RSVP display [$r = -0.14$, $p = 0.57$], but there was a significant relationship between optimal character size and reading rate for the scroll display —as character size increased, reading rates decreased [$r = -0.51$, $p = .020$]. However, there was no relationship between acuity and maximal reading rates for either display [$r = -0.33$, $p = 0.16$ for RSVP and $r = -0.28$, $p = 0.23$ for scroll]. This latter finding is not surprising—very few studies have found a significant relationship between acuity and reading performance.

That we found a benefit to the RSVP display for each subjects' optimal character size indicates that RSVP may provide some benefit to visually impaired readers. This conclusion differs from our previous finding (Fine & Peli, 1995) where character size was constrained and the same for both display formats. However, it is also important to note that the acuity of the readers in our study where we specifically manipulated character size (Mean = 20/98 [6/30]) (described here and in Fine *et al.,* 1996a) was significantly better than that in our prior studies (Mean = 20/149 [6/45]). While we find no correlation between acuity and reading rates, as a group, the readers in our AR study read faster than the readers in our previous studies. However, in a study in which we manipulated the acuity or our readers using cataract simulators, we found that while decreased acuity does decrease overall reading rate, the percentage increase in reading rate for RSVP relative to the scroll display was somewhat greater in the reduced acuity conditions (Fine *et al.,* 1996b).

We are thus left with a somewhat mixed result: for the same (not necessarily optimal) character size, visually-impaired readers read at about the same rate from the RSVP and scroll displays. However, at least in the limited acuity range we tested, when each readers' optimal performance is compared, RSVP is read faster than scrolled text. In that study, we did not test readers with acuity worse than 20/200 [6/60] because we could not generate the largest ARs without changing the physical size of the characters or asking our readers to sit so close to the television screen (less than 12 in) that head movements may have been required to read.

DISCUSSION

For readers with moderate visual impairments (acuity 20/200 [6/60] or better) reading rates are faster from the RSVP display than from the scroll display for each readers' optimally-sized character (AR experiment). However, when comparisons were made with the same sized character (of about 6x), reading rates are the same from the two displays. While we remain unclear why this is so, the most likely explanation is that subjects in the AR experiment had relatively better acuity than our previous participants, and were therefore able to read optimally with somewhat smaller letters. When we look at reading rates for the two displays as a function of AR (see Fig. 5), we replicated our previous finding: at ARs of 4 and 8 (the range within which we tested subjects in our previous experiments) there was no difference in reading rate between the two displays. That reading rates continue to increase for the RSVP display with an AR of 10 is opposite to what would be predicted on the basis of prior data. Rubin and Turano (1994) showed that readers who required larger letters to reach their maximal reading rates with RSVP also read more slowly, and the character sizes they used were in the same range reported here. This may have been confounded with the relatively more reduced acuity of the readers who required larger letters in their study. However, it remains unclear why reading rates for RSVP, which is read fastest by readers who make no eye movements, continue to increase with larger letters. In fact, the average character size for the AR 10 condition was 4.4 deg —no different from the size used in our prior experiments.

While we had maintained the window size in all of our direct comparisons of reading from RSVP and scroll displays, we also confirmed that the window size we had used (13 letters) was sufficient to attain maximal rates (Fine & Peli, 1996a). We also showed that for most subjects, a window containing about 10 letters was necessary for maximal reading rates. Legge *et al.* (1985 b) showed that reading rates leveled-off with only 5 letters visible. However, the average character size used in our study (29 deg) was about half that used by Legge et al (all of their subjects read with 6 deg characters). Thus, the visual angle per window was about the same in both studies. Whittaker *et al.* (1993; see also Legge *et al.*, 1985a for a preliminary report) have reported that the eye movement pattern elicited while reading scrolled text is similar to optokinetic nystagmus (OKN). Although it has yet to be confirmed, if the lock-step pattern of the OKN eye movement is driven by the motion of the text and not the information content of the text, then it is reasonable to conclude that the window requirement for reading scrolled text, unlike other reading tasks (Legge *et al.*, 1985a; Morrison, 1983) would be defined on the basis of visual angle, and not number of letters, at least for visually-impaired readers.

CONCLUSIONS

Visually-impaired readers read text presented using RSVP faster than continuously scrolled text using an optimal character size measured for each subject and each display format. For the same sized letters, up to about 8x the readers acuity threshold, reading rates are the same for the two displays. We are as yet unclear why this pattern exists in the data. In addition, we have found that a window size of about 7 4.5 deg letters is necessary for optimal reading performance with the scroll display. This latter finding may be related to the span in deg visual angle of the letters, rather than the absolute number of letters displayed.

Other dynamic display formats are currently under investigation (see Burns *et al.*, this volume). However, given the choice between RSVP and scrolled text displays, there is no clear benefit to either for most readers, especially those with greater losses in acuity (worse than 20/200 [6/60]). Most of the readers in our studies (both visually-impaired and normally-sighted) had a clear preference for the scroll display, and this preference is likely to be stronger when reading more extended passages of text. Thus, the scroll display may be the better option for most readers who choose to use a computer-based dynamic text display.

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