Scrolled and rapid serial visual presentation texts are read at similar rates by the visually impaired

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Visually impaired observers read dynamically displayed text faster than text displayed in a normal page view. The goal of this study was to compare reading rates from two dynamic-presentation methods that have been proposed to facilitate reading from computer-based displays. Prior research has shown that both normally sighted and low-vision observers read text displayed to the same location, one word at a time [known as rapid serial visual presentation (RSVP)], faster than a page of text. A similar comparison with text scrolled continuously across the screen also shows faster reading for low-vision patients, but the relative change from a standard page view is substantially less (15% faster for the scroll display versus 80% faster for RSVP). In this study we directly compared these techniques. For those with normal vision, reading from the RSVP display was 1.3 times faster than reading from the scroll display [$t(9) = 3.32$, $P = 0.009$]. Although the difference in reading rates for the visually impaired group did not reach statistical significance, as a group they read 13% slower from the RSVP than from the scroll display.

1. INTRODUCTION

This study was designed to investigate how changes in text display format affect reading rates among the visually impaired. Recently the U.S. Secretary of Education recognized the usefulness of electronic aids specifically designed to enable older adults with visual impairments to read.[1] One of the primary benefits of electronic displays is that text can be magnified substantially more than is possible with optical magnifiers. However, when text is appropriately magnified to compensate for reduced acuity, a conventional page format is no longer possible. For example, a 14-in. (36-cm) computer monitor is approximately 25 deg × 35 deg at a standard reading distance of 40 cm. A reader with 20/200 acuity would require characters of at least 3 deg to maintain the same relative character size as a reader with normal vision reading 12-point type at the same distance. With 3-deg characters, only approximately 4 lines of 11 letters each can be displayed. Because of this limitation, alternative display formats have been developed.

Two text display formats that have previously been shown to result in changes in reading rate when compared with a conventional page format are compared here. These display formats are rapid serial visual presentation (RSVP), in which each word is displayed sequentially at the same place on a computer screen, and scrolled text, in which the characters are scrolled continuously from right to left across the screen. Both methods of presentation are compatible with the need to display large letters. The dynamic and continuous presentation of the text in both these display formats requires eye movements different from those required for normal reading,[2,3] and this change in eye-movement pattern is believed to be responsible for the changes in reading rate.

Among the visually impaired (those with acuity of 20/50 or worse), compensation for limited acuity and contrast sensitivity can be achieved with appropriate magnification. For visually impaired patients with intact central fields, nearly normal reading rates are possible. However, for patients with central field loss (CFL), increasing the character size to compensate for their reduced acuity and contrast sensitivity does not allow them to read at rates approaching those of normally sighted subjects (or, in fact, visually impaired subjects with no CFL).[4]

The primary reason patients with CFL are unable to attain normal reading rates is presumed to be their reduced ability to control their eye movements while reading.[5–7] The importance of eye movements in reading has been well established,[8] and it has been shown that, when eye-movement patterns change because of the stimulus display, so do reading rates.[2,3,5,9–11]

The need for efficient eye movements has been implicated in limiting the reading rate of normally sighted observers.[3,12,13] Text displayed by RSVP substantially increases their reading rate.[3,14,15] This increased reading rate is presumed to be due to the elimination of the need for eye movements.[3,12,13]

Observers with low vision are also faster when reading from a RSVP display. Rubin and Turano[5] found that low-vision observers read approximately 80% faster from a RSVP display than from a conventional page format (but see text above for limitations to this technique). This RSVP benefit was due primarily to the more than 200% increase in reading rate for readers without CFL. Low-vision observers with CFL read text displayed by RSVP approximately 50% faster than they read a standard page display. This increase is much less than the fourfold increase in reading rate that they found for normally sighted observers.[14] However, unlike normally sighted readers and low-vision readers with no CFL, the low-vision readers with CFL in the Rubin–Turano[5] study did not eliminate eye movements when reading from the RSVP display. These intraword eye movements are likely to reduce the possible benefits of RSVP. The

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small improvement found probably reflects the elimination of the need for saccades between words and of the return sweep to find the beginning of the next line of text, which is required when reading from a multiline, full-page display.

A scroll display, in which a single line of words is panned continuously across the screen from right to left, has also been shown to affect the pattern of eye movements and the reading rate of observers. Buettner *et al.*[2] compared eye-movement patterns and reading rate for a conventional page display and scrolled text among normally sighted observers. They found that reading was slower for scrolled text (approximately 30%), average fixations were longer (approximately 9%), and saccade length was shorter (approximately 16%). In addition, Legge *et al.*[9] reported that, with larger characters (6 deg), normally sighted observers read approximately 44% slower from a scroll display. Previous research from the same laboratory[16] reported saccades of four to five characters when subjects read from the scroll display, approximately half the normal saccade size.[8] Although the scroll display also eliminates the need for a return sweep to the beginning of the next line of text, which accounts for roughly 10% of reading time for a standard page[2,8] and is often inaccurate, requiring corrective saccades,[17] Buettner *et al.*[2] concluded that the additional processing demands necessary to maintain the pursuit eye movements and saccades in the opposite direction that are seen when observers are reading scrolled text more than neutralize the advantages present from the continuous display.

Low-vision readers, in contrast, were shown to read approximately 15% faster from the scroll display than from a standard page of text.[9] This improvement is probably due to the elimination of the return sweep in the scroll display. It is important to remember that, when appropriately magnified, the number of lines of text required for presenting a passage to a low-vision reader is far greater than the number required for a normally sighted reader. Therefore more return sweeps between each line of text will be required, and they will consume more reading time. In addition, the reduced accuracy and velocity of eye movements in patients with CFL[18,19] would also increase the time required for the return sweep. Thus the time saved by eliminating the need for a return sweep would be substantially more than for the normal-vision observers.

Whittaker *et al.*[20] (see also Legge *et al.*[16]) reported that, when observers are reading from a scroll display, optokinetic nystagmus (OKN) is elicited, and the fast phase of OKN behaves like a saccade. However, unlike a saccade in normal reading, the fast phase of OKN does not require high levels of saccade control. This reduced need for cognitive control may facilitate reading for patients with CFL. However, because the pattern of eye movement relative to the linguistic content of the text is not known when reading from a scroll display, the stimulus-driven pattern of the OKN eye movement may be a detriment to reading. This would be especially true of readers with normal vision who do not have difficulty planning and executing eye movements within and between words when reading and who actively plan where their next saccade will land.

Data from both normally sighted and visually impaired observers imply that reading will be faster for text displayed by RSVP than by the scroll technique. The need for eye movements between words when reading from the scroll display leads to the same prediction. This hypothesis was tested by the following experimental methods.

2. METHODS

A. Subjects

Patients of all ages with documented visual impairments were recruited for this study. Because most of them were elderly (see Table 1), we limited the age range of our normally sighted control subjects to age 55 years or older. Only two of the visually impaired subjects did not meet this criterion. One patient was 51; another, 30. All the subjects were native English speakers. Based on their acuity (see Subsection 2.D for details), subjects were divided into two groups: those with normal vision ($n = 10$), and those with visual impairment ($n = 16$). Normal vision was defined as acuity of 20/40 or better in the better eye; those with visual impairment had acuity of 20/50 or worse in the better eye. Separation of subjects into normal vision and visually impaired groups was based solely on their acuity in their better eye, as measured in the laboratory. Some of the subjects whom we classified as having normal vision had documented impairments in their more debilitated eye.

Subjects with acuity worse than 20/40 in their better eye were further categorized based on the status of their central field. The information was obtained from each patient's medical record. All our normal-vision subjects had intact central fields. Eleven of the visually impaired subjects had documented CFL. All the medical records contained at least one of the following: an Autoplot (Bausch & Lomb) mapping of the patient's central field, a scanning laser ophthalmoscope field, or fundus photographs indicating retinal scars. Nine of the subjects with CFL had age-related macular degeneration. The visual impairments in patients with no CFL were due primarily to cataract. Table 1 shows the average age, acuity, and acuity reserve[21] (ratio of text character size to minimum acuity character size) by subject group.

B. Apparatus

A modified Horizon Low Vision Magnifier (Mentor O&O, Norwell, Mass.) was used for text presentation and data

Table 1. Mean (Standard Error of the Mean) Age, Acuity, and Acuity Reserve by Subject Group

Subject Group	N	Age (years)	Acuity (log MAR) [Snellen equivalent]	Acuity Reserve[a]
All subjects	26	72.1 (2.62)	0.59 [20/78] (0.07)	9.04 (0.78)
Normal vision	10	71.7 (3.57)	0.21 [20/33] (0.02)	13.17 (0.54)
Visually impaired	16	72.3 (3.72)	0.83 [20/134][b] (0.06)	6.45 (0.62)
CFL	11	70.5 (5.09)	0.91 [20/164] (0.06)	6.52 (0.86)
No CFL	5	76.4 (4.12)	0.63 [20/86] (0.09)	6.30 (0.71)

[a]Defined as character size/acuity character size.
[b]Acuity for CFL and no CFL subjects differed significantly [$t(14) = 2.54$, $P = 0.024$].

collection. The text was displayed as white characters on a black background on a 27-in. (69-cm) Sony color-television monitor. The dimensions of the screen allowed for the simultaneous display of as many as 13 characters at the magnification used. A Bitstream san serif, proportionally spaced boldface font was used for character generation. A lowercase e measured 5.6 cm × 4.1 cm at the magnification used and ranged in retinal size (in deg) from 1.8 × 1.3 to 8.4 × 6.1, depending on seating distance (see Subsection 2.C for details).

The modifications made to the Horizon allowed for presentation of RSVP text, as well as direct control of stimulus speed in the RSVP and the scroll displays. In addition, storage of text material on the hard drive of a computer and data collection were also made possible.

For the RSVP format, the presentation rate is based on the desired number of words per minute (wpm), the number of words in the sentence, and the constraints of the 60-Hz monitor that we used. The stimulus duration for each word included a 33.3-ms (two refresh cycles) interstimulus interval. Thus the minimum possible stimulus duration was 50 ms. This display duration corresponds to a maximum display rate of 1200 wpm. The frame rate of the monitor limited the possible display rates for the sentences. When a nominal display rate (in wpm) was specified, the computer determined the closest possible rate (given the constraints of the system), and this rate was used to display the sentence. For the slower display rates (less than 150 wpm), a step size of 5 wpm or less is possible. As the display rate increases, a change in the nominal rate, in wpm, does not necessarily result in a change in the actual display rate. For example, the minimum change in rate from 300 wpm requires an approximate 30-wpm jump. The experimenter used values in wpm based on the protocol described in Subsection 2.D. The data that we report (in wpm) were converted from actual stimulus durations.

The presentation rate for the scroll display is based on the number of pixels and words in the sentence and on the desired wpm rate. To present continuously moving stimuli, which would require precision of movement of less than 1 pixel/frame, the software determined the best possible sequence of display changes such that the average number of pixels traversed over a discrete number of frames resulted in the desired display rate. For example, if the number of words, pixels, and wpm resulted in a need to move 8.2 pixels/refresh cycle, a sequence of movement of 8, 8, 8, 8, and 9 pixels/frame would be repeated until the entire sentence was displayed. Using such sequences, we were able to present sentences at any rate, and the perceived motion of the text (with normal vision) was smooth at all but the slowest (less than 20 wpm) display rates. The choppiness at the slower rates was not noticeable to the visually impaired readers.

The luminance of the characters, as measured with a Minolta LS 100 light meter, was 231.2 cd/m^2. Background luminance varied, depending on the number of characters displayed on the screen. The average luminance was 4.4 cd/m^2, with a standard deviation of 2.71. The average (Michelson) contrast of the display was 96%.

Acuity was tested monocularly with a Mentor B-VAT II visual acuity tester. With this system acuity targets (san serif letters) are randomly chosen and are displayed individually on a 12-in. (31-cm) monitor. The luminance of a 20/200 character was 5.0 cd/m^2, and that of the background was 143.6 cd/m^2. The resulting contrast was 93%.

C. Materials and Design

One hundred sixteen of the MNRead sentences developed by Legge *et al.*[9] were used. Each of these sentences has 55 characters and no internal punctuation and varies in length from 9 to 14 words. The 116 sentences were randomly divided into 4 groups of 29 sentences each.[22] Each subject read sentences aloud from both the scroll and the RSVP displays. The order of display presentation was counterbalanced across subjects, and the order of sentence group was also rotated across subjects. No subject was presented with any given sentence more than once.

Subjects were seated at varying distances from the screen, depending on their acuity. This was done to limit the possible negative impact of high retinal velocities on reading in the scroll condition. (Pursuit gain has been shown to decrease in elderly subjects starting at 50 deg/s.[23]) Although previous research has shown that low-vision readers can read when the rate of presentation exceeds 70 deg/s,[24] the display rate was limited to 40 deg/s or less. The five seating distances that we used were based on calculations of the retinal velocity of the scroll display and on maximum expected reading rates for subjects with different acuities. Expected reading rates were based on previous experiments in this laboratory[24] or on pilot experiments that used similar apparatus and protocol for determining reading rates. Five discrete seating distances were used for ease of execution. Varying seating distance instead of physical character size guaranteed that the number of characters presented on the screen at any one time (window size) was the same for all the subjects. Retinal character size was at least 4× (and averaged 6.5× for the visually impaired readers; see Table 1) the acuity threshold of each subject. (Whittaker and Lovie-Kitchin[21] report that an acuity reserve of 3× is sufficient to allow for maximum reading rates for the simple sentences used in this experiment.)

D. Procedure

For both acuity measurement and reading assessment the room lights were turned off. A 60-W bulb that provided light for the experimenter was positioned such that neither the bulb nor its reflection was in the line of sight of the observers.

Subjects were seated and were told that sentences would be presented on the screen and that they should read them aloud. The display format was described, and a sample sentence was shown. Testing began at 200 wpm for normal-vision subjects, at 100 wpm for subjects with acuity between 20/50 and 20/80, and at 20 wpm for subjects with acuity of 20/100 or worse. Different starting rates and different step sizes were used to decrease the amount of time required for determining the maximum rate. Although acuity is not a good predicator of reading rate for low-vision observers,[25] there are clear differences in reading rate based on acuity when group data are considered. The presentation rate was increased in steps of 10 wpm for subjects who started at

20 wpm and in steps of 20 wpm for all the other subjects, until two or more errors were made on a single sentence. The step size was then halved, and the rate was decreased by one step. After the first reversal, if a subject again made two errors on a given sentence, the rate was repeated. If fewer than two errors were made on the next sentence, testing continued. When two or more errors were made on two consecutive sentences presented at the same display rate, testing was complete for that condition. The actual display rate one step below was converted to wpm and was recorded as the maximum reading rate for that condition. This procedure was repeated with the second display format, except that the starting rate was based on the maximum rate attained for the previous condition. Specifically, if the subject read first from the RSVP display, then the rate for the initial sentence in the scroll display was set to one quarter the maximum rate attained. If the subject began with the scroll display, testing in the RSVP condition was begun at one half the maximum reading rate. If subjects could not read at this rate, testing for the second condition was begun again at the base rate for their acuity group.

Each subject's acuity was measured by means of the Mentor B-VAT II system. With this system single acuity letters can be presented in sizes corresponding to 20/15 through 20/300, with a testing distance of 20 ft (6 m). The system can present letters individually, and it randomly selects letters for each presentation. This method eliminates problems of crowding and chart memorization. For each eye, subjects were asked to name letters that appeared individually on the screen. Subjects stood 10 ft (3 m) from the monitor, which was adjusted for testing from 20 ft (6 m). This method allowed for verification of acuity only down to 20/30 but provided a larger range for determining acuity among the visually impaired. Testing was begun at a letter size corresponding to 10/300 (20/600). Letter size was decreased until the subject could no longer correctly identify four of five letters. The size was then increased one step. If four of the five characters at that size were named correctly, the size was recorded as the acuity in that eye. If not, the size was increased until that standard was attained. Subjects who were unable to identify letters at the 10/300 size were moved closer to the screen [5 ft (1.5 m)], thus increasing the relative character size, and testing continued as described. The character size for which subjects were able to identify four of five target letters was recorded as the acuity in each eye. The size of the minimum acuity character was converted to minimum angle of resolution (MAR), and log MAR in the better eye was used for further analyses.

3. RESULTS

Table 2 shows the average maximum reading rates for each group by display condition. A 2 (vision group: normal or visually impaired) × 2 (display format) analysis of variance showed a significant effect of vision group [$F(1, 24) = 31.01$, $P < 0.0001$], a marginal effect of display format [$F(1, 24) = 3.69$, $P = 0.067$], and a significant interaction between vision group and display format [$F(1, 24) = 16.72$, $P = 0.0004$]. Only the normal-vision group read faster from the RSVP display than from the scroll display [$t(9) = 3.54$, $P = 0.006$].

The data of Rubin and Turano[5] show that low-vision readers behave differently when reading from a RSVP display, depending on the status of their central field. Specifically, those with CFL make intraword saccades, and their increase in reading rate when compared with a standard text display is much smaller (50% versus 200% for low-vision subjects with no CFL). To make the same comparison with these data, a 2 (status of central field) × 2 (display format) analysis of variance was conducted. Because none of the normal-vision subjects had CFL (and because their data are not relevant to this comparison), they were excluded from the analysis. As expected, there was a main effect of status of the central field [$F(1, 14) = 73.76$, $P < 0.0001$]. Those with no CFL read faster than those with CFL. However, there was no effect of display format and no interaction between these variables (both F values were less than 1.5).

RSVP-gain, defined as the ratio of RSVP rate to scroll rate (after Rubin and Turano[5]), is also given in Table 2 and is displayed in Fig. 1. The advantage of using this metric over using the reading rates for the two displays is that it allows a direct comparison of the relative change in reading rate across the two conditions. A 10-wpm change in reading rate for a visually impaired observer reading scrolled text at 30 wpm is far more important than this same 10-wpm change for a normal-vision subject reading scrolled text at 300 wpm. RSVP-gain controls for this difference and provides a better description of the important changes in reading rate. Therefore it was used in the following analyses. There was a significant effect of vision group on RSVP-gain [$F(1, 24) = 11.55$, $P = 0.002$]. When the means for each group were compared with 1.0, only the RSVP-gain for the normal-vision group was significantly different from 1.0 [$t(9) = 3.32$, $P = 0.009$]. This result was expected, based on the analysis of the difference in reading rate across the display conditions within this group. However, the finding of no difference for the visually impaired group regardless of the analysis (absolute or relative difference) was surprising. As discussed above, visually impaired readers are approximately 15% faster for scrolled text[9] and 80% faster for RSVP[5] when compared with reading

Table 2. Average Maximum Reading Rates (Standard Error of the Mean) in wpm for RSVP and Scroll Displays and Average RSVP-Gain by Vision Group

Subject Group	N	Display: RSVP	Display: Scroll	RSVP-Gain
All subjects	26	271.8 (40.00)	244.4 (29.14)	1.03 (0.07)
Normal vision	10	469.1 (41.68)	368.0 (25.08)	1.28[a] (0.08)
Visually impaired	16	148.5 (32.32)	167.2 (32.09)	0.87 (0.08)
CFL	11	72.5 (11.67)	93.2 (19.87)	0.83 (0.10)
No CFL	5	315.7 (40.29)	330.0 (23.45)	0.97 (0.14)

[a]This value differed significantly from 1.0 [$t(9) = 3.32$, $P = 0.009$].

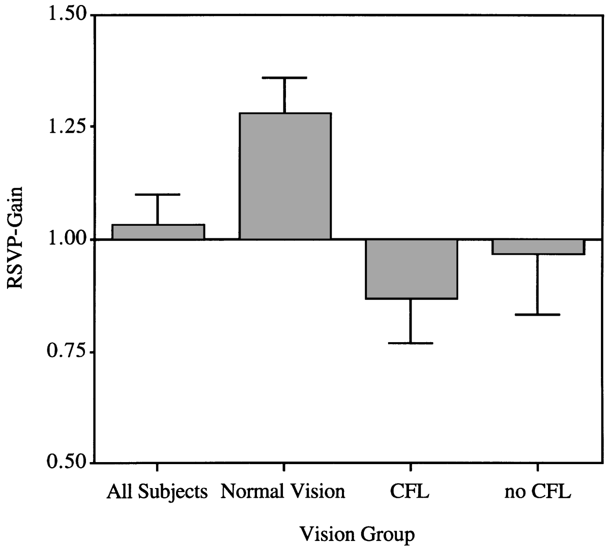

Fig. 1. Average RSVP-gain by vision group. The error bars indicate standard errors of the mean. As with the direct comparison of reading rate between RSVP and scroll displays, the analysis by RSVP-gain shows that only the normally sighted subjects read RSVP faster.

a full page of text. In addition, more eye movements are required for reading from the scroll display. Therefore low-vision observers should have been faster when reading from the RSVP display in this comparison. Surprisingly, they read (nonsignificantly) slower from the RSVP display.

A comparison of RSVP-gain based on status of the central field also failed to show the predicted result. Based on the Rubin–Turano[5] data, the RSVP-gain for readers with no CFL should have been greater than the RSVP-gain for readers with CFL because the former do not make eye movements when reading from the RSVP display. This was not the case [$F(1, 14) < 1.0$]. Any difference may have been masked because of the small number of subjects with no CFL. However, neither the CFL nor the no-CFL group had an average RSVP-gain different from 1.0 [$t(10) = -1.78$, $P = 0.110$; and $t(4) < 1.0$, respectively]. This result can be seen in Fig. 1. It is interesting that, although the CFL group did approach significance in this analysis and may have suffered from a small sample size, the change is in the direction opposite that predicted. Power analyses designed to evaluate whether differences from 1.0 would have been seen given the small sample sizes indicated that, for the CFL group, there was adequate statistical power (0.58), given the large effect size ($d = 1.11$). Because of the small number of subjects with no CFL, there was almost no power associated with the analysis (0.04). However, given the small effect size ($d = 0.24$), a sample of 45 would have been required for a power level of 0.15, and 250 subjects would have been required for attaining the same level of power available for the CFL group. Thus it is reasonable to conclude that RSVP-gain is not likely to differ from 1.0 for either of these groups.

In addition to the analyses of reading rate, it was also important to determine what relationship, if any, existed between RSVP-gain and acuity. It is possible that reduced acuity alone eliminates the possible benefit of the RSVP display relative to the scroll display. Figure 2 shows these data. When taken as a group, these data show that there was a significant relationship between log MAR and RSVP-gain ($r = -0.554$, $P = 0.003$). This result is probably due to the difference in both degree and direction of RSVP-gain between the normal and the visually impaired groups. Within each of these groups there was no relationship between acuity and RSVP-gain.[26]

4. DISCUSSION

A direct comparison of reading rates for scroll and RSVP displays revealed no difference in performance for readers with acuity worse than 20/50 in their better eye. Only those subjects with normal vision were able to benefit from the elimination of the need to make eye movements inherent in viewing the RSVP display.[3] This finding is quite surprising in view of previous reports of reading rates for these two display formats relative to a page display. This discrepancy may be due to the relatively high RSVP reading rates that Rubin and Turano[5,14] reported for both their normal and their visually impaired subjects. For normally sighted subjects they reported an average RSVP reading rate for single sentences, presented with characters of approximately the same retinal size used here, of more than 1000 wpm. Similar rates were reported for a comprehension task. This rate is much faster than those given in previous reports evaluating RSVP reading rates, as Rubin and Turano[14] acknowledge. For example, in her extensive review of reading with RSVP, Potter[3] reported that maximum reading rates with RSVP were approximately 700 wpm. For the normally sighted group in the current study the average reading rate for RSVP was 470 wpm. Although still slower than what would be expected based on the literature, this rate is probably due to the age of the subjects used in this study.[27]

Our visually impaired subjects also read RSVP text slower than the patients in the Rubin–Turano[5] study. Rubin and Turano[5] reported average reading rates for RSVP text of 270 wpm—again, approximately twice the

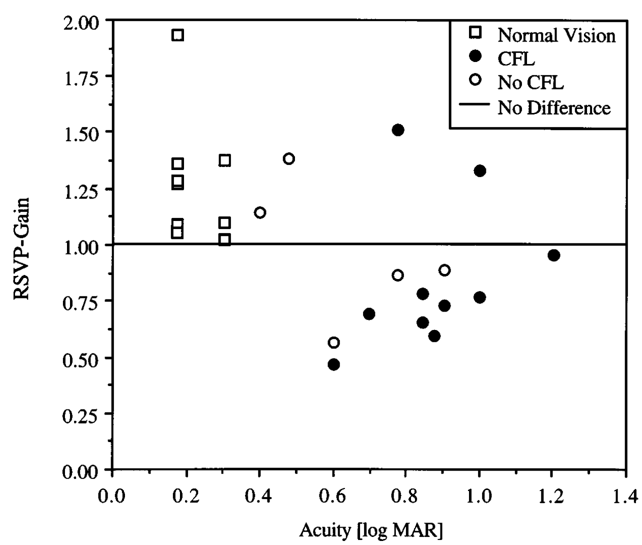

Fig. 2. Relationship between RSVP-gain and log MAR by vision group. Across groups a significant relationship exists. Within the normal-vision and the visually impaired (CFL and no-CFL combined) groups acuity does not predict RSVP-gain.

average rate found in this experiment (150 wpm). There is no reason to believe that the subjects in this study were simply slow readers. Data from a recent report by Fine and Peli,[24] who used the same stimuli and paradigm for determining reading rate as were used in this study, resulted in an average reading rate for scrolled text of just under 110 wpm for a similar patient population. If reading rates for RSVP were overestimated in the Rubin–Turano[5,14] studies, which is possible given their reading rates for normally sighted subjects, the equivalent reading rates that we found for RSVP and scroll displays are reasonable.

Readers with visual impairment but no CFL also showed no benefit from the stable presentation of the RSVP display. Rubin and Turano[5] showed that low-vision readers with no CFL were able to maintain stable fixation and did not make intraword eye movements when reading with RSVP. A comparison of reading performance for those subjects with no CFL showed no difference in reading rate for scrolled text [$t(13) < 1.0$] but a marginally significant difference in reading rates from the RSVP display [$t(13) = 2.32$, $P = 0.037$] when compared with the normally sighted group.[28]

It is possible that the continuous motion of the scroll display benefits visually impaired readers. Studies of dynamic visual acuity have shown an inverse relationship between MAR and the velocity of the stimulus. Long and Homolka[29] found that contrast sensitivity increased for low spatial frequencies (1.0 cycle/deg) for moving stimuli that elicit smooth pursuit eye movements. Targets moving at 30 deg/s required approximately 10% less contrast for detection. Although text is not periodic in nature, Rubin and Legge[30] argued that the fundamental frequency of a line of text is a useful metric, and they defined this frequency as the reciprocal of the center-to-center letter spacing in degrees of visual angle. The retinal character size varied across subjects in this experiment; however, for all the visually impaired subjects, the fundamental frequency of the text (based on the size of a lowercase e) was always less than 1 cycle/deg. Thus the movement of the scrolled text may have made the fundamental frequency of the characters more visible, relative to the same text presented with RSVP, thereby increasing the visual quality of the text for these subjects. Increased visual quality would result in faster reading rates.

The movement of the scroll display may also reduce the usually detrimental effects of reduced eye-movement control for visually impaired observers. Previous research shows that subjects with CFL make intraword saccades when reading from a RSVP display.[5] These intraword eye movements take time both to plan and to execute. For the scroll display, if no planning is required (as argued by Whittaker *et al.*[20]), then reading could be faster from this display format than from RSVP. This contention gains support from Potter's[3] hypothesis that reading is faster from a RSVP display because of the time saved from planning and executing eye movements (see also Chen[13] and Sinclair *et al.*[12] for similar arguments).

Readers with CFL may also benefit from the entrainment of their eye movements. If the scroll display captures the eyes' motion like a typical OKN-producing stimulus,[16,31] this effect may eliminate some of the difficulties in maintaining fixation on the target when these patients are asked to fixate a single letter,[19] thus saving even more time. In addition, if their eyes remain comparatively steadier in relation to the fixated object, the image will be clearer, which should also facilitate reading.[32]

5. CONCLUSIONS

Contrary to expectations based on previous literature and on information about the eye movements required for reading from the RSVP and the scroll displays, observers with visual impairments did not read faster with RSVP. Subjects with normal vision showed the expected benefit when reading from the RSVP display. Inspection of Fig. 2 indicates that 75% of our low-vision subjects either showed no difference in reading rate or read faster from the scroll display. All the subjects with normal vision either read faster with RSVP or read from both displays at the same rate. From this result we conclude that RSVP is read faster than scrolled text by normally sighted observers. This benefit does not extend to readers with low vision. These data also lend support to the idea that the entrainment of the eyes' motion, made possible by the movement of the scroll display, reduces the negative impact of inefficient eye fixations in visually impaired observers with central field loss.

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