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ORIGINAL ARTICLE

Benefits of Rapid Serial Visual Presentation (RSVP) Over Scrolled Text Vary with Letter Size

ELISABETH M. FINE, PhD and ELI PELI, MSc, OD

Wilmer Eye Institute, Johns Hopkins University, Baltimore, Maryland (EMF), and Schepens Eye Research Institute, Harvard Medical School, Boston, Massachusetts (EP)

ABSTRACT: We previously reported that low vision readers do not benefit from a rapid serial visual presentation (RSVP) display relative to a scroll display. Each reader in those studies was presented with only one letter size, and it was the same for both displays. In the current study, we systematically varied the size of the letters and compared reading rates from the 2 displays for letters that were 2, 4, 6, 8, and 10 times each reader's acuity threshold. Using this paradigm, we found that subjects with normal vision (n = 12) read faster with RSVP for all text sizes. Low vision subjects (N = 20) showed no benefit of RSVP until the text was at least 8× their acuity threshold. As in our prior studies, there was a great deal of variability within the low vision group, and for a small number of subjects (25%), reading was faster from the scroll than from the RSVP display. (Optom Vis Sci 1998;75:191–196)

Key Words: reading, low vision, dynamic text displays, acuity reserve

Although possible, reading is difficult when the letters to be read are just at the reader's acuity threshold. This is true regardless of the visual status of the reader. For observers with normal vision, letters that are about 4× acuity threshold are sufficient to allow for maximal reading rates from a page of text.[1] (Twelve-point type at 40 cm is about 3.5× acuity threshold for a reader with 20/20 acuity.) This needed acuity reserve (AR; letter size in deg/threshold letter size in deg)[2] is likely to facilitate reading because the letters are easier to decipher and a larger span of letters can be used for previewing letter shape and guiding eye movements. In their review of the literature and clinical practice, Whittaker and Lovie-Kitchin[2] reported that visually impaired readers require letters up to 18× acuity threshold to reach maximal reading rates. It is unclear as yet why low vision readers apparently require so much more AR than do normally sighted readers.

When very large letters are required, only a few words, or sometimes only a few letters, can be seen at one time through a magnifier or on the screen of a closed-circuit television (CCTV). With the advent of computer-based reading aids, much greater magnification is possible. More importantly, it is also possible to present passages of text to readers in nonstandard formats. For example, Legge et al.[3] introduced a scrolling technique that pans the text continuously from right to left across a video screen. As they noted,[3] this display is similar to the consecutive views seen through a magnifier or CCTV when it is scanned across a page. Using this technique, Legge et al.[4] showed that observers with low vision read about 15% faster than when they were presented with the more familiar page display. They surmised that this increase was primarily due to eliminating the need for return sweep eye movements. This eye movement, from the end of one line of text to the beginning of the next, is time consuming and often inaccurate, even for readers with normal vision.[5] In addition to eliminating the return sweep eye movement, low vision readers can attain their maximal reading rates from a scroll display with only about 6 or 7 letters visible at one time[6] (see also ref. 7). This is much fewer than the 13 or more letters required to reach maximal rates with a stand magnifier[8] or CCTV,[9] or for normally sighted readers to read a page of text (at least 17 letters[10]). In our study on window size requirements, the window size required to reach maximal rates with the scroll display was larger than the average number of letters in each word (5.1).[6] This suggests that, like readers with normal vision reading a page of text,[10] low vision readers may gain some benefit from the additional visual information in the scroll display.

When the need for eye movements is eliminated, observers with normal vision read fastest when only one word is presented at a time. This technique, known as rapid serial visual presentation (RSVP), presents each word, one after the other, to the same place on the screen. Because words are presented individually and at the same location, the need to make between-word eye movements (as well as the return sweep) is eliminated. This allows for substantially faster reading rates for readers with normal vision (up to 1200 wpm by some reports),[1, 11] and more modest increases for readers with low vision (about 80% faster than a page display).[12] Unlike normally sighted observers reading small print, readers with central field loss (CFL) made eye movements within words when they read from the RSVP display.[12] Readers with normal vision also made within-word eye movements when the letters were quite large or the display rate quite slow.

The readers with CFL in Rubin and Turano's[12] study required much larger letters to reach their maximal reading rates than did the low vision subjects without CFL. These larger letters may require eye movements simply because a larger portion of the visual field is required to present a single word. In support of this, their data show a strong correlation between letter size (in degrees) and reading rate from the RSVP display for their low vision subjects; as the required letter size for reading increased, reading rate decreased. In addition, as mentioned above, normally sighted readers also made eye movements when presented with very large letters. In fact, their reading rates decreased sharply after reaching a peak when reading rate is plotted against letter size.[1]

It has been reported that low vision readers require letters about 5× their acuity threshold to reach their maximal reading rates from a scroll display,[13] and reading rates for normally sighted subjects peak when the letters are about 0.4° (4.8× acuity threshold for a 20/20 observer[3]). These numbers are quite similar to the 4× letter sizes found to be sufficient for normally sighted observers to read from a page of text. (Rubin and Turano[1] showed no change in reading rate over a wide range of letter sizes, including 4×.) It is also similar to Whittaker and Lovie-Kitchin's[2] estimate of the required AR for reading simple stimuli (such as the sentences used in Legge et al.'s studies). On the basis of these reports, we chose to use letters of 4× acuity threshold or greater (average of about 6×) in our previous studies comparing reading rates from the RSVP and scroll displays.[14, 15] In those studies, we found that observers with normal vision read significantly faster from the RSVP display than they did from the scroll display. However, there was no difference in the mean reading rates between the two displays for readers with low vision.

This was quite surprising to us. Even though low vision readers showed less of an advantage than normally sighted readers when their performance was compared to a page display,[12] we had expected that there would be some advantage when reading from the RSVP display because no between-word eye movements are required. *Post hoc* discussions of this work lead us to discover that we had chosen a range of letter sizes for our experiments that were within a potential cross-over zone in reading performance from the two displays. Fig. 1 shows reading rate by letter size functions for RSVP and scrolled text that have been adapted from data in the literature (Rubin and Turano[1] for RSVP; Legge et al.[7] for scroll). On the basis of our previous data,[14, 15] which showed no difference in reading rates for text from about 4 to 6× acuity threshold, the curves have been vertically positioned so that they overlap for letters 6× acuity threshold. Note that even had we not made this shift, the different shapes of the functions would still predict changes in the relative reading rates from the two displays across acuity reserves.

As depicted in the figure, had either smaller or larger letters been presented to our subjects (in terms of acuity reserve), we might have expected to see a difference in reading rates between the two displays. The first goal of the current study was to test this hypothesis. We asked our subjects to read from RSVP and scroll displays over a range of letter sizes determined on the basis of their acuity.

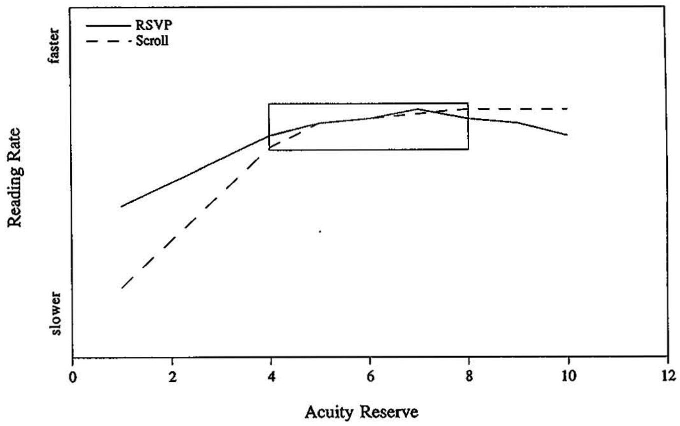

FIGURE 1.
Reading rate by letter size (expressed as AR) functions adapted from the literature (RSVP[1], scroll[7]). The curves have been shifted vertically to account for our previous finding[14, 15] that there was no difference in average reading rates between the RSVP and scroll displays for low vision observers.

The second goal of this study was to determine if the concept of AR, as proposed by Whittaker and Lovie-Kitchin,[2] is a reasonable metric to use in predicting reading performance. As Rubin and Turano[12] showed for their low vision readers, the larger the necessary letter size to reach maximal rates—regardless of the subject's acuity—the slower they read. Using our current design, we will be able to determine how acuity and AR interact to affect reading rate, and thus test Whittaker and Lovie-Kitchin's idea that, for readers with low vision, performance can be predicted in terms of their functional reserve.

METHODS
Subjects

A total of 32 volunteers over the age of 55 completed the study. Each subject was read to and signed an informed consent before testing began. They were separated into two groups on the basis of their acuity, which was determined monocularly in the laboratory using a Mentor B-VAT II (Mentor O&O, Inc., Norwell, MA). Observers identified letters, presented individually and in random order on the monitor of the B-VAT II, from a distance of 10 ft. Five letters were presented one at a time at each size, and the size was reduced until fewer than four were named correctly. The size one step above was recorded as the acuity in that eye, and testing was repeated in the fellow eye. Subjects with acuity of 20/40 or better in at least one eye were defined as having normal vision (N = 12); low vision was defined as acuity of 20/60 or worse in the better eye (N = 20). Thirteen subjects had documented CFL and 1 had recorded field loss due to glaucoma. The others had no reported field loss. We limited the low vision subjects to those with acuity of 20/200 or better so that we could present them with text at a wide range of ARs. Three subjects with acuity worse than 20/200 were tested over a limited range of ARs, but their data are not presented here. Data from these subjects can be found in a preliminary report of this study.[16] Table 1 shows the average age and acuity of each group.

TABLE 1.
Mean (±SEM) age, logMAR (Snellen equivalent), best AR, and maximal reading rate for each display format

Subject Group	Age (yr)	Acuity		RSVP		Scroll	
		Mean	Media N	Best AR	Maximum wpm	Best AR	Maximum wpm
Normal vision	73 ± 2.0	0.12 ± 0.03 (20/26)	0.10 (20/25)	5.5 ± 0.66	460 ± 41	6.2 ± 0.72	331 ± 24
Low vision	71 ± 2.2	0.69 ± 0.04 (20/98)	0.65 (20/90)	6.6 ± 0.67	230 ± 35	6.1 ± 0.69	186 ± 22

Apparatus

We used a modified Horizon Low Vision Magnifier (Mentor O&O, Inc., Norwell, MA) to determine reading rates. Modifications to the system allowed us to display both RSVP and scrolled text, and to precisely control letter size and display rate. Specifics regarding the modifications can be found elsewhere.[14] Black cardboard was attached to the TV cabinet in order to limit the horizontal extent of the screen (see below).

All subjects were presented with white text on a black background. For the low vision group, the text was presented on a 26 inch Sony color television monitor. The average (Michelson) contrast of the text was 96%. The readers in the normal vision group were shown the text on a 5 inch Tektronix 634 monochrome monitor because the pixel resolution of the larger TV did not permit us to display small enough letters. The contrast of the text on that display was 95%.

Design and procedures

Observers read aloud sentences selected from an expanded MNRead corpus.[4] No sentence was seen more than once by a given observer. Reading was binocular under all conditions. Whenever possible, given the constraints of the room within which we were testing, AR was varied by changing the seating distance of the reader. Seating distances ranged from 37.5 to 315.2 cm. Clip-on lenses were available for those subjects who indicated difficulty focusing at the closest seating distances. When AR could not be varied appropriately by changing seating distance, we also changed the physical size of the letters. In order to have the same average number of letters (13; the longest word in any of the sentences) visible on the screen in the scroll display for all ARs, the screen size was limited using black cardboard occluders attached using hook-and-loop tape. Display duration for the scroll display is calculated for the entire screen width (see ref. 14 for discussion). Occluding a portion of the screen decreases the time that the stimulus is visible to the observer. This increases the display rate in words per minute because the sentence is visible to the reader for a shorter period of time, and was accounted for in the data.

All observers read from both the RSVP and scroll displays with letters corresponding to ARs of 2, 4, 6, 8, and 10. AR was determined on the basis of the acuity in each subject's better-seeing eye. AR was calculated by taking the ratio of the acuity threshold letter size (in degrees) to the letter size of the text (in degrees). For example, a 10× target letter for a subject with 20/20 acuity is 0.833°. For a subject with 20/100 acuity, this 0.833° letter results in an AR of 2. The order of AR and display format was counterbalanced across subjects. All ARs within a given display format were completed before reading began in the other format, and the order of ARs was the same for both formats. If unable to read one of the text sizes (7 subjects with low vision were unable to read with an AR of 2 and 2 with an AR of 4), a score of 0 wpm was recorded, and testing continued with the remaining ARs for that display format.[a] Observers who were not able to read using at least three of the AR text sizes from both display formats are not included in these analyses.

Maximum presentation rate was determined for each of the 10 combinations of AR × display format using a modified staircase procedure. Details can be found elsewhere.[15] Briefly, we presented subjects with sentences at increasing presentation rates until they were no longer able to read a given sentence with fewer than two errors. The rate and step size were then decreased and testing continued through two reversals. The fastest rate at which a subject could read a sentence with fewer than two errors was defined as their maximal reading rate for that condition. We also asked subjects to read two additional sentences at their maximal rate for each condition to assure good performance at that rate. All subjects were able to read with fewer than 2 errors at these rates, and data from these sentences were not included in the analyses.

RESULTS

Fig. 2 shows the mean reading rates by AR and display format for the two subject groups (normal and low vision). An analysis of reading performance within the low vision group showed a main effect of central field status (those with CFL read more slowly; $F_{1,18} = 5.23$, $p < 0.05$), but no interaction between central field status and either display format ($F_{1,18} = 1.53$, $p = 0.23$) or AR ($F_{4,72} < 1.0$). The three-way interaction also failed to reach significance ($F_{4,72} = 1.23$, $p = 0.31$). Therefore, the low vision data have been collapsed across central field status in the remaining analyses.

The data for ARs of 2 to 10 for all subjects were included in a 2 (subject group: normal or low vision) × 2 (display format: RSVP and scroll) × 5 (AR) mixed model analysis of variance (ANOVA). Not surprisingly, the group with normal vision read faster than the low vision group ($F_{1,30} = 22.96$, $p < 0.001$). There was also a main effect of display format, indicating that sentences were read faster when they were displayed with RSVP ($F_{1,30} = 29.81$, $p < 0.001$), and a significant interaction between these two variables ($F_{1,30} = 7.78$, $p < 0.01$). However, unlike our previous studies,[14, 15] when we looked at the data from the two groups sepa-

[a] Because we used single letter acuity to calculate AR, it is not surprising that some subjects were unable to read sentences even with an AR of 4. Although each individual letter was above the reader's acuity threshold, they may not have been sufficiently so to overcome factors such as lateral masking.[17]

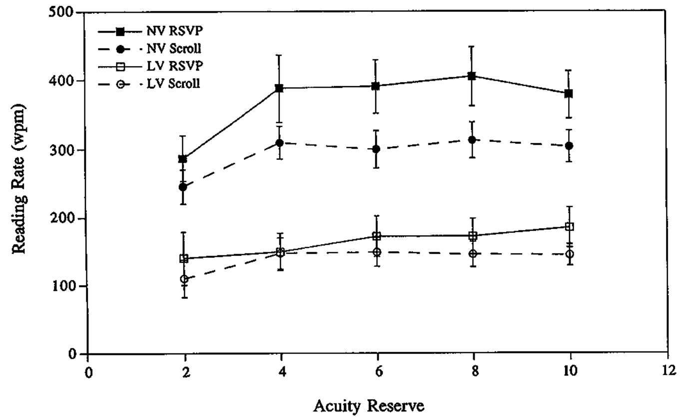

FIGURE 2.

Reading rate in words per minute (mean ± SEM) for the normally sighted and low vision groups by display format and AR. For the low vision group, reading rates differed between the two displays only at ARs of 8 and 10. The normally sighted group always read faster from the RSVP display.

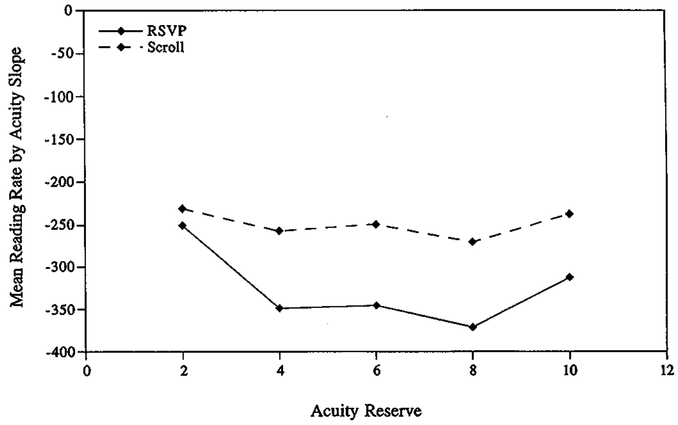

FIGURE 3.

Slopes of reading rate (in words per minute) by acuity for each of the ARs tested by display format. Slopes were fairly constant for the scroll display, but were quite different at AR 2 and 10 for the RSVP display.

rately, we see a main effect of display format for both, indicating that across ARs, RSVP was read significantly faster than the scroll display ($F_{1,11} = 29.14$, $p < 0.001$ for normal vision; $F_{1,19} = 4.58$, $p < 0.05$ for low vision).

In order to determine whether the choice of letter size in our prior studies could account for the equivalent reading performance from the two display formats among low vision subjects, we compared reading rates between the two displays at each of the ARs tested. Reading rates from the RSVP and scroll displays were not significantly different when low vision subjects were presented with letters up to 6× their acuity threshold (all t's < 1.7, all p's > 0.11). When the letters were 8 or 10× acuity threshold, these subjects, as a group, read faster from the RSVP display (t's > 2.19, p's < 0.05). This confirms our hypothesis that the letter size we chose to use (AR 4 minimum, AR 6 average) may have lead to our previous null results. Even so, 4 (20%) of the low vision subjects showed no difference in reading rates from the two displays across ARs, and 4 read faster with the scroll display than the RSVP display when we looked at their maximal reading rate for each (see Fig. 4 and discussion below). For the readers with normal vision, RSVP was read faster than the scroll display at all ARs (all t's > 2.4, p's < 0.05).

This study was also designed to evaluate the usefulness of the AR concept. Whittaker and Lovie-Kitchin[2] proposed that we could evaluate reading potential by looking at the functional reserve available to the observer. One way to test this hypothesis is to determine if the changes in performance that we see with acuity are constant at different ARs. If the functional reserve available to a reader (in this case, AR) explains a large portion of the variability in reading rate across subjects, then the difference in reading rate we see between two readers with different acuities should be the same across ARs. Of course, this only holds for slower reading rates because there are limits to how fast one can read even under optimal conditions. To test this idea, we calculated the slope of the reading rate by acuity functions for each of the ARs we tested (Fig. 3; the slopes were calculated from the data of all of the subjects who contributed complete data to this study). If relative reading rates are constant across ARs (the differences between any two subjects are the same), the slopes of these functions should be the same. For the scroll display, this was the case, indicating that changes in reading rate due to acuity are fairly constant across the ARs we tested. This finding provides some support for Whittaker and Lovie-Kitchin's[2] proposal. However, for the RSVP display, the slopes are not the same. We see a decrease in slope for both the smallest and largest ARs we tested. This indicates that the reserve available to the reader is not a consistent predictor of performance when reading from the RSVP display.

The figure also shows that the average slopes for the two displays are quite different (−325.8 ± 47.0 for RSVP; −248.9 ± 15.6 for scroll). When reading from the RSVP display, decreased acuity resulted in a greater decrease in reading rate within each AR than when reading from the scroll display. The most likely reason for this is the much faster reading rates normally sighted observers are able to attain when reading RSVP than when reading scrolled text.

DISCUSSION

The data presented here indicate that, on average, RSVP is read at faster display rates than scrolled text by low vision observers (acuity 20/60 to 20/200) when the text is quite large relative to their acuity thresholds. When we look more closely at our data, we find that those readers who reached their maximal rates with smaller text read faster from both displays (see Table 2). This is in agreement with the data of Rubin and Turano,[12] who found that subjects who required larger letters to reach their maximal reading rates read more slowly. The same is true of readers with normal vision. The fastest readers in that group reached their maximal rates with ARs of 4 and 6, and the readers who required larger letters (ARs 8 and 10) read more slowly. For the readers with low vision, there was no relationship between acuity and the AR required to read at a maximal rate (r = 0.03 and 0.14 for RSVP and scroll, respectively, both p's > 0.56). This indicates that the necessary reserve required to read from these displays is not related to the observer's acuity. There is not a sufficient range in acuity to perform a similar analysis for the normal vision group. (Analyzed across all subjects, the correlation coefficients for the RSVP and

TABLE 2.
Number of subjects reaching their maximal reading rates for each AR and the mean rate attained by subject group and display format

Subject Group		RSVP					Scroll				
		AR 2	AR 4	AR 6	AR 8	AR 10	AR 2	AR 4	AR 6	AR 8	AR 10
Normal vision	Subjects	1	5	3	2	1	1	4	1	5	1
	No. wpm	451	481	512	426	277	352	290	510	338	260
Low vision	Subjects	3	4	3	4	6	4	5	2	4	5
	No. wpm	402	195	233	198	187	283	192	120	158	152

scroll displays were 0.15 and 0.05, respectively, neither of which was statistically significant.)

An important implication of these data is that comparisons of reading rates between different displays must be done over a range of letter sizes. In our earlier reports[14, 15] we tested our subjects at one letter size only. From that, we concluded that there was no difference in reading rates between the RSVP and scroll displays for low vision readers as a group. When we combined the data across those two studies, we found that many of the subjects did read faster from one of the two displays. About 59% read at least 10% faster from the scroll display, and about 32% read at least 10% faster with RSVP (25% of the subjects who read faster with RSVP read at least 30% faster than they did from the scroll display). To make a similar comparison here, we looked at the AR for which each subject attained the most benefit from RSVP (the ratio of reading rates from the RSVP and scroll displays, which we[14] have called RSVP-gain), as well as the RSVP-gain calculated from each subject's maximal reading rates from the two displays (often at different ARs). Only low vision subjects were included in this analysis.

The solid bars in Fig. 4 show the distribution of maximal RSVP-gains, and the stippled bars are the RSVP-gains calculated from each subject's maximal reading rate from each of the two displays. As is evident from the figure, the shapes of these two distributions are quite different. If we look at the distribution of maximum RSVP-gains (calculated for a single AR; solid bars), we see that almost all of the subjects (17, or 85%) read substantially faster from the RSVP display for at least one of the letter sizes. However, if we look at the RSVP-gain derived from each subject's maximal rates (which may have been at different ARs), fewer subjects (10, or 50%) read faster from the RSVP display. Of the remaining subjects, half read from the two displays at the same rate, and the remaining subjects read faster from the scroll display. This again points to the individual variability in reading performance among low vision observers and the need for careful assessment of reading ability across display formats.

This study has also shown that the concept of AR^2 can, at best, serve as a guiding principle to predict reading potential. Although not a substantial number, 15% of the subjects in the current study attained their maximal reading rates when the text was only 2× their acuity threshold. Equally important, many of the subjects (in both groups) showed nonmonotonic changes in reading rate across the ARs we tested, once again arguing for systematic testing of reading ability at several letter sizes.

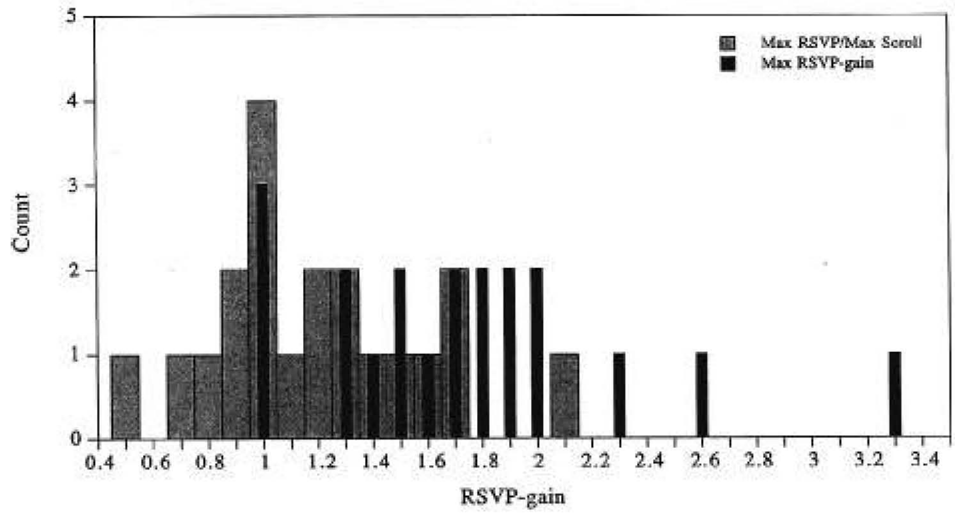

FIGURE 4.
Distribution of RSVP-gains (RSVP reading rate/scroll reading rate) for the low vision subjects. The solid bars are the maximum RSVP-gain attained across ARs. The stippled bars are for RSVP-gains calculated from each subject's maximal reading rate from each of the two displays.

CONCLUSIONS

Normally sighted observers read faster from an RSVP than a scroll display for all letter sizes tested. For readers with low vision (acuity 20/60 to 20/200), optimal reading performance was both display- and letter size-dependent. This finding argues for more systematic testing of reading ability across a range of letter sizes before determining the reading potential for a given patient and the rehabilitative potential of a display device.

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Elisabeth M. Fine
550 N. Broadway, 6th Floor
Baltimore, Maryland 21205
email: fine@lions.med.jhu.edu