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Simulated Cataract does not Reduce the Benefit of RSVP

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Normally sighted younger and older (mean age 71 years) observers read sentences and random lists of words from a rapid serial visual presentation (RSVP) display and a scroll display using their normal vision and through two levels of cataract simulators. Unlike patients with central field loss (CFL), there was no decrease in the benefit of RSVP with reduced vision due to the cataract simulators. However, the usefulness of sentence-level context was reduced as visual acuity was reduced. In addition, older readers did not benefit as much from RSVP as younger readers, and many in the older group were unable to read using the more severe cataract simulators from either display format. From these data we conclude that the benefits of RSVP are not reduced with reduced acuity and contrast sensitivity, and that there are age-related changes in reading rates from dynamic text displays not related to acuity. © 1997 Published by Elsevier Science Ltd

Reading   Rapid serial visual presentation   Low vision   Simulated cataract

INTRODUCTION

Recently, we (Fine & Peli, 1995b) reported that, unlike readers with normal vision, readers with visual impairments do not benefit from a rapid serial visual presentation (RSVP) display, relative to a display that scrolls the text continuously from right to left across the screen. The primary benefit of RSVP is that, because each word is presented to the same place in the visual field, no eye movements are necessary to read (Rubin & Turano, 1994; Potter, 1984). Rubin and Turano (1994) have shown that observers with central field loss (CFL) make eye movements within words when reading from an RSVP display. These eye movements would be expected to substantially slow reading rates, and their data show that readers who made more intra-word eye movements read more slowly from both the RSVP and static page displays used in their study. In addition, the relative benefit of RSVP (RSVP-gain) was reduced for those subjects who made more eye movements within words.

In our prior study (Fine & Peli, 1995b), readers with visual impairments and no CFL also showed no benefit of RSVP relative to scrolled text. However, there were very few readers in this group (five), and in a subsequent study (Fine, 1995; Experiment 2) visually impaired observers with no CFL read RSVP about 85% faster than they read scrolled text, similar to the benefit shown by normally sighted readers in the same study. (Again there were only five observers in this group.) In addition, while Rubin and Turano's (1994) visually impaired subjects with no CFL showed significantly greater RSVP-gains than their CFL counterparts, the benefit they derived from the RSVP display was substantially less than it was for readers with normal vision (Rubin & Turano, 1992).

Also important is that unlike readers with CFL in our two prior studies (Fine & Peli, 1995b; Fine & Peli, 1996), for visually impaired readers with no CFL there was a significant negative correlation between RSVP-gain and acuity, such that those readers with worse acuity (larger MAR) benefited less from RSVP [$r = -0.667$, $P = 0.033$]. While there was no overall difference in acuity between the subject groups in our two prior studies to explain the disparate results, the trend was in the right direction (the group that showed substantial RSVP-gain had somewhat better acuity).

Because we did not specifically manipulate acuity, and so few of our visually impaired patients had no documented CFL, we cannot make strong conclusions regarding the relationship between reduced acuity and RSVP-gain on the basis of our prior data. However, what data we do have indicate that as acuity is reduced, so too are the benefits derived from the RSVP display. This trend does not support the hypothesis put forth by Chen (1986), that when the need for eye movements is eliminated (when reading with RSVP), more processing resources are available to support other tasks related to reading. This would predict larger RSVP-gains as visual ability is reduced.

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TABLE 1. Mean (range) age and acuity for each subject group

		Mean snellen acuity (range)		
Age group	Mean age (range)	Normal vision	Middle vision simulators	Low vision simulators
Younger	29(24–42)	20/16(20/15–20/20)	20/56(20/40–20/70)	20/169(20/125–20/200)
Older	71(62–78)	20/24(20/15–20/40)	20/84(20/50–20/100)	20/250(20/160–20/600)

Acuity was measured with habitual correction and while wearing the two different cataract simulators. The younger subjects had better acuity under all vision conditions.

In order to test the relationship between RSVP-gain and acuity, we asked normally sighted observers to read with two levels of cataract simulators (as well as their natural vision). We chose to use normally sighted readers, instead of patients, in order to have more direct control over the acuity of our readers, and to ensure that no other ocular pathologies contributed to reading performance. We will refer to three different vision conditions: normal vision (habitual correction); middle vision (moderate cataract simulators); and low vision (severe cataract simulators). This technique allows us to make within-subjects comparisons across both display formats and acuity levels, thereby reducing the between-subjects variability that can often mask important differences.

In addition to investigating the relationship between acuity and RSVP-gain, we will also look at how changes in the quality of the visual stimulus affect the readers' ability to use context. Patberg *et al.* (1981) found that for beginning readers, decoding the visual stimulus consumes most of their available processing resources. Because of this, beginning readers do not make use of contextual information. Baldesare & Watson (1986) have made a similar assumption about readers with low vision: specifically, that decoding the visual stimulus in the presence of visual impairment requires more of the finite processing capacity available to the reader. This would limit the amount of input from other sources (such as context) that also require resources from the same finite capacity. On the other hand, Whittaker & Lovie-Kitchin (1993) have proposed that low vision readers are more likely to use context to compensate for the reduced visual input when only poor quality visual information is available.

To test these competing hypotheses, we asked our observers to read both sentences and lists of random words from both display formats and under all three vision conditions. Past research has shown that, not surprisingly, sentences are read faster than random lists of words, regardless of stimulus quality (see, e.g. Legge *et al.*, 1989; Fine & Peli, 1996). This advantage of sentences over random words is due, at least in part, to the additional information the reader can gather from the syntactic and semantic content of sentences. If we calculate the ratio of rates for reading sentences and random words, and sentences are read faster, this ratio will be greater than 1.0. We will call this ratio sentence-gain, and it will be used to determine to what extent readers are able to use context when reading. On the basis of Baldesare and Watson's (1986) hypothesis, we would predict that sentence-gain would be reduced as acuity is reduced. Whittaker & Lovie-Kitchin (1993) would predict the opposite.

We will also be able to determine if the usefulness of context is display-format dependent. In his initial report on RSVP, Forster (1970) showed that at the same display rates, more words were remembered correctly from simple six-word sentences than from strings of six random words. This same pattern was seen when similar stimuli were typed with reduced contrast and presented as a stationary line of text. Subsequent investigations have shown that the effects of context on reading rates for RSVP are more robust than when reading from a page of text presented at the same level of contrast (see Potter, 1984 for a review). The relative benefit of context when reading from a scroll display has not yet been reported.

In addition to comparing RSVP-gain and sentence-gain for different levels of acuity, we also examined whether age interacts with reduced acuity, display format, and the usefulness of context in determining reading rates. This question is particularly important in light of the fact that most visually impaired people are elderly. While a recent study by Akutsu *et al.* (1991) shows no difference in reading rates between older and younger subjects under optimal reading conditions, most studies (see, e.g. Madden, 1992) have shown that, all else being equal, older observers identify words and read more slowly than younger observers.

METHODS

Subjects

Twenty-five paid volunteers with normal or corrected-to-normal vision were recruited to participate in this study. They were divided into two groups on the basis of their age: younger than 50 years ($n = 13$) and older than 55 years ($n = 12$). The data from one subject in the younger group were not included in the final analyses because of failure to complete the experiment. Table 1 displays the average age of each subject group, as well as their average acuity in the three vision conditions. The younger group had better acuity in each vision condition.

Apparatus

We used a modified Horizon Low Vision Magnifier (Mentor O&O, Inc., Norwell, MA) interfaced with an

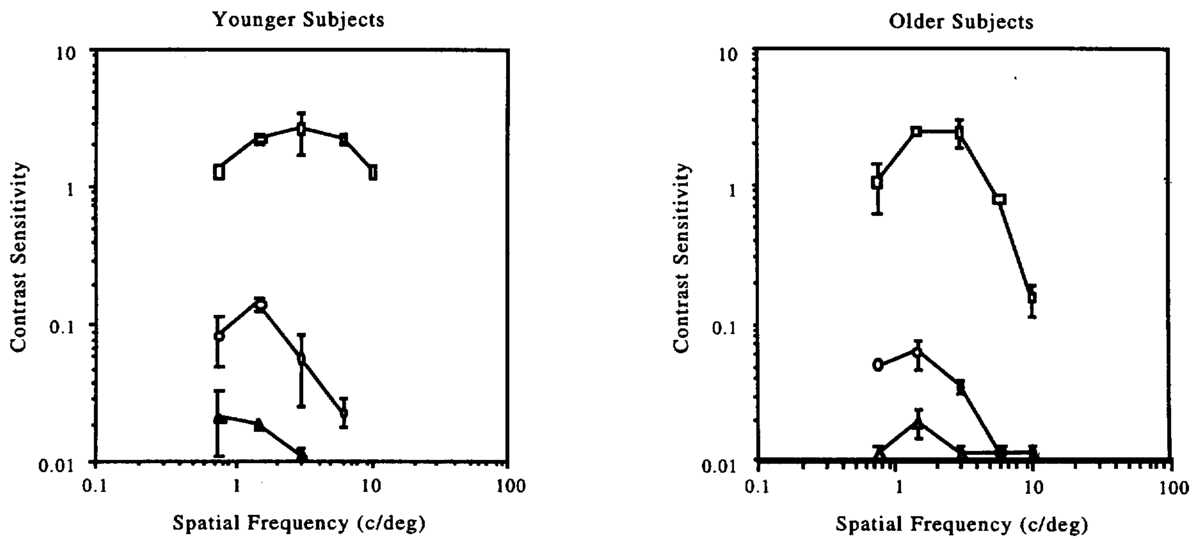

FIGURE 1. Average CSF of two younger (left) and two older (right) subjects with their normal vision and wearing the two cataract simulators. □: normal vision; ○: middle vision; △: low vision. The error bars represent the range of the data for the two subjects. Note that sensitivity was reduced most at high spatial frequencies, but that the older subjects also became insensitive to the very low spatial frequencies when wearing the low vision simulators.

IBM-compatible PC to present the text. The modifications allowed us to display text using RSVP and to control the timing of the display in both formats. A complete description of these modifications can be found in Fine & Peli (1995b). A Mentor B-VAT II was used to measure acuity and contrast sensitivity.

The text was displayed on a 27 in. Sony color television monitor using reverse polarity (white characters on a black background). Up to 13 proportionally spaced characters, generated using a Bitstream™ sans serif font, could be displayed simultaneously at the magnification used. A lower-case "e" measured 5.6×4.1 cm. Its angular subtense in the normal vision and middle vision simulator conditions was 1.8×1.3 deg. When using the low vision simulators, subjects sat closer to the screen and the retinal character size ranged from 4.9×3.6 deg to 8.4×6.1 deg depending on seating distance (see below). Measured with a Minolta LS100 light meter, which uses a 1 deg test spot, the luminance of the characters was 231 cd/m^2. The background luminance varied depending on the number of characters displayed; the average was 4.4 cd/m^2 with a standard deviation of 2.71. The average (Michelson) contrast of the display was 96%.

Cataract simulators. Two sets of cataract simulators that varied in thickness were created using milky-white, light-scattering filters (Vistech Consultants, Inc., Dayton, OH). A number of filters were superimposed and mounted on frames. The amount of light scatter increases as the number of filters increases, which results in a greater reduction in contrast sensitivity across spatial frequencies. The number of filters superimposed for each vision condition (middle and low) was selected in order to obtain the desired acuity levels (20/60 and 20/200 for the middle and low vision conditions, respectively) in the younger subjects.

We measured contrast sensitivity functions (CSFs) through the simulators for two representative subjects of each age group in order to assess changes in sensitivity across spatial frequencies (Fig. 1). Each data point is the contrast threshold determined using a three-alternative forced-choice staircase procedure with four reversals, available with the Mentor B-VAT II. The first reversal was eliminated and the remaining three averaged within each subject. As can be seen in the figure, there was a marked reduction in contrast sensitivity at all spatial frequencies when observers wore the cataract simulators. Using the middle vision simulators, these subjects were unable to see the 10 c/deg stimulus at the highest possible contrast (98%). With the low vision simulators, the stimuli with spatial frequencies higher than 3 c/deg were not visible. At the lowest spatial frequency (0.75 c/deg), there was an approximately 1.0 log unit decrease in contrast sensitivity from normal vision with the middle vision simulators and about a 1.5 log unit drop with the low vision simulators for the younger observers, while the older observers showed even greater decreases. While wearing the low vision simulators, the sensitivity of the older observers to frequencies other than 1.5 c/deg was almost completely eliminated (see Fig. 1).

Stimuli

Two hundred MNRead sentences (Legge *et al.*, 1989) and 120 lists of random words were used as stimuli. Each of the sentences had between 9 and 14 words and 55 characters, including spaces. The random word lists each had eight nouns, approximately matched in word length and frequency of use (Francis & Kučera, 1982) to the words in the sentences. The nouns were all 3–10 letters long, and the lists contained between 48 and 52 characters and spaces. (More complete statistics regarding these stimuli are reported in Fine, 1995). For both sentences and random word lists, the average word was 5 letters long, and each sentence and list was preceded by a string of five Xs. This additional "word" was included in order to orient the reader to the position of the text at the beginning of each trial. The sentences and lists were randomly divided into groups of 20 stimuli each to accommodate the computer memory limitations of the Horizon.

Design and procedure

Each subject was asked to read in each of the 12 combinations of vision condition (normal, middle, and low), display format (RSVP and scroll), and stimulus type (sentences and random words). More than half (seven) of our older observers were unable to read with the low vision simulators. This was true even though we compensated for their reduced acuity by seating all subjects closer to the screen in the low vision condition.* This was done to maintain an acuity reserve (text character size in deg / acuity threshold character size in deg) of at least 4 while wearing the simulators, which is sufficient to read the simple sentences we presented at maximal rates (Legge *et al.*, 1985; Whittaker & Lovie-Kitchin, 1993). After several of the subjects in the older group proved unable to read with the low vision simulators, we modified the procedure for the older subjects so that the low vision simulation condition was always last. This was done to provide them with as much practice as possible before they encountered the most difficult condition. Even so, they were unable to read under these degraded conditions.

Maximal text presentation rate was determined using an adaptive staircase procedure.† Observers then read five sentences at their maximal presentation rate and any errors were recorded. From this, reading rate was computed. Reading rate was defined as maximal presentation rate × percent correct. The order of display format was counterbalanced across subjects (half read first using RSVP) for both the older and younger groups. The order of vision condition was also counterbalanced for all the younger subjects. While testing of the older subjects began with a counterbalanced design, this was abandoned after the first few subjects were unable to read in the low vision condition. The remaining older subjects read with their habitual correction, followed by the middle and low vision simulators (if they were able). Within each display format, sentences were always read before random word lists to provide some practice with the display format and cataract simulators within the easier of the two reading tasks. The order of the stimulus group for both sentences and random words was randomly determined for each subject.

Before reading in each condition, binocular acuity was measured using the subjects' habitual correction with the appropriate simulator (none for the normal vision condition). Observers were asked to name randomly selected letters displayed individually. The size of the letters was decreased until they could no longer correctly name four of five letters. The size was then increased until at least four letters were correctly named. The corresponding acuity for that character size was recorded as the acuity in that condition.

RESULTS

One clear finding from this study is that many older observers were simply unable to read when presented with substantially degraded vision. This was surprising, since the letter size (in deg visual angle) was adjusted to compensate for acuity loss, and also because the acuity of these older, normally sighted observers wearing the low vision simulators was better than many of the visually impaired readers we have tested in previous studies (Fine & Peli, 1996, 1995a,b; Fine, 1995), who were able to read from these displays.

Because so few of the elderly observers were able to read using the low vision simulators, it is impossible to compare performance for the two age groups across the three vision conditions. Thus, our focus will be on the data from the normal and middle vision conditions, and the low vision condition of the younger subjects will be treated separately.

Question 1: does reduced visual quality reduce the advantage of RSVP?

We have previously argued (Fine & Peli, 1995b) that RSVP-gain, which is calculated for each subject and then averaged within each group, is a useful metric for

*There was a great deal of variability in the acuity measurements for the older age group in the low vision condition. Thus, seating distance (and therefore retinal character size) also varied more. We deemed it more important to maintain sufficient acuity reserve than to have all observers read from the same distance, regardless of their acuity with the simulators. Although there was variability in acuity in the other vision conditions, different seating distances were not necessary to maintain the minimum 4× acuity reserve.

†For the scroll display, testing began at 200, 100 and 20 wpm in the normal, middle, and low vision conditions, respectively. The rate was increased by 40 wpm in the normal and middle vision conditions, and 20 wpm in the low vision condition until two or more words were read incorrectly from a single sentence. The rate was then decreased by 20 (10) wpm, and this step size was maintained until two or more errors were again made on one trial, at which point the step size was again halved, and testing continued as before until the subject again misread a sentence. That rate was then repeated. If the subject made two or more errors on two consecutive sentences, the rate one step slower than the current display rate was recorded as the maximum rate in that condition. The same procedure was used to determine reading rate for random word strings, except that the starting rate was half the maximum presentation rate for sentences. If the subject was unable to read the random word lists at that rate, testing began at the starting rate for the current vision condition (200, 100, or 20 wpm for the normal, middle, and low vision conditions, respectively). Testing for the RSVP display was similar, except that stimulus duration was used to define step sizes instead of words per minute because of the temporal limitations of the 60 Hz display we used. Stimulus duration was converted to wpm for data analyses. Testing began in the normal vision condition at 333 msec (180 wpm) and at 633 msec (95 wpm) in the middle vision condition. The starting step size was 50 msec (3 frames). Because of the expected slower reading rates, it was not necessary to modify the procedure for the low vision condition.

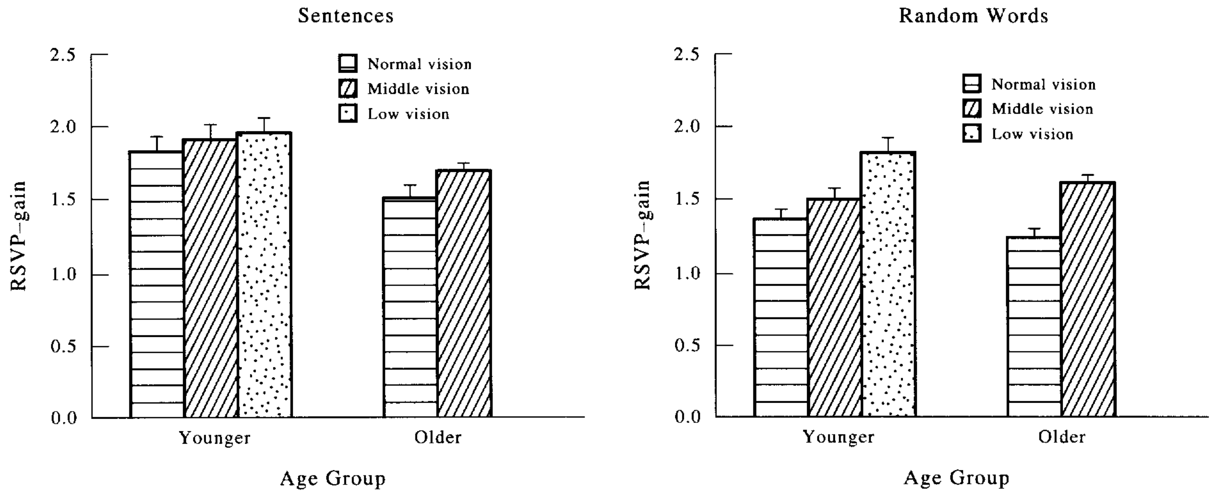

FIGURE 2. Mean RSVP-gains for sentences (left) and random word lists (right) by age group and vision condition. Error bars are standard errors of the mean. RSVP-gain increases as the quality of the visual stimulus decreases.

assessing the advantages of RSVP because it normalizes any differences between subjects in reading rate from the scroll display. Examination of Fig. 2 shows that RSVP-gain is not reduced when reading with the cataract simulators. In fact, there was an increase in RSVP-gain in the middle vision condition relative to the normal vision condition [$F(1,22) = 8.65$, $P < 0.008$] (and a further increase in the low vision condition for the younger subjects). There was no interaction with age group [$F(1,22) = 1.80$, $P = 0.194$] nor stimulus type [$F(1,22) < 1.0$, n.s.]. That is, the increased benefit of RSVP in the middle vision condition was about equal for both age groups, and when reading both sentences and random lists of words.

There was a main effect of age in our analysis of RSVP-gain: the younger subjects gained more benefit from the RSVP display than did the older subjects [$F(1,22) = 6.01$, $P = 0.023$]. In addition, there was a marginally significant interaction between age group and stimulus type [$F(1,22) = 4.07$, $P = 0.056$], such that RSVP-gains for random words did not differ across age groups, but younger subjects showed greater RSVP-gains for sentences. To investigate this further, we looked at reading rates (in wpm) to determine if this was simply the result of slower reading overall by the older subjects or if it was specifically related to reading from the RSVP display.

Figure 3 displays the average reading rates in the normal vision condition for the RSVP and scroll displays by age group. For both sentences and random word lists, younger subjects read faster than older subjects [$F(1,22) = 9.79$ and 25.80, both $P < 0.005$], as one might expect. The primary interest here is whether this overall difference in reading rate varies depending on the display format. There was a significant interaction between age group and display format for both stimulus types [$F(1,22) = 8.58$ for sentences and 7.02 for random words, both $P < 0.02$]. Inspection of the data indicates that this interaction is due to relatively faster reading from the RSVP display in the younger group. This confirms the age difference we found when we analyzed the data using RSVP-gain.

As noted in the description of the subjects, the younger group had better acuity than the older group. Had decreased acuity reduced the benefits of RSVP, then the larger difference in reading rates between the two groups for the RSVP display would not have been surprising. However, it is apparent from our discussion above that this explanation cannot account for these data. To confirm this, we compared reading rates for sentences for the younger subjects using the middle vision simulators to the older subjects using their habitual correction. As can be seen in Table 1, under these conditions, the younger subjects had reduced acuity relative to their older counterparts. Figure 4 displays the relevant data. As can be seen there, reducing acuity among the younger readers equalized reading rates for the two age groups—but only for the scroll display. Thus, it appears that the difference in reading rates from the RSVP display can be explained by the difference in age of the two groups, and not the difference in their acuity. This result leads us to conclude that there are age-related differences in reading rate that are dependent on the display format.

Analysis of the wpm data also shows a significant interaction between stimulus type and age group [$F(1,22) = 6.07$, $P = 0.022$]. As with the marginal trend in the analysis of RSVP-gain, there was little difference in reading rates between the two groups for random words, but the younger subjects read sentences significantly faster. This might imply that younger readers are better able to make use of context while reading; however, our evaluation of sentence-gain (see below), does not support this idea. A more likely explanation is that the younger subjects could not read random words any faster because it is more difficult to consolidate rapidly acquired unrelated units in short-term memory (see, e.g. Potter *et al.*, 1980 for a discussion of memory

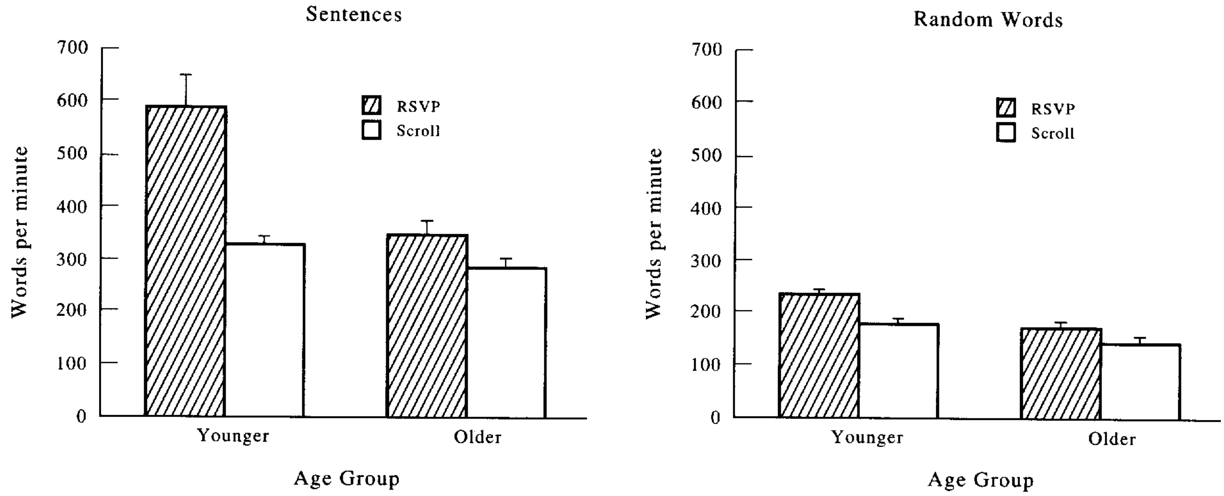

FIGURE 3. Mean reading rates for sentences (left) and random word lists (right) by age group and display format in the normal vision condition. Error bars are standard errors of the mean. Note that the younger subjects not only read faster overall, but there was an even greater relative difference between the age groups when they read from the RSVP display.

limitations in processing scrambled sentences in RSVP). Had this ceiling been higher, there might have been parallel performance for the two age groups across stimulus types. From this we conclude that older readers were not relatively slower when reading sentences than their younger counterparts, but that the younger observers read the random words more slowly than anticipated because of memory limitations.

Question 2: how does visual quality affect the use of context when reading?

To answer this question, we calculated sentence-gain (the ratio of reading rates for sentences to random words) for each subject in each condition and then averaged across subjects within conditions. These data are shown in Fig. 5. A 2 (age group) $\times 2$ (vision condition) $\times 2$ (display format) ANOVA indicated no effect of age [$F(1,22) < 1.0$, n.s.], but significant effects of both vision condition and display format [$F(1,22) = 10.59$ for vision condition and 19.29 for display format, both $P < 0.004$]. Sentence-gain was greater in the normal than the middle vision condition and also greater for the RSVP than the scroll display.

The relatively larger sentence-gains for RSVP than for the scroll display indicate that the usefulness of context is also display-dependent. While the interaction between vision condition and display format did not reach significance when we looked at just the normal and middle vision conditions [$F(1,22) = 1.43$, $P = 0.245$], the data displayed in Fig. 5 show that the gap in sentence-

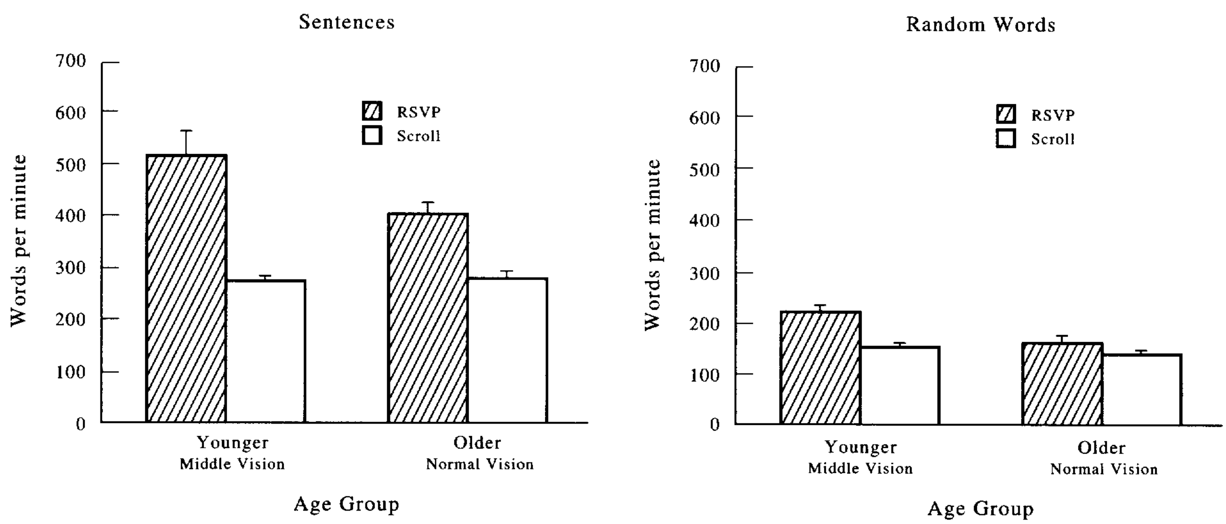

FIGURE 4. Comparison of reading rates for younger subjects in the middle vision condition and older subjects reading with their habitual correction. Sentences are on the left, random words on the right. Error bars are standard errors of the mean. For both stimulus types, reading rates from the scroll display were approximately equal. However, younger subjects continue to read faster from the RSVP display.

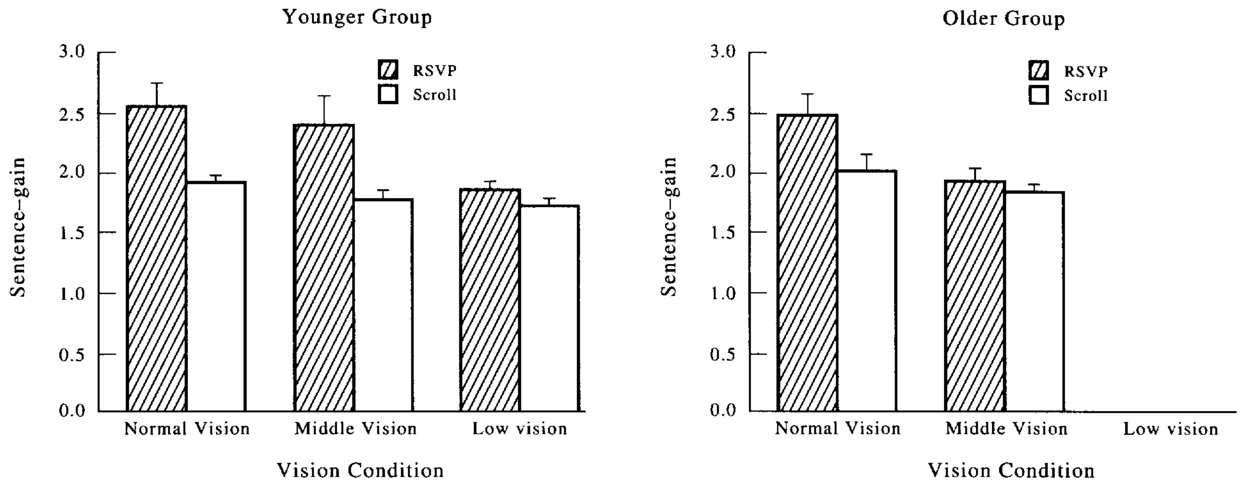

FIGURE 5. Average sentence-gains for the younger (right) and older (left) groups with their normal vision and wearing the cataract simulators. Error bars are standard errors of the mean. Sentence-gain was reduced as visual quality was reduced, especially when reading from the RSVP display. There was no difference in sentence-gain between the two displays for the younger subjects using the low vision simulators and the older subjects using the middle vision simulators.

gain across display formats disappears in the low vision condition for the younger group and the middle vision condition for the older group. This was confirmed with *t*-tests that showed that neither the 13% difference for the younger group nor the 10% difference for the older group was different from chance [both $t < 1.18$, $P > 0.261$].

When the middle and low vision conditions of the younger group are analyzed together with the normal and middle vision conditions of the older group, we see a significant interaction between vision condition and display format [$F(1,22) = 6.27$, $P = 0.020$]. As can be seen in the figure, there is almost no change in sentence-gain when reading from the scroll display across vision conditions, but a significant decrease when reading from the RSVP display.

DISCUSSION

Decreased acuity was correlated with smaller RSVP-gains in the patients with no CFL that we tested in our prior studies (Fine & Peli, 1995b; Fine, 1995). Data from the current experiment show the opposite pattern—decreased acuity resulted in larger RSVP-gains. This supports Chen's (1986) notion that RSVP would provide a greater benefit to less efficient readers if one presumes that reduced visual quality reduces the efficiency with which the physical stimulus can be analyzed.

However, the decrease in sentence-gain with decreased acuity indicates that as the quality of the stimulus is reduced, so too is our ability to use context to facilitate reading, and this was especially true when reading from the RSVP display. This finding supports Baldesare and Watson's (1986) hypothesis that context will be less useful to visually impaired readers because a disproportionate amount of their processing capacity is devoted to analyzing the visual stimulus. However, when a similar study was carried out using patients with CFL, there was no difference in sentence-gain relative to the normally sighted group (Fine & Peli, 1996). This difference between the patients' data and the data from the current simulation study could indicate that context is more useful in the presence of CFL than when other pathologies reduce acuity and contrast sensitivity. It is more likely, however, that the ability to use context to read continuous text in the presence of visually degraded stimuli requires some adaptation to the visual impairment.

As discussed in the Introduction, effective reading using RSVP is strongly dependent on context (see, e.g. Potter, 1984 for a review). At rates that allow for 100% recall of sentences, only 60% of their scrambled versions are recalled (Potter *et al.*, 1980). Potter and her colleagues concluded from these data (among others) that reading at rapid rates from an RSVP display is relatively effective, but that the ability to consolidate the information read for later recall is limited. This idea is supported by Masson's (1983) finding that comprehension for RSVP paragraphs is increased when a short pause (equivalent in duration to one or two words) is included between sentences, slowing the effective rate of presentation for the RSVP display (in wpm). With slower presentation rates (as we have seen in this study in the younger group's low vision and older group's middle vision data), the advantage of context when reading with RSVP is diminished.

Masson's finding could also help explain why younger readers benefit more from RSVP than older readers. If greater processing capacity is required to identify words with age, which is likely given that word identification is slower for older readers (Madden, 1992), the potential reading speeds of elderly observers would be reduced, but only for RSVP. Because reading from the scroll display is inherently slower (at least with normal vision or simulated cataract), no additional time would be necessary to process the individual words. Thus, as we found in the current study, when acuity—and therefore processing difficulty—is equalized, so too are reading rates for the scroll display across age groups.

It remains unclear to us why so many of our elderly observers were unable to read with the low vision simulators. As with the reduced effects of context we found in this study, but not in a similar study using a patient sample (Fine & Peli, 1996), it is possible that greater exposure to vision loss was required before they could adjust their reading strategies sufficiently. Even for the younger observers, this was a very frustrating condition, and this frustration may have been even greater for the older subjects because their acuity was even worse when wearing the simulators.

Allen *et al.* (1993) reported that older observers are more sensitive to changes in the difficulty of encoding words (i.e., changing the shape of the words using aLteRNatinG case) than younger observers in a word/non-word discrimination task. It is possible that when wearing the low vision simulators, word encoding was slowed to such an extent that continuous reading was not possible. This would predict some lower limit on reading rates for continuous text. While we have not tested this idea directly, we have seen patients in prior studies read as slowly as 5 wpm. The older observers in this study could not attain even this very limited reading speed.

Unlike visually impaired patients with central field loss (CFL), observers who are asked to read using cataract simulators that substantially reduce acuity and contrast sensitivity are able to read significantly faster using RSVP than from a scroll display. In fact, as their acuity was reduced, the subjects in this study showed even larger RSVP-gains. From this, and Rubin and Turano's (1994) data showing that reading RSVP at eccentricity is faster in normally sighted subjects than in patients with CFL, we can conclude that it is the presence of central field loss, and not simply the reduced acuity and contrast sensitivity associated with eccentric fixation, that limits the benefits of RSVP.

The increase in RSVP-gain with reduced acuity strengthens the claims made by others (see e.g. Sinclair *et al.*, 1989; Chen, 1986; Potter, 1984) that the consistent location of the RSVP display frees processing resources that would otherwise be required to synchronize needed eye movements with the text. Rubin and Turano's (1994) report that patients with CFL make intra-word eye movements when reading RSVP, and that they cannot match the reading rates of normally sighted subjects presented with text at similar eccentricities, also supports this idea.

The data from the current experiment do not parallel those found in the small groups of patients with no CFL that we tested in previous experiments (Fine & Peli, 1995b; Fine, 1995). That is, we did not see a reduction in RSVP-gain to near 1.0, even in the low vision condition. Unfortunately, most of our elderly subjects were unable to complete this condition, and since we see a clear effect of age on RSVP-gain, we cannot extrapolate from the younger observers. For the few elderly readers for whom we have data for both the RSVP and scroll displays when reading sentences, we see RSVP-gains ranging from approx. 1.1 to 2.7. This is in the range reported for the no CFL patients in Fine (1995; Experiment 2). For both that study, and Fine & Peli (1995b), central field status was determined on the basis of patient records. If several of the patients in the Fine and Peli study had undocumented field loss, this could help to explain the discrepancies we see across experiments. Their reduced acuity relative to the patients in Fine (1995), support this idea.

None of this explains why normally sighted observers wearing cataract simulators show an increase in RSVP-gain over their normal vision, while visually impaired observers with no CFL do not reach even the same levels of RSVP-gain we have shown for observers with normal vision (Fine & Peli, 1995b; Fine, 1995; Rubin & Turano, 1994). Eye movement recordings while reading RSVP have not been reported for visually impaired readers without central field loss. If they too are making intra-word eye movements (especially patients with pathologies other than cataract), this would explain why their RSVP-gains never reach those of normally sighted readers.

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