Effects of presentation complexity on rapid-sequential reading

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In two experiments, text segments were presented successively to a single location on a computer-controlled CRT screen. In Experiment 1, either one or three segments were presented in each display, and in the three-segment displays either one (scrolling) or all segments provided new information. Comprehension was assessed using both multiple-choice questions and passage summarization. Lower comprehension was found in the three-segment displays relative to the one-segment display. In Experiment 2, segments presented in each display in the scrolling condition were arranged either vertically or horizontally. In addition, a highlight technique was introduced to manipulate the distinguishability between the center segment and the surrounding segments in each display. Comprehension was not affected by the horizontal or vertical presentation dimension, but the highlighting cue did improve comprehension. Overall, the results clarify the effects of the complexity of the visual display on the processing of rapidly presented text segments.

Because of the way in which texts are presented for conventional reading, the only way to process textual information is to execute a series of eye fixations spaced between voluntary eye movements called saccades. Thus, a great deal of research has been devoted to monitoring eye-movement and fixation-duration patterns during reading. However, because reading is one of the most complex mental activities, the more we learn from the relevant research, the less adequate any single approach seems to be. Recently, as the technology has evolved, reading researchers have used high-speed computers to develop a variety of novel methods for text presentation (see, e.g., Aaronson, 1984; Kieras & Just, 1984, for relevant reviews and discussions). Although these procedures may not have direct or obvious implications for eye movements during conventional reading, they certainly can contribute to the formation of a broader and more complete picture of reading in general (see, Aaronson, 1984, for discussions on relevant issues). Reading research with different text presentation procedures has led us to more complex and revealing theories of how people read and, more crucially, how people comprehend written text.

It is commonly found that motor components of conventional reading are not very efficient (e.g., irregular

regressions and mislocations of line beginnings by inaccurate eye movements; for relevant reviews see, e.g., Juola, Ward, & McNamara, 1982; Ward & Juola, 1982) and that planning and executing eye-movement control activities demand attention and processing resources (see, e.g., Gilbert, 1959; Lawrence, 1971; Rayner, Slowiaczek, Clifton, & Bertera, 1983). However, the need for eye movements in reading, and therefore the associated errors and resource demands, can be eliminated by using a method for text presentation called rapid, serial visual presentation (RSVP, Forster, 1970; Gilbert, 1959). In RSVP, the reader fixates a single location on a screen to which a computer presents text segments successively. Research on RSVP reading (with different kinds of memory and comprehension measurements, such as recall, sentence recognition, sentence verification, passage summarization, and multiple-choice comprehensive questions) indicates that when the need for eye movements is eliminated, readers can still read naturally without loss of memory and comprehension due to distraction or the need to learn new reading strategies (for relevant findings and reviews, see, e.g., Chen, *in press*; Juola et al., 1982; Masson, 1983; Potter, 1984; Ward & Juola, 1982). Because the RSVP procedure allows experimental control over important input variables, such as the size and duration of the text segments presented, without interfering with the general comprehension processes, it has attracted a great deal of attention as a research topic itself and has been widely used to study reading and related processes (see, e.g., Chen, *in press*; Cocklin, Ward, Chen, & Juola, 1984; Daneman & Carpenter, 1983; Healy, Oliver, & McNamara, 1982; Juola et al., 1982; Just, Carpenter, & Woolley, 1982; Kintsch & Mross, 1985; Krueger & Shapiro, 1979; Masson, 1983; McLean, Broadbent, & Broadbent, 1983; Potter, Kroll, & Harris, 1980; Staller, 1982; for a recent review, see Potter, 1984).

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The RSVP format differs in a number of ways from the conventional text display format (see, e.g., Just et al., 1982). The two main differences are: (1) In the typical RSVP format, parafoveal and peripheral information are not available, whereas they are available in the conventional format. (2) What is seen and for how long are under subject control in the conventional format (therefore planning and executing eye-movement control activities are required), whereas they are under experimenter control in the RSVP format. Although, in conventional reading, the roles of parafoveal processing and control over input information have been considered to be facilitative (see, e.g., Just et al., 1982; Rayner, Well, Pollatsek, & Bertera, 1982), their impacts on RSVP reading have not been extensively investigated. The present study was therefore designed to address the following questions: First, what is the role of parafoveal information in RSVP reading? Second, does providing control over displayed information to the reader facilitate RSVP reading?

Recently, Juola and his associates (Cocklin et al., 1984, Experiment 1) reported a study in which the usefulness of parafoveal information in RSVP reading was investigated. Text segments were presented successively in one fixed window on the viewing screen. However, unlike previous studies, in some conditions (i.e., 20- and 30-character display conditions), the segments either did not overlap or had 10- or 15-character overlap. In the overlap conditions, the rightmost portion of any window reappeared in the leftmost portion of the subsequent window. The results showed that subjects' comprehension scores were worse in the overlap conditions relative to the nonoverlap conditions with equivalent words-per-minute (WPM) rates. These investigators pointed out that the lack of clear expectations about where successive stimuli would occur might have led to greater difficulty in reading the text displayed in the overlap conditions. To avoid possible confusion over unexpected sequences of visual inputs, in the present study we used three distinctive, vertically arranged windows to simulate successive parafoveal and foveal views of text in conventional reading (see Experiment 1 for a detailed description of this modified RSVP condition).

The present study also investigated the role of control over information input (i.e., what is seen and for how long) in RSVP reading. As mentioned previously, in conventional reading, readers spend different amounts of time on various parts of the text. These fixation durations are highly variable and seem to be related to the general text structure (Just & Carpenter, 1980) and reflect the on-line processing of text (Just et al., 1982). These observations have led to the suggestion that the control over information input (and especially over fixation duration) in conventional reading is an important concomitant of general comprehension operations. If control over information input and over fixation duration is essential for general comprehension, one would expect that when such control is not available to the readers, as in the case of RSVP reading, comprehension processes would be disrupted. This

prediction was tested in a study by Juola et al. (1982), who compared comprehension performance in a conventional text display format with that in an RSVP format in which each single word or text segment was presented at a uniform rate. The results showed no reliable difference in comprehension performance between the RSVP and conventional conditions. However, the possibility exists that the methodology used in the study by Juola et al. (1982) was not sufficiently sensitive to detect differences between the two conditions. Furthermore, since conventional reading is a well-practiced task for adult readers whereas RSVP reading is a novel task, such factors as practice and experience may have confounded the comparison between the conventional and RSVP conditions in their study. By this reasoning, in order to avoid possible confounding with subjects' previous experience, a better way to test the hypothesis about control over information input would be to contrast the standard RSVP condition, in which a reader has no control over input information at all, with a modified RSVP condition in which some control over input information is available to the reader.

Specifically, in the present study, we varied experimentally the amount of parafoveal information available to readers and the extent to which readers had control over fixation durations. In Experiment 1, modified RSVP conditions were used to provide parafoveal information and to give subjects some degree of control over what was seen and for how long. Subjects' comprehension performance under these modified RSVP conditions was compared with that in the standard RSVP condition in which parafoveal information and control over fixation durations were not available. Experiment 2 further examined the effects of parafoveal information on RSVP reading by manipulating the presentation location of that information and its saliency.

EXPERIMENT 1

Along with the standard "one-window" condition used in previous RSVP studies (e.g., Chen, *in press*; Juola et al., 1982; Potter et al., 1980), two modified conditions were constructed in Experiment 1. In both the "three-window" and "three-scrolling" conditions, text segments were presented three at a time in a vertical array with a single space between segments. Constant WPM reading rates across conditions were used.

The purpose of the three-scrolling condition was to assess whether providing parafoveal information facilitates RSVP reading. In this condition, although there were three segments in each successive display, exposure duration for each display was only long enough to read a single segment. Subjects were instructed to read only the central segment in each successive display. In other words, the middle (i^{th}) window in each display presented the segment that the subject was asked to fixate, whereas the top ($i-1^{\text{th}}$) and the bottom ($i+1^{\text{th}}$) windows presented parafoveal information. Therefore, the only difference be-

tween the three-scrolling and the one-window conditions was whether parafoveal information was available; they were equivalent in such other respects as exposure duration for each successive display.

The purpose of the three-window condition was to allow relatively more subject control over input information, although the control allowed was not as extensive as that in conventional reading. Subject control was achieved by presenting the contents of three successive segments in a single, three-window display. The exposure duration for one three-window display was equal to three times that for a one-window display because subjects were instructed to process all segments in a display. Because three vertically arranged segments are unlikely to be processed foveally in a single fixation, the subjects would have to execute eye movements as in conventional reading to process all three segments in a single three-window display.

If parafoveal information can facilitate RSVP reading, then the additional parafoveal information should improve reading performance in the three-scrolling condition relative to the one-window condition. However, since eye movements are the major tool that serves to bring information into foveal view for detailed processing in conventional reading (Just & Carpenter, 1980; McConkie, 1979; Potter, 1983; Rayner, 1978), it is possible that the role of parafoveal information is only to guide eye movements. If this is the case, then when text is presented via RSVP, which eliminates the need for eye movements, parafoveal facilitation should not be found. Similarly, if control over fixation duration is critical for reading comprehension, then reading performance in the three-window condition should be enhanced, since it allows relatively more subject control over what is seen and for how long. On the other hand, if this kind of control is not crucial for reading comprehension and if related control activities such as eye movements place additional demands on the limited processing resources, then higher levels of comprehension might be found for the one-window condition relative to the three-window condition.

Previous researchers (see, e.g., Chen, in press; Cocklin et al., 1984; Masson, 1983; Potter, 1984) have reported that display rate, segment size, subject differences, and comprehension measures are important variables in RSVP reading. Therefore, although these variables were not the main concern of the present experiment, they were manipulated in order to assess their relationship to the main variable, presentation format. In Experiment 1, presentation rate was fixed at two levels, namely 250 and 500 WPM, to compare various conditions at both normal and high rates. In addition, segment size was varied at three levels. The average segment sizes of 5, 8, and 12 characters were selected to span the limits of useful vision during reading successively presented text segments (Cocklin et al., 1984). Further, to take into account the factor of individual differences in reading, each subject's individual reading skill was assessed by the stan-

dard Nelson-Denny (1976) reading inventory. Finally, both multiple-choice questions, a popular comprehension measure used in a number of standard reading tests (e.g., McCall-Crabbs, 1950, 1961, test sessions; Nelson-Denny, 1976, reading inventory), and passage summarization, a sensitive measure of readers' macrostructure representations of a passage (Kieras, 1980, 1981; Masson, 1983), were used to evaluate subjects' comprehension and memory.

Method

Subjects. One hundred and eighteen undergraduate students participated for class credit in an introductory psychology class at the University of Colorado. All subjects received a standard Nelson-Denny (1976) reading inventory (Form D) in an initial group testing session of about .5 h, in which their effective comprehension scores (i.e., the percentage of correct responses for multiple choice comprehension questions in a 20-min test session) and reading speed were collected. Among the 118 subjects, 93 reported that they were able to return for further sessions. Three groups of 18 subjects who had the highest 18, the middle 18, and the lowest 18 effective comprehension scores were chosen from the set of 93 available subjects. The average effective comprehension scores for the high, medium, and low performance groups were 79.7%, 64.5%, and 46.8% correct, respectively. The differences among these groups were significant [high vs. medium groups, $t(34) = 12.08$; medium vs. low groups, $t(34) = 9.20$; both $ps < .001$]. However, when the reading speeds of high, medium, and low groups were compared (average reading rates were 321.8, 294.7, and 280.8 WPM, respectively), no significant differences were found [e.g., high vs. low groups, $t(34) = 1.56$, $p > .10$].

Apparatus. The stimuli were presented on a Visual 200 Video Display terminal interfaced to a PDP-11/T03L minicomputer. The display materials were composed of illuminated white dots against a dark background with a potential 7×9 dot matrix for each letter space. From the subject's viewing distance of approximately 50 cm, a five-letter word subtended about 1.4° of visual angle. To reduce glare on the terminal screen, the experiment was conducted in a semidarkened room.

Materials. Thirty-six paragraphs (mean length = 159 words) from Cocklin et al. (1984) were used. These paragraphs were originally selected from the McCall-Crabbs (1950, 1961) test sessions, books A, B, C, and D.

For each of the 36 paragraphs, six four-alternative multiple choice questions were prepared. An example of a paragraph and a comprehension question is shown in the Appendix. About two-thirds of the questions were selected from the test materials, and the remaining one-third were constructed by the authors. In selecting and constructing the questions and alternative answers, care was taken to ensure that the questions were not readily answered without the paragraphs previously having been read.

Procedure. Each of the 54 subjects selected from the initial group test session participated in an additional 1.5-h session. The paragraphs were displayed in three different RSVP formats: one-window, three-window, and three-scrolling. In the one-window condition, text segments were left justified and displayed sequentially one at a time to a common central location on the terminal screen. In the three-window and three-scrolling conditions, text segments were presented three at a time (all were left justified) in a vertical form with a single space between them. In the three-window condition, segments in each successive display included new information, whereas in the scrolling condition the text segments overlapped across displays. As discussed above, in both the one-window and three-window conditions, the subjects were instructed to read all the information presented in each successive display, whereas, in

Figure 1. Examples of the n^{th} and $n+1^{\text{th}}$ displays in the one-window, three-window, and three-scrolling conditions (Experiment 1).

the three-scrolling condition, they were told to concentrate on the middle window of each display. Examples of two successive displays (n and $n+1$) in the one-window, three-window, and three-scrolling conditions are shown in Figure 1.

A computer program was used to break the 36 paragraphs into segments of 5, 8, or 12 characters. The computer scanned the text for a fixed number of characters and then found the nearest inter-word space. The text was segmented at that location, and then the search for the next segment began. After each sentence, the program inserted one segment consisting solely of hyphens. In the 250-WPM condition, the average segment durations for the 5-, 8-, and 12-character conditions were 242.7, 337.9, and 463.8 msec; in the 500-WPM condition, they were 121.3, 169.0, and 231.9 msec, respectively. Note that the computer required varied amounts of time to display segments of different sizes. The segment duration in the various-size conditions was therefore adjusted and was individually determined for each paragraph so that display rates, as measured by WPM, were constant in each cell of the design. This calculation was performed by taking the total display time for a paragraph (number of words in that paragraph divided by the desired presentation rate in WPM) divided by the number of segments for the paragraph in a particular segment-size condition.

The combination of two presentation rates (250 and 500 WPM) by three presentation formats and three segment sizes yielded 18 conditions, and every subject read two paragraphs in each of these conditions. The one-window, three-window, and three-scrolling conditions were blocked, and the order of these display conditions was counterbalanced across subjects. Furthermore, each paragraph occurred equally often in each experimental condition across subjects. The order of paragraph presentations within each display mode was randomized. Each of 18 different randomly ordered paragraph sequences was used for three subjects (one from each reading-ability group).

Each experimental session began with instructions and four practice paragraphs to familiarize subjects with the experimental procedures and the characteristics of the computer displays for the first condition. The practice paragraphs were also repeated at the start of every other condition. Each trial began with the presentation of a masking field in the center of the terminal screen. The mask consisted of either one row (in the one-window condition) or three rows (in the other conditions) of asterisks for 2 sec followed immediately by the first display of the paragraph. Each window was indented one space from the edge of the mask. The last display of each paragraph was followed immediately by the masking field. Immediately after the final masking field, the subjects were asked to write a one-sentence summary of the story they had just read. After the subjects finished writing the summary, they were asked

to press the RETURN key on the keyboard. Then six four-alternative forced choice comprehension questions were presented one at a time on the terminal screen, and the subjects responded by pressing one of four keys on the keyboard.

Results

Percentage of correct responses. Mean percentages of correct responses to the comprehension questions were computed for each subject in all cells of the design. Table 1 presents the means for the three reading-ability groups. The standard error of the values in Table 1, as determined by an analysis of variance (ANOVA), is 4.9%. An arcsin transformation was applied to the data, and the transformed scores were analyzed using an ANOVA with one between-subjects factor (high-, medium-, or low-performance group) and three within-subjects factors (display rate—250 or 500 WPM; mean segment size—5, 8, or 12 characters per segment; presentation format—one-window, three-window, or three-scrolling).

The analysis revealed significant main effects for reading ability [$F(2,51) = 9.12$], display rate [$F(1,51) = 209.34$], segment size [$F(2,102) = 4.00$], and presentation format [$F(2,102) = 19.45$] (all $ps < .05$). The high-performance subjects tended to have higher comprehension scores (average of 68.3% correct) than the medium (58.2%) and low (56.0%) performance groups, with both differences being significant [$ts(34) = 3.12$ and 4.23 , $ps < .005$]. The overall performance was better in the normal-rate condition (250 WPM: 67.8% correct) than in the fast-rate condition (500 WPM: 53.9%). Among the different segment-size conditions, the overall performance was better in the 8-character condition than in the 5- or 12-character conditions (62.4%, 59.7%, and 60.3% correct, respectively), with both differences being significant [$ts(53) = 2.37$ and 2.39 , $ps < .03$]. This segment-size effect will be discussed with the segment and format interaction in the following section. Most critically, sub-

Table 1
Mean Percentages of Correct Responses as a Function of Subject Group, Presentation Format, Display Rate (WPM), and Mean Segment Size (Number of Characters) in Experiment 1

Presentation Format	Display Rate					
	250			500		
	5	8	12	5	8	12
High-Performance Subjects						
One-Window	78.6	80.5	75.5	66.6	69.9	67.1
Three-Window	73.1	73.9	69.4	52.3	59.7	56.5
Three-Scrolling	68.1	79.2	66.6	63.3	65.7	62.0
Medium-Performance Subjects						
One-Window	64.3	63.8	71.2	55.5	55.1	59.2
Three-Window	68.6	64.3	70.4	49.0	49.9	50.4
Three-Scrolling	61.1	60.6	55.5	47.2	55.6	45.3
Low-Performance Subjects						
One-Window	68.0	72.6	68.0	47.6	48.2	51.4
Three-Window	59.6	65.7	67.4	43.0	41.2	43.9
Three-Scrolling	62.1	65.3	56.0	46.6	51.3	49.5

jects' abilities to answer comprehension questions were better in the one-window condition (64.6% correct) than in the three-window (58.2%) or three-scrolling (56.0%) conditions, with both differences being significant [$t(53) = 5.40$ and 4.87 , $ps < .001$].

In addition, the interaction between format and rate was significant [$F(2,102) = 7.25$, $p < .005$] and the interaction between format and segment size was marginally significant [$F(4,204) = 2.25$, $p < .07$]. As shown in Figure 2, the format $\times$ rate interaction indicates that the one-window over three-scrolling advantage was greater for 250 WPM (7.6% correct decline) than for 500 WPM (3.7% decline) [$t(53) = 2.03$, $p < .05$], whereas the one-window over three-window advantage was greater for 500 WPM (8.3% decline) than for 250 WPM (3.4% decline) [$t(53) = 2.22$, $p < .03$]. Presumably, in the three-scrolling condition, the presentation of parafoveal information disrupted the readers' attention, and under the slower display rate (when more time was provided) the readers had greater difficulty fixating the center segment. On the other hand, the three-window disadvantage may be due to the processing resources demanded by controlled eye movements in the three-window condition. Consequently, under the faster display rate, those additional demands produced greater interference with reading performance in the three-window condition. The format $\times$ rate interaction further suggests that although both three-window and three-scrolling conditions were inferior to the one-window condition, the underlying mechanisms responsible for these disadvantages were not the same.

As shown in Figure 3, the interaction between format and segment size was due largely to the differences between the 8- and 12-character segments for the three-scrolling condition. (Note that this result for the three-scrolling condition is also responsible for the main effect

Figure 2. Comprehension scores (percent correct) for one-window, three-window, and three-scrolling conditions plotted against display rate (Experiment 1).

Figure 3. Comprehension scores (percent correct) for one-window, three-window, and three-scrolling conditions plotted against segment size (Experiment 1).

of segment size discussed earlier.) When segment size increased from 8 to 12 characters, a dramatic performance decrease was found (7.1% correct decline) [$t(53) = 3.86$, $p < .001$]. No similar differences were found for the one-window and three-window conditions (the differences between the 8- and 12-character conditions were $-.4\%$ and $-.6\%$ correct, respectively). Moreover, when segment size increased from 5 to 8 characters, performance tended to increase. However, the difference was significant only in the three-scrolling condition (4.9% correct increase) [$t(53) = 2.26$, $p < .05$]. No other significant effects were found.

Finally, the group factor significantly interacted with display rate [$F(2,51) = 3.73$] and presentation format [$F(4,102) = 2.96$, $ps < .05$]. When the display rate increased from 250 to 500 WPM, the performance decrements were greater for the low-performance group than for the high and medium groups (average of 18%, 11%, and 12% correct declines, respectively) [$ts(34) = 2.31$ and 2.26 , both $ps < .03$]. The group $\times$ format interaction is due largely to the difference between one-window and three-window conditions for the different groups. For both the high- and low-performance groups, the percentage of correct responses was greater in the one-window condition than in the three-window condition [$ts(17) = 5.62$ and 3.34 , both $ps < .004$], whereas the similar difference was not significant for the medium performance group. For all three groups, the percentage of correct responses was greater in the one-window than in the three-scrolling condition [$ts(17) = 2.89$, 3.09 , and 2.70 for the high-, medium-, and low-performance groups, all $ps < .05$].

Summaries. The degree to which the one-sentence summaries reflected the main idea of the passages was determined by 108 additional subjects. These subjects were given a booklet that included one of the 36 passages

and 54 associated summaries produced by the subjects who had participated in the formal experiment. The order of summaries in each booklet was randomized. The subjects were instructed to read the passage for as long as necessary and to rate the attached sentences in terms of how they summarized the main ideas of the passage using a 7-point scale from 1 = poor to 7 = excellent. The subjects were encouraged to use all the scale values. Each summary received three scale values (one from each of three raters). Mean scale values so obtained were computed for each cell of the design and submitted to ANOVA. The mean values are shown in Table 2. The standard error of the values in Table 2, as determined by the ANOVA, is .21.

Most of the significant main effects and interactions obtained in the ANOVA of the summaries were also obtained in the previous analysis of percentages of correct responses to the comprehension questions: subject group, display rate, presentation format, group $\times$ rate, group $\times$ format, and format $\times$ rate, all $F_s > 3.35$, all $p_s < .05$. The correlation between these two sets of comprehension measurements (i.e., the percentages of correct responses and the scale values) was substantial [$r(52) = .67$, $p < .001$]. The pattern of the scale values was consistent with the pattern for percentages of correct responses except for the group $\times$ format interaction. Specifically, the comparison between the one-window and the three-scrolling conditions differed from that in the previous analysis. For both the medium and low groups, the overall performance was greater in the one-window condition than in the three-scrolling condition (mean scale values were 3.23 and 2.95 for the medium group, and 3.14 and 2.66 for the low group [$ts(17) = 2.63$ and 4.80 , both $p_s < .05$], whereas for the high group, the difference not only was nonsignificant but also was in the opposite direction (means were 3.53 and 3.60).

Table 2
Mean Scale Values of Summaries as a Function of Subject Group, Presentation Format, Display Rate (WPM), and Mean Segment Size (Number of Characters) in Experiment 1.

Presentation Format	Display Rate					
	250			500		
	5	8	12	5	8	12
High-Performance Subjects						
One-Window	3.57	3.63	3.58	3.47	3.44	3.47
Three-Window	4.12	3.58	3.62	2.41	2.59	2.82
Three-Scrolling	3.75	4.25	3.60	3.30	3.33	3.34
Medium-Performance Subjects						
One-Window	3.41	3.47	3.60	3.14	3.06	2.71
Three-Window	3.60	3.70	3.43	2.76	2.89	2.76
Three-Scrolling	3.66	3.43	2.89	2.76	2.68	2.29
Low-Performance Subjects						
One-Window	3.52	3.39	3.83	2.52	2.83	2.75
Three-Window	3.43	3.11	3.40	2.14	2.32	2.08
Three-Scrolling	3.48	3.49	2.51	2.10	2.38	2.00

Finally, the effect of segment size was significant in the previous analysis but was only marginal in the analysis of the summaries [$F(2,102) = 2.55$, $p < .09$], and the segment size $\times$ format interaction was marginal ($p < .07$) in the previous analysis, but was significant in the analysis of the summaries [$F(4,204) = 2.79$, $p < .03$]. Nevertheless, the overall patterns of results for the two sets of analyses were highly similar.

Discussion

The present experiment demonstrated that, rather than being helpful, the presentation of parafoveal information in fact disrupted RSVP reading. The three-scrolling inferiority effect is consistent with the findings reported previously by Cocklin et al. (1984, Experiment 1). By using conventional one-window displays, they found that comprehension was worse in conditions with partial overlaps in successive windows than in corresponding conditions without information overlaps. Note that the parafoveal disruptive effect obtained in the present study stands in interesting contrast to the parafoveal facilitative effect on word naming and reading rate in tasks that required eye movements reported by previous researchers (e.g., Balota & Rayner, 1983; McConkie & Rayner, 1975; Rayner et al., 1982). Although there are many procedural differences between the studies yielding facilitating effects of parafoveal information and the RSVP technique which yields the opposite results, one factor may be crucial—the need for eye movements. There is evidence in the literature that information obtained from parafoveal vision (e.g., word-boundary information) is used to guide eye movements (see Pollatsek & Rayner, 1982, for a review of related findings) and to select a viewing location (see Rayner, 1983). Thus, parafoveal information may be useful in conventional reading situations. In the three-scrolling condition of the present study, however, subjects were asked to read only the center segment of each display. Unlike conventional reading, this task did not require or encourage (due to time limitation) subjects to move their eyes to parafoveal information for subsequent analysis. Thus, under these conditions, parafoveal information might have been attended to and consequently might have distracted attention and processing resources from the center segment in each successive display.

It is, then, no surprise that the three-scrolling inferiority effect was greatest when the presentation rate was relatively slow (i.e., 250 WPM) or when the segment size increased to 12 characters (i.e., the largest segment size used). This result indicates that especially when additional time was provided or when the size of the distracting segment was very large, subjects experienced the greatest difficulty in concentrating on the center segment. Consistent with this three-scrolling inferiority effect, Shaffer and LaBerge (1979) demonstrated that when three words were presented vertically and simultaneously, semantic categorization of the center word was distracted by the surrounding words.

An alternative interpretation for the one-window over three-scrolling superiority is that the three-scrolling condition may create some kind of apparent motion effect which induces subjects to follow the fixated segment with their eyes from one location in a display to another location in the following display. However, such an apparent motion effect (and therefore its induced distraction) should be stronger in the fast than in the normal rate condition, but the format $\times$ rate interaction shows the opposite pattern (see Figure 2).

The present experiment further demonstrated that reading performance was not enhanced by giving subjects more control over input information and fixation durations (see Gilbert, 1959, Juola et al., 1982, for similar findings). This result indicates that subject control over input information may not be as critical as Just et al. (1982) have suggested. When the possible confounding of previous experience and practice, as in the case of conventional reading, was eliminated by comparing two novel RSVP tasks (i.e., the one-window vs. three-window condition), a three-window inferiority effect was found. Note that in order to comprehend a text presented in the three-window condition, subjects need to fixate three vertically presented segments in each successive display by executing eye movements. Such eye-movement control activities demand extra attention and processing resources as well as processing time. In fact, Rayner et al. (1983) reported that in reading preplanning an eye movement alone may take 50 msec (see also Just & Carpenter, 1980; Rayner, 1983). Consequently, less capacity or time was available in the three-window condition for processing the presented text segments for comprehension. It is no surprise, then, that the one-window over three-window advantage was greater under the faster display rate, which suggests that the additional demands on processing resources disrupted comprehension to a lesser extent when more time was provided.

In addition, there is some evidence to suggest that individual differences exist in reading text presented in the three-scrolling condition. For high-performance subjects, no reliable difference was found between the scrolling and one-window conditions in the summarization task; in fact, a small difference was observed in the direction opposite to that for the other groups (i.e., three-scrolling was better than one-window). Finally, when the display rate increased from 250 to 500 WPM, the performance decrements were greater for the low group than for the high and medium groups.

The final concern of the present experiment was whether multiple-choice questions and passage summaries would show different sensitivities to comprehension and memory associated with the various reading conditions. Those two comprehension measures revealed very similar patterns of results. In fact, a highly reliable correlation was found between these two comprehension measures. Since the summarization task is more difficult to score and the scoring is more subjective than that of the multiple-choice questions, we decided to use the multiple-

choice questions in the second experiment with reasonable confidence that they would provide a valid comprehension measure.

EXPERIMENT 2

The results of Experiment 1 indicated that the presentation of parafoveal information could disrupt comprehension in RSVP reading. The second experiment was designed to test two proposed explanations for this parafoveal impairment effect. First, the subjects of Experiment 1 might have been confused by the unexpected location of the parafoveal information (i.e., it was presented along a vertical dimension rather than along a horizontal dimension), possibly making it more difficult to incorporate noncentral text segments. Alternatively, parafoveal information itself might have confused the readers regardless of its location. If the first hypothesis was true, one might expect to minimize the disruptive effect in conditions in which text segments were presented in the more conventional horizontal format. If, on the other hand, the second hypothesis was true, then presenting parafoveal information along the horizontal dimension might also disrupt performance.

If the subject is distracted by parafoveal information regardless of location, then providing a cue to help differentiate the focal, center segment from the surrounding segments could result in better performance. Therefore, in addition to the variable of presentation dimension (horizontal or vertical), a highlight technique was introduced in Experiment 2 to manipulate the distinguishability between the center segment and the surrounding segments. Highlighting was achieved by manipulating the contrast between the center and surrounding segments. Specifically, there were two highlighting conditions, center segment highlighted and surrounding segments highlighted. The surround-highlighted condition was introduced to prevent the confounding of the presence of highlighting with the position of highlighting. If a higher level of comprehension performance were found only for the center-highlighted condition rather than for both the center- and surround-highlighted conditions relative to the no-highlight condition, then it would be possible to argue that those surrounding segments in the center-highlighted condition were too dim to be perceived. On the other hand, if it was the distinguishability of the center and surrounding segments that facilitated readers' comprehension, then both highlighting conditions should result in better performance to an equivalent extent.

Finally, because the results of Experiment 1 had indicated that the 250-WPM rate and the 12-character segment size produced the most striking scrolling disadvantage, the display rate and segment size for the present experiment were fixed at these levels.

Method

Subjects. Forty-two undergraduates participated for credit in an introductory psychology course at the University of Colorado. None

of these subjects had participated in the group or the individual testing session of Experiment 1 (i.e., no reading ability was recorded in the present experiment). All subjects reported normal or corrected-to-normal vision.

Materials and Apparatus. Twenty-one paragraphs were selected from those used in Experiment 1. The apparatus and viewing conditions were the same as those used in Experiment 1.

Procedure. Each of the 42 subjects participated in a 45-min session. The paragraphs were displayed in seven different formats via RSVP: one-window, three horizontal moving conditions (no highlight, center segment highlighted, and surrounding segments highlighted), and three vertical scrolling conditions (no highlight, center highlighted, and surround highlighted). Examples of the center- and surround-highlighted displays in the moving and scrolling conditions are shown in Figure 4. In the scrolling conditions, as in Experiment 1, there were three segments arranged vertically in each display with a single space between them. In the moving conditions, text segments were also presented three at a time but in a horizontal format with two character spaces between each segment and the first letter of the center segment always appearing in the same location. Furthermore, the moving and scrolling conditions were similar to the previous scrolling condition in the sense that segments overlapped across displays. Finally, except in the one-window condition, subjects were instructed to read the middle window in each successive display. The seven different display conditions were blocked, and the order of conditions and the assignment of paragraphs to conditions were counterbalanced across subjects.

Each display condition began with one practice paragraph. The procedure for each trial was the same as that used in Experiment 1, except that the summary writing part was eliminated in Experiment 2.

Moving condition:

Although the **place had** always been

Center segment highlighted

Although the place had **always been**

Surrounding segments highlighted

Scrolling condition:

Although the
place had
always been

Center segment highlighted

Although the
place had
always been

Surrounding segments highlighted

Figure 4. Examples of the displays in the moving and scrolling (center segment highlighted and surrounding segments highlighted) conditions (Experiment 2).

Figure 5. Comprehension scores (percent correct) for the one-window, no highlighted, and highlighted conditions (Experiment 2).

Results and Discussion

Mean percentages of correct responses to the comprehension questions were computed for each subject in all cells of the design. The arcsin-transformed percentages of correct responses for all the scrolling and moving conditions were analyzed using an ANOVA with two within-subjects factors (presentation dimension—horizontal moving vs. vertical scrolling; highlight condition—no highlight, center highlighted, or surround highlighted). The main effect of highlight was significant [$F(2,80) = 3.96$, $p < .03$]. The subjects' comprehension scores were worse in the no-highlight condition (average of 70.9% correct) than in the center- and surround-highlighted conditions (75.3% and 74.7% correct, respectively), with both differences being significant [$ts(41) = 2.80$ and 2.06 , both $ps < .05$]. Clearly, providing the highlight cue to differentiate the center segment from the surrounding segments improved comprehension performance. Furthermore, no significant difference was found between the center-highlighted and surround-highlighted conditions, indicating that the position of the highlighting was not critical.

Experiment 2 also assessed the possible effects of presentation dimension. The results showed no reliable difference between the moving and scrolling conditions (averages of 73.1% and 74.2% correct, respectively), indicating that the vertical presentation dimension was not responsible for the three-scrolling disadvantage found in Experiment 1. These results suggest, instead, that the presentation of parafoveal information distracted the subjects' attentional focus from the center segment. No other significant effects or interactions were found in this analysis.

Finally, three planned comparisons were conducted to compare paragraph comprehension in the one-window, no-highlight (across presentation dimensions), and highlight conditions (across presentation dimensions and highlight positions). As shown in Figure 5, mean percentages of correct responses to comprehension questions were higher in the one-window condition than in the highlight and no-highlight conditions [$ts(41) = 2.32$ and 4.09 , both

ps < .05]. This result replicates the earlier finding from Experiment 1 that the one-window condition had an overall superiority over the scrolling condition (no highlight). Moreover, the difference between the highlight and no-highlight conditions was reliable [$t(41) = 2.77$, $p < .01$]. These results indicate that the subjects retained more information from the one-window condition than from the highlight or no-highlight conditions, and that the subjects' comprehension was better in the highlight condition than in the no-highlight condition. Thus, presentation of parafoveal information distracted the subjects from processing the center segment and highlighting served to diminish that distraction to some extent.

GENERAL DISCUSSION

The present study investigated the role of parafoveal information in RSVP reading. Overall, the results of Experiments 1 and 2 showed that the presentation of parafoveal information was not helpful, and, in fact, disrupted subjects' comprehension when subjects were not required to move their eyes or to shift their attention to the parafoveal information. This reliable parafoveal impairment effect stands in strong contrast to findings of prior research. Previous investigators (e.g., Balota & Rayner, 1983; McConkie & Rayner, 1975; Rayner et al., 1982) have reported a facilitative effect of prior parafoveal exposure on reading rate in sentence reading and on word naming (but see McConkie, Zola, Blanchard, & Wolverton, 1982). Note that the present RSVP task differs from tasks used in earlier studies in important respects (see Just et al., 1982, and Potter, 1984, for relevant reviews). Most critically, the tasks in the previous studies showing parafoveal facilitation required subjects to execute eye movements. On the other hand, our one-window, scrolling, and the moving RSVP tasks required subjects to concentrate on the processing of foveal information only, without the necessity for making eye movements to bring subsequent text segments into the foveal area for the processing of meaning. Under these conditions, perhaps the parafoveal information competes with the foveal information for the reader's limited attention and processing resources and consequently interferes with comprehension. This attention-divergence proposal is strengthened by the finding in Experiment 2 that when highlighting was used to differentiate the foveal, center segment from the parafoveal, surrounding segments, comprehension was significantly improved.

The second issue of concern in the present study was whether providing relatively more control over input information and fixation durations facilitates RSVP reading. This idea was tested by comparing comprehension performances under the one-window and three-window conditions. In the one-window condition, exposure durations for the various text segments were uniform and were determined by the experimenter, whereas in the three-window condition, they were under partial control by the subject. The results of Experiment 1 showed that the subjects' comprehension was not enhanced by having more

control over information input. This result is consistent with the suggestion of Ward and Juola (1982) that the subject control over information input (and the consequent variability of fixation durations) in conventional reading might not be an essential condition for the occurrence of general comprehension operations. Specifically, when the possible confounding factors of practice and previous experience were controlled via the sequential display technique, a three-window relative to one-window disadvantage was found. This three-window inferiority effect is probably due to the fact that subjects must execute eye-movement control activities in order to process three vertically displayed segments in each successive display. This additional task demand is likely to require processing time and resources and consequently to lead to a reduction in comprehension capacity and performance.

In fact, although it is possible that planning and executing eye-movement-control activities become automatic through intensive practice (LaBerge & Samuels, 1974), many studies have demonstrated that eye-movement control activities (e.g., motor programming and motor execution) demand attention and processing resources (see, e.g., Gilbert, 1959; Lawrence, 1971; Rayner et al., 1983). Gilbert (1959), for example, investigated the role of saccadic movements in reading by using a movie projector to present eight-word sentences two words at a time to the same location on the screen (i.e., a one-window condition) or in conventional left-to-right positional sequences (i.e., a horizontally arranged four-window condition). He found that subjects were able to read and recall the sentences more accurately in the same-location condition than in the conventional spacing condition, indicating that executing saccadic movements decreases reading efficiency. Consistent with the idea that the three-window condition in our study demands extra processing resources, the results of Experiment 1 demonstrated that the three-window disadvantage diminished when the presentation rate was reduced, presumably because the extra time was used to meet the added task demands created by the need to execute eye movements.

In summary, the present study found that the one-window condition is superior to all three-segment conditions (i.e., three-window, three-scrolling, three-moving). In the one-window condition, the visual display is relatively simple. No parafoveal information is presented to distract and complicate text processing as in the three-scrolling and three-moving conditions. Furthermore, only one segment is presented in each display so that there is no need to execute eye-movement-control activities to fixate different segments as in the three-window condition. This procedure probably allows subjects to devote their full capacities to the task of comprehension, and consequently results in the highest comprehension performance among all the conditions used. We therefore conclude that availability of parafoveal information and variability in fixation durations are not critical for comprehension in the rapid sequential reading condition, although they might be useful (e.g., to bring in new information for meaning analysis) in the conventional reading situation.

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APPENDIX

Example of a Paragraph and a Comprehension Question

The discovery was entirely accidental. The two boys were searching for cattle that had strayed from the herd. The part of the plain over which they rode was separated from the inaccessible, and apparently useless, mesa by a turbulent stream. Jack had once seen a horse swim the river and disappear up the narrow box canyon of the mesa. Although the place had always been avoided by herders with cattle, the boys decided to cross and reconnoiter in search of the strays. They made their objective a high point that seemed to be the edge of the mesa. After an hour's climb, they reached their lookout and beheld, in the cliffs above them, a city—a sleeping city of stone! There, nestled in a great cavern, beautifully proportioned and symmetrically made, was a village of little tinted, flat-roofed houses. "Mirage" was their first thought. Then they realized that they were looking at the ruins of an ancient, extinct civilization. Preserved, in calm repose, were the homes of some of the forebears of our American Indians.

Comprehension question:

What did the boys discover?

(1) a pasture (2) a plain (3) a mountain (4) cliff dwellings

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