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Asymmetry of the effective visual field in reading

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In three experiments, subjects' eye movements were recorded as they read from a computer-controlled CRT. The amount of information available to the left and right of the fixation point was varied in order to determine the characteristics of the effective visual field in reading. Experiments 1 and 2 demonstrated that readers do not obtain useful information during a fixation more than 3 or 4 letters to the left of their fixation point. The results of Experiment 3 indicated that the effective visual field does not extend any further to the left than the beginning of the word currently fixated, independent of the number of letters available to the left of fixation. When combined with the results of other research on the perceptual span in reading, the results of these experiments indicate that the effective visual field extends from the beginning of the currently fixated word (but no further than 4 characters to the left of fixation) up to about 15 characters to the right of fixation.

A great deal of recent research on the perceptual span in reading has indicated that readers obtain useful information from a relatively small region during an eye fixation (McConkie & Rayner, 1975; O'Regan, 1979; Rayner, 1975; Rayner & Bertera, 1979; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, in press). In these experiments, an eye-movement-controlled display system allowed a computer to monitor eye position as a subject read from a computer-generated text display, and changes in the text were made contingent upon the position of the eye. In the McConkie and Rayner (1975) study, a version of mutilated text in which every letter from the original text had been replaced by another letter was initially displayed on a cathode ray tube (CRT). However, when the reader fixated the text, the display was immediately modified by the replacement of letters within a certain region around the fixation point with corresponding letters from the original text. This created an experimentally defined *window* region of normal text for the reader to see on that fixation. When the reader made an eye movement, the text in the window area returned to its unreadable form and a new window of normal text was created at the location of the new fixation. Thus, wherever the reader looked, there was normal text to read. Moreover, the experimenter could determine the size and location of that region with respect to the reader's fixation point. In more recent studies (Rayner & Bertera, 1979; Rayner et al., in press), a visual mask covered all of the text except the window area around the fixation point and the size of the window area was varied.

The results of these studies have indicated that the effective visual field in reading (i.e., the area from which subjects obtain useful information) extends about 15 characters to the right of fixation. Because the window areas in these studies were symmetric about the fixation point, it has been impossible to determine whether or not the area of useful vision was asymmetric about the fixation point as implied by tachistoscopic word identification studies (Bouma, 1973). However, McConkie and Rayner (1976) employed windows that were asymmetric about the fixation point in order to determine whether visual information used in reading tends to be acquired further to the left or the right of the fixation point. In their experiment, the window (1) extended 20 character positions to the left and 20 character positions to the right of fixation, (2) extended 20 characters to the left and only 4 to the right, or (3) extended only 4 characters to the left and 20 to the right. They found that reading performance in the right-shifted (4 left and 20 right) window condition did not differ from the symmetrical condition but that shifting the window to the left seriously disrupted reading. McConkie and Rayner (1976) concluded that the region of useful vision in reading was asymmetric around the fixation point.

The experiments reported here were an extension of the McConkie and Rayner (1976) study. The information necessary for making semantic identification of words appears to be obtained from a relatively small region around the fixation point (Rayner, 1975; Rayner & Bertera, 1979), coinciding with the foveal region and the beginning of the parafoveal region. If the effective information available to the reader depends mainly on the structure of the eye, then the quality of the incoming information should be as

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good on the left side as on the right side and information necessary for semantic identification should be obtained within the foveal area both 1 deg to the right and 1 deg to the left of fixation. On the other hand, McConkie and Rayner's (1976) data demonstrate that there is significant asymmetry in how information is extracted. They conjecture that the area of useful vision to the left of fixation may even be less than the four characters used in their smaller window. However, their data do not allow detailed statements about the area of useful vision inasmuch as only three window sizes were employed. The purpose of these experiments was to examine more closely the area of useful vision in reading and, in particular, the area to the left of fixation. To this end, two different techniques were employed. In Experiment 1, we varied the size of the window, concentrating on asymmetric windows that extended less than 4 characters on one side of the fixation point. In Experiment 2, we presented a visual mask that covered 5 characters and was offset at different distances to the left and right of fixation. This allowed us to make an independent determination of the extent to which the perceptual span was asymmetric and the extent to which attention could be deployed to different locations within a fixation. Experiment 3 expanded on the results of the first two experiments and will be described later.

EXPERIMENT 1

In Experiment 1, we used the window technique in order to explore further McConkie and Rayner's (1976) finding that the perceptual span is asymmetric. McConkie and Rayner found that when the window extended only 4 characters to the left of fixation, reading performance did not differ from the condition in which it extended 20 characters to the left. They suggested that the area of useful vision might actually be less than 4 characters to the left of fixation but were unable to determine this from their data. In Experiment 1, asymmetric windows that extended 3, 1, or 0 characters to the left or right of the fixation point and a symmetric window 29 characters in extent were used in order to determine more precisely the asymmetric characteristics of the effective visual field.

Method

Subjects. Seven adult subjects from the University of Massachusetts community served as subjects in the experiment. All of the subjects had had prior experience in eye-movement experiments, and each of them received practice in the task prior to the beginning of the experiment. They all had normal, uncorrected vision.

Procedure. A bite bar, which served to eliminate head movements during the experiment, was prepared for each subject as he or she arrived for the experiment. Then the eye-movement recording system was calibrated for the subject. Since the subjects were all experienced in this type of experiment, initial subject calibration was usually accomplished in less than 5 min. After the initial subject calibration, subjects were instructed that individual sentences were to be displayed on the CRT and that they were to read the sentences. After reading a sentence, the subject pushed a button located near the right hand and the sentence disappeared from the CRT. Then the subject released the bite bar and reported the sentence to the experimenter. The subjects were told that they could paraphrase the sentence or report it verbatim (most of them reported it verbatim). After reporting the sentence, the subject went back on the bite bar and the experimenter checked the calibration of the eye-movement recording system. The subject then fixated a dot on the left edge of the CRT. When the experimenter pushed a button, the dot disappeared and a sentence appeared beginning slightly to the right of the fixation dot.

A complete description of the technique used in the experiments has been provided by Rayner et al. (in press). In the present experiment, a window moved in synchrony with the reader's eye movements across the text. The characteristics of the window were manipulated in the experiment, but all of the text outside of the window area (including spaces between words) was replaced by a visual mask that consisted of an interlaced square-wave grating. Seven different window sizes were used in the experiment. In the *symmetric* window condition, which served as a baseline, 14 characters to the left and right of the fixated character were visible on each fixation. In addition to the symmetric condition, there were three conditions (referred to here as the *asymmetric-right* conditions) in which the window extended 14 characters to the right of fixation, but only a few characters to the left of fixation. In these conditions, 3, 1, or 0 characters to the left of the character that the fixation point fell on were visible. In the remaining three conditions *(asymmetric-left)*, the window extended 14 characters to the left of fixation and 3, 1, or 0 characters to the right of the fixated character.

Materials and Apparatus. Sets of sentences with each sentence containing 5 to 8 words were used as stimuli in the experiment. The sentences were obtained from a number of sources and contained a variety of syntactic structures. All of the sentences were easy to understand.

The sentences were displayed on a Hewlett-Packard 1300-A CRT. The CRT has a P-31 phosphor with the characteristic that removing a character resulted in a drop to 1% of maximum brightness in .25 msec. The letters making up the sentences appeared in lowercase on the CRT. A black theater gel covered the CRT, so that the letters and the mask appeared white on a black background.

Eye-movement recording was accomplished by using a Stanford Research Institute Dual Purkinje Eyetracker. The eyetracker has a resolution of 10 min of arc, and the output is linear over the visual angle (14 deg) occupied by the sentences. Thus, the accuracy is such that we are confident that, for its computations of the window, the program is using the letter that the subject is actually fixating. The eyetracker and the CRT were interfaced with a Hewlett-Packard 2100A computer which controlled the experiment. The signal from the eyetracker was sampled every millisecond by the computer through an A-D converter. The computer determined if the eye was in a saccade or fixation by comparing the horizontal voltage level each 4 msec with the value obtained during the prior 4 msec. The computer also kept a complete record of the duration, sequence, and location of each fixation. These values were stored on the computer disk for later analysis. In addition to storing the raw data, the computer also provided summary data for each sentence the subject read.

In the experiment, the subject's eye was 46 cm from the CRT and 3 characters equaled 1 deg of visual angle. Eye movements were monitored from the right eye, and viewing was binocular. Luminance on the CRT was adjusted to a comfortable level for the subjects and held constant throughout the experiment. The room was darkened, except for a very dim indirect light source behind the subject.

Prior to beginning the experiment, each subject read 16 practice sentences, half with the window area offset to the left and half with the window offset to the right. Upon completion of the practice sentences, each subject read all 56 experimental sentences.

All of the subjects read the sentences in the same order, and the seven experimental conditions were presented in counterbalanced order to the seven different subjects. The window area moved in synchrony with the reader's eye movements across the sentence. More details about the characteristics of the display change that occurred when an eye movement took place have been described by Rayner et al. (in press).

Results and Discussion

The number and mean length of forward and regressive saccades were computed, as were the mean durations of fixations preceding forward and regressive eye movements. An index of effective reading rate which combined information from several of these dependent variables was also computed. Effective reading rate for a condition was defined as the number of words presented divided by the effective reading time. Table 1 displays the results for effective reading rate and forward fixations. Information about regressive eye movements is not displayed because there were few regressions in the symmetric and asymmetric-right conditions and between-subjects variability was high (one subject contributed almost 40% of the regressions in these conditions). Consequently, discussion of subsequent analyses will be confined only to the dependent variables shown in Table 1. It should be noted, however, that the effective reading rate does include regressions and that the total number of fixations includes forward and regressive eye movements.

Changing window size clearly influenced all of these variables (all $Fs > 13.2$, $p < .0001$). Moreover, as McConkie and Rayner (1976) have reported, there is strong evidence that the field of useful vision is asymmetric. According to Newman-Keuls tests (at the .05 level of significance), effective reading rate was significantly higher in all asymmetric-right conditions than in the corresponding asymmetric-left conditions. Significant differences were also found for the other dependent variables, with the exception of the 3-left/14-right and 14-left/3-right conditions for fixation duration.

A major goal of the present study was to determine how far to the left the field of useful vision extends. If it extends n characters to the left of fixation, then performance in an asymmetric-right condition in which the window extends n or more characters to the left should be the same as in the symmetric control condition. Performance in the various asymmetric conditions was compared with that in the symmetric control condition, using Dunnett's test (Myers, 1972). It can be safely concluded that the effective visual field extends more than one character to the left, since effective reading rate ($p < .005$), saccade length ($p < .005$), and fixation duration ($p < .05$) differed between the 1-left/14-right and control (14-left/14-right) conditions. However, the situation in which the window extends 3 characters to the left is somewhat ambiguous. While there were no significant differences for any variable between the 3-left/14-right and control conditions, effective reading rate was higher by 60 words/min in the control condition.

Experiment 2 was designed to determine more precisely the extent to which the perceptual span is asymmetric by offsetting a mask at various distances to the left and right of fixation. Thus, more subjects and more distances from fixation were used than in Experiment 1.

EXPERIMENT 2

In Experiment 2, a visual mask moved in synchrony with the eye (Rayner & Bertera, 1979) but was offset certain distances to the left or right of the fixation point. The mask was 5 character spaces in extent, and 1, 2, 3, or 4 characters were available to the left or right of fixation prior to the boundary of the mask.

Method

Subjects. Nine adult subjects from the University of Massachusetts community served as subjects in the experiment. Four of the subjects had participated in Experiment 1 and all had normal uncorrected vision.

Procedure. As in Experiment 1, the subjects received practice in the task prior to the beginning of the experiment. The initial calibration of the eye-movement equipment and sequencing of events in the experiment were identical to those of Experiment 1.

Nine different conditions were used in the experiment. In the control condition, the sentence was presented without any type of mask. In the *mask-right* conditions, the 5-character mask was off-

Table 1
Means for the Dependent Variables in Experiment 1

Window Size	Total Fixations	Forward Fixations	Fixation Duration	Forward Saccade Length	Reading Rate
14L-14R	6.0	4.9	223	7.4	306
3L-14R	6.6	5.3	249	7.3	246
1L-14R	9.5	7.3	269	6.3	167
0L-14R	10.4	7.7	273	6.3	147
14L-3R	12.8	9.9	276	4.2	112
14L-1R	20.5	14.5	324	4.0	72
14L-0R	22.2	14.7	344	3.8	55
F(6,36)*	20.82	18.97	13.26	55.88	17.13

Note—*Fixation duration is given in milliseconds; forward saccade length is given in characters; reading rate is given in words per minute. *p < .001 in all cases.*

set to the right so that 1, 2, 3, or 4 characters were displayed between the fixated character and the boundary of the mask. Thus, in the mask/4-right condition, all of the characters to the left of fixation, the fixated character, and 4 characters to the right of fixation were displayed. However, the 5th through the 9th characters to the right of the fixation point were replaced by the mask on each fixation. The remaining characters to the right of the 9th character to the right of the fixation point were displayed. In the *mask-left* conditions, the mask was offset such that 1, 2, 3, or 4 characters to the left of fixation were presented on each fixation. In the mask/4-left condition, all of the letters to the right of fixation were displayed on each fixation, but the 5th through the 9th letters to the left of fixation were replaced by the mask.

The 5-character mask consisted of an interlaced square-wave grating and, as indicated previously, moved in synchrony with the eye.

Materials and Apparatus. The apparatus used in Experiment 1 was used in Experiment 2. The characteristics of the sentences used in Experiment 2 were very similar to those of the sentences used in Experiment 1. Prior to the beginning of the experiment, the subjects read 16 practice sentences with the mask offset different distances to the left and right of fixation. Upon completion of the practice sentences, each subject read 72 experimental sentences. All of the subjects read the sentences in the same order, and the nine conditions were presented in counterbalanced order.

Results and Discussion

Table 2 contains the results for effective reading rate and forward fixations. Information about regressive eye movements is not displayed, since the rate of regressions did not exceed .5 per sentence for the no-mask or any of the mask-left conditions. As in Experiment 1, only the reading rate and forward fixation variables will be discussed.

Mask location clearly influenced all of these variables (all $Fs > 16.0$, $p < .0001$). Again, there was strong evidence for asymmetry. Effective reading rate was higher in each mask-left condition than in the corresponding mask-right conditions (Newman-Keuls tests, $p < .01$). Significant differences between mask-left and mask-right conditions were also found for all mask displacements for number of fixations and saccade length and for displacements of 1 or 2 characters for fixation duration.

The Dunnett test was again used to compare performance in the mask conditions with that in the no-mask control condition. The general result is that the field of useful vision extends at least 3 characters to the left but probably no further than 4. Reading rate was 43 words/min higher ($p < .05$) in the no-mask condition than when the mask was displaced 3 characters to the left of fixation. When the mask was displaced so that 4 characters were visible to the left of fixation, reading rate differed by only 14 words/min and no difference between the mask and no-mask conditions approached significance.

EXPERIMENT 3

The results of Experiments 1 and 2 indicated that the effective visual field during a fixation in reading can extend between 3 and 4 characters to the left of fixation. There are two possible explanations for this finding. First, it is possible that the foveal region is always included within the effective visual field. If so, since the foveal region extends 1 deg to the left and right of the fixation point and since 3 characters equaled 1 deg in our experiments, we would expect reading to be disrupted when the window area (Experiment 1) or mask (Experiment 2) reduces the number of letters presented immediately to the left of fixation to 3 or less. According to this foveal disruption hypothesis, when the mask begins four or more characters to the left of fixation, it should be sufficiently far from the center of vision to leave reading unimpaired. The fact that neither retinal cell density nor acuity exhibit a sudden decline as one moves from the fovea to the parafovea is consistent with our finding that the closer the mask occurs to the fixation point, the more reading is disrupted.

The second explanation as to why the effective visual field extends about 4 characters to the left of fixation could be related to word boundaries and fixation locations in words. O'Regan (1980) and Rayner (1979) have demonstrated that where the eye lands in words

Table 2
Means for the Dependent Variables in Experiment 2

Mask Condition	Total Fixations	Forward Fixations	Fixation Duration	Forward Saccade Length	Reading Rate
No Mask	4.9	4.9	214	6.4	350
Four Left	4.9	4.7	221	6.6	336
Three Left	5.3	5.1	223	6.1	307
Two Left	5.5	5.4	233	5.9	283
One Left	5.9	5.4	255	5.8	244
Four Right	7.4	7.1	229	5.0	218
Three Right	8.4	7.6	240	4.7	188
Two Right	9.2	8.1	263	4.5	155
One Right	11.3	9.4	294	4.2	117
F(8,64)*	30.99	27.91	20.90	16.04	47.13

Note–Fixation duration is given in milliseconds; forward saccade length is given in characters; reading rate is given in words per minute. *$^*p < .001$ in all cases.*

of different lengths is not haphazard or random. Rayner reported that the eye tends to fixate the center of short words and slightly left of center for longer words. He suggested that there were preferred viewing locations in words related to where the eye tends to fixate. O'Regan reported similar results and suggested a convenient viewing position in words. Given these results, one could argue that the letter information extracted from the left of fixation is confined to the word currently fixated. Thus, since for 10-letter words the ideal viewing position is the 4th letter, most fixations allowing 4 characters visible to the left of fixation would not result in the mask's perturbating any letters of the currently fixated word. On the other hand, when the mask was closer to the fixation point, the probability would increase that letters in the word currently fixated would be replaced by the mask. Experiment 3 was designed to determine whether the foveal disruption hypothesis or the word perturbation hypothesis was most appropriate in accounting for the observed data pattern from Experiments 1 and 2.

Method

Subjects. Fourteen adult subjects from the University of Massachusetts community participated in Experiment 3. Three of the subjects had participated in both of the previous experiments, one of the subjects had participated in Experiment 1, and another had participated in Experiment 2. All subjects had normal uncorrected vision and had had practice in the task prior to the beginning of the experiment.

Procedure. The initial calibration of the equipment and sequence of events in the experiment were identical to those of the previous experiments.

Seven different conditions were used in the experiment. In the control condition, the sentence was presented without any type of mask. In the letter (L) conditions, 1, 2, 3, or 4 characters to the left of fixation were displayed on each fixation. There were two major differences between this condition in Experiment 3 and the mask-left condition in Experiment 2. First, the mask extended to the left boundary of the sentence on each fixation. Thus, if the two characters to the left of fixation were visible, all of the other letters to the left of fixation were replaced by the mask. Second, the mask consisted of Xs (rather than the square-wave grating) and spacing between words was preserved. In the word (W) conditions, either (1) all of the letters to the left of fixation in the word currently fixated were displayed and everything else to the left of fixation was replaced by the mask, or (2) all of the letters in the word currently fixated as well as the word to the left of fixation were displayed and everything else to the left was replaced by the mask. In all of the conditions in this experiment, all of the characters to the right of fixation were displayed.

Material and Apparatus. The sentences used were very similar to those used in Experiments 1 and 2, and the apparatus was identical. Prior to the beginning of the experiment, the subjects read 16 practice sentences with the mask offset different distances to the left of fixation. Then each subject read 56 experimental sentences. All of the subjects read the sentences in the same order, and the conditions were presented in counterbalanced order.

Results and Discussion

Table 3 contains the results for effective reading rate and forward fixations. As in Experiments 1 and 2, only the reading rate and forward fixation data will be discussed, since there were fewer than .5 regressions per sentence.

There were significant differences among the experimental conditions for all dependent variables, with the F test reaching significance at the .05 level for saccade length and at or near the .001 level for the other four. Using Dunnett's test, we found that the 1L condition was significantly worse than the control condition for all measures ($p < .01$), that the 2L condition was worse than the control condition for average fixation duration and effective reading rate ($p < .01$), and that the 3L condition was worse than the control condition for effective reading rate only ($p < .05$). Since effective reading rate is a synthesis of the other measures, the data analyses below used effective reading rate as the dependent variable.

Since the effective reading rate for the 1W condition was only 9 words/min slower than the control condition (standard error of the difference = 16 words/min), there is little evidence that subjects used any information to the left of the fixated word. This result is particularly impressive given that detailed analyses of fixation locations in the 1W condition indicate that more than 1 letter was available to the left of fixation for only about half of the fixations (that is, for about half of the fixations, subjects fixated on a space between words or on the 1st or 2nd characters of a word).

Table 3
Means for the Dependent Variables in Experiment 3

Condition	Total Fixations	Forward Fixations	Fixation Duration	Forward Saccade Length	Reading Rate
No Mask	5.31	4.84	228	7.0	328
Two Words	5.18	4.89	226	7.1	331
One Word	5.25	4.85	237	6.9	320
Four Letters	5.46	5.04	239	6.8	303
Three Letters	5.56	5.06	237	6.8	294
Two Letters	5.80	5.32	252	6.7	266
One Letter	6.88	6.04	260	6.4	237
$F(6,78)$	4.16**	4.59*	10.03*	2.36†	9.87*

Note–Fixation duration is given in milliseconds; forward saccade length is given in characters; reading rate is given in words per minute. *$p < .001$. **$p < .005$. †$p < .05$.

In order to test more precisely whether the left-hand boundary of the effective visual field can be better defined in terms of words or letters, we estimated what the reading rate should be in the 1W condition if word boundaries were irrelevant. We obtained R_i, the effective reading rate for each letter condition in which i letters were presented to the left of fixation and the probability, p_i, with which i letters remained available to the left of fixation in condition 1W. Assuming that word boundaries are irrelevant, reading rate in the 1W condition should be estimable as the weighted mean of the rates in the letter conditions.[1] Some difficulties in estimating this reading rate resulted from the fact that the letter conditions presented only 1, 2, 3, or 4 letters to the left of fixation, while in the 1W condition subjects could fixate on the space between words or the 1st character of a word (in which case no letters would be available to the left of fixation) or more than 5 letters into a word (in which case more than 4 letters would be available to the left of fixation). In the latter case, the control (no-mask) reading rate was used, while in the former, the 1L reading rate was employed. Both substitutions were conservative in that they would tend to inflate the estimate of 1W reading rate based on letter conditions. Even so, the mean reading rate estimated for the 1W condition from the letter conditions was 275 words/min, approximately 45 words/min slower than the rate actually obtained in the 1W condition [$t(13) = 4.16$, $p < .002$]. Thus, reading in the 1W condition is considerably better than would be predicted from the data of the letter conditions.

The finding that the 1W condition differs minimally from the control condition suggests that virtually no useful letter information is extracted to the left of the currently fixated word. The detailed analysis of fixation locations established that this result is not simply a consequence of subjects tending to fixate 4 or more letters into a word. While our methodology does not allow us to conclude that *no* information is available to the left of the currently fixated word, we can state that such information is not useful in reading.

To further check the plausibility of this conclusion, we looked at the letter conditions to see whether one could predict rates in the L conditions from the percent of time the word fixated was not completely displayed. (For this analysis, it was assumed that when a space was fixated, the subject was fixating the word to the right.) For the 4L, 3L, 2L, and 1L conditions, the probabilities that some part of the fixated word was replaced by the mask were .11, .23, .34, and .56, respectively. We then tried by a least squares fitting procedure to fit the reading rates in each of the above four conditions as a probability mixture of the control condition (in which the fixated word is never perturbated) and a hypothetical condition in which the fixated word is always perturbated using the above probabilities calculated from the data.[2] The free parameter in the least squares fit (the estimated reading rate in the hypothetical condition in which the fixated word is always perturbated) was 197 words/min, and the predicted reading rates in the 4L, 3L, 2L, and 1L conditions were 305, 284, 267, and 239 words/min, respectively. These predicted reading rates correspond quite closely to the obtained reading rates of 303, 294, 266, and 237 words/min for the 4L, 3L, 2L, and 1L conditions, respectively.

The preceding analyses indicate that there is no disruption of reading performance when the beginning letters of the currently fixated word are unmasked. However, even if the first letters of the currently fixated word are replaced by a mask, reading performance is not seriously disrupted as long as at least 4 letters are available to the left of fixation. The eye fell beyond the 5th letter of a word (independent of word length for words longer than 5 letters) on about 20% of the fixations. Although, for these fixations, the mask replaced the beginning letters of the fixated word, reading performance was not seriously disrupted, as evidenced by the fact that the 4L condition did not differ drastically from the control condition. The reduction in reading rate that did occur can safely be attributed to problems associated with word perturbation, but the fact that the reduction is not any greater than it is may be due to two factors. First, as word length increases, the probability of more than one fixation on the word increases (Rayner, 1979). Thus, with longer words, many of the fixations falling beyond the 5th letter were second fixations on the word and the first fixation was near the beginning of the word where these letters could be seen clearly (O'Regan, 1980; Rayner, 1979). Second, in many cases in which a fixation falls on the last letter or two of a word, attention may actually be directed to the next word in the text (Rayner, 1975) so that perturbation of the currently fixated word is not disruptive.

To summarize, the data of Experiment 3 support the theory that the effective visual field in reading does not extend beyond the beginning of the word actually fixated for left-to-right saccades. It is possible that the small differences between the 1W and control condition could be explained by the times when the reader fixated the spaces (particularly on a regressive fixation). It is possible (see Rayner, 1979) that on such fixations, the reader intended to fixate the previous word and was intending to process that word rather than the following word.

GENERAL DISCUSSION

McConkie and Rayner (1976) reported that the perceptual span in reading is asymmetric, with considerably more information obtained from the right of fixation than from the left. They reported that the effective visual field for subjects reading pages of text extends no more than 4 characters to the left of fixation and conjectured that it might be even smaller than 4 characters. The experiments reported here replicated their basic finding and expanded on those results to determine more precisely the extent to which information to the left of fixation is useful during an eye fixation in reading. The results of our experiments indicate that the effective visual field in reading extends up to 4 characters to the left of fixation. However, the results of Experiment 3 indicate that the only useful information to the left of fixation comes from the word currently fixated. Thus, our data are in support of the word perturbation hypothesis rather than the foveal disruption hypothesis discussed previously. Since readers typically fixate to the left of the center of words (Rayner, 1979), the 4 letters to the left of fixation would include the beginning letters of the word for all but the longest words. When the window was adjusted so as to coincide with the word boundary to the left of fixation of the currently fixated word, effective reading rate did not differ from the control condition in which nothing to the left of fixation was masked.

Although we did not specifically vary the amount of useful information to the right of the fixation point, previous research (McConkie & Rayner, 1975; Rayner & Bertera, 1979; Rayner et al., in press) has indicated that the effective visual field extends about 15 characters to the right of the fixation point. Summarizing over the different experiments, it can be concluded that the effective visual field extends from the beginning of the word currently fixated (or about 4 letters to the left of fixation when fixating on or beyond the 5th letter in a word) to about 15 characters to the right of the fixation point. To the right of fixation, different types of information seem to be acquired with information necessary for semantically identifying words limited to the foveal and near parafoveal region and more gross types of information acquired further into the parafovea (Rayner, 1975).

The finding that information is acquired to the left of fixation for currently fixated words is consistent with the results of a series of experiments reported by Rayner, McConkie, and Zola (1980). They suggested that subjects do some type of preliminary letter identification of the beginning letters of parafoveally presented words and that this information is useful in identifying the word after an eye movement that brings the word to the fovea. However, they also reported an experiment in which a word like TRAIN was initially presented in the parafovea, and during the saccade to its location TRAIN was replaced by CLASH. If subjects make preliminary letter identifications of the beginning letters of words prior to moving the eye to that location, it seems reasonable to assume that they could devote attention to the end of the word following the eye movement. In the situation in which TRAIN is replaced by CLASH, it might be expected that subjects would misread the word on the CRT as TRASH (by combining the beginning letters of the word prior to the eye movement with the end letters after the eye movement). However, subjects never misread CLASH as TRASH. Apparently, some final check of the beginning letters of the word occurs following the eye movement and attention is not automatically directed toward the end of the word. Thus, while there is evidence (Rayner, 1975; Rayner & Bertera, 1979; Rayner et al., in press) to indicate that readers obtain information about the beginning letters of words in parafoveal vision, the results presented here indicate that the readers do engage in some type of confirmation of any preliminary letter identifications they may have made about words lying just to the right of fixation in the region from which it is difficult to obtain information useful for semantic identification.

Finally, the results of the experiments reported here, dealing with the asymmetric characteristics of the effective visual field, have implications for the relative importance of reading habits vs. hemispheric specialization. Since, for English readers, most of the useful information available from the text goes first to the left hemisphere, it is not possible to assess the relative contributions of reading habits and factors underlying hemispheric specialization to the asymmetry of the effective visual field. However, Israeli readers who are bilingual in Hebrew and English have been shown (Pollatsek, Bolozky, Well, & Rayner, Note 1) to have effective visual fields that are asymmetric to the left while reading Hebrew and asymmetric to the right while reading English. Thus, we conclude that the asymmetric characteristics of the effective visual field are determined by attentional factors that develop as a function of direction of reading and the direction of the majority of the eye movements.

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NOTES

1. Since we were averaging rates over conditions, the appropriate average rate is given by the harmonic mean, $1/\Sigma_{p_i t_i}$, where $t_i = 1/R_i$ is the average time per word in the letter condition with i characters available to the left of fixation. More precisely, the actual equation used for the estimated time per word in the 1W condition was $\Sigma p_i t_i$, where p_i is the proportion of instances that i characters were available to the left of fixation in the 1W condition (counting the space in order to be conservative) and t_i was the observed time per word in condition L_i. As mentioned in the text, fixations on the space were counted in estimating p_i, and for $i > 4$ the probabilities were summed and the time per word in the no-mask condition was employed. Estimated time per word was then converted back to reading rates in the 1W condition.

2. Again, the analysis was done on *time per word* (see footnote 1). The time per word for letter condition i was estimated to be $p_i t_p + (1 - p_i) t_{nm}$, where p_i is the observed probability that the word fixated is not fully visible in condition L_i (the four values reported in the text), t_p is the estimated time per word in a hypothetical condition where the fixated word is always perturbated (the free parameter of the model), and t_{nm} is the observed time per word in the no-mask condition. In this analysis, individual differences were ignored and a single fit was made for the grouped data.

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