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Contextual Effects on Word Perception and Eye Movements during Reading

SUSAN F. EHRLICH

Harvard University

AND

KEITH RAYNER

University of Massachusetts

Subjects read passages of text which differed in the extent to which the context constrained or predicted the occurrence of particular target words. In Experiment 1, misspellings were introduced into target words and we examined the extent to which fixation duration and probability of fixating the target word was influenced by contextual constraint and the misspelling. Subjects had a lower probability of fixating the target word in the high-constraint passages than in the low-constraint passages. Furthermore, when subjects did fixate the target, the fixation duration was shorter in the high-constraint passages. In Experiment 2, subjects read passages which included either a predictable target word or a visually similar word which was unpredictable. Fixation durations on the target word were shorter when the predictable word was in the target location than when the unpredictable word was present. The implications of the results for the role of contextual constraint in reading are discussed.

The effect of context on perceptual processing has been documented with a number of experimental paradigms. For example, it has been demonstrated that objects are identified more accurately when they appear in appropriate context (Biederman, 1972). Other studies have demonstrated that context affects word perception, particularly when the visual information is impoverished (Morton, 1964; Tulving & Gold, 1963; Tulving, Mandler, & Baumal, 1964; Meyer, Schvaneveldt, & Ruddy, 1975; Schuberth & Eimas, 1977; Marcel, 1974; Stanovich & West, 1979; McClelland & O'Regan, 1981; Fischler & Bloom, 1979; Stanovich, 1980). This general line of research supports the hypothesis that context facilitates word perception and allows decreased dependency on visual information. According to one conceptualization, the reader is assumed to be actively using the linguistic context to predict the next word and uses fewer visual cues to perceive it. The reader is assumed to be minimally sampling the text in order to confirm ongoing hypotheses about words that are based on context (Goodman, 1967; Smith, 1971; Haber, 1978). Others have suggested that access to the representation of words in memory is facilitated by contextual constraint via (1) an associative priming mechanism (Meyer et al., 1975) or (2) by partial cues obtained from parafoveal vision interacting with context (McConkie & Rayner, 1976). According to either the hypothesis testing or the contextual facilitation theories, the context enables the reader to use fewer

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visual cues in order to more rapidly process the text.

In the present experiments, we have attempted to examine the locus of contextual facilitation in word recognition in connected prose by recording readers' eye movements and examining the probability that subjects will directly fixate words that are highly constrained. At the same time we have examined sensitivity to featural information by measuring subjects' awareness of misspellings that are made in words. If contextual constraint is used to guide eye movements, we should expect that direct fixation on highly constrained words would be less frequent than on words that were not highly constrained by context. On the other hand, if context influences the degree of analysis that is applied to words that are encountered in central vision, then sensitivity to substitutions of letters should be lower when those words are highly constrained even when those words are directly fixated.

In an experiment designed to examine the influence of context on word perception, Zola (1982; see also McConkie & Zola, 1981) asked subjects to read passages of text as their eye movements were recorded. Passages that were identical except for one adjective were constructed. The adjective either highly constrained the following noun or was neutral with respect to it. For example, subjects were asked to read a passage about the movie industry. One of the sentences read as follows: "Since movie theaters must have buttered popcorn to serve to their patrons. . . ." When subjects were given the passage up through the word *buttered* in a modified cloze task, they responded with the word popcorn 83% of the time. On the other hand, when the word *buttered* was replaced with the word *adequate,* subjects chose *popcorn* as an acceptable completion only 8% of the time. A different group of subjects read the passages with constraining and nonconstraining adjectives and their eye movements were recorded. In some conditions, Zola systematically introduced spelling errors in the critical noun (for example, the *c* in popcorn was replaced with an *e* or a *t*). He found that the probability of fixating on the target noun was not influenced by the type of adjective or by whether or not there were misspellings. The probability of fixating on the target noun in the four conditions (formed by crossing these two variables) averaged about .97. The mean fixation duration and total time spent fixating the critical noun (determined by adding together all fixations on the word) were significantly longer in the cases in which there was a misspelling. In the cases in which there was no misspelling, the average fixation duration on the critical noun in the high-redundancy condition was 221 milliseconds and in the low-redundancy condition it was 237 milliseconds. The total time fixating the critical noun (including regressive fixations) was 290 and 313 milliseconds in the high- and low-redundancy conditions, respectively.

On the basis of the results of his experiment, Zola (1982) concluded that the reader encounters all the visual detail that is afforded by the text. The fact that the misspellings affected fixation duration even when they were in the middle letter position of seven-letter words does seem consistent with the view that the reader responds to all of the visual information that is specified by the printed message. More importantly, Zola concluded that contextual and redundancy patterns do not influence eye movement characteristics and that while context did decrease the fixation duration on the highly redundant noun, the "savings" was slight.

Zola's experiment is important because it represents the first attempt to use eye movement data to measure local contextual effects on word perception in the ongoing task of silent reading. However, there appear to be two potential problems associated with the study. First, Zola's target

words were all seven or eight letters long. This is problematic because Rayner and McConkie (1976) have demonstrated that with normal reading speeds of 250–400 words per minute, words that are seven to eight letters long will be fixated 95% of the time. Hence, there is the strong possibility of a ceiling effect. In fact, given that the critical noun was fixated 97% of the time it appears there were ceiling effects. Second, the target word in Zola's experiment only became highly redundant as a result of the immediately preceding word. We will argue that the effect of context on processing words in reading is strongest when constraint builds up over time.

The present experiments differ from Zola's experiment in a number of ways. Our target words were all five letters long. Also, the context for the critical target word built up throughout the passage rather than from only the preceding word. The probability of fixating five-letter words has been found to be .64 (Rayner & McConkie, 1976). Our experiments employ a design similar to that of an experiment reported by Ehrlich (1979; 1981) in which children read passages aloud that were either highly predictive or neutral with respect to words occurring in certain locations. As in Zola's experiment, Ehrlich inserted misspellings; however, those misspellings resulted in real words (i.e., *horse–house*) so that sensitivity to the letter would result in oral reading of a word that was anomalous in the context. In general, the children were more likely to overlook letter substitutions when the words containing the substitutions were highly constrained. The subjects were particularly sensitive to misspellings in the beginnings of the words and to misspellings that altered the overall shapes of the words as revealed by accurate identification of the anomalous words that resulted from the letter substitutions and by pauses and hesitations. In the experiments reported here, college students read paragraphs with the same characteristics as those of the paragraphs used by Ehrlich, and their eye movements were recorded.

Experiment 1

Method

Subjects. Twenty-four members of the University of Massachusetts community were paid to participate in the experiment. All of the subjects had normal, uncorrected vision and they all had previously participated in experiments dealing with eye movement recording. The subjects were naive with respect to the purpose of the experiment.

Materials and apparatus. Twenty-four five-letter word pairs were found, the members of which differed from each other in terms of a single letter. The letter differences occurred in either the first (*night–right, witch–pitch*), middle (*horse–house, ankle–angle*), or last (*steak–steal, shark–sharp*) letter position of the words. The letter differences resulted in either the same overall word shapes for a pair or in different shapes for the two words, in terms of ascending and descending letters. Thus, there were six types of words determined by the factorial crossing of letter position and the effect of the differing letter on overall word shape. For convenience, the first of each pair will be called the target and the second will be called the substitute.

For each target word, both a highly constraining and a contextually neutral paragraph were developed. Degree of constraint was measured using a modified cloze procedure. Twenty college students were presented 48 paragraph contexts each, in which the target words and the following context had been deleted. They were asked to write down the word that they thought should come next in each paragraph. The percentages of correctly selected target words averaged across passages was 93% for the high-constraint paragraphs and less than 15% for the low-constraint condition. The low-constraint condition resulted in a wide

range of responses for any particular paragraph. Table 1 contains an example of a high- and low-constraint paragraph. In many of the high-constraint passages, the target word also occurred earlier in the passage. All of the target words were common nouns. In both the high- and low-constraint passages, the letter substitution created a word that was anomalous in the context that was provided. The position of the target word in the paragraph varied, but it never occurred within two words of either end of the line of print.

Eye movements were recorded by a Stanford Research Institute Dual Purkinje Eyetracker which was interfaced with a Hewlett–Packard 2100A computer. The position of the eye was sampled every millisecond and each 4 milliseconds the average horizontal and vertical position of the eye was compared to the prior 4 milliseconds to determine if the eye was in a fixation or a saccade. A complete record of the eye movement behavior was stored on the computer disk for later analysis. The passages were presented on a Hewlett–Packard 1300 Cathode ray tube (CRT) in standard lowercase format. Each letter was made up of dots from a 5 × 7 matrix. A bite bar was used to stabilize the subject's head and the eyes were 46 cm from the CRT so that three character spaces equaled 1° of visual angle. The passages were presented on the CRT extending over 7 to 10 lines with up to 42 characters on a line. The room was dark except for an indirect light source which enabled the experimenter to keep a complete record of the subject's responses to a set of questions presented in conjunction with the passages. At the beginning of the experiment, the luminance of the CRT was adjusted to a comfortable level for the subject and then held constant throughout the remainder of the experiment. Prior to the presentation of each passage, subjects were asked to blink a number of times and then encouraged not to blink during the passage. This procedure, coupled with the fact that the subjects were all experienced in eye movement experiments, resulted in the loss of only 2% of the data due to track losses associated with blinks.

TABLE 1
EXAMPLE OF A HIGH-CONSTRAINT AND LOW-CONSTRAINT PASSAGE

High constraint
He saw the black fin slice through the water and the image of sharks' teeth came quickly to his mind. He turned quickly toward the shore and swam for his life. The coast guard had warned that someone had seen a shark off the north shore of the island. As usual, not everyone listened to the warning.
Low constraint
The young couple were delighted by the special attention they were getting. The zoo keeper explained that the life span of a shark is much longer than those of the other animals they had talked about. The scientists decided that this man would make a great ally.

Note. The target word is underlined in the examples, but was not in the experiment.

Procedure. When a subject arrived for the experiment, the bite bar was prepared and the eye movement recording system was calibrated. Since all of the subjects were experienced in eye movement experiments, the initial calibration was accomplished in less than 5 minutes. Then the purpose of the experiment was explained to the subjects. They were told that the experiment dealt with an investigation of where in a passage subjects directed their attention as they read for comprehension. Half of the subjects were given a comprehension question prior to reading each passage and half were given the questions after reading each passage. After the subjects finished reading the passage, they pushed a lever with their right hand; this resulted in the passage disappearing from the CRT. The subject then released the bite bar and answered the comprehension question. The instructions emphasized that the most important part of the experiment was to be able to answer the questions. Subjects were further instructed that there might occasionally be words that seemed out of place, but they were not to give undue attention to these words.

None of the answers to the comprehen-

sion questions were located in a single spatial location in the passage, but rather they required the subject to draw inferences on the basis of information obtained from different places in the passage. In many cases, there was not a single correct answer to a question. It is important to note that virtually all of the subjects believed the purpose of the experiment was to determine where readers look to answer inference questions about a passage of text.

During the experiment, each subject initially read two passages for warm-up and then 30 passages. Included within the 30 passages were 12 passages with misspellings, 12 passages which served as the control passages, and 6 filler passages (which also did not include any misspellings). There were four sets of passages. Each subject saw only one of the four possible versions of each paragraph that resulted from the crossing of level of constraint with whether or not there was a misspelling present. Within each set, the paragraphs were arranged in a random manner and all subjects receiving a particular set read all of the passages in the same order. Within each set, the 12 passages containing a misspelling included an equal number of same-shape and different-shape substitutions and an equal number of substitutions in the beginning, middle, and end letter.

At the conclusion of the experiment, the subjects were informed that there were anomalous words in the text and asked if they had noticed them. They were then shown copies of each passage and specifically asked to indicate if they had noticed the anomalous words during their initial reading of the passage.

Results

The data from Experiment 1 were analyzed in a number of different ways. We shall report analyses dealing with (1) the probability of fixating the target word, (2) fixation durations on the target word and total reading time for each target word, (3) the probability of fixating the target word and fixation durations related to the characteristics of the misspellings, and (4) the probability of reporting the misspelling. In the cases in which the effect of context was evaluated in relation to whether or not there was a misspelling, a 2 (question before vs question after) × 2 (constraint: high vs low) × 2 (misspelling vs no misspelling) ANOVA was performed on the data with the latter two variables being within-subject manipulations and the question before or after variable being a between-subjects manipulation. In the case in which the effects of specific types of misspellings were considered, we collapsed across the level of context variable and conducted as 2 (question before vs question after) × 2 (shape preserving vs shape altering) × 3 (letter position) ANOVA.

Probability of fixating the target word. Table 2 presents the probabilities of fixating on the target word as a function of the level of context and the presence of a misspelling. When only forward fixations (left-to-right) are considered, readers had a lower probability of fixating on words when the context was highly predictive of the target word than when it was not, $F(1,22) = 23.11$, $p < .001$. In addition, there was a higher probability of fixating on target words when there was a misspelling, $F(1,22) = 14.68$, $p < .01$, than when there was not. However, this latter point is qualified by the significant interaction, $F(1,22) = 6.95$, $p < .05$, of the two variables. That is, as seen in Table 2, although the difference between the control condition in which there was no misspelling was slight in the high-constraint passages (.51 vs .56), the difference is considerably greater in the low-context passages. It should be noted, however, that

TABLE 2
PROBABILITY OF FIXATING ON THE TARGET WORD AS A FUNCTION OF CONTEXT AND WHETHER OR NOT THERE WAS A MISSPELLING

	High constraint	Low constraint
Control	.51 (.54)	.62 (.71)
Misspelling	.56 (.73)	.79 (.87)

Note. Values in parentheses include regressions.

when regressive eye movements to the target word were included, the interaction was no longer significant ($F < 1$) while the main effects of misspelling, $F(1,22) = 26.27$, $p < .001$, and constraint, $F(1,22) = 44.65$, $p < .001$, remained significant. There were no significant differences in the probability of fixating the target words between the subjects who received the questions prior to reading or after reading nor did this between-subjects variable interact with any of the other variables.

We also calculated for each subject the mean distance of the preceding fixation from the beginning of the target word. These means were then subjected to an analysis of variance. There were no significant differences between the two groups of subjects or as a function of constraint or misspelling. In general, the average distance that subjects fixated from the beginning of the target word was 5.5 character spaces. However, an ANOVA on the average length of the subsequent saccade indicated longer saccades (9.9 characters) in the high-constraint condition than the low (8.6 characters)-constraint condition, $F(1,22) = 12.28$, $p < .01$.

Fixation duration on the target words. The average fixation duration on the target word was computed and the data are shown in Table 3. The average fixation duration on the target word was considerably longer when there was a misspelling than when there was not, $F(1,22) = 137.52$, $p < .001$. The high-constraint passages resulted in shorter average fixation durations than did low constraint, $F(1,22) = 8.09$, $p < .01$. In the cases in which there was not a misspelling, the high constraint resulted in an average fixation duration that was 33 milliseconds shorter than that in the low-constraint condition, $t(23) = 4.04$, $p < .001$. The significant effect of fixation duration held when only forward fixations were considered. If we consider only forward fixations the means were 215 for the high-constraint and 240 milliseconds for the low-constraint passages, $t(23) = 3.88$, $p < .01$.

TABLE 3
AVERAGE FIXATION DURATION (msec) ON THE TARGET WORD AS A FUNCTION OF CONTEXT AND WHETHER OR NOT THERE WAS A MISSPELLING

	High constraint	Low constraint
Control	221 (248)	254 (305)
Misspelling	313 (476)	324 (541)

Note. Values in parentheses indicate total reading time for the target word.

Following Zola (1982), we also computed the *average total reading time* per target word. In computing *average fixation duration,* all fixations on the target words within each condition were summed and divided by the number of fixations. In computing average reading time per word, rather than dividing by the number of fixations, we divided by the number of words that received at least one fixation. This measure resulted in results analogous to the average fixation duration measure for both misspelling, $F(1,22) = 140.42$, $p < .001$, and constraint, $F(1,22) = 9.33$, $p < .01$. For the average fixation duration measure, subjects who received the questions after reading had longer fixations (295 msec) than those receiving questions before (261 msec) reading, $F(1,22) = 5.97$, $p < .05$, and the interaction with misspelling was also significant, $F(1,22) = 6.01$, $p < .05$. However, when the total reading time per word measure was computed neither effect was significant ($F < 1$). Thus, this result seems to suggest that the subjects who received the questions after the passages were reading more carefully on the initial pass through the passage, but that the effect of the misspelling was so overwhelming that when it was detected it tended to obscure any difference between the two groups of subjects. We will present other data later to indicate that the subjects who received the questions after the passages read more carefully than those who received the questions prior to reading.

Probability of fixating and average fixation duration as a function of misspelling.

Table 4 presents the probability of fixating on the target word, fixation duration, and the average reading time per word as a function of the type of misspelling. When only forward fixations were considered, there were no significant effects although the effect of preserving or altering the shape of the target word approached significance, $F(1,22) = 3.33$, $p < .08$. When regressions were also considered, substitutions which altered the shape of the target word led to a higher probability of fixating the target word $F(1,22) = 6.31$, $p < .02$. In both analyses, there was some indication that there was an influence of letter position with the change in the middle letter leading to a lower probability of fixation than a change in either the beginning or end letter. However, this effect failed to reach significance ($F < .16$), due to the great amount of variability between subjects. In a later section, we will present other evidence to indicate that readers were more likely to miss the misspelling when it was in the middle letter position of the word.

For the fixation duration data, misspellings that altered the shape of the target word resulted in longer average fixations than those that did not, $F(1,22) = 35.91$, $p < .001$. The same result held for the total reading time per word measure, $F(1,22) = 22.23$, $p < .001$. For the total reading time per word measure, there was a significant effect of letter position of the substitution, $F(2,44) = 6.40$, $p < .01$. A Newman–Keuls test indicated that less time was spent (471 msec) on substitutions in which the middle letter was changed from the target word than when either the beginning letter (587 msec) or end letter (563 msec) was changed. Consistent with the main analyses we described above dealing with fixation duration and reading time per word as a function of misspelling and level of constraint, subjects who received the questions after the passages had longer average fixation durations than those who received the question prior to reading, $F(1,22) = 10.96$, $p < .01$, but when total reading time per word was computed there was no difference between the two groups.

Probability of reporting misspelling. As we indicated previously, after the subjects completed reading all of the passages they were asked to indicate which misspellings they had noticed as they read. A 2 (question before vs after) × 2 (constraint) ANOVA indicated that subjects had considerably more difficulty reporting a misspelling in the high-constraint passages than in the low-constraint passages, $F(1,22) = 33.33$, $p < .001$. The probability of reporting a misspelling was .64 in the high-constraint passages and .86 in the low-constraint passages. Subjects who received the questions after reading the passages were more likely ($p = .83$) to report misspellings than those who received the questions prior ($p = .67$) to reading, $F(1,22) = 4.83$, $p < .05$. This result is consistent with the argument that

TABLE 4

PROBABILITY OF FIXATING THE TARGET WORD AND AVERAGE FIXATION DURATION AS A FUNCTION OF THE LOCATION OF THE MISSPELLING IN THE TARGET WORD AND WHETHER OR NOT THE SUBSTITUTION ALTERED THE SHAPE OF THE TARGET WORD

	Beginning	Middle	End
Same shape			
p for fix[a]	.69 (.88)	.58 (.73)	.69 (.83)
Fix duration (msec)[b]	291 (512)	278 (379)	307 (521)
Different shape			
p for fix[a]	.75 (.88)	.69 (.88)	.79 (.92)
Fix duration (msec)[b]	334 (661)	337 (563)	316 (605)

[a] Values in parentheses include regressions.

[b] Values in parentheses indicate total reading time.

those receiving the questions after reading read the passages more carefully than those receiving them prior to reading.

We also examined the probability of reporting a misspelling as a function of letter position and type of substitution. Misspellings were reported 68% of the time if they altered the shape of the target word and 81% of the time if they did not, $F(1,22) = 5.62$, $p < .03$. There was also an effect of letter position, $F(2,44) = 5.17$, $p < .01$, such that misspellings were much more likely to be detected if they occurred in the beginning letter position (.83) than at the end position (.64), and misspellings in the middle position (.76), which did not differ significantly from the beginning position, were detected more frequently than in the end position (Newman–Keuls test, $p < .05$). There was no interaction of the between-groups variable with the within-subjects manipulations.

A final question of interest related to the probability of reporting the misspelling concerns whether or not subjects fixated on misspellings that they could not report. Table 5 shows a contingency table indicating the percentage of times that subjects did (or did not) report the misspelling. As expected, most of the time that subjects reported the misspelling, they also fixated on the word. There were some instances in which subjects did not fixate on the misspelling, but still were able to report it. Examination of the raw data revealed that in these cases, subjects fixated just prior to the beginning of the word. Twelve percent of the time subjects did not fixate on the word, and did not report the misspelling. Of most interest is the fact that for 13% of the total number of cases subjects fixated on the target word *and* did not report the misspelling. It seems unlikely that subjects noticed the letter substitutions but forgot them when asked at the end of the session because those letter substitutions created anomalous words which should have had a strong impact on the comprehension process. Most of the time when subjects did not report the misspelling the average fixations on the target word were considerably shorter than instances in which they did report the misspelling. Seventeen of the subjects had entries in both of the top two cells of Table 5 and we computed the average fixation duration associated with each entry for these subjects. The average fixation duration was 316 milliseconds when the misspelling was reported and 251 milliseconds when it was not, $t(16) = 4.76$, $p < .001$. When the misspelling was not reported, there was seldom more than one fixation on the word, while there were often a number of fixations on (and regressions to) the target word when it was reported. The total reading time for the target word was 278 milliseconds when it was not reported and 497 msec when it was, $t(16) = 9.16$, $p < .001$.

TABLE 5
CONTINGENCY TABLE OF PROBABILITY OF REPORTING (OR NOT REPORTING) THE MISSPELLING CONTINGENT ON WHETHER OR NOT THE TARGET WORD WAS FIXATED

	Report misspelling	Report misspelling	Total
Fixate	.66	.13	.79
Fixate	.09	.12	.21
Total	.75	.25	

Discussion

The first experiment was designed to examine two possible types of influence of contextual constraint on perceptual analysis of words. High levels of constraint may (1) influence readers to skip fixation of words and (2) influence readers to be less sensitive to visual features encountered in central vision. The results of this experiment provide evidence for both kinds of effects. Subjects were indeed less likely to fixate on a highly constrained word. This effect was not found by Zola (1982) perhaps because his contextual manipulation was not strong enough (a single adjective distinguished the high- and low-constraint conditions) and perhaps because he used seven-

and eight-letter words which in general have a high probability of being fixated.

When subjects directly fixated a word with a letter substitution, they were likely to be aware of that substitution. This was revealed by increased fixation durations and by the recall task. However, on 13% of the total number of cases, subjects did *not* notice the letter substitution in a word that was directly fixated. The large majority of these cases were in the high-constraint passages (88%). Thus, this experiment provides evidence that contextual constraint also influences subjects to be less sensitive to visual features that are encountered in central vision. The mechanism supporting this effect will be addressed in the General Discussion.

Fixation durations were found to be substantially shorter on control words that were presented in highly constraining context as compared to those presented in low-constraint context. It could be argued that both the fixation location and fixation duration effects found in this study reflect a global effect of context because the high-contraint passages were generally more coherent and redundant. A theory of eye movement control which holds that fixation location and fixation duration are controlled at a general level (i.e., in terms of the general ease of reading the text) might predict a general reduction in number of fixations and shorter fixation durations, independent of the local constraints for particular words. However, recent research in which various syntactic and semantic factors have been manipulated seems to indicate that fixation location and duration are influenced by factors that are specifically relevant to the words near the position of fixation (Rayner, 1977, 1978; O'Regan, 1979; Frazier & Rayner, 1982; Carpenter & Daneman, 1981; Just & Carpenter, 1980). The paragraphs for the present study encompassed a number of different types of constraint. It will be important in the future to examine the independent contributions of conceptual, semantic, and syntactic constraint on the effects that have been demonstrated here.

Experiment 2

The second experiment was designed to further examine the influence of contextual constraint on fixation duration. In this experiment, all of the paragraph contexts were designed to be highly predictive of particular words. There were two conditions. In the first condition, the highly constrained target word was included in the paragraph. In the second condition, a letter substitution changed the identity of the word just as in Experiment 1. However, the resulting word was not anomalous in the context. The substitute word was consistent with the ideas of the paragraph even though the paragraph was highly predictive of the other alternative word. It is important to stress that there were *no* low-constraint paragraphs like those used in Experiment 1, where no particular word was highly predicted by the context.

Pairs of words were found that differed by a single minimally confusable letter in the middle letter position (*house–horse*) and two passages were written for each pair. For each passage, one of the words of a pair was highly predictable from the context and the alternative word was consistent but not highly predictable. Thus, single letters in the middle of the target word distinguished the conditions in this experiment. Because there was no manipulation of the context prior to the target word, no difference in the probability of forward fixations on the target word was predicted. However, we hypothesized that there would be a difference in the number of regressive eye movements made to words that were less likely in the context and also longer fixation durations on those words. Note that because the second alternative in a pair resulted from a same-shape letter substitution in the middle letter position, parafoveal information obtained prior to a direct fixation was essentially equated for the two conditions.

Note again that our experimental manipulation in Experiment 2 parallels the spelling manipulation for the high constraint paragraphs of Experiment 1. The only difference is that the "substitute" word made sense in the context in the second experiment. It was of interest to determine if an alternative word that was consistent with context but unpredictable would produce more regressive movements and longer fixations than another consistent word that was more predictable. It is possible that the fixation duration and regression effects from the first experiment were due to the anomalous nature of the substituted word.

Method

Subjects. Ten members of the University of Massachusetts community were paid to participate in the experiment. All of the subjects had normal, uncorrected vision and had previously participated in experiments dealing with eye movement recording. They were taken from the same pool of subjects as were the subjects who participated in Experiment 1. The subjects were naive with respect to the purpose of the experiment.

Materials and apparatus. Eight pairs of five-letter words were found that differed in a single letter in the middle letter position (*house–horse, bones–boxes, boots–boats, fires–fines*). The pairs of words differed by a minimally confusable letter so that both words had the same overall word shape and, to the extent possible, the letters that differed were highly similar.

For each pair of words, two passages were written such that one passage constrained one member of the pair and the other passage constrained the other member. However, the passages were written such that the member of the pair for which the passage was not written could fit into the passage and still make sense, yet be rather unexpected. As in Experiment 1, a modified cloze procedure was used to measure the constraint of the passages. Twelve college students were presented 16 passage contexts in which the target word and the following context had been deleted. They were asked to guess what the next word should be. The probability of correctly guessing the target word was .60. If the subject did not correctly guess the predictable target word on their first guess, they were asked to guess again. The second guess increased the probability to .73. If they had not guessed the word on the second guess, context following the target word was given and the subjects were allowed two more guesses. With this added information, the probability increased to .91. None of the subjects ever guessed the unpredictable member of the pair. To make sure that the passages were not considered anomalous, another group of eight subjects was given all of the passages from the second experiment, as well as passages from the first experiment that included misspellings (and hence were anomalous). Subjects were asked to read the passages and sort them into piles corresponding to highly meaningful, meaningful, and anomalous. None of the passages used in Experiment 2 were rated anomalous. As in Experiment 1, the location of the target word in the passage varied, but did not occur at the beginning or end of a line. Table 6 contains an example of a passage used in Experiment 2.

The apparatus used in the experiment was identical to that used in Experiment 1. As in Experiment 1, about 2% of the data were lost due to track losses.

Procedure. The general procedure was the same as for Experiment 1. However, in the second experiment, the comprehension questions, while often still involving inferences, required the subject to respond with the target word as part of the answer. The questions were always presented just after each paragraph had been read. In this way, we were able to get a more immediate test of the extent to which subjects misread the target word. Again, as in Experiment 1, subjects were instructed that the experiment was about where people look to answer questions when reading. No mention

TABLE 6
EXAMPLES OF PASSAGES FROM EXPERIMENT 2

It is often said that dead men tell no tales. But, Fred was very nervous as he put his shovel into the ground where he knew the makeshift grave was. He soon uncovered the skeletal remains and cleared the dirt away. He reached down and picked up one of the bones and quickly threw it aside realizing that it was not what he was searching for.

Real estate values had been rising each year and John decided that if he was going to keep up with inflation, he would have to act soon. He talked with his wife and they decided it was finally time to buy the new house they had dreamed about. He assured his wife that diversifying one's assets was a smart plan.

Note. The target word is underlined in the examples, but was not in the experiment. In the upper passage, the word *boxes* was inserted in the target location. In the lower passage, the word *horse* was inserted in the target location.

was made of misspellings or unusual words in the text.

During the experiment, each subject initially read two warm-up passages. Included within the 24 passages in the body of the experiment were 8 filler passages, 8 passages in which the predictable or expected word occurred, and 8 passages in which the unpredictable word occurred. There were two sets of passages with the order of passages the same in both sets. Each set contained an equal number of predictable and unpredictable target words. Each passage of the second set included the member of the word pair that was *not* used in that passage in the first set.

Results and Discussion

For the data from Experiment 2, we shall report analyses dealing with (1) the probability of fixating the target word, (2) fixation durations on the target word and total reading time for each target word, and (3) the probability of reporting the unpredictable word.

Probability of fixating a target word. Table 7 presents the probabilities of fixating on the target word as a function of whether or not the predictable or unpredictable word was present in the passage. When only forward fixations were considered, there was no difference in the probability of fixating the target word between the predictable and unpredictable conditions. However, when regressive eye movements to the target word were included, there was a higher probability of fixating the target when it was unpredictable, $t(9) = 3.39$, $p < .01$. This result replicates our finding in Experiment 1 that there was no difference within the high-constraint condition between the control and misspelling conditions for forward fixations.

TABLE 7
PROBABILITY OF FIXATING ON THE TARGET WORD AND AVERAGE FIXATION DURATION (msec) AS A FUNCTION OF WHETHER THE TARGET WORD WAS PREDICTABLE OR UNPREDICTABLE

	Probability of fixating[a]	Fixation duration[b]
Predictable	.68 (.72)	228 (269)
Unpredictable	.68 (.82)	283 (429)

[a] Values in parentheses include regressions.
[b] Values in parentheses indicate total reading time for target word.

Fixation duration on the target words. Table 7 also shows the average fixation duration on the target word, as well as the average total reading time for the word. The average fixation duration on the target word was considerably longer when the unexpected word was present in the passage than when the predictable word was present, $t(9) = 6.87$, $p < .001$. This result held when only forward fixations were considered with means of 229 milliseconds for the predictable word and 264 milliseconds for the unpredictable word, $t(9) = 2.88$, $p < .05$. When the total reading time for the word was computed, the difference between the predictable and unpredictable target word remained highly significant, $t(9) = 5.01$, $p < .001$. We also examined the duration of the fixation immediately preceding the fixation on the target word and the duration of the fixations following the target word. There was no difference be-

tween the two conditions for the preceding fixation (230 msec for the predictable target word and 234 msec for the unpredictable target word). The fixation following the target word resulted in a longer fixation (253 msec) in the unpredictable condition than in the predictable (220 msec) condition, $t(9) = 3.86$, $p < .01$.

Probability of reporting the unpredictable word. The unpredictable word was correctly reported in the subjects' answers to the comprehension questions 84% of the time. In Experiment 1, subjects correctly reported the misspelling 75% of the time so that the results we obtained in Experiment 2 are quite consistent with our first experiment.

Table 8 shows a contingency table indicating the percentage of times that subjects did (or did not) report the unpredictable word contingent on whether or not they fixated on it. As in Experiment 1, most of the time that subjects reported the unpredictable word, they also fixated on it. Ten percent of the time, subjects did not fixate on the unpredictable word yet were still able to report it. As in Experiment 1, most of the entries in this cell consisted of fixations just to the left of the beginning of the target word. When subjects did not fixate on the unpredictable word, the probability of reporting the predictable word was .08. Finally, again as in Experiment 1, 8% of the time the subjects fixated on the unpredictable word but reported the predictable word. In the second experiment subjects were required to respond with an answer to a question immediately upon completing the reading of a given passage. The required answer involved the target word and so we were able to get a good estimate of the frequency with which the target words were misread. The results were quite consistent across the two experiments. As was the case in Experiment 1, it was generally the case that when the subject fixated on the unpredictable word but reported the predictable word the fixation duration was considerably shorter than when the unpredictable word was reported. Five of the subjects had entries in both of the top two cells of Table 8 and we computed the average fixation duration associated with each entry for these subjects. All of the subjects had shorter fixations when the predictable word was reported (190 msec) than when the unpredictable word (292 msec) was reported, $t(4) = 2.91$, $p < .05$). When the predictable word was reported (with the unpredictable word actually in the passage), there was not a single case of more than one fixation on the word. On the other hand, when the unpredictable word was reported there were often multiple fixations on the word and regressions to the word. The results of both experiments indicate that for a small percentage of cases even when the target word was directly fixated, it was misread.

TABLE 8
CONTINGENCY TABLE OF PROBABILITY OF REPORTING (OR NOT REPORTING) THE UNPREDICTABLE WORD CONTINGENT ON WHETHER OR NOT THE TARGET WORD WAS FIXATED

	Report unpredictable word	Report unpredictable word	Total
Fixate	.74	.08	.82
Fixate	.10	.08	.18
Total	.84	.16	

GENERAL DISCUSSION

The results of our experiments provide strong support for the hypothesis that context affects eye movements and fixation durations on words during reading. The results of our first experiment indicated that the more constraining passages resulted in lower probabilities of fixating the target words and shorter fixation durations on those words that were fixated. The results of our second experiment, where the passages were identical up to the target word, also indicated that fixation durations were dependent upon the predictability of the target word. It is important to note, however, that the probability of making a for-

ward fixation on the target word was not influenced by whether the predictable or unpredictable word was present in the text. The passages were identical except for one single letter in the target word. It was only when regressive eye movements were included in the analysis that there was a difference between the two conditions.

In Experiment 1, if the misspelling was embedded in a high-constraint passage, subjects were much less likely to detect the misspelling. It was also the case that the characteristics of the misspelling very much influenced the probability of reporting the misspelling. If the misspelling preserved the shape of the target word, it was more likely to be missed. If the misspelling occurred in the middle or end letter position it was much less likely to be detected than if it occurred in the beginning letter position. It is interesting that while the probability of detecting a misspelling was influenced by the type of misspelling, eye movement behavior was strongly influenced by whether or not a misspelling was detected, independent of the type of misspelling. It was quite clear that in both of our experiments, when subjects did not report the substitute words, their reading behavior was very much like their performance in conditions in which there was no misspelling. When subjects detected the misspelling or unpredictable word, irrespective of the location in the word or whether or not the shape was preserved, the effect was that there was rather considerable disruption in reading.

The subjects' eye movement patterns seemed to be influenced by the substitute words primarily when the subjects were able to verbally report knowledge of the existence of those substitutions. This result is analogous to results reported recently by Inhoff and Rayner (1980). They simultaneously presented an ambiguous word in foveal vision and a disambiguating word in the parafovea. Immediately after the presentation of the display, subjects were asked to choose between the alternative meanings of the ambiguous foveally presented word. Subjects were biased in their choice of meaning only on those trials in which they were able to verbally report the identity of the parafoveal word. Under conditions in which they were unable to report the disambiguating word, they were not biased in their choice of phrases. Likewise in our experiments, when subjects were able to report the presence of the substitute word, their eye movements had clearly been affected by it, but when they could not report it, there seemed to be little influence. These data suggest that readers must be conscious of word identities if word meaning is to influence eye movement patterns.

Our results are also generally consistent with research dealing with speech perception (Cole, 1973; Morton & Long, 1976; Marslen-Wilson & Welsh, 1978; Cole & Perfetti, 1980). In particular, our results parallel those from a study reported by Marslen-Wilson and Welsh (1978) in which subjects were asked to shadow passages of text. The subjects were more likely to fail to detect a mispronunciation when the word was highly constrained by context. They also found differences in subjects' ability to detect errors as a function of the location of the error, with subjects being more sensitive to errors in the first parts of the word.

Our results suggest that contextual information does allow a reduction in readers' reliance on visual information (Morton, 1969; McConkie & Rayner, 1976; McClelland & O'Regan, 1981). If it is assumed that there is a threshold associated with word identification during reading, more powerful context might well reduce that threshold in comparison to a less powerful context. Hence, there would be somewhat reduced fixation durations when the word in question is directly fixated. The reduced fixation duration may also reflect the fact that less time is needed to integrate the word that is accessed in the lexicon into the conceptual network that represents the meaning relationships of the text. The lower-threshold notion could also explain why the target word was fixated less frequently in the high-constraint condition than in the low-

constraint condition in Experiment 1. If the reader were fixated to the left of the beginning of the target word, the visual information picked up from the target word would be the same as if the reader were fixated in the same location and the target word were in a low-constraint paragraph. However, since the threshold for word identification is lower in the high-constraint condition, the visual information acquired may be sufficient to convince the reader of the identity of the word. Hence, when a misspelling occurred in the middle or end letter position and the shape was preserved, the visual information was consistent with the misspelling and would easily lead the reader to identify the misspelled word as the target word. Even under conditions in which the shape was changed or the beginning letter was the location of the misspelling, it was still the case that much of the visual information was consistent with the target word.

We would like to stress that we assume that the quality of the information picked up from parafoveal vision is constant independent of the level of constraint. However, information from parafoveal vision can be utilized more effectively in the high constraint condition because the threshold for identifying a parafoveal word is lower than in the low-constraint condition. Only in this sense, may it be assumed that the perceptual span region or the effective visual field in reading (Rayner, 1975) is variable depending on context.

Finally, the results of our experiment and the results of Zola's (1982) experiment are relevant to distinguishing between hypothesis testing and contextual facilitation theories of reading. Although readers in our experiment failed to detect the misspelling or fixate on the target word on some occasions, it was still the case that the misspellings were detected 75% of the time in Experiment 1 (64% in the high-constraint condition) and the unpredictable words were reported 84% of the time in Experiment 2. Likewise the target word was fixated 64% of the time in the high-constraint condition of Experiment 1 and the predictable word was fixated 70% of the time in Experiment 2. With longer words, Zola found that the target word was fixated 97% of the time. These probabilities of fixating the target word are interesting in light of the fact that in a cloze task other subjects were able to correctly identify the target word approximately 90% of the time in both Zola's experiment and in our Experiment 1, and 60% of the time in Experiment 2. It would seem that under such high-redundancy conditions the reader would not have to fixate on the target word at all (Smith, 1971). According to the hypothesis testing model, during each fixation the reader spends the major portion of the time generating a prediction of what will come next based upon what has already been read. The reader then moves the eyes and confirms the hypothesis and starts the cycle over again. However, given that the target word is highly predictable in the high-constraint condition, the reader should be able to generate accurate hypotheses which could be confirmed with the partial cues available from the parafovea without ever really fixating on the word. Yet we found, as did Zola, that readers fixate on these highly redundant words a good portion of the time. Such findings seem inconsistent with the hypothesis testing model. We further believe that the hypothesis testing model itself is untenable because it cannot explain recognition of words under the more common conditions of low constraint. The information in context is simply insufficient to allow for the isolation of single candidates. Because of this, direct visual analysis is clearly more efficient and we found clear evidence that readers are highly sensitive to even minor feature manipulations in low constraint. Hence, we prefer a contextual facilitation account as we have outlined in the present paper to explain context effects on word perception and on eye movements during reading rather than a hypothesis testing account.

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