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ABSTRACT

Thirty-six college students read a portion of a contemporary novel presented on a cathode ray tube while their eye movements were being monitored and recorded in an effort to determine how soon after the onset of a fixation during reading the mind begins to deal with characteristics of the language being perceived. The passage contained a total of 994 lines of text. Prior to reading, the participants were told that they would encounter words that had been replaced by other words or nonword strings in order to make reading more difficult. They were instructed that their task was to try to read and understand the text despite these obstacles. The passage was broken into 15 segments of approximately equal length. Subjects answered true-false comprehension questions after reading each segment, including a practice passage. The data indicated that eye movement control was affected by orthographic characteristics of the language within 140-159 msec. The results were found to be comparable to those of a previous study that utilized orthographically irregular strings, but involved stimulus changes during fixations. (HOD)

Mental Chronometry During Fixations in Reading

Processing Orthographic Characteristics of the Text

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Abstract

College students read text on a CRT while their eye movements were being monitored and recorded. The text contained orthographic errors. Hazard distributions of fixation durations on original words and substituted irregular orthographic strings were examined. The data indicated that eye movement control is affected by orthographic characteristics of the language within 140-159 msec. The results are interpreted within the framework of a chronology of processing events occurring during a single fixation in reading, and are in agreement with a similar study that entailed display changes.

Mental Chronometry During Fixations in Reading: Processing the Orthographic Characteristics of the Text

The purpose of the present paper is to explore some of the temporal characteristics of the perceptual processes that take place during fixations in reading. Specifically, how soon after the onset of a fixation during reading does the mind begin to deal with characteristics of the language being perceived.

There has been a long-standing dispute about whether language processing (related to the words perceived on a fixation) can take place fast enough to influence the time of onset, and extent of the immediately following saccade. Some researchers argue that little time is available during a fixation in reading within which to permit the reader to recognize foveal and peripheral information, to make a decision on the basis of that information concerning where to send the eyes, and to set up the proper sequence of motor commands necessary for the execution of the next eye movement (Bouma & deVoogd, 1974; Shebilske, 1975). Such a view is buttressed by the observation that the average minimum latency of an eye movement is 175-200 msec (Rayner, Slowiaczek, Clifton, and Bertera, 1983), while the median fixation duration in reading is only about 25-50 msec longer than this. However, in a recent review of temporal factors related to eye movement control Rayner (1984) concluded that sufficient visual information is acquired during the first 50-75 msec of a fixation in reading to program the next saccade. Specifically, he suggests that during the first 50-75 msec of a fixation the decision is made as to where to send the eyes with the remaining 150-175 msec consumed in programming and initiating the subsequent saccade. Rayner's hypothesis allows

for other processes (e.g., lexical access) to occur in parallel with this 150-175 msec latency period.

Another perspective is acquired on this issue by considering estimates of neural transmission time (Russo, 1978). If one places upper limits of 60 msec to transmit a new visual stimulus to the cortex and 30 msec to transmit a movement command to the motor control system, then only 135 msec of an average 225 msec fixation is available within which the material currently fixated can have an effect on eye movement control (see McConkie, 1983, for a review regarding this estimate). If one assumes that cognitive processing begins only after some minimal visual encoding, then even less time (i.e., 135 msec minus minimum visual encoding time) may remain for aspects of the language encountered on the current fixation to be processed prior to making decisions concerning where and when to move the eyes. Although this estimate is somewhat greater than Rayner's it still represents a small amount of time. The question is whether language processing can actually be carried out in such a short period. That is, can it occur early enough in a fixation to influence the onset time and extent of the following saccade.

McConkie, Underwood, Zola, and Wolverton (1985) found that, when a string of letters, violating orthographic constraints, is present in the text immediately to the left of the currently fixated letter during a fixation in reading, then the effects can be observed on the current fixation duration within 140-160 msec after the fixation begins. This is only 50-70 msec greater than the assumed afferent neural transmission time, and suggests that this initial level of language processing (dealing with the orthographic characteristics of the language) is reached very quickly during a fixation in

reading. There was one characteristic of the McConkie et al. (1985) study which leaves open the possibility of an alternative explanation. In their study the text display was changed from one fixation to the next such that no erroneous letters were present during one fixation, but all letters to the left of the directly fixated letter were replaced by other letters on the next fixation, the one on which a longer fixation duration was observed. Display changes, when they occurred, took place during the first 10 msec of the fixation. It is possible then, that the increase in the durations of fixations that occurred 140-160 msec into the fixation was due to a detection of this stimulus change, rather than to the presence of an orthographically inappropriate string of letters. The present study investigated the same issue, but this time no display changes were used. Orthographically irregular strings were permanently substituted for certain original words in the text. We hypothesized that if orthographic characteristics of the language are dealt with early in a fixation during reading, then results similar to those reported by McConkie et al. (1985) would be observed.

Methods

Subjects

Thirty-six University of Illinois undergraduate students participated in the experiment (23 females and 13 males). All participants had normal uncorrected vision. Students were recruited by newspaper advertisement and were paid for their participation. Age and reading measures were collected for 33 of the 36 participants. The mean age of male and female participants was 21.5 (n=11) and 20.31 (n=22) respectively. The Davis Reading Test (Davis & Davis, 1962) was administered to obtain comprehension and reading speed

measures. Seventy-two percent of the participants scored above the 74th percentile on Level of Comprehension while 75 percent scored above the 74th percentile on Speed of Comprehension. The level and speed of comprehension percentile scores ranged from 37-99 and 18-99 respectively. Percentile norms were based on the performance of college freshmen (Davis & Davis, 1962). Reading time scores were also obtained. Participants were timed as they read four segments of a contemporary novel. Comprehension questions were administered upon completion of each section. Seventy-five percent of the sample had reading rates above 220 words per minute (range: 168 - 409 words per minute).

Materials

Subjects read a portion of a contemporary novel as their eye movements were being monitored. The passage contained a total of 994 lines of text (10,487 words), with a maximum of 73 character positions per line. Three-hundred and six word locations were selected for experimental manipulation. These will be referred to as critical word locations. Each critical word location could contain one of six alternative stimuli: original word, orthographically irregular string, pseudo-word, syntactic violation, within-clause semantic violation, or thematic violation. Only the first two alternatives will be considered in this report, each occurring 51 times in the text.

Original word length ranged from four to eight character positions. Each alternative was the same length as the original word. The orthographically irregular strings contained the same letters as the original word, but were rearranged to violate the normal rules of English orthography as much as

possible. For example the word pile was transformed into the orthographically irregular string lpei.

Six versions of the passage were prepared, counterbalancing error types across critical word locations in the text. A short practice passage containing 66 lines of text (319 words) was also prepared. It was similar to the experimental passage. Each of the six types of alternative stimuli were represented twice within the text of the practice passage.

Apparatus

Text was displayed in upper and lower case letters, one line at a time, on a Digital Equipment Corporation VT-11 Model CRT. The CRT was placed 68 cm from the subjects eyes, allowing for 1 degree of visual angle to correspond to approximately 4 characters. The subject was given a hand held button that caused a new line of text to appear when pressed.

Eye movements were monitored with an SRI Dual Purkinje Eyetracker. Horizontal eye position was sampled every msec with an accuracy of 1/4 deg of visual angle.

Procedures

Prior to reading the participants were told that they would encounter words which had been replaced by other words or non-word strings in order to make reading more difficult. They were instructed that their task was to try to read and understand the text in the face of these obstacles. After reading the practice passage subjects proceeded with the experiment itself. The experimental passage was broken into 15 segments of approximately equal length. True-false comprehension questions were asked after the participant read each segment including the practice passage.

Data selection. Only certain fixations were selected for analysis. To qualify, a fixation must have been: 1) the first fixation on the critical word, 2) preceded by a saccade originating seven character positions or more to the left of the first letter of the critical word, and 3) located on either the first four letters of the critical word or on the space before the first letter of the critical word. Furthermore, if the subject had previously fixated within six letters to the left of the critical word or six letters to the right of it, the fixation was excluded. Underwood and McConkie (1985) failed to find evidence that distinctions among letters during reading were made more than about six or seven letters to the right and 3 letters to the left of fixation. We assume then, that our selection criterion established a data base of fixations on which the letters of the critical word location were first attended.

Results

The results presented here represent two goals of our present research. The first goal was to determine if the orthographically irregular string had any effect on eye movement control. Given that it did, the second goal was to determine the earliest point during a fixation that such an effect could be reliably observed.

Hazard analysis was utilized to accomplish the first task. The frequency of fixations of differing durations were tabulated in 20 msec blocks. A hazard value (Benedetti, Yuen, & Young, 1983) was then computed for each block and the resulting distribution plotted (see Figure 1). In this instance each point on the curves (each hazard value) represents the probability that a fixation duration which has survived to the beginning of this period will

terminate during any particular msec within that 20 msec block.

Insert Figure 1 about here

The hazard distributions for the experimental and control conditions were tested for equality using a 1 DF Breslow test (Benedetti, Yuen, & Young, 1983). A Breslow test is analogous to the Kruskal-Wallis or generalized Wilcoxon test. The two distributions were found to differ significantly ($H = 17.34$, $p < .0000$).

Visual inspection of the curves indicates three things. First, the early part of the curves are very similar. Second, the hazard distributions clearly diverge, and remain separated, beginning at the 140-159 msec block of fixation durations. Third, the probability of terminating a fixation in each interval decreases for the orthographic condition compared to the control condition beginning around 140-159 msec. It is apparent then, that when the reader encounters an orthographically irregular string a decision is made to extend the duration of that fixation beyond what it normally would have been had there not been orthographic errors. However, such a decision cannot be executed with respect to the current fixation, if the fixation is terminated in less than 140 msec.

Next, a sequential series of 1 DF Chi square tests (beginning with the first 20 msec block) were conducted in order to determine the earliest point in time that there was a statistically significant difference between the two hazard distributions (Mantel & Haenzel, 1959, cited in Lee, 1980). Such knowledge is helpful for estimating the earliest point in time during a

fixation that the orthographic characteristics of a word can be utilized. Chi square analysis indicated that the two distributions first became reliably different when data up through the 160-179 msec block of fixation durations are included [$X^2(1, S = 8) = 5.60$, $p < .025$]. Furthermore, the hazard distributions remained reliably different from that point on at the p=.05 to p=.005 level of significance. These observations suggest that orthographic characteristics of the text can be utilized within 140-159 msec of the fixation on which they were acquired, and that the effect can be reliably observed throughout the remainder of the distrubution of fixations.

We also examined the effect that encountering an orthographically irregular string nad on the saccade following the first fixation. The frequency of these saccades and their average lengths (forward and regressive) were examined for the following conditions: 1) saccades which took the eyes to a second fixation on the critical word, and 2) saccades which took the eyes to some other word.

Encountering an orthographic error caused an increase in the frequency with which the critical word was fixated a second time. The length of forward saccades taking the eyes to the same word was also reduced in the orthographic condition ($M = 3.37$, $SD = 1.35$) compared to the control ($M = 4.03$, $SD = 1,29$). This difference was statistically significant, $t(157) = 3.29$, $p < .0012$.

The frequency of forward and regressive saccades leaving the critical word was decreased for the orthographic condition compared to the control. Furthermore the mean forward saccade length (taking the eyes to some other word) after encountering an orthographic error ($M = 8.18$, $SD = 2.61$) was significantly shorter, $t(476.4) = 4.18$, $p < .0000$, compared to the control (M

= 9.23, SD = 2.91). It is obvious then, that in some instances, the programming of the following saccade was affected within the duration of the first fixation on which an orthographically irregular string was encountered.

Discussion

The results of the present study will be compared to a similar experiment (McConkie et al., 1985). Furthermore, the data, as analyzed thus far, will be interpreted in light of estimates of neural transmission times, allowing for several important observations.

The results of the present experiment are comparable to those of the previous study (McConkie et al., 1985) that utilized orthographically irregular strings, but involved stimulus changes during fixations. In that study, on occasional fixations during reading, all letters to the left of fixation were replaced with an orthographically inappropriate letter string. Results indicated that, 1) the time it takes for a stimulus manipulation occurring during the fixation to reach the cortex and affect eye movement control (the basic response time of the eyes) was 80-99 msec, and 2) the presence of orthographically irregular strings at the beginning of a fixation affects characteristics of eye movement control (fixation duration) 140-159 msec into the fixation. It is important to note that the latter estimate is only 60 msec longer than the basic response time of the eyes. The present study, which did not utilize display changes, agrees with this second finding. Specifically, the mind must be dealing with the most basic characteristics of the language (the orthography) within at least 140-159 msec of the fixation. If 30 msec of this time occurs after the eye movement decision is made, during which the command is sent to the ocular muscles, then it appears that, during

fixations in reading, gross stimulus characteristics can be dealt with within 50-69 msec of the fixation on which they are encountered (McConkie et al., 1985), with orthographic characteristics being processed about 60 msec later.

It can also be argued that the results of this experiment, in conjunction with those of McConkie et al. (1985), demonstrate that the basic response time of the eyes, and processing time estimates (for orthography at least), are faster than previously believed. It is clear that eye movement decisions can be made later in a fixation than previously suggested (Rayner, 1983, 1984) thus, 1) allowing time for the processing of certain characteristics of the text to occur early in the fixation, and 2) allowing processing of the text to have an impact on eye movement control on the current fixation.

It is also clear that aspects of eye movement control, other than fixation duration, were affected during the first encounter of an orthographically irregular string. That is, immediate effects were observed for the direction and length of subsequent saccades in some instances.

Finally, this experiment demonstrates that the methodology utilized in the present study provides a useful research technique for examining the temporal aspects of language processing during fixation pauses in reading. It is important to emphasize that the technique utilized here did not involve stimulus changes at any time during reading, allowing for a more ecologically valid experimental procedure.

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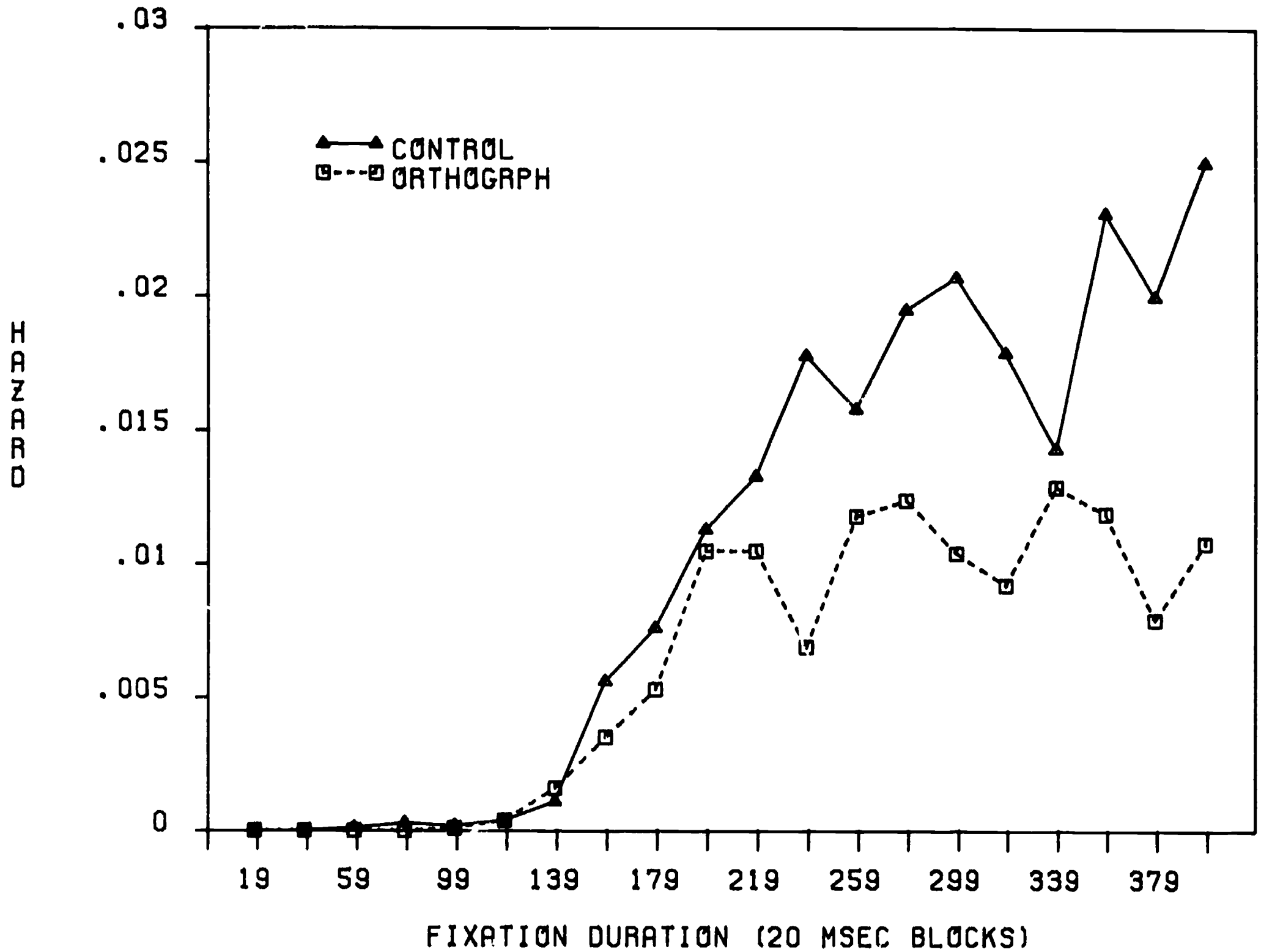
Figure Caption

Figure 1. Hazard distribution of fixation durations after the first encounter of original word and orthographically irregular string critical word locations.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FIXATION DURATION (20 MSEC BLOCKS)