Technical Report No. 333

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Center for the Study of Reading

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Abstract

College students read text displayed by computer as their eyes were being monitored. On occasional fixations or saccades the text was removed and the subject reported the last word that had been read and tried to guess the next word. Distributions of the location of the last read word with respect to the last fixated word give an indication of what words are being read during a fixation. The data do not support an anticipation model of reading nor the acquisition of peripheral cues concerning upcoming words.

Eye Position and Word Identification During Reading

One way to study the on-going mental processes taking place during reading is to interrupt reading at certain times and to have the readers introspect on some aspect of their mental state. This can be done using eye movement technology by programming the computer to detect when the eyes have reached a particular place in the text or have executed a certain movement pattern and then to remove the text from the display screen. This serves as a signal for readers to report their introspections. We will refer to this as the Disappearing Text technique.

The authors conducted a series of pilot studies with themselves and others, causing the disappearance of the text at random times during reading and attempting to see what aspects of processing could be reported. These studies indicated that the dominant experience which the reader has when the text disappears is that certain words are being read. One of the authors (GWM) spent ten hours reading a novel with the text being removed at random times averaging about every tenth line of text, and attempting to introspect on some aspect of the syntactic processing taking place. He was unable to introspectively grasp any aspect of syntactic processing and, as was found previously, the overwhelming experience was that of reading certain words. Attempts to introspect about hypotheses or predictions of upcoming words were equally unsuccessful. While it was possible to predict what words would

occur next, this required a special effort and a shift of perspective rather than being a natural part of the ongoing reading process.

For these reasons, the initial studies performed using the Disappearing Text technique, as reported in this paper, investigated the relationship between the location of the words being read and the location of the eyes in the text. This was done by occasionally removing the text during reading and having the reader report the last word which had been read. Distributions of the locations of the last word read, in relation to the location of the last word on which the eyes were centered prior to the text's disappearance, served as data and were compared for different conditions. The first study reported here compared these distributions when the text disappeared during vs. following a fixation and when the text was simply blanked out vs. being replaced by a masking pattern. The second study manipulated the time during the fixation at which the text disappeared. The third study replicated results from the earlier studies.

EXPERIMENT I

Method

Design

In this experiment, two variables were manipulated, each with two levels. The first variable was Text Replacement Type: when the text disappeared it was replaced either by an unbroken line of upper-case X's

or by a blank screen. The second variable was Replacement Time: the text disappeared either 120 msec following the beginning of a fixation, or after the fixation was complete (that is, during the following saccade). These two variables were combined into a 2 X 2 factorial design, with each of the four conditions occurring four times for each subject during the reading of a single passage. In addition, the text disappeared twice during regressive saccades, but insufficient data were obtained in this condition and it will not be discussed further.

Passage

The passage was 720 words in length and discussed supposed characteristics of gnomes. It was formatted with a maximum line length of 73 character positions, yielding 54 lines of text. This passage was then divided into 18 segments, each being one to five lines in length. The last line of each segment was that on which the text disappeared. The reader had no indication as to when the disappearance would occur. The experimental conditions were assigned to text segments randomly, with the restriction that all four conditions must occur before any of them could be repeated.

Subjects

Eleven undergraduate students were paid to participate in the study. All had been subjects in at least one previous eye movement study and were familiar with the equipment and general procedures.

Procedures

The text was displayed one line at a time on a cathode-ray tube, refreshed every 3 msec, as the reader's eyes were being monitored. After completing one line, the reader pressed a button to cause the next line to appear. Readers were instructed to read and try to comprehend the passage. They were also told that at unpredictable times during reading the text would disappear from the screen, sometimes being replaced by X's and sometimes just being blanked out. When this occurred, they were to immediately report the last word they had read before the text disappeared. In addition, they were asked to guess what the next word was beyond the last word they remembered reading. After recording this report, the experimenter would cause the line of text to reappear and they could continue reading the passage. In this way, the readers could check the accuracy of their reports and guesses. The computer program removed or replaced the text either during or after the fixation which followed the fourth forward saccade on a critical line.

Prior to reading each segment, the reader performed a calibration task by looking directly at a dot and pressing a button, as it moved to each of five locations along the line where text would appear.

The entire session required 20 to 40 minutes, and the time between text segments, during which readers gave their reports, typically ranged from 20 to 60 seconds. Longer intervals occurred when people had difficulty generating a guess about the next word. The time elapsing

between the disappearance of the text and the report of the last word read was typically less than 5 sec.

Equipment

Eye movements were monitored using a Biometrics Model SG limbus reflection eye movement monitor, with the eye position being sampled every msec. A bite bar was used to stabilize head position. Text was displayed on a cathode-ray tube with fast-decay phosphor and was refreshed every 3 msec. A description of the equipment and programs used in creating the eye-movement contingent display manipulations and in reducing the data is presented elsewhere (McConkie, Zola, Wolverton, & Burns, 1978).

Results

Data for 27% of the trials were discarded for the following reasons: occurrence of blinks, 11%; fewer than four forward saccades on the line, 8%; equipment failure, 5%; and eye movement patterns that rendered the data uninterpretable, 5%.

For each remaining trial, the last correctly reported word was identified, as well as the first word indicated as being a guess. Subjects frequently reported a three or four word sequence, often a complete or partial phrase, rather than reporting a single word, even though asked to report just the last word read. In earlier pilot work, subjects showed this same tendency; this seemed easier for them to do than to report a single last word read. Sometimes in guessing the next word, a word sequence was also given.

In these cases, the last word of the reportedly read sequence, and the first word of the guessed sequence were used as data.

Subjects had little trouble with the task of reporting what they had read. The words reported as having been read occurred on the line of text 88% of the time. Errors were of two types: reporting words not present on the line, and reporting punctuation marks that were not present. The most common error was reporting commas where none occurred. Under 6% of the instances were erroneous word reports.

In contrast to this, subjects' guesses about the following word were correct only 31% of the time. The words "the" and "and" accounted for 36% of the correct guesses, while nouns, verbs and adjectives together accounted for only 32%. Most of the remaining correct guesses were short words such as "in," "of," and "by." Only 9.9% of all guesses were correct content words.

For each correct trial, the distance was computed between the last read word and the word which was fixated during the last fixation on which text was present. This distance was measured in terms of words, regardless of their length. If the last word reported was also the last word fixated, this distance was 0. If the last word reported was the word prior to the last fixated word, this distance was -1. Figure 1 presents the relative frequency distributions for this distance.

As Figure 1 indicates, the distributions are quite different when the text was masked than when it was simply blanked out. When masked, the median word reported was that which was directly fixated; when blanked, the median word reported was one or two to the right of the fixated word. The data for each condition were grouped according to whether the last read word was the fixated word, a word lying to the left of it, or a word lying to the right. These frequencies were collapsed across the text removal time conditions, and the mask vs. no-mask conditions were compared using a Chi-square test. This yielded a Chi-square value of 14.30 which, with 2 degrees of freedom, is significant at the .001 level. It is clear that the mask interferes with processing that continues in the absence of the mask.

Insert Figure 1 about here

When the text was removed during a saccade, the computer recorded where the following fixation was located, even though the text was not present on that fixation. This makes it possible to ask where the last reported word was located with respect to the location of the word to which the eyes were being sent for the next fixation. A distribution of these data indicates the relationship between the location of the last word read during one fixation, and where the eyes were sent for the next fixation. These distributions are presented in Figure 2.

Insert Figure 2 about here

As Figure 2 indicates, in 66% of the cases in which the text was masked the saccade was taking the eyes to a word beyond the last word that could be reported; in all but one of the remaining cases the eyes were going to the last reported word. However, the pattern is quite different when the text was simply blanked out during the saccade. Here, on half the instances the eyes were centered on the last reported word, and on all but three of the remaining instances, the last reported word lay to the right of the fixated word. Grouping the data according to whether the last read word was on, to the left of, or to the right of the word to which the eyes were sent, and comparing these data for the mask and no-mask conditions yields a Chi-square of 18.15 which, with 2 degrees of freedom, is significant at the .001 level.

The time at which the text was removed had very little effect. A Chi-square test on the data collapsed across text replacement type yielded a Chi-square value of 0.73.

Discussion

This study demonstrates that adult subjects are quite able to perform the task of reporting the last word or words read when they are interrupted during reading, and it provides initial data concerning the location of this word with respect to the location of the eyes during

the last fixation on which text was present, and to the location of the following fixation.

There was a clear distinction between the accuracy of the last word reported as having been read, and the guess concerning what the next word was. The last read word was highly accurate; the guess was not. Subjects' reactions to the two tasks were also quite different. The last word read was reported with great confidence, whereas subjects felt they had no information about the immediately following word and were making a pure guess. These facts suggest that there was a clear dichotomy between the last word read, which could be reported, and the immediately following word, about which the reader had little or no information beyond that provided by language constraints. It seems likely that the subjects were being accurate in indicating the last word that had been identified, and that the words beyond it simply had not been dealt with; little or no information had been obtained about them that would substantially constrain their identity. The other option, of course, is that whatever information had been obtained from these latter words was quickly forgotten and not available to assist in forming the guess. A more carefully designed study is needed to determine whether the guessing rate for these words might be elevated somewhat as a result of peripherally-obtained information, but with a guessing rate of 31% such influences must be small.

At the end of a fixation, the distance between the last word read and the word being fixated showed a considerable amount of variability.

However, it is important to note that the nature of the distribution was strongly influenced by the type of replacement stimulus used when the text disappeared. Apparently, when the text is simply blanked out sufficient visual information is maintained to permit some continued processing of the text. Replacing the text with a mask corrupts this information or otherwise interferes with processing so the last read word does not lie as far to the right. In contrast, studies of letter and word perception do not find effects of masking following presentations of 100 msec or longer (Taylor & Taylor, 1983, p. 175). The masking which occurs during reading may result from the greater complexity of the stimulus pattern presented by a full line of text, or from the possibility that the utilization of the visual information may not take place as early in the exposure period during fixations in reading (Blanchard, McConkie, Zola, & Wolverton, 1984) as it does in word-identification tasks.

Haber and Hershenson (1980, p. 152) suggest, on the basis of research by Breitmeyer and Ganz (1976), that the suppression associated with the making of a saccade serves to isolate individual fixations from the effects of masking from prior and following fixations. The present results do not support that conclusion, since the distribution of locations of the last read word were quite different when a mask occurred on the following fixation than when the screen was simply blanked out. Replacing the text with a mask during a saccade shifted the distribution of the last word read to the left as compared to the blanking condition. Apparently the presence of the mask on the

following fixation either corrupted lingering visual information from the prior fixation or interfered with its processing in some way.

In reading, the normal case is to have text present on each fixation, with the potential for the pattern present on each new fixation to reduce the amount that could have been read from the last. Therefore, it is concluded that the results obtained when the text is masked during a saccade give the most accurate indication of what words are being read during a fixation while reading a passage. However, as will be discussed later, even this condition may overestimate what is normally read.

The distribution for the last read word for the condition in which the text was masked during a saccade, presented in Figure 1, indicates that in a majority of cases the last read word was the word on which the eyes were centered during that fixation or the word immediately to the right of it. This agrees with prior research which indicates that the visual region within which letter information is used during a fixation is relatively small and is asymmetric to the right (McConkie, 1983; Rayner, 1983). Instances in which the last read word lay to the left of the fixated word could include cases in which identification of the fixated word had failed and another fixation on it would normally be required, and cases in which the fixated word was simply not attended for some reason. Instances in which the last read word lay further to the right could include cases where the lengths of the words concerned were very short and where the eyes were centered near the end of the fixated word.

Finally, the results indicated that the time at which the text was removed had little effect on the distribution of the last read word. Experiment II was performed to further explore the effects of masking the text at different times during the fixation.

EXPERIMENT II

Method

This study was conducted in the same manner as Experiment I, using the same text and with subjects obtained in the same manner. Four conditions were used in the study, consisting of four different times during the fixation at which the text was removed and replaced by a line of X's. These times were 60, 120 or 180 msec following the onset of the fourth fixation on the line, or during the saccade following the fixation. Each subject received each of these conditions four times according to the same design as was used in Experiment I. Again, subjects were asked to report the last word read and to guess what the next word would be.

Results

As before, subjects' reports were frequently in the form of word sequences, often phrases. The last read word was actually on the line being read 92% of the time, but the following word was guessed correctly only 31% of the time.

Figure 3 presents the distributions of the location of the last read word. The top three distributions present this location with respect to the location of the last fixated word for conditions in which the text was removed during the fixation, either 60, 120 or 180 msec following its onset. The bottom two distributions present data for the condition in which the text was removed during the saccade. In the left distribution, the data are plotted with respect to the location of the last fixated word. This will be referred to as the Fixation N distribution. In the right distribution, these same data are plotted with respect to the location of the following fixation, after the saccade during which the text was removed. This will be referred to as the Fixation N+1 distribution.

Insert Figure 3 about here

Each distribution was partitioned into three categories: instances in which the last read word was the word fixated, a word to the left of it, or a word to the right of it. A series of Chi-square tests indicated that all the distributions plotted with respect to the last fixated word did not differ from each other, but all did differ significantly ($p < .001$) from the Fixation N+1 distribution. The means of these distributions were as follows: 60 msec, -0.21; 120 msec, 0.08; 180 msec, 0.08; Fixation N, 0.18; Fixation N+1, -1.26.

Discussion

The Fixation N+1 distribution can be taken as indicating the situation that exists at the beginning of a fixation, prior to receiving any visual information. In this distribution, the location of the last read word is plotted with respect to the fixation following the removal of the text, so no information about the text was obtained on that fixation. The Fixation N distribution indicates the situation that exists after a fixation. Here the data are plotted with respect to the location of the last fixation on which the text was seen, and the text was present for the full period of that fixation. Thus, a comparison of these two distributions indicates the degree of advancement through the text that results from a single fixation in reading. The means of these two distributions differ by 1.44, indicating an average advancement of 1 1/2 words as a result of a fixation.

The three top distributions in Figure 3 indicate the situation as a result of having visual information available for three intermediate periods. Thus, we might expect them to show a gradual transition between the two distributions just considered. The difference between the mean for the Fixation N+1 distribution and the 60 msec distribution is 1.05, or about 3/4 of the advancement that occurs during a fixation. The remaining 1/4 occurs with additional visual exposure to the text.

These results indicate that the visual system is capable of registering most of the information needed to support reading during the first 60 msec of a fixation in a form little influenced by a visual

mask. Providing additional exposure time allowed some further advancement but the added benefit was relatively small compared to the amount of time involved. This finding agrees with the findings of Rayner, Inhoff, Morrison, Slowiaczek and Bertera (1981) who reported that relatively normal reading is possible when the text is present for only the first 50 msec of each fixation.

From the fact that most of the visual information needed for reading can be registered within the first 50 msec of a fixation, Rayner, et al. (1981) argued that this must be the period of word identification, and that the remainder of the fixation is then spent in further processing and determining where the eyes are to be sent next. However, a more recent study (Blanchard, McConkie, Zola, & Wolverton, 1984) suggests that a distinction must be made between the registration and the utilization of the visual information. Blanchard, et al. provide evidence that the utilization of the information in the text can actually take place at any time throughout the fixation. In many instances, readers showed no awareness of a word which was present during the first part of a fixation, and reported having seen only a word that was present during the latter part. Thus, while the nature of the visual system is such that the stimulus pattern present at the beginning of a fixation is registered and can be used for reading, it appears that the normal utilization of that information does not necessarily take place during that early period. In fact, when transmission delays in the visual system are taken into account, it seems unlikely that words are ever identified during the initial 50 msec

of a fixation (McConkie, Underwood, Zola, & Wolverton, 1985).

The Fixation N+1 distribution in Figure 3 provides information about eye movement control during reading. It indicates that in the majority of instances when a forward saccade is made the eyes are being sent beyond the last read word. In only about 25% of the instances were the eyes sent to the last read word and seldom were they sent short of it.

EXPERIMENT III

In order to replicate some of the findings of Experiment II, a third experiment was conducted. This study repeated the mask condition of Experiment I, with the text always being removed during a saccade.

Method

The equipment and procedures used were identical to those of Experiment I. Ten subjects participated who were drawn from the same subject pool as in the earlier studies. A new 47-line passage was used, which gave information about backpacking. It was broken into 18 segments, varying in length from 1 to 5 lines. As the subjects read the last line of each segment, the text was replaced with a line of X's during the third forward saccade. When that occurred, the task was to report the last word read and to guess what the next word would be. There was the possibility of 18 data points per subject.

Results

Again subjects were accurate in their reporting of the last read word, in that it appeared on the target line 95% of the time. Guesses of the word following that word were correct 24% of the time, with function words accounting for 70% of the correct guesses. 26% of the trials were lost for various reasons. In order to increase the sample size, the data from the Experiment I condition in which the text was masked during a saccade were added to the sample.

When the location of the last read word was plotted with respect to Fixation N (the last fixation on which the text was present), the last read word was the fixated word in 40% of the instances, the word to the left of it in 22%, and the word to the right in 38%. When the location of the last read word was plotted with respect to Fixation N+1 (the fixation following the saccade on which the text was removed), the last read word was the word fixated 25% of the time, it lay to the left 69% of the time, and to the right 5% of the time. It lay one word to the left 22% of the time, and two to the left 24% of the time. Thus, as in Experiment II, the likelihood of sending the eyes to the last read word, or one or two words beyond it, were all approximately equal, and subjects seldom sent their eyes short of it.

The means of the two distributions are -1.50 for Fixation N+1 and 0.07 for Fixation N, again showing an advancement of about 1 1/2 words as a result of making a fixation.

The results from this study are very consistent with those found in Experiment II, in terms of the amount of advancement resulting from making a fixation, and the means and shapes of the distributions.

GENERAL DISCUSSION

The Disappearing Text technique was used in three studies to investigate the relation between the location of the last word that could be reported when the text disappeared and the location of the last fixation on which the text was seen. The results showed both variability and consistency in this relationship. On the one hand, the last word reported as having been read was most commonly the word fixated during the last fixation, or the word to the right of it, in agreement with earlier studies indicating a rightward assymmetry in the perceptual span during reading (McConkie & Rayner, 1976; Pollatsek, Bolozky, Well, & Rayner, 1981). On the other hand, the responses were not restricted to these two word locations. On about one-third of the trials, words from other locations were reported. Most of these were words lying to the left of the fixated word, with the fixated word not being reported. The current data do not permit a conclusion as to whether the fixated word was not reported because it had not been identified on that fixation (either because of inattention to it, having obtained insufficient visual information on that fixation to identify it, or because the reader was not yet ready to utilize that word in the on-going reading and hence did not use the visual information which had been available), or because it had been identified but quickly

forgotten. Subjects in the experiment did not report the experience of having known what a word was only to be unable to report it as might be expected if forgetting were the primary reason for this phenomenon.

An arguement against the forgetting explanation is the striking difference between the readers' ability to accurately report the last word read, and their poor performance on guessing the next word. If words were frequently being identified and then forgotten, we might expect that some information about the forgotten word would still be available and could raise the guessing probability for the word. However, the guessing rates observed, 24% to 31%, were in the range that would be expected as a result of guessing from context alone, without the aid of perceived information from the word itself. While these observations do not rule out a forgetting explanation, they do provide some evidence against it.

It may be that in some instances in which the last read word lay 2 or more words to the left of the last fixated word, the reader was not attending to the visual information available during the fixation. In normal reading it may have been necessary to later regress to these words in order to read them. The interruption produced by the disappearance of the text prohibited us from observing such regressions, if they would have occurred. It is also possible that readers sometimes ignore portions of the text as they read, but from the parts of the text to which they do attend they are able to satisfactorally comprehend the message. Other studies will be required to investigate these possibilities more specifically.

The distributions obtained in the studies conducted would appear to indicate the distribution of the location of words identified during a fixation while reading. It is important to note, however, that these results may not generalize to normal reading quite that completely. In reading, the fixation studied would have been followed by another fixation on which reading would have continued. In the Disappearing Text task reading is terminated during or after the last fixation, and the reader is then free to focus attention on any cues from the visual display which remain in memory and to use them to try to identify an additional word. It is quite possible that some words reported in the Disappearing Text task would normally not have been identified until the following fixation. Thus, this task may overestimate the frequency with which the fixated word or words to the right of it are identified during a fixation in reading. However, the fact that the results are quite harmonious with previous studies estimating the size of the perceptual span during reading suggests that any such overestimate is not great.

It has often been suggested that skilled readers form hypotheses and anticipations of upcoming text, and that these facilitate perception of the words (Goodman, 1976). Peripherally abtained information is assumed to facilitate this process by reducing the number of alternatives, thereby leaving relatively little further perceptual work to do when a word is brought into the fovea (Haber & Haber, 1981). If this were the nature of perceptual processing during skilled reading, we

might have expected the readers in the studies reported here to make accurate guesses of upcoming words based on the peripherally obtained information, and to make such guesses quite readily when reading was terminated. However, the subjects showed a reluctance to try to guess, felt very unsure of their guesses, and in fact were usually incorrect. These observations do not seem harmonious with a model in which peripheral information about upcoming words is accumulated and anticipations are formulated to facilitate perception. Furthermore, in most cases the word being guessed was the word immediately to the right of the fixated word, or the word just beyond that. In other cases, it was actually the word being directly fixated or a word to the left of it. In only about 3% of the cases did the word to be guessed lie more than 2 word positions to the right of the directly fixated word. Thus, this word was typically within a region in which visual information about it could be obtained from the fovea or near periphery; at least such information as the word length, word shape and extreme letters. Haber, Haber and Furlin (1983) have demonstrated that when readers are given cues to the length and shape of words, their guesses of those words from context rises dramatically. The low guessing rate of the subjects in the present studies indicate that either they had not obtained this type of information from the words not yet read, or, if they had, they were not using it in their guesses. Thus, the data do not support this type of anticipation model of reading.

The results from these studies suggest a model of perception in reading in which there are neither anticipations nor extensive use of

peripheral vision for acquiring cues from upcoming words. Rather, words are attended and identified within a small visual area, and the reader has little or no information about words that are not attended and identified, even when they lie within the fovea itself. It is not necessarily the case that a directly fixated word is identified; rather the identification depends on whether it is attended on that fixation. This strong link between attention and identification would account for the variabiality in the location of the last read word as obtained in these studies. Finally, there is a possibility that where the eyes are sent for the next fixation is related to the location of the last read word, with the eyes sometimes going to that word but more commonly going one or two words beyond it. A mechanism of this sort has the virtue of simplicity; there is no need for complex machinery to preview peripheral stimuli or to form anticipations or eliminate possible words based on certain visual characteristics. Rather, the focus of mental activity can be on language processing with words being attended and identified as needed to support this activity.

The Disappearing Text technique is quite similar to a method used to study the eye-voice span during reading. Although some studies of the eye-voice span have simultaneously recorded eye position and voice (Buswell, 1920; Fairbanks, 1937), others have obscured the text at particular times and recorded how far the voice continued in the absence of the text (Gray, 1917; Levin & Addis, 1979; Quantz, 1897). This presumably indicates how far the eyes were ahead of the voice at the time the text was obscured. Buswell (1920) noted that the eye-voice

spans obtained with this latter technique tended to be larger than the distance typically obtained with actual monitoring of the eyes and voice. This leads to the suspicion that words are sometimes identified beyond the location of the eyes, a suspicion that is confirmed by the present study.

The Disappearing Text technique is similar to that used in the eye-voice span studies, but is used to investigate a somewhat different relationship: how far along the line of text processing proceeds using visual information available from the current fixation. This might be termed the eye-mind span. As with the eye-voice span, the eye-mind span raises both temporal and spatial issues. The current studies have not dealt with temporal delays between fixating and identifying a word. They have focused only on the spatial issue, identifying the distribution of distances of the last read word from the word being fixated.

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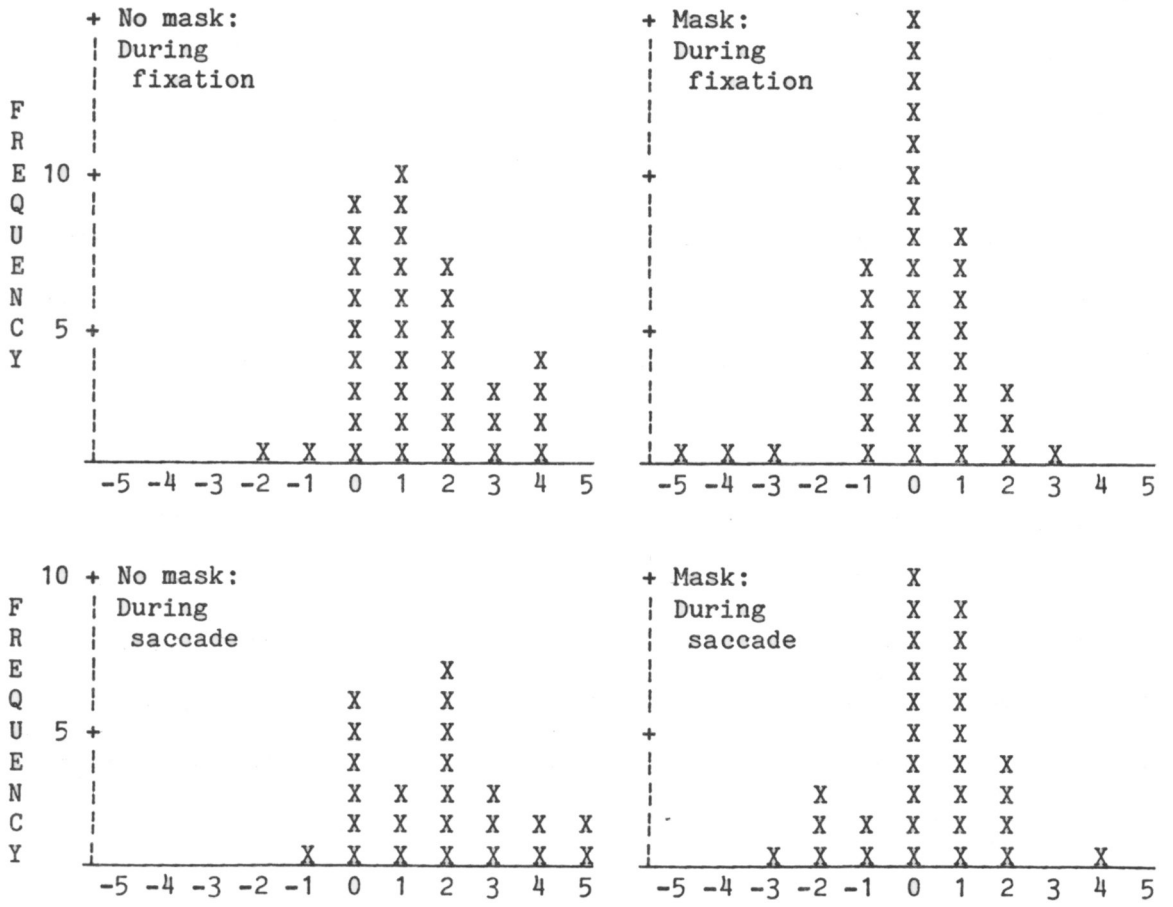
Figure Captions

Figure 1. Frequency distributions of the location of the last read word with respect to the location of the last fixation on which text was present. Distance is measured in word units, without regard for word length.

Figure 2. Frequency distributions of the location of the last read word with respect to the location of the fixation following the last fixation on which the text was present. Distance is measured in word units, without regard for word length.

Figure 3. Frequency distributions of the location Figure 3: Frequency distributions of the location of the last read word with respect to the location of the last fixation on which text was present (Fixation N) or the fixation following (Fixation N+1). The text was removed either 60, 120 or 180 msec following the onset of Fixation N, or during the saccade following Fixation N.


No mask:
During
fixation
Mask:
During
fixation
No mask:
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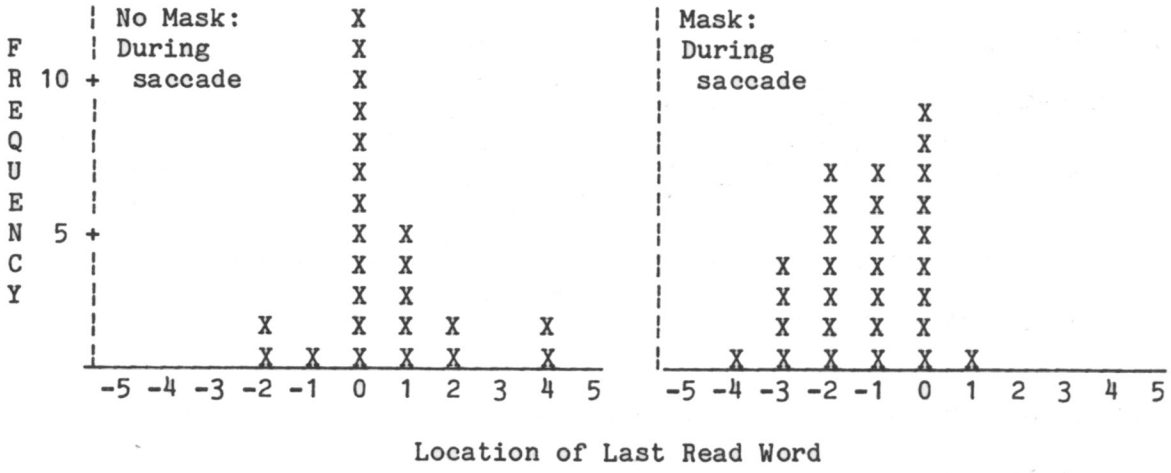
saccade
FREQUENCY
10
5
-5 -4 -3 -2 -1 0 1 2 3 4 5
Location of Last Read Word


No Mask:
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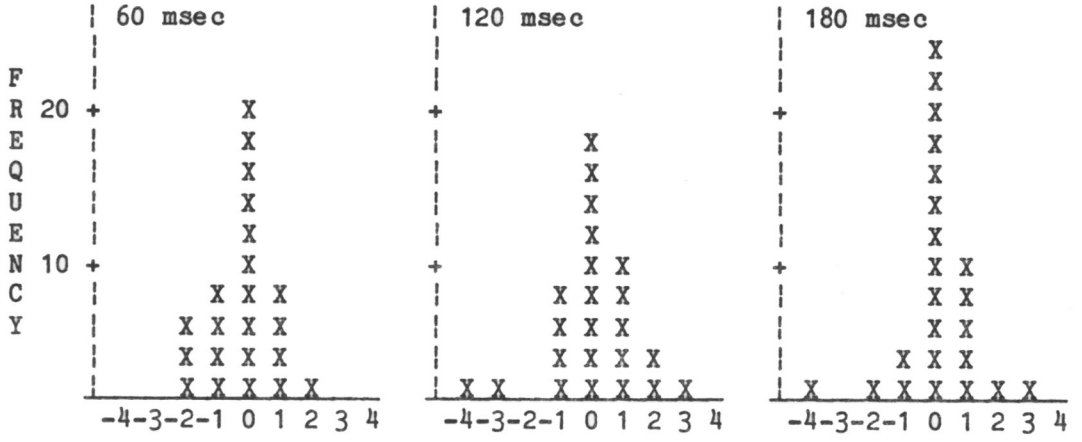
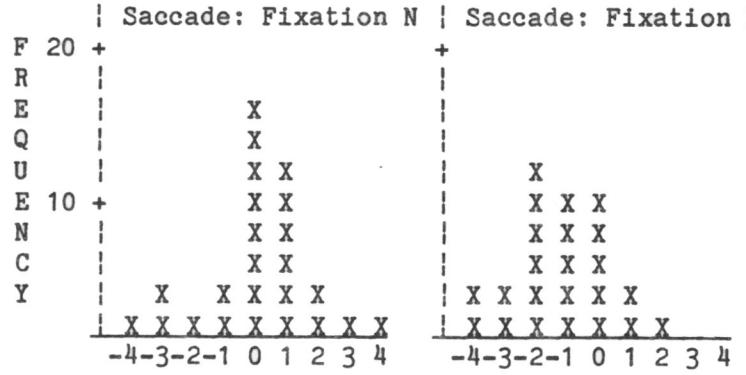
-5 -4 -3 -2 -1 0 1 2 3 4 5
Location of Last Read Word





Location of the Last Read Word