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The Perceptual Span and Peripheral Cues in Reading

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Skilled readers read passages that were displayed on a Cathode Ray Tube controlled by a computer. The readers' eye movements were monitored and certain critical words were changed by the computer as the eye was in motion. The experimental technique utilized in the study provided data on how wide the area is from which a reader acquires information during a fixation in silent reading. The results also delineate different types of visual information that are acquired from various areas within the perceptual span. It was found that a reader was able to make a semantic interpretation of a word that began 1–6 character spaces from his fixation point. When he fixated 7–12 character spaces prior to a word, he was able to pick up such gross visual characteristics as word shape and initial and final letters. It was concluded that the skilled reader is able to take advantage of information in the periphery. However, the size of the area from which he does is rather small.

Determining the size of the area from which a person picks up information during a fixation in reading has long intrigued psychologists (Woodworth, 1938; Huey, 1908). In the past, five general types of research have been used to identify the perceptual span in reading. However, each of these techniques has particular problems associated with it that have led to equivocal results and differing estimates of the perceptual span. The first and simplest type of research has been to divide the number of letters per line by the number of fixations per line (Taylor, 1957; Taylor, 1965). This method of estimating the perceptual span is based on the assumption that on successive fixations the perceptual spans do not overlap or they overlap the same amount. This assumption is probably false.

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The second, and oldest, type of research has utilized the tachistoscopic presentation of letters and words. Since the material is generally presented for very brief exposures to exclude the possibility of an eye movement during the presentation, this method has often been thought of as being analogous to a single fixation in reading. A limitation of this method of determining the perceptual span was pointed out by Woodworth (1938) and later verified by Sperling (1960). Sperling found that subjects are able to see much more than they can retain and later report. Thus, what subjects report from a brief presentation cannot be taken as a complete specification of what they actually saw. Geyer (1970) has pointed out that even if the verbal report coincided with what the person actually saw, there is no particular reason to believe that the perceptual span obtained in a tachistoscopic presentation actually coincides with that of a fixation in reading. One conclusion that recent research in cognitive psychology is forcing upon us is that subjects are able to adapt their strategies to the task in which they are engaged. It is very likely that normal reading and tachistoscopic report vary enough to induce different strategies in subjects. The tachistoscopic studies generally involve the isolated presentation of some stimulus material, whereas reading involves fixations at the rate of four or five per second, with a very complex stimulus pattern having a great deal of redundancy. Due to these differences, the perceptual span in reading could be either larger or smaller than that found with tachistoscopic presentations. It could be larger because the contextual constraint allows a reader to identify words with less visual information, or it could be smaller because of the rapid sequence of fixations and the complexity of the surrounding stimulus pattern which may lead to what Mackworth (1965) has referred to as tunnel vision.

The third method of investigating the perceptual span is to have a subject fixate some point and then have him identify stimuli presented at various distances from his fixation point (Feinberg, 1949; Bouma, 1973). Although this information regarding the area of visual acuity is valuable for setting the upper bounds of the perceptual span, it cannot be taken as evidence for what information a person actually uses during a fixation in reading.

The fourth technique is to manipulate the amount of text which is visible to a subject at a given moment. Poulton (1962) had subjects read aloud from text over which a mask containing a window was passed. The speed and size of the window varied systematically on different trials and the subjects' eye movements were recorded electronically. In this research, the text was immobile and the window passed over it, allowing only a certain amount to be seen at once. Newman (1966) presented text on a screen, with the letters moving from right to left, and varied the number of letters on the screen at any moment, the number of new letters that were added at once, and the rate at which they were added. Both of these investigations found that smaller windows create greater disruption in reading. These techniques, however, disrupt normal reading because the person's natural eye movements are inhibited. Also, the subjects were required to read the text orally.

All of the techniques mentioned so far, with the exception of the first, involve either tasks quite unlike normal reading or a task which greatly interferes with a reader's normal reading pattern. Since these previous studies have yielded different estimates for the size of the perceptual span in reading, it is obvious that there is not a satisfactory answer to the question: How wide is the area from which a person picks up information during a fixation in reading? The ideal technique for determining the size of this area would be one which engages the subject in the normal act of reading for meaning and which allows the collection of data as he does so. Recently, there has been some research that has attempted to move in this direction. McConkie and Rayner (1973; Rayner & McConkie, 1973) developed an on-line computer technique, involving an eye-tracking system, which allows the reader to control the area of text that is displayed by making his normal eye movements. Passages of mutilated text were initially displayed on a Cathode Ray Tube. However, when the reader fixated on the first line, the display was changed so that for a specified region around his fixation point, called the window, the mutilated text changed into readable text. When the reader made a saccade, the readable text changed back to mutilated text and a new window area appeared around his new fixation point. From saccade length and fixation duration data, McConkie and Rayner concluded that good readers pick up letter and word shape information from a rather limited area during a fixation, only about 17 to 19 character spaces at most (about five degrees of visual angle). They also found that word length information affects reading further into the periphery than word shape or specific letter information.

Although this fifth technique represents a closer approximation to the normal reading task, there are still limitations associated with it. There were rather substantial display changes with each fixation which might be thought capable of producing considerable disruption in reading. Also, when the window was rather narrow, the readers may have reduced their area of attention to a greater extent than they would normally do.

The present study was a further attempt to gather data concerning the size of the area from which a reader acquires information during a fixation and to delineate different types of visual information that are acquired from various areas within this perceptual span. The types of peripheral information studied were word shape and initial and final letters of words, both of which have been suggested as valuable cues for the reader (Woodworth, 1938). There were two major assumptions behind the research, one a methodological assumption and the other theoretical. Since the research involved changing a word in the text display while the subject was making a saccadic movement, the methodological assumption was that during a saccade and for a brief interval after the eye comes to rest there is enough visual suppression or retinal blur that the reader would not see the change take place (Haber and Hershenson, 1973).

The theoretical assumption deals with the use of fixation durations as a dependent variable. Although current theories of reading have not specifically attempted to deal with the duration of fixations, some can easily be extended to make predictions about fixation durations on the basis of cognitive processes assumed to be taking place. First, the type of experimental manipulation used in the research to be presented here will be described; then two theories of reading will be described together with their predictions for fixation durations in this situation.

The experimental technique used in the present study established a situation in which there was an inconsistency between information that a reader may have picked up from his periphery from a particular word and the details of that word when it was centrally fixated. Short paragraphs were written and one word within each paragraph was identified as a base word. This base word was then replaced with a word or letter string that did or did not maintain certain visual or semantic characteristics of the base word. The paragraphs containing the replacement words or letter strings were initially displayed to the subjects. However, when the reader's eye crossed a predetermined boundary location while making a saccade, the word or letter string initially displayed was replaced by the base word. The boundary was not visible, but rather represented a location on the line containing the base word. The change occurred while the reader's eyes were still in motion. Thus, when the reader's eyes arrived at their designated target, there was often an inconsistency between the information that he had acquired on a previous fixation and that available on the present fixation.

The first theory to be considered is Hochberg's (1970) Hypothesis Testing Theory of Reading. It suggests that on the basis of the information that a reader has from reading a passage up to a given point, plus partial information obtained from the periphery, he generates a hypothesis of what will be encountered next. He than moves his eye ahead and checks his hypothesis against the visual information. If the visual information agrees with his hypothesis (as the theory assumes usually occurs), he then repeats the cycle. If the visual information and his hypothesis are not in agreement, further processing is required, which would seem to result in longer fixation durations or regressions. If a hypothesis were based partially on peripheral information which was then changed during the next saccade, the hypothesis would have a lower likelihood of agreeing with the changed text. Thus, the fixation duration should be increased due to extra processing required under these conditions

The second theory, the Direct Perception Theory (McConkie & Rayner, 1974), assumes that the fixation period is spent primarily in determining the nature of the text within the fixated region, rather than in hypothesizing what is to come. However, this position also states that visual information obtained from the periphery is important to the reader, being integrated with additional visual detail obtained on later fixations. If a person acquired certain visual information from a word location in the periphery on fixation n and then found on fixation $n + 1$ (when the word location that was previously in the periphery became the area of central fixation) that this information conflicted with the pattern he had already detected, this attempted integration would fail and the result would be some reanalysis of the visual input, thus producing a longer fixation duration. Furthermore, if he had made a semantic identification of a word some distance from his fixation point and then found when he fixated that area that he was incorrect, the result would be a longer fixation duration that was indicative of reanalysis and extra processing. Thus, both theories lead to the expectation that if visual information is acquired from peripheral retinal areas on one fixation which conflicts with information obtained from central vision on the next fixation, an increased fixation duration would be expected. The experiment to be described here used this expectation to explore how far into the periphery certain types of information are acquired during a fixation in reading.

METHOD

Subjects

Ten undergraduate students at the Massachusetts Institute of Technology, six male and four female, served as subjects. They were recruited from a subject pool list kept by the Department of Psychology and were paid $2.00 an hour for their services. They were told the purpose of the study was to determine what people look at when they read, and that their eye movements would be monitored and recorded by a computer. All of the subjects had normal, uncorrected vision. The reading speed of the subjects was in the range of 200–400 words/min. An experimental session lasted for about two and a half hours and the subjects were given a 10 min break about half way through the session.

Materials

A set of 225 sentences was prepared, with each sentence being of the following grammatical form (ignoring function words):

(Sentence: Subject + Verb + Object + Prepositional Phrase)

One word location in each sentence was identified as the critical word location (CWL) and five alternative words or letter strings were prepared which could be inserted into that area. For example, if the critical sentence were:

The rebels guarded the ________ with their guns

the first alternative was to have the base word (palace) in the CWL. This condition was called the *W-Ident*, signifying a word (W) identical to the base word. The second alternative was another word (police) which fit into the sentence both semantically and syntactically, and which began and ended with the same letters and maintained the basic external word shape of the base word. This was called *W-SL* since it was a word (W), and both word shape (S) and extreme letters (L) were identical to the base word. The remaining three alternatives were all nonwords (N) which bore certain graphic similarities to the base word. In the *N-SL* alternative (pcluce) both extreme letters and word shape were maintained. To produce this alternative the *W-Ident* and the *W-SL* alternatives were compared and all of the letters that were common to them were left untouched in the *N-SL* alternative. Every letter that differed in the *W* alternatives was replaced by a letter that was visually confusable with the letter in the *W-SL* alternative. In addition, ascenders were always replaced by ascenders and descenders by descenders. The *N-L* alternative (pyctce) was formed by replacing every letter, except those which were common to both *W* alternatives, with letters that are not visually confusable and did not share prominent distinctive features. For example, a descender was replaced by an ascender or a letter that did not extend above or below the line. Thus, the shape of the base word was destroyed in the *N-L* alternative but the extreme letters remained the same. The final alternative, *N-S* (qcluec), was formed by comparing the *W-Ident* and *W-SL* alternatives. Any letter in the middle of the word that was the same in both *W*-alternatives was left the same, but every other letter, including the initial and final letters, was replaced with a letter that was visually confusable with its corresponding letter in the *W-SL*. Therefore, in this condition the word shape was maintained but not the extreme letters. The confusable letters were determined from a confusability matrix and grouping (Bouma, 1971). The sentences were so constructed that the base words in the CWLs were equally often five, six, and seven letter words, and served as subject, verb, and object in their respective sentences equally often. In order to insure that one of the two *W* alternatives would not be more predictable than the other, for most *W* alternative pairs two sentences were written in which both words could reasonably fit. Then the selection of which word to use as the *W-Ident* alternative for two given sentences was made randomly. Both sentences were used in the study. Where a single sentence was written for a *W* alternative pair, the choice as to which word would function as the *W-Ident* was also made randomly. Table 1 shows some examples of the types of sentences used and the base word plus the four other alternatives.

Each of the 225 sentences was embedded into a short paragraph by writing two or three other sentences which could serve as a reasonable context for it when either of the *W* alternatives occurred at the CWL. The CWL occurred equally often in the first, second, or third line of the paragraph, and all paragraphs were about 35–40 words in length.

After the subjects had read a block of 15 paragraphs, they were given a set of 12 sentences and asked to identify which of the sentences came from the passages they had just read. This task was included to insure that the subjects actually read the paragraphs and did not simply move their eyes across the text.

The 225 paragraphs were presented in the same order to all subjects. There were five CWL conditions, defined by which alternatives occurred in the CWL when the passage was first displayed, and five

TABLE 1

EXAMPLES OF SENTENCES, THE BASE WORD AND OTHER CWL ALTERNATIVES FOR EACH SENTENCE USED IN THE STUDY

Examples of sentences used in the study

1. The children tasted the chemical in the hall.
2. The king watched the traitor from his throne.
3. The owner heard the boys in the backroom.
4. The captain granted the pass in the afternoon.
5. The mayor picked a volunteer for the assignment.

Sentence	*W-Ident*	*W-SL*	*N-SL*	*N-L*	*N-S*
1.	tasted	tested	tcrted	tflmed	fcstcb
2.	traitor	teacher	tcaobcr	tifjrir	fcaobcn
3.	heard	hired	hrvcd	hcbid	krvcb
4.	granted	guarded	gmavbed	gkfbned	pmavbcd
5.	mayor	major	magor	macor	nogan

boundary locations that were used in the study. The five boundary locations were: (1) nine character spaces to the left of the first letter of the CWL, (2) six character spaces to the left of the CWL, (3) three character spaces to the left of the CWL, (4) the first letter of the CWL, and (5) the fourth letter of the CWL. Since there were five boundary locations and five CWL alternatives, the CWL in each paragraph could be presented in any of 25 possible conditions. The conditions for a particular paragraph to be tested under were selected by using a series of 5×5 Greco-Latin squares.

Apparatus

The equipment used to track the eye was very similar to apparatus described by Reder (1973) and consisted of a Biometrics Model SG Eye Movement Monitor which was interfaced with a PDP-6 computer, thus providing the capability for on-line continuous monitoring of eye position. Since the Biometrics equipment records vertical eye movements from the eyelids rather than the eye, it is subject to a number of artifacts and sources of unreliability. Thus, for the present research, the signal indicating vertical movement of the eye was ignored and the following heuristic was used instead. It was assumed that the reader began a page by fixating a dot at the upper right of the display, as he was instructed to do. When he made a leftward movement of the eye of a distance greater than 45 character positions, it was assumed that he was fixating the first line and beginning to read. It was further assumed that he was continuing to fixate that same line until he made a leftward movement (or series of leftward movements) which totaled 45 character spaces. At that time, it was assumed that he had made a return sweep and moved on to the next line.

Head position was fixed by means of a biteboard and a forehead rest. Once in position, the subject's eye was about 21 in. from the face of the display scope, and a full line of text (72 characters) occupied about 18° of visual angle. Calibration was accomplished by having the subject fixate a series of points on the display, pushing a button as he looked directly at each. Each time the button was pressed, the computer read the signal coming from the eye movement monitor and stored the values. Once data were obtained for all calibration points, the computer calculated parameters needed to identify from the eye movement monitor's signal where the subject was looking. Although the eye movement monitor's output was quite linear with respect to eye position on the horizontal dimension, nonlinearity was taken into account in the algorithm for calculating eye position. The subject went through the calibration routine prior to reading each series of paragraphs. Since a series of paragraphs were read in about 2 min, there was little problem with signal drift during such a short interval. Pilot work with the apparatus showed that it was seldom that the computer indicated that a person was fixated more than one or two character positions away from the character he reported he was trying to fixate.

The display scope was a Digital Equipment Corporation Model 340, which has a character generator for upper and lower case letters. The P-7 phosphor has a yellow afterglow to reduce flicker, which was filtered out with a sheet of dark blue theater gel. This resulted in the display changes being very crisp in appearance, and there was no detectable afterglow. It was possible to display text within an area 8.25 in. wide and 7.25 in. high. Within this area, it was possible to display 40 single spaced lines of 80 characters each. In the present study, text was displayed on the first, fourth, and seventh lines and each line was around 72 characters long. Thus, only the upper third of the scope was utilized to display text. This minimized "crosstalk" between horizontal and vertical eye movement information.

Procedure

Each subject was tested individually. When a subject arrived for the experiment, a bite bar was prepared by molding a heavy type dental compound on a brass frame and getting the subject's dental impression. Then the eye tracking sensors, which were mounted on glasses frames and held securely by a head band, were placed on him. The glasses and the sensors were adjusted for each subject. The subject was told that he would be required to read a series of paragraphs to understand them. He than read three warm-up passages, in which there were no display changes taking place, so that he could become accustomed to the experimental apparatus. After that, the first test paragraph was displayed, and he began the experimental sequence. The subjects were instructed not to skip lines as they read and to refrain from making long regressive movements. They were also instructed not to reread any lines.

Prior to reading each block of 15 paragraphs, the subject was engaged in a calibration task. This consisted of looking at 25 dots which appeared on the display scope and pushing a lever as he fixated each dot. When the subject pushed the lever for the final time, he fixated on a large dot on the upper right-hand corner of the screen. An additional push of the lever resulted in the display of the first paragraph. He was told to continue fixating the dot as he pushed the lever to advance the first paragraph and to count silently to 25 after pushing the lever. Then he moved his eyes to the beginning of the paragraph and began reading. After the subject finished reading the first paragraph, he again fixated the dot, pushed the lever, remained fixated on the dot long enough to count to 25, and then read the next paragraph. The same sequence was repeated until all of the paragraphs in the block were read. The requirement of counting to 25 was included to insure that the subject continued fixating the dot for a short time after pressing the lever, a requirement of the program. Even so, two subjects frequently anticipated the button press and began reading too soon, causing the display change to occur while they were reading the wrong line. This event was clearly identifiable in the data, and 15–20% of their data had to be eliminated. Also, if a subject made a long regression or reread a line, the computer sometimes caused the display change to occur at the wrong time. This occurrence was also clearly marked in the data, and the data were discarded.

As the subject read each paragraph, the computer kept a complete record of the location and duration of each fixation. Occasionally, the computer specified two separate fixations on characters immediately adjacent to each other. Over 90% of the time when this happened, one of the fixation durations was in the normal range (150–300 msec) while the adjacent fixation was very short in duration (16–30 msec). Hence, it was assumed that the eye had drifted slightly at the beginning or the end of a fixation and the velocity of this drift was sufficient for the computer to specify a separate fixation. Thus, the duration of these adjacent fixations were combined into one duration. The computer also kept a record of the movement time for each saccade. All of the times were recorded in 60ths of a second and later converted to milliseconds. With each sampling of the eye, the present eye position was compared to the last position and the stimulus change at the CWL took place if: (1) the eye was to the right of the boundary, (2) the eye was on the line containing the CWL, (3) the eye had made a previous fixation to the left of the boundary on the line containing the CWL, and (4) since the last sample the eye had moved more than a certain amount. To insure that condition (3) was met, the first letter of the CWL was always at least 20 character spaces into the line, and there were always 15 character spaces after the last letter of the CWL remaining on the line. Condition (4) was included to insure that the stimulus change was initiated while the eye was still in motion.[1] If the eye crossed the boundary as it was just finishing a sac-

[1] Since this research was completed the author became aware that a considerable lag existed in the signal. A filter in the Biometrics eye movement monitoring equipment was left engaged during the research which produces a rise time in the output signal of about 25 msec. When a change is made in the input signal to the equipment the output signal begins to change within 2 msec but the time required to achieve the new level is as much as 25 msec. With the equipment having this characteristic, it is difficult to determine just when the display changes were taking place. Some changes may have occurred during the period of the saccade itself, however, it is certain that many of the changes must have taken place after the saccade was actually finished, particularly during the first 20 msec of the next fixation. The fact that *S*s generally did not report seeing the display change is probably due to a combination of two factors, visual suppression following the saccade (Haber & Hershenson, 1973) and masking.

cade, and was thus moving slowly, the change was not made until the eye had reached an acceptable velocity on the next saccade made. If the boundary was set in the CWL this sometimes meant that the display change occurred after the subject had moved his eye some distance beyond the CWL. When this was the case, the data were eliminated from further analysis. About 5% of the data had to be eliminated for this reason. Thus, there were several bases on which data were discarded. Altogether, however, about 90% of the data were acceptable and used in the various types of analyses.

The display change was accomplished by storing two versions of the paragraph being read; one with the stimulus alternative which was to be displayed initially in the CWL, and the other with the final stimulus word (the base word) in that location. The change was made by simply switching from the use of one of these versions as the display list to using the other. When the *W-Ident* alternative (the base word) was initially displayed, it was replaced by itself.

After the subject finished reading the 15th paragraph of each block, he came off from the bite bar and was given the test sentences. He was asked to put a check by any of the sentences which had appeared in the paragraphs. While the subject completed the test items, the experimenter specified the next block of paragraphs and boundary locations to the computer.

RESULTS

Since there was a great deal of data collected during the experiment, it became necessary to devise methods to categorize the data for statistical analyses. In this study, it was expected that some of the CWL alternatives initially displayed in the text would produce some disruption of the normal reading pattern. It seemed reasonable to assume that as the reader's eye got closer to the CWL when it contained a nonword letter string, he would become aware of an irregularity in the text and this would be manifest in a change in the eye movement pattern. Thus, data from the fixation prior to crossing the boundary were analyzed to determine how far from the CWL evidence could be obtained that the reader detected the irregularity. It was also expected that display changes as a result of the reader crossing the boundary location would produce disruption in the eye movement pattern. Thus, data from the fixation after crossing the boundary were analyzed to provide an indication of how far into the periphery information of the different types that were studied were obtained. If the reader obtained information about the CWL when it was in the periphery and then found an inconsistency between the information he had previously acquired and the present information when the CWL was foveally fixated, the result would be a longer fixation duration.

In the data analyses, the location of the boundary was disregarded, and the data were grouped according to the location of the fixation prior to crossing the boundary and the location of the fixation following the display change. Means for each subject were used as the basic data in the analyses.

The first analysis that was carried out dealt with the duration of the last fixation which occurred prior to crossing the boundary. These fixation durations were grouped according to the location of the fixation and categorized according to the type of stimulus alternative which was initially displayed in the CWL. Thus, fixation durations when the last fixation occurred 18–16 character spaces prior to the beginning of the CWL were grouped together, as were fixation durations 15–13, 12–10, 9–7, 6–4, and 3–1 character spaces to the left of the CWL and finally fixations on the first three letters of the CWL itself. For each subject, a mean fixation duration was calculated at each of these seven areas for each of the CWL conditions. Figure 1 shows these mean scores averaged over all subjects for each of the CWL alternatives at each of the seven areas. A one-way Analysis of Variance was then carried out at each of the seven areas. There were no significant differences for any of the areas 6–4 character spaces or more to the left of the CWL. In the area 3–1 character spaces prior to the beginning of the CWL there was a significant F (F (4,45) = 2.62, $p < .05$). In the area containing the first three letters of the CWL, there was also a significant F (F (4,45) = 4.69, $p < .01$). Newman–Keuls tests (Winer, 1962) carried out for each of the areas divided the five CWL alternatives into two groups that corresponded to the N and W conditions ($p < .05$). Thus, when the eye was

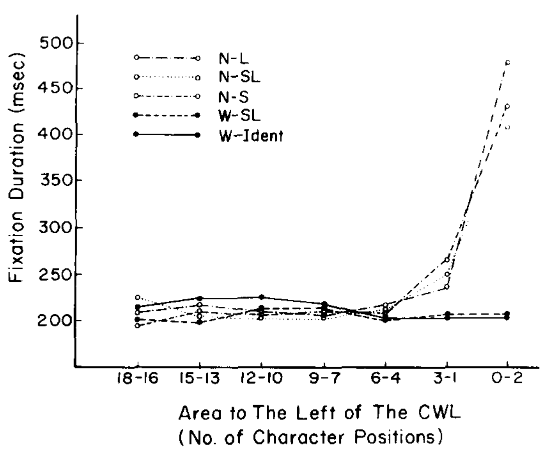

FIG. 1. Mean fixation durations in the seven areas prior to the CWL. All means represent data prior to the display change.

in one of these areas, a nonword letter string in the CWL produced a longer fixation duration than did a word. These results failed to show any evidence that readers recognize that a letter string is not a word when they are fixating more than three or four character positions to the left of the beginning of that string.

The second type of data analysis involved the duration of the fixation following the stimulus change. Fixation durations which landed in the region of the CWL (between three spaces to the left of the CWL and eight character spaces to the right of the first letter of the CWL) were grouped according to the area the saccade which crossed the boundary was launched from and categorized according to the CWL alternative initially displayed. Thus, a mean fixation duration was calculated for each subject for saccades that began 15–13, 12–10, 9–7, 6–4, and 3–1 spaces prior to the beginning of the CWL and landed in the region of the CWL when each type of CWL alternative was initially displayed. All other data were ignored. Figure 2 shows the mean fixation duration on the CWL for each CWL condition when the eye was launched from different areas with respect to the CWL. The mean fixation durations on the CWL for the ten subjects were subjected to a three-way Analysis of Variance with 10 subjects × 5 CWL alternatives × 5 areas from which the saccade was launched. There was a significant main effect for the CWL alternative initially displayed ($F(4,36) = 9.80$, $p < .0001$) and for the area that the saccade was launched from ($F(4,36) = 7.907$, $p < .0002$). The interaction of these variables fell short of the significance level ($F(16,144) = 1.397$, $p > .16$). Although the interaction was

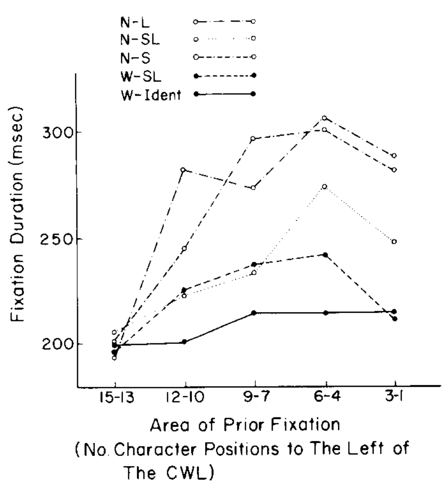

FIG. 2. Mean fixation duration on the CWL for each CWL condition according to the area the eye was launched from.

not significant, it was examined further. This was justified for two reasons. First, the area from which the eye was launched is limited by the length of the saccades that the subjects made. Since all of the CWL conditions are equal at the 15–13 area, presumably they would be equal at 18–16 and 21–19. The data that were available when the eye was launched from 18–16 character spaces prior to the CWL and landed on the CWL supported this assumption. However, most of the subjects did not consistently make saccades that long. If there had been sufficient data to include areas beyond 15–13, the addition of those areas where the CWL conditions were equal would have resulted in a significant interaction. Second, and more importantly, the *W-Ident* condition was a control condition to which the other conditions could be compared. Prior to the inspection of the data, comparisons were planned between the control and the other conditions. Both the Dunnett test (Winer, 1962) for comparing all means with a control and the Newman–Keuls test (Winer, 1962) yielded similar results. The results of those tests can be seen in Table 2.

As can be seen in Table 2 and Fig. 2, when the saccade was launched from an area 15–13 character spaces before the CWL, regardless of the CWL alternative initially displayed, there were no differences in mean fixation durations on the CWL. The curves do differ in the 12–10 range and there are differences at each of the other areas. The *N-L* and *N-S* conditions differ a great deal from the *W-Ident* condition at every area. Thus, it appears that when the reader was fixated within 12 characters from the beginning of the CWL that he acquired information about the general word shape and about specific letters. The curves for the two *SL* conditions separate only at the 6–4 area. These two alternatives are very similar in visual characteristics and the fact that they separate from each other at the 6–4 area is probably produced by the fact that the *W-SL* condition involved a word whereas the *N-SL* condition did not. Finally,

TABLE 2

RESULTS OF THE NEWMAN–KEULS TEST FOR EACH CWL ALTERNATIVE AT EACH AREA FROM WHICH THE SACCADE WAS LAUNCHED

The data are fixation durations for the first fixation after crossing the boundary. Conditions with common lines were not significantly different at the .05 level of significance. Means are in milliseconds.

Area 15–13		Area 12–10		Area 9–7		Area 6–4		Area 3–1	
Cond.	Mean	Cond.	Mean	Cond.	Mean	Cond.	Mean	Cond.	Mean
N-SL	214.85	*N-L*	279.27	*N-S*	295.87	*N-L*	299.83	*N-L*	287.25
N-S	208.00	*N-S*	244.13	*N-L*	272.10	*N-S*	299.73	*N-S*	280.55
W-Ident	207.18	*W-SL*	224.78	*W-SL*	236.92	*N-SL*	279.12	*N-SL*	245.50
W-SL	200.82	*N-SL*	221.35	*N-SL*	230.20	*W-SL*	242.55	*W-Ident*	212.57
N-L	198.05	*W-Ident*	202.67	*W-Ident*	212.97	*W-Ident*	211.10	*W-SL*	208.07

the *W-Ident* and *W-SL* conditions do not differ statistically except in the 6–4 area. However, in the 12–10 and the 9–7 areas the difference between the two conditions in terms of fixation durations is very similar. It is, therefore, very difficult to determine if the small visual differences between these two conditions were detected at the earlier location. The fact that the *W-Ident*, *W-SL*, and *N-SL* conditions separate from each other in the 6–4 àrea indicates that the actual wordness characteristics of a letter string (the capability for a semantic interpretation, for instance) were identified for strings which began no more than six character positions to the right of the fixation point. In the 3–1 area, the two *W* conditions are equal in terms of fixation durations. When a saccade was begun from this particular area, it generally landed at the end of the CWL or to the right of it. In this case, the reader had most likely reached a semantic interpretation regarding the *W-SL* alternative in the CWL and since that interpretation fit into the sentence frame the reader devoted his attention to the next portion of the text and failed to perceive the change.

DISCUSSION

The results of this study replicate the research by McConkie and Rayner (1973) dealing with the perceptual span in reading. They used the same principle that was used in this research, i.e., the use of computers and rapid display changes, and reported that a reader acquires information about word shape and specific letters no more than ten character positions into the periphery. The present research implies a slightly larger area. This difference is probably due to the differences in (1) techniques, since the study by McConkie and Rayner resulted in a large amount of stimulus change while in the present study only a single word changed, or (2) subjects, since the former study used high school students and the present study used college students. In addition, McConkie and Rayner reported that word length information is acquired somewhat further from the fixation point, at least 12–15 characters. The present study did not investigate this variable, but both studies are consistent in indicating that the area of the effective stimulus in reading is rather small.

In addition to providing data on the size of the perceptual span in reading, the present study also delineates different types of information that are obtained within this area. When the reader was fixated 1–6 character spaces prior to the CWL, he was able to make a semantic interpretation for the word in the CWL. If he was fixated 7–12 character spaces prior to the CWL, he was able to pick up such gross visual characteristics as word shape and initial and final letters. These findings are in agreement with a great deal of data concerning the area of visual acuity. The fovea, or the area of maximum acuity, is rather small, subtending an angle of only about one or two degrees (Llewellyn-Thomas, 1968; Haber & Hershenson, 1973). Words or letter strings presented to peripheral vision are recognized with decreasing accuracy as the degree of visual angle is increased (Woodworth, 1938; Feinberg, 1949; Bouma, 1973). Based on Feinberg's data, Taylor (1965) has estimated the fall-off of visual acuity for the normal eye reading a line of text. At an angle of 1°28′, visual acuity is estimated at 75%. At an angle of 2°45′, visual acuity is estimated at 45% and at an angle of 6°30′, it is estimated at 25%. Bouma's results on the recognition of letters in words or letter strings parallel these estimates, although the estimated acuities from his data would be slightly higher.

In the present study, a line of text (about 72 characters) subtended a visual angle of 18°. Thus, when a reader was fixated on the fourth character space prior to the CWL, the first letter of the CWL would be at an angle of 1° and the fourth letter would be at 2°. Thus, it seems clear that the capability of distinguishing between a word and a nonword or making a semantic interpretation is made only when the CWL is within the area of high visual acuity.

Although the capability for making a semantic interpretation for a word is limited to words that begin less than four to six character spaces from the point of fixation, the reader is able to acquire other characteristics further into the periphery. However, this study failed to find any evidence that the reader is able to pick up word shape and specific letter information any further into the periphery than about five degrees of visual angle to the right of his fixation point. Beyond that area, the reader does not pick up this type of information most likely because of the reduced acuity and visual interference from letters between the fixation point and the CWL (Mackworth, 1965; Bouma, 1973).

Finally, the results of this study indicate that information is integrated over two separate fixations. Although it is certainly true that when the eye moves and fixates a new location the new stimulus pattern overrides or masks the pattern produced by the prior fixation, it also appears that at a higher level in the processing system information from the two fixations is brought together into a single representation of the stimulus. Thus, while at one level of perceptual processing masking may occur as the input from one fixation overrides the image from the prior fixation, at a higher level the information from the two fixations is integrated. In the present study, when visual or semantic discrepancies were introduced between two successive fixations, this integration failed.

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