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ABSTRACT

Research involving eye movement monitoring can help in understanding the nature of the mental processes involved in reading, how these develop as one learns to read, and what processing strategies or characteristics are more common in those children who fail to show normal progress in learning to read. First, eye movement records show that the eyes pause longer on some words than on others, move various distances and directions between pauses, and exhibit patterns of movements indicating what is being attended to at different moments, what kinds of processing are taking place, and when processing difficulties arise. Second, eye movement data are useful in analyzing simultaneously collected data, such as brain wave records or oral reading protocols. Finally, eye movement data can be used for controlling experimental manipulations during ongoing reading. The ability to control the nature of the stimulus pattern that is present on any given fixation during reading provides a powerful technique for studying the perceptual processes that are taking place. Research techniques involving the monitoring of eye movements provide powerful new ways of studying the characteristics of the reading process, even when eye movements themselves are not involved in the etiology of the reading disorder. (HOD)

CENTER FOR THE STUDY OF READING

Technical Report No. 377

EYE MOVEMENT TECHNIQUES IN STUDYING DIFFERENCES AMONG DEVELOPING READERS

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Abstract

This report discusses three ways that eye movement recording can be employed in the study of developing reading skill. First, eye movement records are a rich data source. Data from four children illustrate similarities and differences in their reading style. Secondly, eye movement data are useful in analyzing other data. An example illustrates their use in selecting concurrently-collected EEG data to explore issues of mental processing at specific moments in reading. Finally, eye movement data are used for controlling experimental manipulations during on-going reading. Eye movement contingent display control techniques are used to study perceptual and attentional processing during reading. A few relevant examples of current contingent display research are presented. Individual differences among children learning to read are manifest in eye movement records. We suggest that eye movement monitoring can play a critical role in the study of dsylexia.

Eye Movement Techniques in Studying Differences Among Developing Readers

Research on reading tends to be divided between studies which directly investigate reading itself and studies that investigate the relationship between reading performance and other variables, such as characteristics of the readers or their performance on tasks thought to be related to reading in particular ways. The goal of research that directly investigates the reading process is to understand the nature of the perceptual and language processing taking place; the deployment of attention to the text; the information being acquired; and the way that information is being represented in the mind. In research that investigates these issues in real time where people are studied as they actually engage in reading, eye movement monitoring plays a critical role.

There are three different ways in which eye movement recording can be involved in studying reading. Many studies employ more than one of these techniques. First, monitoring the eyes yields an eye movement record which can be a rich source of data. The eyes pause longer on some words than on others, they move various distances and directions between pauses, and they exhibit patterns of movements which can indicate what is being attended at different moments, what kinds of processing are taking place, and when processing difficulties arise. Second, the eyes can be monitored as a basis for analyzing simultaneously collected data, such as brain wave records or oral reading protocols. Third, on-line eye movement information can be used to exert experimental control over aspects of the stimulus or of response recording devices. Our own work has focused primarily on this last use of eye movement monitoring; much of it involves eye movement contingent display changes that are made during reading as a means of studying the perceptual processes. All of these techniques are useful in studying the nature of the processing that takes place during reading and the processing differences that exist among readers.

Eye Movement Records as a Source of Data

Eye movement behavior itself is a part of the act of reading. Furthermore, there is increasing evidence that characteristics of the eyes' behavior relate to characteristics of the mental processing taking place (see reviews by Levy-Schoen and O'Regan, 1979; McConkie, 1983; Rayner, 1978). Thus, eye movement records can be examined either in an attempt to understand the nature of eye movement control, or, by making assumptions about eye movement control, to understand the mental processes which were taking place. In so doing, it is possible to focus either on the discrete components of the eye movement record, that is, on individual eye fixations and saccadic movements, or on the patterns present in sequences of fixations and saccades.

Individual Components of the Eye Movement Record

Eye movement records taken during reading are usually reduced to two components, i.e., fixations and saccades. The record then indicates where in the text the eyes were directed during each fixation, how long they remained at that location, and where they were sent next. In early eye movement studies (Buswell, 1937; Huey, 1908), these data were further reduced to indicate the mean duration of fixations, the mean saccade length, and the frequency of regressive movements for different groups of readers. It was found that these measures differed by grade and ability level. Typically, better readers showed shorter fixations, longer saccades, and fewer regressive movements (Taylor, 1965). These same trends were also found when text difficulty was reduced (Patberg & Yonas, 1978; Walker, 1933).

While these trends have been documented for several decades, their significance for understanding reading is not yet understood. For this purpose, it is necessary to become more analytical in our description of the eye movement data. To accomplish this goal, we have collected eye movement data from nine third graders as they read an entire children's novel. The eye movement records contained between 12,000 and 25,000 fixations per child. Data from four of these children, whose independent reading test scores range from 11 months above grade level to 12 months below, according to the Woodcock Reading Mastery Tests (Woodcock, 1973), will be used here to illustrate characteristics of children's eye movements during reading.

Durations of fixations. The termination of a fixation is the result of a decision that it is time to move the eyes to a new location. Figure 1 presents the frequency distributions of fixation durations for four of our young readers. While there is a difference in the mean fixation duration for these students, and this varies directly with their reading ability level, the most impressive characteristics are the great amount of within-subject variability and the great amount of overlap among the distributions. The small observed differences in the means, while harmonious with previous findings, are not especially illuminating about the nature of these differences.

Insert Figure 1 about here

From a processing perspective, the duration of a fixation is the time that passes from the beginning of that fixation until a decision to move the eyes is executed. The distribution of fixation durations results from the differences in the time when this decision is made and when it is executed for different fixations. From this perspective, it is possible to describe these frequency distributions in a rather different way. By dividing time into intervals, it is possible to calculate for each interval the proportion of those fixations entering the interval that terminated during that interval. The resulting curve is similar to those used in survival analysis (Miller, 1981). For each time period included, the curve indicates the proportion of the surviving fixations which terminated during that period. Figure 2 presents curves of this type for the four children studied.

Insert Figure 2 about here

Figure 2 indicates that the likelihood of fixations terminating within the first 80 msec is very low; this likelihood then rises rather quickly and levels off to some degree about 180 msec after the onset of the fixation. While the distributions for these four children begin to rise and to decelerate at slightly different intervals, the primary difference among them is in the maximum level attained. That maximum is much lower for the poorest reader in our group, David, which results in more fixations continuing for longer periods of time, including many that last for 500 msec or more. Of course, the interesting question, and the one which we cannot answer at present, concerns what it is about the nature of the processing that leads one of these children to continue his fixations for so much more time than the others. Does this simply reflect the greater amount of time required by David to accomplish the mental processing that is required at most points in the text? And if so, what aspects of the processing are requiring this additional time? Equally intriguing is the question of why each of these children sometimes terminates a fixation after only 100 msec or less and sometimes continues it for 500 msec or more. Certainly this must be related to the nature of the processing taking place at different locations in the text. However, current evidence indicates that there is not a simple relationship between the duration of a fixation and the amount of time required to process the information acquired during that fixation (Hogaboam, 1983; McConkie, Underwood, Zola, & Wolverton, 1985). Studies with adult readers do show longer fixations on unusual words (Just & Carpenter, 1980; Kliegl, Olson, & Davidson, 1983; Rayner, 1977), words with spelling errors (Zola, 1984), and words for which there is less contextual constraint (Ehrlich & Rayner, 1981; Zola, 1984). Similar studies have not yet been conducted with developing readers.

In research with adult readers we have found that fixations with a duration of less than 140 msec are too short to be affected by the information being perceived during those fixations. Thus, these fixations are being terminated by decisions based on previously acquired information. It is interesting that the number of short fixations of the four children studied are quite different, ranging from 5% to 25% of all fixations made. It seems likely that this is also an indicator of some not-yet-understood, aspect of processing during reading.

Direction and length of saccades. Every fixation is terminated by a saccadic eye movement that takes the eyes to some new location in the text. Figure 3 presents the frequency distributions of saccades of different directions and lengths for the four children studied.

Insert Figure 3 about here

These distributions are strikingly different from those of skilled adult readers in three ways. First, these children show many more regressive eye movements than adult readers do. In the data from Jean, Fred and David, 35% of all saccades are regressive, as compared to 20% for a group of college students recently studied. Second, there are many more short saccades in the children's data. For the same three children, nearly 40% of all saccades are less than 3.5 character positions in length. (In our eye movement monitoring system, four character positions occupy one degree of visual angle.) This could reflect a necessity for children to deal with smaller segments of text on each fixation, a difficulty in coordinating visual input and language processing aspects of reading, or some other factor.

The data presented in Figure 3 also indicates how children of the same age can differ in their eye movement characteristics. The saccade length distributions of one child, Nancy, are very different from those of the other three, and are quite similar to those of adults. Interestingly enough, this student is not particularly advanced in her reading ability, as indicated by the Woodcock test, on which she scores close to her grade level.

It is the nature of overall distributions of saccade lengths, such as those presented in Figure 3, that they cannot indicate the factors which lead to the variance observed. This requires a further breakdown of the data. One example of such a breakdown is shown in Figure 4. Figure 4a shows the distribution of saccade length and direction for two of the children, Jean and Fred, following all fixations in which the eyes were centered on the first letter of a six-letter word. The two curves are very similar, and differ greatly in shape from those in Figure 3. These curves seem to show three modes: one corresponding to a return to the prior word, another corresponding to refixations of the same word (with the 3rd letter of the word being the most probable location), and the third corresponding to fixations on the following word (with the eyes tending to go to one of the initial letters). This clearly suggests different mental states of the reader leading to the different alternative eye movement outcomes.

Insert Figure 4 about here

Figure 4b shows comparable distributions for a slightly different condition for two children, Jean and Nancy. In this case, their eyes were centered on the 3rd letter of a 6-letter word, rather than on the 1st letter. A comparsion of Jean's data in Figures 4a and 4b shows a striking contrast. In Fig. 4b the likelihood of refixating the word is greatly reduced and the predominant tendency is to move the eyes to the following word. Fred, whose data are not shown here, again shows a very similar pattern. In contrast, Nancy's data are presented. This is the child who shows a more adult-like pattern. While she also shows the same preference for making a saccade to the next word, in other respects her distribution is quite different. Most notably, she is much less likely to refixate the same word. Apparently one of the differences between Nancy and the rest of the children lies in her ability to identify a word of this size on a single fixation.

These few examples serve to illustrate the fact that, buried in the saccade length data of children is a great deal of detail which is useful in detecting individual differences among readers and in suggesting some of the bases for these differences.

Eye Movement Patterns

The examples given so far deal with the eye movement data at a molecular level, that is, the analysis of individual fixations and saccades. The next level of complexity involves the examination of sequences of fixations and saccades in terms of their pattern. This is more difficult because eye movement behavior can be so variable. However, Frazier and Rayner (1982) were able to demonstrate that readers responded differently at different times when they encountered difficulties in reading garden path sentences (e.g., The horse raced past the barn fell). Furthermore, no subjects exhibited one pattern that had been expected. At a still more global level, Olson and his co-workers have found that when children are grouped by overall eye movement pattern, indexed as the ratio of regressive to forward saccades, the groups show differences on other tests as well, indicating differences in their general reading strategies.

The fact that eye movement patterns are different at different places in the text, and for different subjects, is obvious as one peruses the data. So far, only minimal progress has been made in classifying these patterns and relating them to the mental processes which give rise to them. We do not know, for instance, what processing differences lead a reader to make multiple fixations on one difficult word prior to proceeding forward, and then to fixate another similar word only once before going on and later returning to the word for additional fixations.

Further Comments

It is our assumption that what children do with their eyes as they read, reflects the way they are attending to the text. This oculomotor behavior is, in turn, assumed to reflect both the nature of the processing of visual information and the child's ability to coordinate the controlling processes necessary to provide the information as it is needed. If these assumptions are accurate, then detailed explorations of eye movement patterns will give clues to processing differences that are taking place.

Eye movement data have been particularly useful in indicating whether experimental manipulations of the text, or of the manner of text presentation, are disruptive to on-going reading processes. A careful comparison of the eye movement data resulting from a control and an experimental condition can indicate whether the experimental manipulation involved caused a disruption in reading, and if so, just when this disruption occurred. The data can also suggest how the reader responded to the disruptive influence. Thus, eye movement data are useful both in studies in which the eye movements themselves are the primary focus of interest and in studies in which the eye movement record is used as an indicator of the effects of manipulations of other aspects of reading.

In almost all reading research involving eye movement monitoring, a single eye has been monitored. There are no studies in which highly accurate equipment has been used to monitor simultaneously the activities of both eyes during reading. This is important to note, since claims have been made that some reading disorders have at their base a failure properly coordinate the movements of the two eyes during reading (Bedwell, Grant, & McKeown, 1980; Taylor, 1966). It is possible that our history of monocular eye monitoring is a critical limitation on current research in the field, blinding us to an important causative factor in reading disorders. On the other hand, it may be that with adequate equipment we would learn that lack of binocular coordination is an extremely rare source of reading difficulty. Clearly, research is needed on this issue, but it must be done with high precision equipment. Only by having two eyetrackers that have nearly identical dynamic characteristics can we be sure that coordination failures are true differences between what the eyes are doing, rather than differences in the characteristics of the eye movement monitors themselves. Considering the high cost of precision equipment and the added difficulty of adjusting, not one, but two eyetrackers, such research will be both expensive and painstaking.

Eye Movement Data as a Basis for Analyzing Other Data

A second use of eye movement records is as a basis for analyzing other, concurrently-collected data. Our laboratory is initiating a study which will use EEG data to investigate questions of processing at certain locations in the text. This research will involve the use of evoked potentials, that is, the Average Evoked Response technique. This technique requires that a subject encounter a particular situation a number of times, with brain waves being recorded during each. These EEG data from the different trials are then averaged by beginning at some known time, typically the onset of the stimulus, and then taking the average of the data samples across different trials at successive points in time, perhaps every 20 msec. The resulting averaged curve shows the characteristics of the brain signal that are common to the series of trials with transient characteristics of the individual trials removed. This is known as an Average Evoked Response, or sometimes referred to as an Event Related Potential. Such curves can be obtained from different conditions and then compared in order to study the characteristics of the brain processes in these conditions (Donchin, 1984).

We plan to take a similar approach to studying ongoing processing during reading. EEG data will be recorded simultaneously with eye movements as the subject reads. It will then be possible to identify fixations that occur at particular locations in the text (for example, on particular words of interest) and the EEG data can be averaged as described above, beginning when the eye movement data indicate that the fixation began. In addition, the eye movement record can be used to select EEG data recorded during the execution of eye movements. This data can be similarly averaged in order to identify the brain signal that accompanies such eye movements. For some purposes, this signal can then be subtracted from the EEG data as a means of reducing artifacts produced by eye movements.

This technique may indicate how soon brain processes of different types are initiated after the visual stimulus is encountered. It may also indicate the areas of the brain that are involved in different processing.

Another example of the simultaneous collection of two types of ongoing data would be to monitor both eye movements and voice during oral reading. In this way, the time of vocalization of words can be related to the time the words are fixated. In addition, the eye movement data may clarify the mental activities and strategies that result in vocalizations as a beginning reader attempts to identify and say a novel word.

Thus, in any study in which recordings are made continuously of some aspect of the reader's behavior, and in which it is necessary to select those parts of the data record that correspond to the reading of a particular part of the text, eye movement records can provide a basis for this data selection. In addition, the eye movement record may also yield information about the nature of the reading processes taking place at the different points of interest in the text which can help specify how the data taken in parallel should be analyzed.

Use for Real-time Experimental Control

A third use of eye movement data is for real-time experimental control in studies of on-going reading. While there are other possible examples of potential research of this type, we will focus on research involving eye movement contingent display control.

In this research, the reader's eye movements are monitored while reading from computer-controlled text displays. Using this arrangement, it is possible to program the computer to make changes in the text display as it is being read, contingent upon the behavior of the eyes. Thus, the computer can change the display as the eyes are moving from one location to another so that the stimulus pattern present during one fixation is different than it was during the last. This ability to control the nature of the stimulus pattern that is present on any given fixation during reading provides a powerful technique for studying the perceptual processes that are taking place. We will illustrate this paradigm by describing two recent studies which have been conducted in our laboratory, and two other studies that are in progress.

The Perceptual Span of Children During Reading

In order to investigate the size of the region within which letter distinctions are being used during a fixation in reading, Underwood and Zola (1986) conducted a study using the technique originated by McConkie and Rayner (1975). Two versions of each line of text were stored in the computer's memory, one being the original line and the second being a line in which each letter had been replace by a different letter. These will be referred to as the original line and the replacement line. The original line was initially displayed on the screen. However, on selected fixations as the child read, parts of it were replaced by parts of the replacement line. This manipulation was made in such a way that the text in the region where the eyes were centered on that fixation was from the original line, and text outside this region was from the replacement line, as shown in Figure 5. In one experiment, the region of normal text (referred to as the window) was made to be of different sizes in order to determine how large the region is within which young readers distinguish among letters while reading. It was assumed that if the window were smaller than the region within which letter information was used, then erroneous letters of the replacement text would be perceived during that fixation. Perceiving incorrect letters would interfere with normal word processing, resulting in disruptions which would be revealed in the eye movement pattern. Thus, the experiment was designed to see how small the window could be made without causing a disruption in reading. This would give an estimate of the region within which letter distinctions were made during reading.

Insert Figure 5 about here

In our study, two groups of fifth-grade children were used: one group reading at or above grade level, and one group reading below, mostly at the third grade level. The results indicated that there was no difference between the two groups on this measure. Thus, differences in their perceptual spans were not involved in their difference in reading ability.

Further research of this type needs to be carried out with younger and with more seriously disabled readers, examining individual differences in this aspect of reading.

Combining Information Across Fixation

In a second study using third-grade children, we investigated the visual images obtained on successive fixations during reading to see if they are integrated into a single image in the brain. This was done using a technique from an earlier study with adult readers (McConkie & Zola, 1979). The text to be read was presented in AlTeRnAtInG cAsE, with every other letter capitalized. During certain eye movements, the case of every letter was changed, so that for the next fixation the shape of every letter and of every word would be different than it had been during the last fixation. An example is shown in Figure 6. We postulated that if the visual images from successive fixations are being integrated into a single image, the images from these two fixations would not fit together and, thus, the perceptual process would be disrupted. The results were similar to those found earlier with adults, in that the experimental manipulation produced no evidence of a disruption in their eye movement records. Thus, there was no evidence for a disruption of the ongoing reading process. However, whereas none of the adults were consciously aware of the change being made, a few of the children gave an indication that they had noticed that something was happening as they read. When they were interviewed after the experiment, some reported seeing flashes. One child was even able to describe the manipulation: "All the little letters changed to big letters, and all the big letters changed to little ones."

Insert Figure 6 about here

This study was originally conducted in order to investigate the possibility that, although people may integrate visual images across fixations while viewing non-textual stimuli, in learning to read they learn to deal with the stimulus pattern in a different way, using it as a source of linguistic information rather than as a picture to be perceived. One implication of this change, we thought, might be the elimination of the across-fixation integration. The fact that some children did seem to be aware of the changes in a way that the adults were not, indicates the need to study children at earlier grades to see if there is a point at which the hypothesized transition in style of processing takes place. If such a transition is found, this type of task may indicate whether one aspect of perceptual learning is progressing normally for a given child.

Other Studies Involving Eye Movement Contingent Techniques

The two studies just described represent only the beginning of the application of eye movement contingent display control techniques to studying questions about the perceptual and cognitive processes taking place as children read, how these develop over time, and how children differ in their reading. Two other examples of studies currently underway illustrate further uses of this approach to studying reading.

As noted earlier, children frequently make multiple fixations on a word as they read. We would like to know whether, on these different fixations, they are seeing the entire configuration of the word, or are examining different parts of the word. To study this question, groups of words were identified that differ at two letter positions, for example, cat, cap, mat, and map. A sentence was written into which any of these four words fit appropriately, as shown in Figure 7. One of the words is in the text as the child begins to read. However, if the computer detects an eye movement that is taking the eyes to this word location a second time after initially encountering it, both critical letters of the word are changed. This manipulation places a new word at that location. If the entire word is being seen on each fixation, this type of change should be extremely disruptive to reading, showing up both through changes in the eye movement data and in the reader's conscious report. On the other hand, if different parts of the word are being examined on different fixations, the change will not disrupt reading but will produce an interesting perception on the part of the reader. For example, if the word *mat* is present on one fixation and *cap* on the next, the reader is likely to report having read the word *map* in the text, part of which was acquired during one fixation and part during the next. Of course, the results may be different for different children, indicating differences in the types of perceptual units being used during reading.

Insert Figure 7 about here

It is also possible that when children make a second fixation on a word, this indicates that the word was not identified on the first fixation. To investigate this possibility, a second study is being initiated. We are programming the computer to identify the initial fixation on certain words in the text. During the eye movement following such a fixation, the text will be removed and replaced by a patterned mask. Thus, no useful information will be obtained from the text during that or any following fixations. The subject's task will then be to report the last words read. In addition to the children's reports, we will have eye movement data indicating whether the fixation following the first fixation on the word was to be on the same word or a different word. The hypothesis being tested predicts that when the following fixation is to be on the same word, the reader will not include that word in his or her report. On the other hand, when the following fixation is to be on some other word, the initially fixated word will be reported.

There are, of course, a number of other ways in which the eye movement contingent display control technique can be employed to investigate specific questions about the nature of the processing taking place during and across fixations as children read. However, these four examples illustrate the power of this approach to studying reading. Eye movement contingent display control actually makes it possible for the researcher to manipulate experimentally the stimulus pattern that is present during any particular fixation during reading, and, at the same time, to obtain a detailed eye movement record that can indicate when these manipulations are producing effects on reading and what the nature of the effects are. The use of these techniques to study the development of children's reading ability has only begun, and even less has been done in using them to study the nature of reading disorders.

Other Uses of Eye Movement Contingent Techniques

The use of eye movements to control the display is only one of a variety of eye movement contingent techniques that can be used. It would also be possible to study the "cognitive load" at certain points in the text by having a click sound a certain length of time after the fixation on which a particular word in the text was perceived, and by measuring the latency of a response to the sound. Another possible use would be to examine the interference in reading that is produced by having the computer "say" a word into the reader's earphones just at the time when some related word is fixated. In any research where it is necessary to make an experimental manipulation in real time as the reader is encountering visually some specific part of the text, or is exhibiting some particular eye movement pattern, such as regressing to an earlier word, eye movement contingent experimental manipulation techniques become critical.

A Relation to Dyslexia

In this paper, we have attempted to show that various techniques involving the monitoring of readers' eye movements can play an important role in understanding the on-going processing taking place during reading. We assume that the study of dyslexia is essentially the study of individual differences among children learning to read. Research involving eye movement monitoring can help in understanding the nature of the mental processes involved in reading, how these develop as one learns to read, and what processing strategies or characteristics are more common in those children who fail to show normal progress in learning to read.

Thus, we suggest that one important branch of research on dyslexia will continue to investigate the nature of the perceptual and mental processes that are taking place as children are reading, or trying to read. Within this approach, eye movement monitoring will play a critical role. It may be that problems in the control of eye movements are a causative factor in the reading difficulties for occasional readers. However, of much greater importance is the fact that research techniques involving the monitoring of eye movements provide powerful new ways of studying, in detail, characteristics of the processing taking place during reading, even when eye movements themselves are not involved in the etiology of the reading disorder. Furthermore, it is likely that, at some point, eye movement monitoring techniques will play an essential role in the diagnosis of reading disorders.

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Figure Captions

Figure 1. Frequency distribution of four children's fixation durations during reading. All fixations were preceded by a forward saccade.

Figure 2. Smoothed curves which indicate the likelihood that surviving fixations will terminate during different time intervals following the onset of the fixation. These four curves are derived from the same data used in Figure 1.

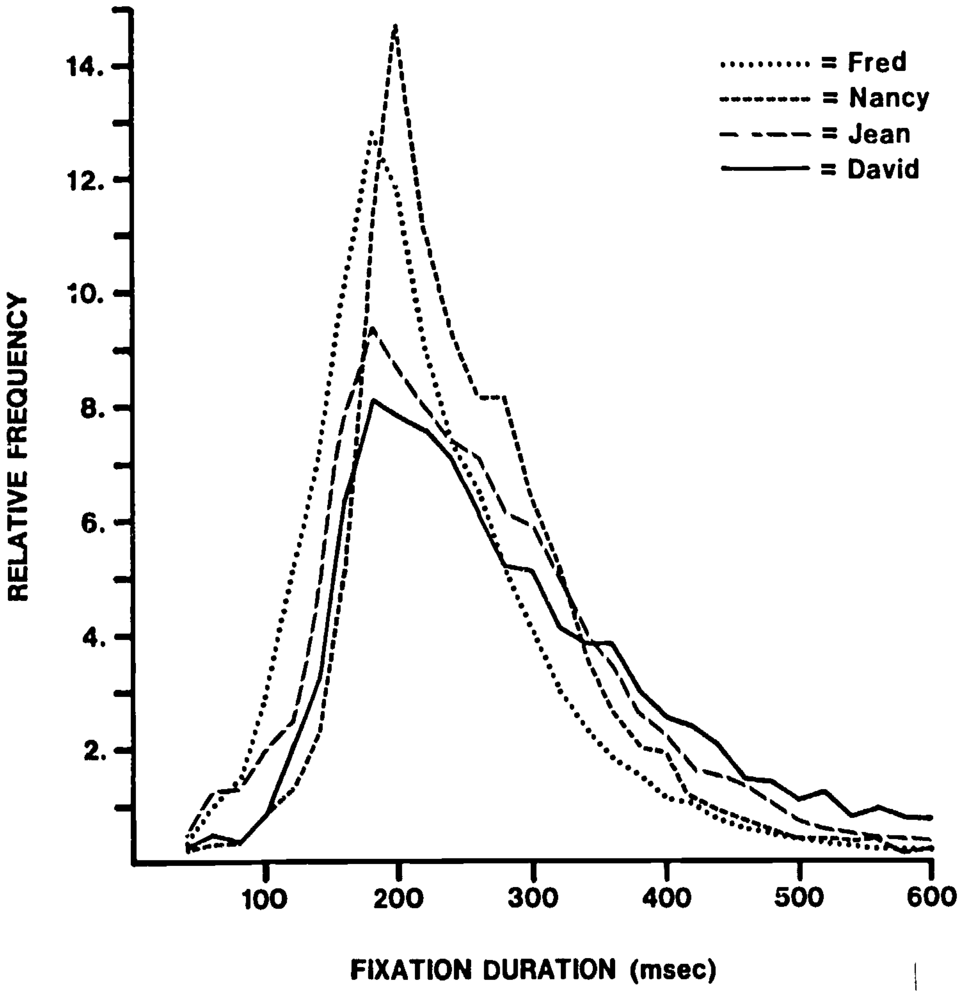
Figure 3. Frequency distributions of the lengths of four children's forward and regressive saccades.

Figure 4. Frequency distributions of saccade directions and lengths for selected children. Figure 4a compares the distributions for Jean and Fred for saccades which follow fixations centered on the first letter of a 6-letter word. Figure 4b compares the distributions for Jean and Nancy for saccades following fixations on the third letter of a 6-letter word.

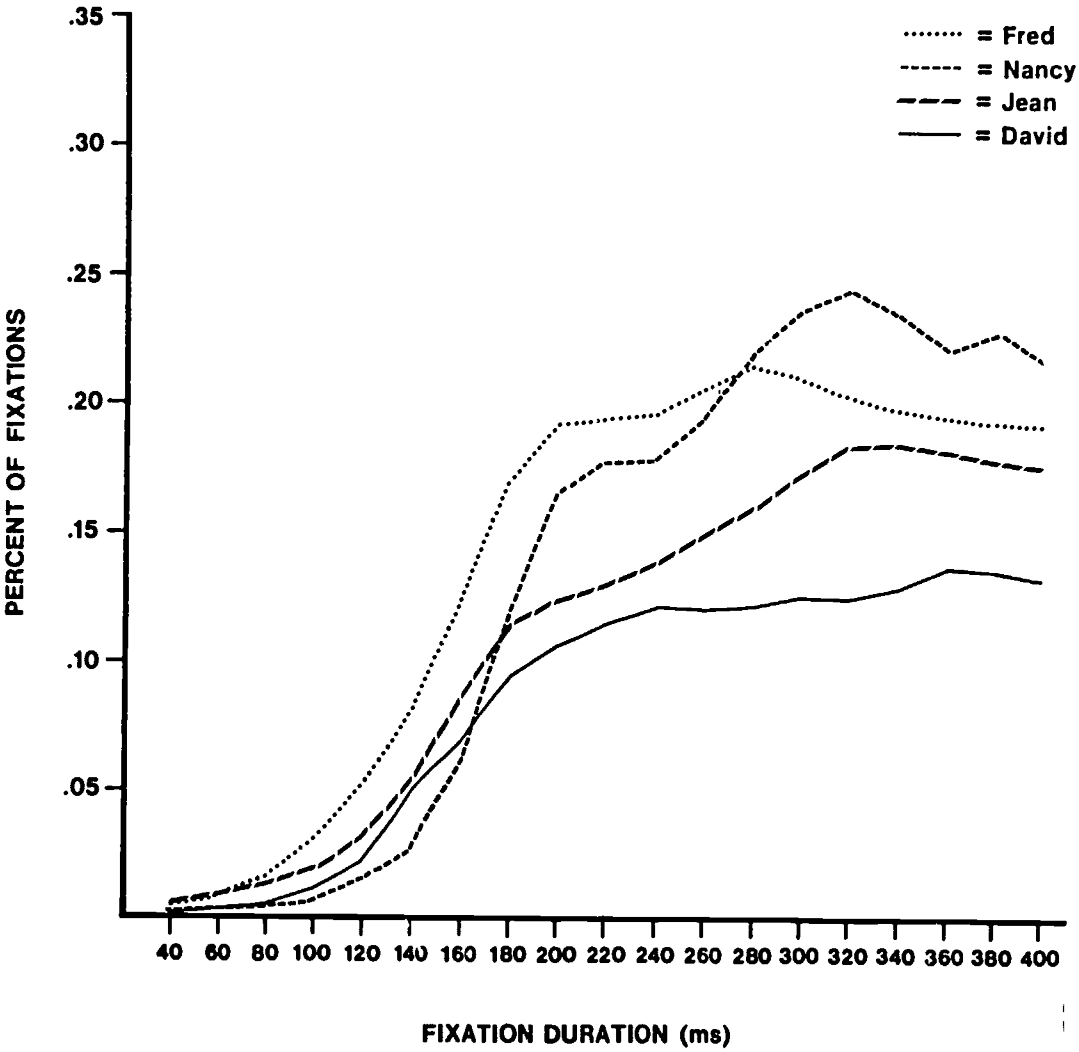
Figure 5. An example of a line of text showing how it might appear when parts of the Original Line are replaced by parts of the Replacement Line contingent on the location of the eyes on that fixation. The arrow (^) indicates the letter where the eyes are centered.

Figure 6. Two versions of a line of text printed in alternating case. During selected saccades, one version was replaced by the other as children read.

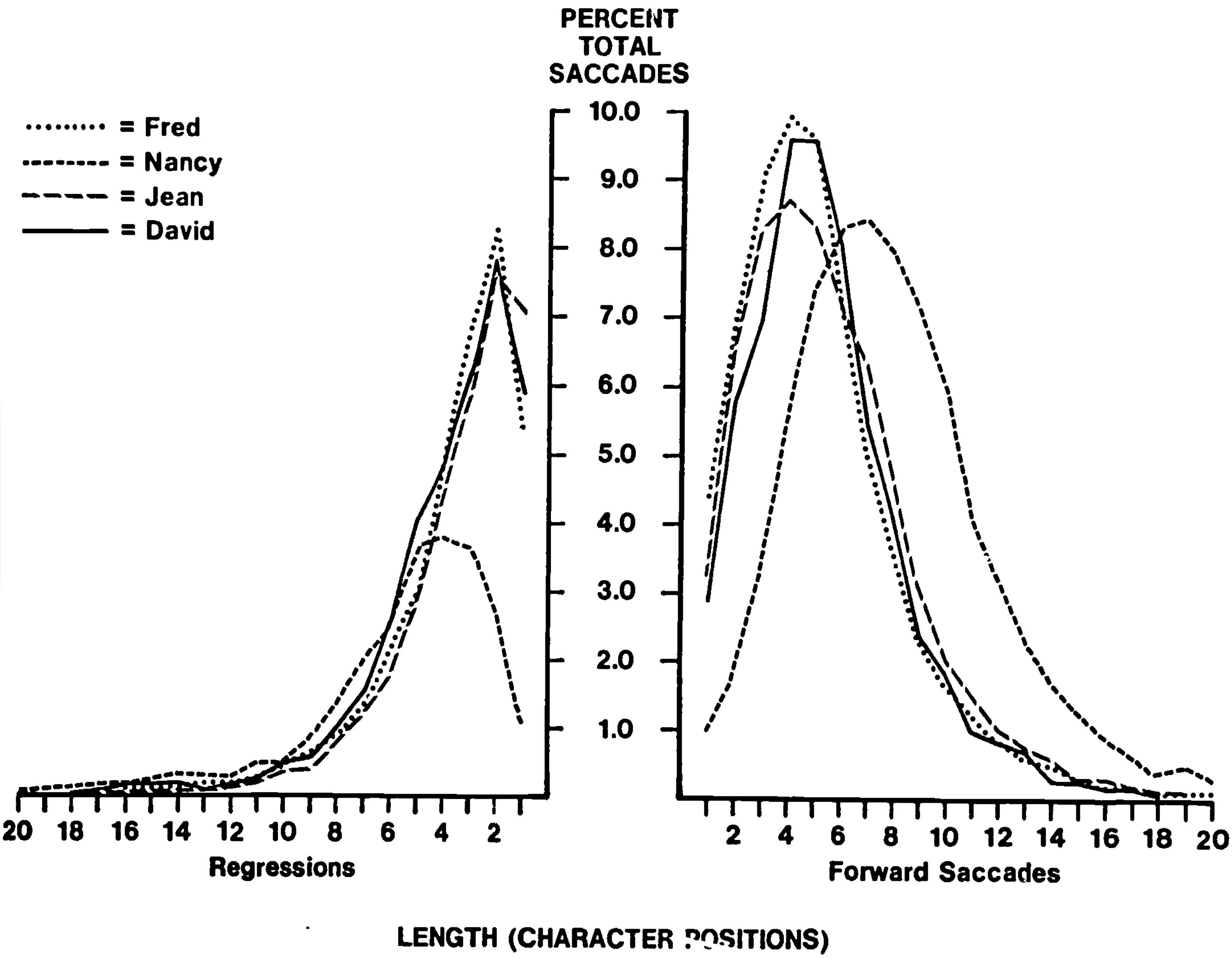
Figure 7. An example of a sentence in which any of four words, differing at two letter positions, fits appropriately. Words are substituted during selected saccades as children read.



RELATIVE FREQUENCY
14.
12.
10.
8.
6.
4.
2.
100
200
300
400
500
600
FIXATION DURATION (msec)
= Fred
= Nancy
= Jean
= David

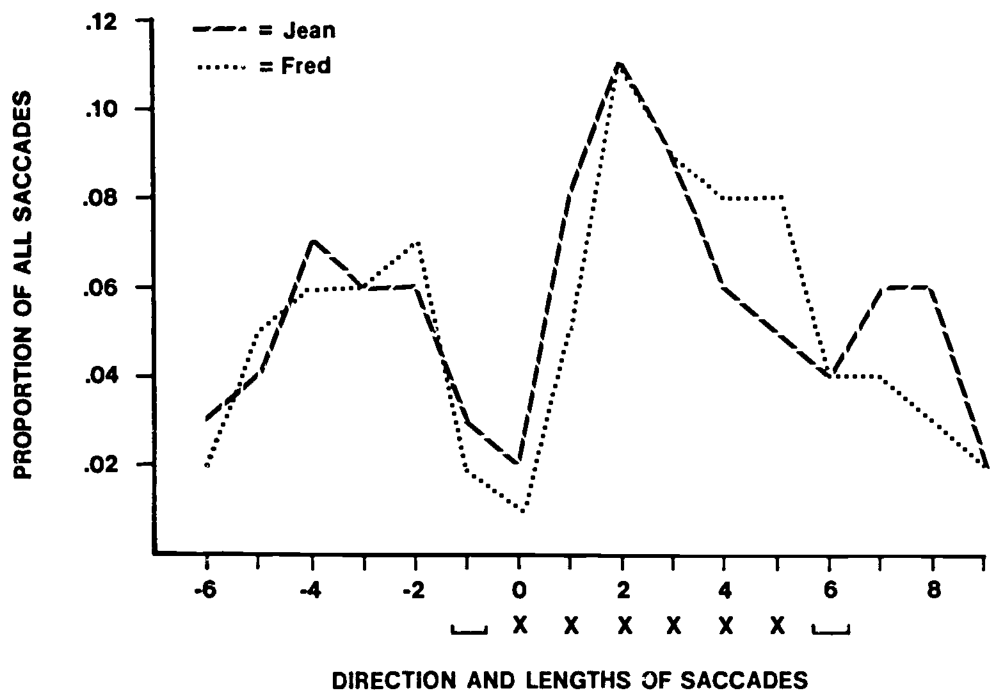


PERCENT OF FIXATIONS
.35
.30
.25
.20
.15
.10
.05
········ = Fred
------ = Nancy
— — — = Jean
——— = David
40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
FIXATION DURATION (ms)

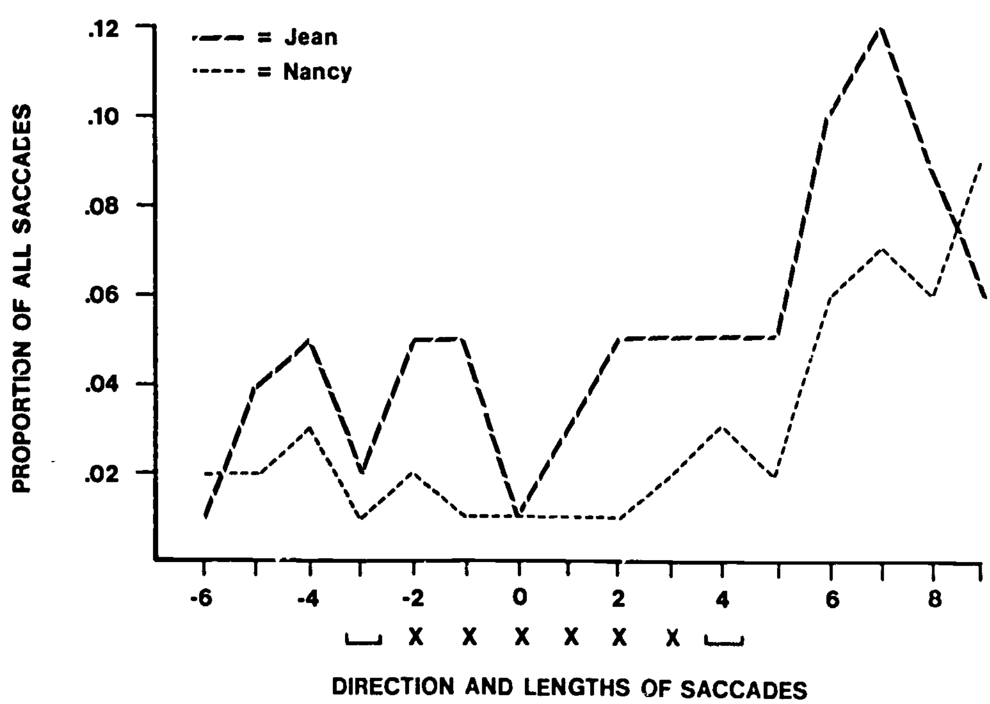


PERCENT
TOTAL
SACCADES
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
= Fred
= Nancy
= Jean
= David
20 18 16 14 12 10 8 6 4 2
Regressions
2 4 6 8 10 12 14 16 18 20
Forward Saccades
LENGTH (CHARACTER POSITIONS)

A.


= Jean
= Fred
.12
.10
.08
.06
.04
.02
PROPORTION OF ALL SACCADES
-6
-4
-2
0
2
4
6
8
X X X X X X
DIRECTION AND LENGTHS OF SACCADES

B.


= Jean
= Nancy
.12
.10
.08
.06
.04
.02
PROPORTION OF ALL SACCADES
-6
-4
-2
0
2
4
6
8
X X X X X X
DIRECTION AND LENGTHS OF SACCADES

Original Line

One of the few stories about a cat saving someone happened

Replacement Line

Zen ui hfn inx rhusbnr mluoh m vmh rmcbey ruanuen fmjjnent

Contingent Display Line

Zen ui hfn inx rhusies about a cat sacbey ruanuen fmjjnent

It wAs tHe tImE Of tHe cIvIl wAr bEtWeEn tHe nOrThErN AnD SoUtHeRn

iT WaS ThE TiMe oF ThE CiViL WaR BeTwEeN ThE NoRtHeRn aNd sOuThErN

Mary said to Jim, "Did you see that ___ on the coffee table?"

cat
cap
mat
map