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Eye movement guidance in reading :: the role of parafoveal letter and space information.

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EYE MOVEMENT GUIDANCE IN READING

THE ROLE OF PARAFOVEAL LETTER AND SPACE INFORMATION

A Thesis Presented

By

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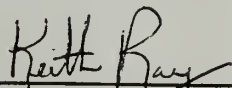
EYE MOVEMENT GUIDANCE IN READING:

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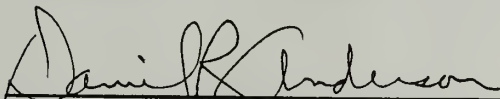
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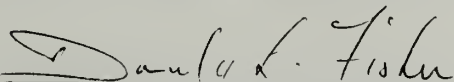
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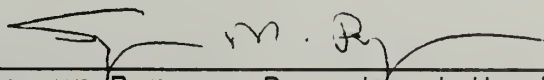Alexander Pollatsek, Member

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Daniel Anderson, Member

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Donald Fisher, Member

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Albrecht Werner Inhoff, Consultant

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INTRODUCTION

There is a considerable body of data in the literature on eye movement control in reading that shows a close relationship between visual characteristics of the text and the pattern of fixations. This relationship is evident from the fact that word length patterns in the text are related to where the reader fixates next. If the word to the right of fixation is long the amplitude of the saccade tends to be greater than if the word is short (Rayner,1979). If a word of three letters or less is immediately to the right of fixation there is a high probability it will be skipped (Rayner,1979). In addition, the location of fixations within a word is not random; there is a preferred location between the first and middle letters of a word (O'Regan,1981;Rayner,1979).

All these pieces of evidence point to the conclusion that the decision of where to move the eye next is not made on a random basis. There is also now fairly substantial evidence to indicate that gross visual characteristics of the text in the parafovea to the right of fixation influence the location of the next fixation. In particular, it seems clear that word length is a factor in determining where the eye will land. However, it remains unclear at this point what the separate effects of letter and space information are, and how they interact with one another in the process

of programming a saccade. Before looking more closely at what kind of information is utilized to program a saccade let us turn to a model of when and how the programming of a movement could occur.

A Model Of Saccade Programming

To what extent are eye movement decisions under the direct control of the reader? That is, can these decisions be made on the basis of information received in the course of a single fixation (direct control), or must some decisions be made in advance and then held in a buffer until the appropriate time to execute them (preprogramming)? Second, what might the process of programming these movements look like?

Rayner and Pollatsek (1981) investigated the first question by manipulating the size of an eye contingent "window" of readable text either in fixed blocks or varied randomly from fixation to fixation. Earlier studies (McConkie & Rayner, 1975; Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981) had shown that the length of the saccade increased as the size of the window increased. Rayner and Pollatsek reasoned that if eye movement decisions are under direct control (i.e., decisions are made within an individual fixation), parameters such as saccade length should be affected equally in the two conditions. On the

other hand, if only delayed control is possible, or if saccade length is preprogrammed (i.e., the saccade is programmed on the previous fixation and held in a buffer), then it could not change as a function of window size in the variable condition. The data showed that saccade length varied with window size almost identically in both conditions. However, further analyses indicated that there was also a small effect of the size of the window on the previous fixation.

Rayner and Pollatsek (1981) also created a stimulus onset delay by means of an eye contingent mask that was presented foveally at the beginning of a fixation and then removed after some time to reveal the text. As before, trials were either blocked or random. In general, fixation duration increased by an amount nearly equal to the delay of the text in both conditions. For the most part subjects simply waited out the mask on each fixation and programmed their eye movements only after there was sufficient information available to process the current fixation.

However, this is a complete picture only at short delays. When stimulus onset delays were extended to 200-300 ms, Rayner and Pollatsek reported evidence suggesting that preprogramming of saccades may occur. That is, a saccade would be programmed on fixation n, held in a buffer, and then executed to terminate fixation n+1. The eyes sometimes moved before the delay period ended, without ever having

seen the text. These saccades and the fixations they terminate were termed "anticipations", and they contributed to a bimodal distribution of fixation duration. To account for their data, Rayner and Pollatsek proposed a mixed control model in which most decisions are made based on information received within that fixation; preprogramming occurred on exceptional occasions. However, these data could also be explained by a model which included parallel programming of saccades (Becker & Jurgens,1979; Morrison,1984).

Becker and Jurgens (1979) used a double-step paradigm to demonstrate the phenomenon of parallel programming of saccades in response to simple stimuli. Subjects were asked to fixate a single target and track any change of location of the target with their eyes. As the subject fixated the target it jumped to a different location, and then again to a second new location. By varying the delay between the first and second jump of the target they obtained data showing a variety of patterns of saccades: two independent saccades which mimicked the two steps of the target, a single saccade to some intermediate location between the first and second target position, or a single saccade that skipped the first location entirely and landed on the second target position.

Perhaps the clearest evidence of parallel programming is the case in which there was an extremely short fixation

on the first target location terminated by a saccade to the second target location. The saccade to the second target location could not have been preprogrammed since the second target location was not known early enough for that to be possible. The saccade could not have been programmed during the fixation on the first location since that fixation was extremely short. Becker and Jurgens reasoned that the saccades may have been programmed in parallel if the programming consisted of two stages; a computation stage and an execution stage. When two responses compete for the same stage of programming they interact with one another and the end result may be a saccade to some intermediate location between the first and second target steps. If two responses are separated by enough time that they do not compete for the same stage then they will be independent. Thus, an extremely short fixation on the first target step reflects a brief time between the programming of two eye movements, not an extremely fast latency for the second one.

However, reading is not directly analogous to the isolated target location task employed in Becker and Jurgens' double-step experiments. Reading is much more complex, both in terms of stimulus complexity and cognitive processing load. For this reason it is not necessarily the case that the Becker and Jurgens model is adequate to describe the saccadic system as it operates in reading.

Morrison (1984) conducted a reading study which

provided evidence that anticipation eye movements like those reported by Rayner and Pollatsek (1981) can be explained by a parallel programming model very similar to that of Becker and Jurgens. In Morrison's experiment (as in Rayner & Pollatsek, 1981) an eye contingent foveal mask was used to delay the onset of the stimulus in each fixation. The duration of the delay was again manipulated either in fixed or randomized blocks. Morrison extended the delay conditions to include delays of up to 300 ms in the random delay conditions. This is something that had not been done in the Rayner and Pollatsek (1981) study.

Although the length of the text delay strongly affected fixation duration, there was no difference in fixation durations between the fixed and randomized presentation conditions. This replicated the Rayner and Pollatsek (1981) finding that fixation duration is under direct control. However, as with Rayner and Pollatsek (1981), not all fixations were lengthened by the period of the delay. Some fixations ended while the mask was still present, suggesting that the saccade terminating that fixation had been preprogrammed. But these anticipation saccades could not have been completely determined before the fixation was processed because their length and the duration of the prior fixation were affected by the spatial extent of the mask (which varied randomly). Neither preprogramming nor existing serial control models of eye movement guidance

could adequately account for these data. Thus, Morrison posited a direct control model, in which saccades could be programmed in parallel, to account for the data.

Morrison's model does not stipulate what characteristics of the display are used to determine the intended landing position of the eye, nor does it define how different sources of information might interact. It does, however, contain some strong assumptions about the role attention plays in the reading process.

The Role Of Attention In Reading

The concept of attention and its relation to eye movements had been curiously absent from models of eye control in reading until an article by McConkie appeared in 1979. Apparently, up until that time, it was thought that visual attention and eye position were redundant in reading, although several studies demonstrated that spatial attention can be dissociated from eye position in other tasks (Kaufman & Richards, 1969; Engel, 1971).

McConkie (1979) suggested that spatial attention shifts discretely across the text, and that these shifts of attention trigger eye movements in a serial fashion. Morrison's model assumes that while attention shifts serially word by word across the text saccades may be programmed in parallel. When shifts of internal spatial

attention exceed threshold there is an irrevocable committment to an eye movement in that direction. That is, the eyes move to where internal attention has already been, or shifts of attention preceed eye movements.

Morrison's model also assumes multiple shifts of attention can occur within the same fixation, without waiting for feedback from earlier attention shifts. This suggests that if the reader continued to monitor parafoveal information even after the next movement was programmed he or she would have the potential to alter the subsequent landing position based on more slowly processed, or late arriving, information. This model does not stipulate how the intended location of the movement is determined. That is, what information is used to make this decision?

According to the evidence presented thus far, we have a fair sketch of how the reader might guide his or her eyes across the text. The reader fixates a word, encodes that word, shifts attention to the right, and initiates the programming of a saccade to follow the shift of attention. More than one shift of attention may occur in the course of a single fixation and this would result in the initiation of a second motor program. The extent to which these programs overlap will determine the outcome in much the same way that Becker & Jurgens (1979) described the programming of movements to simple stimuli. Now, the question remains, what characteristics of the text are utilized in this

process, and when?

The Role Of Word Boundaries

There are at least two ways to look at the effect of word boundary information on the programming of saccades. One is to examine the position of fixations within words relative to the word's length. Another way of stating this would be: do readers land on systematically different letter positions within words of differing lengths? An alternative is to look at average saccade length (i.e., to look at changes in average saccade length based on the availability of space information).

Rayner & McConkie (1976) investigated the relationship between the number of letters in a word and the position in the word that the reader fixates. They computed the probability of a fixation landing on words of different lengths and the probability of fixating a letter position within a word of a given length. They found that as word length increased, the probability of fixating the word increased. However, even a random sequence of fixations would produce this result. The more interesting finding was that a letter in a word four to seven letters long was more likely to be fixated than a letter in a longer or a shorter word. This is partially due to the fact that shorter words tend to be skipped more often than do longer words (O'Regan,

1979; Rayner, 1979).

More evidence pointing to the fact that the locations of fixations within words is not random comes from the preferred viewing location studies (Rayner, 1979; O'Regan, 1981). Both researchers found that readers tend to fixate between the first and middle letters of words. Rayner termed this the "preferred viewing location". O'Regan's data indicated a location more closely approximating the middle letter of the word, and he termed this the "convenient viewing position". The differences between the two are minor, and it seems reasonable to conclude that readers systematically fixate somewhere between the beginning and middle of words.

Pollatsek and Rayner (1982) conducted a series of experiments to investigate the role of word boundary information in reading by evaluating changes in average saccade length. In these experiments, spaces between words were filled contingent upon the reader's fixation. There were three conditions: all spaces to the right of fixation filled, all spaces to the right of fixation except the first filled, or only the first space to the right of fixation filled. The space between the currently fixated word and the first word to the right of it will be referred to throughout this paper as the "first space". Several space-filling characters were used: random letters, random numbers, or gratings. In addition, the time in the fixation when the

space filler appeared was varied from 0-150 ms. In the conditions in which the first space was preserved the space-fillers had no effect if they were delayed more than 50 ms and there was very little difference in the amount of interference across the various types of space fillers. In those conditions in which the first space was filled, filling the spaces produced interference at all delays, and letters were more confusing than digits or gratings.

Pollatsek and Rayner's results support a two-process direct control model in which encoding of sufficient visual information to program the next saccade can occur within the first 50-75 ms of a fixation, and in which the processes which determine when to move and where to move are affected differently. Filling parafoveal spaces disrupts the guidance of the next eye movement, while filling foveal spaces (i.e., the first space) disrupts the processing of the fixated word as well. Since these manipulations affected average saccade length and fixation duration independently, they provide additional support for the claim made earlier by Rayner & McConkie (1976), that decisions of where to move and when to move are made independently.

A Model Of Eye Guidance

Now let us put this evidence together into a single model of eye guidance in reading. The assumptions of the

model are fairly straight forward: a) attention shifts when foveal processing of the currently fixated word is complete; b) attention moves forward word by word; c) eye movements follow these shifts of attention; d) more than one shift of attention can occur in the course of a single fixation; e) later eye movement programs can cancel or modify earlier ones; f) the landing position of a saccade can be computed before the decision to execute the saccade; g) the landing position of a saccade is calculated on the basis of word boundary information; h) decisions of where to move and when to move are independent of one another.

The key questions to be addressed here relate to the role of parafoveal letter and space information, and the role of attention. Are saccades programmed solely on the basis of word length information, or does parafoveal letter information influence the decision of where to move? Does attention move serially word by word? What prompts these shifts of attention, and when do these things occur? Does the reader attend to parafoveal information throughout the duration of a fixation and utilize the additional information to update their eye movement decisions?

C H A P T E R II

EXPERIMENT 1

This experiment was designed to investigate an assumption of the model presented previously. That is, are saccades programmed solely on the basis of word boundary information, or does parafoveal letter information play a role as well? If letter information does have an effect on the programming of saccades, how do these two sources of information interact; and when in the course of a fixation can these decisions be made? This experiment was carried out using the "moving window" technique developed by McConkie & Rayner (1975). Readers were free to move their eyes whenever and wherever they wished, but the amount of useful information available on each fixation was controlled by the experimenter. Each time the reader moved his or her eyes, a new region of text was exposed and another mutilated. This exposure or mutilation of information was controlled to occur at the onset of a fixation, or at one of several experimentally determined delays.

In the present experiment, either word boundary or parafoveal letter information to the right of fixation, was delayed. In all cases, a mask made of a "square wave grating", was used to obscure parafoveal information to the right of the currently fixated word. The word the reader was currently fixating and all information to the left of

that word was always available. If the reader made a regressive movement the mask followed the eyes to the new location, covering the information the reader had just left. Five delay conditions were employed: the parafoveal mask was lifted either 0, 50, 150, or 250 ms, after the beginning of a fixation or not at all (infinite delay). If the relevant information can be used throughout the duration of a fixation, then even when that information is not available until late in the fixation it may still affect the pattern of when the eyes move and where they land.

The type of information initially available in the parafovea was systematically manipulated in order to test the nature of the relationship between word boundary information in the parafovea and the pattern of fixations. There were three parafoveal mask conditions considered.

In the _Letters Released_ (LR) condition word boundary information remained intact. A parafoveal mask of gratings was used to cover the letters. After a delay period the letter information was released. An example of a two fixation sequence using a delay of 150 ms might look like the following (gratings are represented as x's in all examples):

The cat xxxxx xxxx xxx xxxxxx xx xxxx. (onset of
fixation)
The cat drank from the saucer of milk. (150 ms later)
The cat drank xxxx xxx xxxxxx xx xxxx. (new fixation)

The dot indicates the position of the current fixation.

The model presented in the introduction predicts that the data from this condition would most closely approximate normal saccade length data, since the assumption is that saccades are programmed solely on the basis of word boundary information and that information was available from the onset of the fixation in this condition. If the assumption that when and where to move are independent decisions is correct, then fixation durations could increase as delay increases in this condition due to the lack of parafoveal preview of letter information without affecting the saccade length data.

In the <u>Spaces Released</u> (SR) condition everything to the right of the currently fixated word was masked with gratings. At the appropriate onset time, word length information was released and the letters remained masked until they were brought into foveal vision. A typical two fixation sequence looked like this:

The catxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx   (onset of
fixation)
The cat xxxxx xxxx xxx xxxxxx xx xxxx   (50 ms later)
The cat drankxxxxxxxxxxxxxxxxxxxxxxxxxxx   (new fixation)
In this case no information other than word length was released to the reader until the word was fixated. Therefore any effect on saccade length found in this condition could reasonably be attributed to the impact of

word boundary information on the programming of saccades. The model predicts that saccade length should decrease as delay increases in this condition. If it is the case that space information can be attended to throughout the course of a fixation and that the late arriving information can be used to modify movement programs, then there could be a benefit even at the 250 ms delay, relative to the complete mask condition (infinite delay).

In the <u>Letters and Spaces Released</u> (LSR) condition everything to the right of fixation was masked with gratings. After some period of time parafoveal letter and space information was released to the end of the line of text. The following is an example of a two fixation sequence in the Letters and Spaces Released condition with a 50 ms delay:

    The catxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx   (onset of
    fixation)
    The cat drank from the saucer of milk. (50 ms later)
    The cat drankxxxxxxxxxxxxxxxxxxxxxxxxxx   (new fixation)

In this case the model predicts that the average saccade length should be no different than in the previous condition (SR). The release of word boundary information is identical in the two conditions. Thus, the fact that letter information is released in this condition and not in the Spaces Released condition should have no impact on the programming of the saccades. However, the fixation duration

data should more closely approximate the Letters Released condition data since the assumption is that the decision of when to move is more strongly affected by letter information, and both of these conditions release letters.

Note that the first and the third conditions provided normal reading conditions at the 0 delay interval, and that the second and third conditions provided no parafoveal information at the infinite delay. Thus the zero and infinite delay conditions provide useful baseline information for comparison purposes.

Finally, the extent of the information available at the onset of a fixation was varied by limiting the size of the initial window of readable text to either one or two words from the point of fixation. In the One Word Window condition (1WW) parafoveal masking began on the word immediately to the right of the currently fixated word (word n+1). Conditions which masked space information began on the space between word n and word n+1. The previous examples and the predictions that followed were representative of the 1WW case.

In the Two Word Window condition word n and word n+1 were available to the reader at the onset of each fixation. The parafoveal mask began on word n+2, or on the space between word n+1 and word n+2. Examples of this condition would look like the previous examples if the reader was fixating the word immediately preceeding the dotted word.

Large numbers of studies (McConkie & Rayner, 1975; Ikeda & Saida, 1978; Rayner & Bertera, 1981; O'Regan, 1980; McConkie & Rayner, 1976; Rayner, et al, 1981; Rayner, Well & Pollatsek, 1980) using the moving window technique have found that the perceptual span extends from the beginning of the currently fixated word (no more than three to four characters to the left of fixation) to about 15 characters to the right of fixation. Within the perceptual span region to the right of fixation, different types of information are acquired (Rayner, 1975; Rayner & McConkie, 1977). It appears that readers obtain information useful for directly identifying a word when it is in foveal vision or just to the right of it. Beyond that area, readers are able to obtain some letter feature information. But the area from which they are able to obtain this information is less than 12 character spaces to the irght of fixation. Word length information is acquired from a slightly larger region, approximately 15 character spaces to the right of fixation.

Although the appropriate unit of measure for the perceptual span to the right of fixation appears to be character spaces, rather than number of words (Rayner, Well, Pollatsek & Bertera, 1982), it is true that in most cases the limit of the perceptual span for letters is contained within the boundary of a two word window to the right of fixation. Thus, the expectation was that there would be little or no effect of letter releasing conditions in the

2WW session of this experiment, since most usable information would have been available from the onset of the fixation. Because the perceptual span for space information is somewhat larger than the span for letters there are more occasions in which the space information beyond the two word window could potentially be utilized. Therefore an effect of releasing space information on the saccade length data would not be surprising. However, any effects found in the 2WW session should of a markedly smaller magnitude than those found in the 1WW session.

The design of the experiment consisted of five (delay) by three (parafoveal mask) by two (window) conditions. It was designed to address the extent to which parafoveal word boundary information is used to guide eye movements in reading.

Method

Subjects. The subjects in the experiment were 14 paid volunteers from the University of Massachusetts. All subjects had previously participated in eye movement experiments and were native English speakers with uncorrected vision.

Apparatus. The sentences were displayed on a Hewlett-Packard 1300-A cathode ray tube (CRT). The CRT has a P-31

phosphor with the characteristic that removing a character resulted in a drop to 1% of maximum brightness in 0.25 ms. The letters making up the sentences were printed in lower case on the CRT. Each letter was made up of dots from a 5 x 7 matrix. A black theater gel covered the CRT so that the letters and the mask appeared clear and sharp to the subjects. The visual mask consisted of an "interlaced square wave grating".

Eye movement recording was accomplished by using a Stanford Research Institute Dual-Purkinje Eyetracker (Clark, 1975; Cornsweet & Crane, 1973). The eyetracker has a resolution of 10 minutes of arc, and the output is linear over the visual angle (14) that was occupied by the sentences. The eyetracker and the CRT were interfaced to a Hewlett-Packard 2100 computer that controlled the experiment. The signal from the eyetracker was sampled every millisecond by the computer through an A-D converter. Over each 4 ms, the horizontal voltage level was compared to the prior 4 ms, and as the result of these values, the computer determined whether the eye was in a saccade or fixation. Our calculations and photoelectric testing have indicated that the display change can be accomplished within 2-7 ms after the termination of the saccade. This value includes the time for the computer to determine the new location of the eye, the lag in the signal from the eyetracker to the computer (about 1 ms), and the time to

output the mask to the CRT. In the experiment, the subject's eye was approximately 46 cm from the CRT, and three characters were equal to 1 of visual angle. Eye movements were monitored from the right eye, and viewing was binocular. The room was dark, except for a dim, indirect light source. The CRT was adjusted to a comfortable brightness for each subject (approximately 8 cd/m as measured by a Tektronics J16 photometer for three characters directly in front of the luminance probe) and the luminance was occasionally reduced because of pupillary responses when the masks appeared. Pupillary constrictions and blinks resulted in a track loss for the eye tracker, hence the reduction in luminance. Sentences in which there was a track loss (in which case the mask did not move with the eye) were discarded from later data analysis.

The computer kept a complete record of the duration, sequence, and location of each eye fixation. These values were stored on the computer disk for later analysis.

Stimuli. Twenty-eight passages, eight sentences long, were written for this experiment (see Appendix B). Each sentence was five to eight words in length, spanning no more than the 42 character spaces per line allowed by our equipment. The passages were presented to the reader one line at a time. Stimulus materials were created as sets of related text, rather than single sentences, to keep readers motivated to

read for comprehension.

Comprehension questions which required a yes/no response from the reader were created for each story. Questions were asked only at the end of a passage to encourage active integration of the information on the part of the reader in order to answer the question correctly. A yes/no response could be made without leaving the bite bar and thereby simplified the experimental procedure. Comprehension questions also allowed a check on performance across all conditions to verify that subjects were acquiring the meaning of the text under all parafoveal manipulations and delays. Subjects responded correctly approximately 90% of the time.

Procedure. When the subject arrived for the experiment a bite bar was prepared which served to eliminate head movements during the experiment. Then the eye movement recording system was calibrated for the subject. Calibration was achieved by having the subject fixate on a target presented successively on the left and then on the right of the display. The target cross remained in each position for 1 second, and the eye position was sampled over the final 500 ms. The subject was asked to fixate the left cross and then to move his/her eyes to the right and fixate the right target position when the cross disappeared from the left and reappeared on the right of the display. Next the calibration target on the right disappeared and three

crosses appeared simultaneously to the left, to the right, and in the center of the display, equidistance apart. The subject was then asked to fixate the center cross and a fourth cross moving in synchrony with the eye was observed by the experimenter. If the cross was superimposed over the center cross the calibration process was considered complete and the experimenter proceded with the experiment. If the cross was not superimposed on the center target the calibration process was repeated. Since all subjects were experienced in this procedure, initial calibration took less than five minutes in most cases.

After the initial calibration, subjects were instructed to look to the left side of the display when they were ready to read. The experimenter then pushed a button to display the stimulus sentence. Subjects were told to read the sentence and press a key when they were finished. When the key was pressed the sentence disappeared and the target crosses appeared to the left and right of the display for calibration checking. The next sentence was presented immediately following the calibration check.

All subjects were told at the beginning of the experiment, that they would be reading short passages, each one separated by the heading "new paragraph", and that various aspects of the information to the right of fixation would be masked in some cases. Their task was to read the passage to understand it and to answer comprehension

questions at the end of some passages.

The experiment was divided into two sessions, with a 10-15 minute break between sessions. Each session began with eight practice sentences that were representative of the mask manipulations contained in that session. Upon completion of the practice sentences each subject read 14 experimental passages. Comprehension questions were asked after every second story on the average. This procedure was repeated for the second session.

Experimental Design. During the reading of the experimental passages, the parafoveal mask was manipulated contingent upon the reader's eye position. In one session all parafoveal masking began with the space immediately to the right of the currently fixated word and extended to the end of the line of text. In the other session the mask began on the space immediately to the right of word n+1. These conditions, as indicated earlier, will be refered to as One Word Window and Two Word Window, respectively. The order of presentation of these sessions was counterbalanced across subjects.

The three parafoveal mask conditions (Letters and Spaces Released, Letters Released, Spaces Released) by five delay conditions (0,50,150,250,infinite) yielded a total of 15 possible combinations. However, since the Letters and Spaces Released condition and the Letters Released condition

both resulted in a normal reading condition at the 0 delay interval, these two cells were reduced to one. There were a total of 14 conditions within each session. Each condition was presented for one eight sentence block.

One session consisted of one window condition, with the order of three parafoveal mask by five delay conditions (minus 1) partially counterbalanced across the 14 subjects. The counterbalancing of parafoveal mask by delay was completed across the two sessions.

Results and Discussion

For each subject, reading performance was assessed by the average reading rate, in words per minute (wpm), and by other more detailed analyses: the average length of a forward saccade (measured in character spaces), the average duration of a fixation (measured in ms), the average number of occurrences per line of two consecutive forward fixations on the same word (consecutive fixations), and the average number of times per line a forward saccade resulted in the skipping of word n+1 given the reader had fixated word n and word n+2 consecutively (word skipping).

For each data set a 2(window size) x 3(parafoveal mask) x 3(delay) ANOVA was done on all the data except the control conditions. However, for purposes of comparison, the control conditions are included in the figures. In addition

to the overall analyses, a separate 3(parafoveal mask) x 3(delay) ANOVA was performed on the data from each session, and in some cases post hoc comparisons were done to clarify relevant points. These are specified in their respective sections.

Reading rate. The 2(window size) x 3(parafoveal mask) x 3(delay) ANOVA of the reading rate data yielded clear effects of window size, $F(1,13)=26.84$, $p<.001$; parafoveal mask, $F(2,26)=18.12$, $p<.00001$; and delay, $F(2,26)=14.17$, $p<.001$. There was also an interaction of window size and delay, $F(2,26)=3.56$, $p<.05$. In the Two Word Window session delay had virtually no effect, while in the One Word Window session reading rate decreased as delay increased. Separate analyses of each window size session suggests that most of the impact of these effects occurs in the One Word Window session (see below).

An ANOVA done on the data from the Two Word Window session yielded no significant overall effects. However, an ANOVA of the Letters Released versus the Spaces Released condition was significant, $F(1,13)=4.45$, $p<.05$. Reading speed was faster when there was parafoveal preview of letter information, given that space information was available from the onset of the fixation.

In contrast, a 3x3 ANOVA on the data from the One Word Window session indicated clear effects of parafoveal mask,

F(2,26)=19.11, p<.0001, and delay, F(2,26)=25.32, p<.0001. There was also an interaction between the type of information available parafoveally and when that information was present, F(4,52)=5.97, p<.001. The release of letter information had no effect beyond that of space information released alone after 50 ms, while the two conditions which delayed release of space information continued to decline across delays of up to 250 ms. This interaction suggests that parafoveal letter information may be helpful only if it is available very early in a fixation.

Is there continuous processing of parafoveal information beyond the 50-75 ms normally used to extract the information to program a saccade (see Pollatsek & Rayner, 1982)? The curves decreased as the delay of parafoveal information increased, up to the point where no parafoveal information was released at all in the One Word Window session (see the right panel of Fig.1). Some aspects of the parafoveal information were utilized in reading, even when delayed as much as 250 ms. But in general, the longer the delay interval was, the smaller the benefit. The type of information being utilized will be addressed in more detail later in this paper.

Reading rate is a global measure of reading performance. These data indicated that (1) letter and space information in the parafovea may play different roles, at different times in the reading process, (2) manipulation of

parafoveal Information beyond word n+1 has little to no effect on reading rate, and (3) some parafoveal information presented late in a fixation can be utilized. We can not interpret from these data which aspects of parafoveal Information are influencing the computation of saccades (where to move), and which are influencing processing of the currently fixated word (when to move). We must examine more specific measures in order to construct a more detailed interpretation.

Fixation duration. A 2x3x3 ANOVA of the fixation duration data indicated that fixation durations were shorter with a two word window (see the upper panel of Figure 2) than with a one word window (see the lower panel of Figure 2), $F(1,13)=25.93$, $p<.001$. Fixation durations were also affected by parafoveal mask manipulations, $F(2,26)=9.55$, $p<.001$, and there was a significant interaction of window size and parafoveal mask, $F(2,26)=4.35$, $p<.05$. Fixation durations were shorter when parafoveal letter information was presented than when it was not, in the One Word Window session, but not in the Two Word Window session. When word n+1 was present from the onset of fixation, limiting the availability of parafoveal information beyond that point had no systematic effect on fixation duration. With the two word window the average fixation duration was 232 ms and parafoveal manipulations had no reliable effect. The

analysis of the Two Word Window session showed no effect of text, or delay ($\underline{F}$s < 1), and no interaction p>.10. This is consistent with the past findings on perceptual span of useful information (Rayner, 1975). In most cases the two word window encompassed the perceptual span of useful letter information. Thus any manipulations outside the window had no effect on fixation duration.

An ANOVA of the One Word Window session yielded a main effect of mask, F(2,26)=9.72, p<.001, and an interaction of text by delay, F(4,52)=4.90, p<.01. As seen in the lower panel of figure 2, fixation durations were shorter in the letter releasing conditions (Letters Released, Letters and Spaces Released) than in the condition in which only space information was released (Spaces Released). This suggests that availability of parafoveal letter information does facilitate processing of word n+1 when it is subsequently fixated. There was no effect of delaying parafoveal information.

In the One Word Window session, having had access to parafoveal letter information facilitated processing of the word when it was subsequently fixated. Fixation durations were shorter in letter preview conditions than in space only conditions. We will return to the issue of the benefits of parafoveal letter information when we look at the word skipping and consecutive fixations data.

Saccade length.   Statistical analysis of the saccade length
data was as follows.   All main effects and interactions of
the 2x3x3 ANOVA were significant beyond the .0001 level, as
were the effects in the 3x3 ANOVA of the One Word Window
session and the same analysis of the Two Word Window
session.

    In general, saccades were longer in the Two Word Window
session than in the One Word Window session (see Figure 3).
This suggests that the spaces defining the beginning and end
of word n+1 are important in determining where to move.
However, in order to evaluate the relative importance of
each of these boundaries a condition in which only the first
space is released is needed (see Experiment 2).

    The relationship between parafoveal letter and space
information was more complicated.   If saccades were
programmed solely on the basis of word boundaries, then a)
there should have been no effect of delay in the Letters
Released condition, and b) saccades should have been longest
in the Letters Released Condition at all delays (space
information was available from the onset of fixation in this
condition), and in the Spaces Released Condition at a zero
delay.   The pattern of the data, however, is quite
different, as the mean saccade length in the Letters
Released condition decreased with increasing delay. Instead
the best characterization of the One Word Window condition
is that the Letters and Spaces Released condition is the

same as the Letters Released condition for the first 50 ms and then the same as the Spaces Released condition after that. Thus it appears that, the letter information received late in the fixation was not providing any benefit beyond that of the space information that had been available since the onset of the fixation. This suggests that a reader may process some parafoveal letter information early in a fixation, and use that information when determining the next landing position. By 150 ms decisions are being made on the basis of parafoveal space information alone. The pattern was similar in the Two Word Window condition (see Figure 3); however, the effects were smaller.

It may be that utilizing low-level information like spaces is much faster than utilizing letters. Thus, there may not be enough time remaining in a fixation after the first 50 ms to utilize the letter information to program the next saccade.

Word skipping. Two characteristics have dominated all of the data thus far. First, processing of parafoveal information was possible far into the fixation. Second, both letter and space information from the parafovea were utilized early in a fixation. However, there is no evidence that letter information was utilized when delayed longer than 50 ms.

Saccades may have been longer when letter and space

Information was available early because readers skipped over words more frequently when they had the letter Information available In the parafovea and/or because they were less likely to require two fixations on a word when they had parafoveal letter information. Thus, it could be that readers were just as efficient at computing the landing position with space information as with space and letter information, but that letter information in the parafovea allowed more efficient processing of words in the text. That is, the average saccade length may have been shorter in these conditions, not because readers were unable to compute the preferred viewing location accurately, but because either a second fixation was required in order to process the current word, or the succeeding word was skipped. In order to address this the data were analyzed looking at the number of times per sentence that the reader skipped a word given they landed on the word immediately previous and post, consecutively. The number of times the reader looked at the same word on two consecutive forward fixations was also analyzed.

First, let us consider the word skipping data. Words were skipped more frequently when there was a two word window than when there was a one word window. An ANOVA done with all the data excluding controls showed effects of window size, $F(1,13)=4.95$, $p<.05$, parafoveal mask, $F(2,26)=4.05$, $p<.05$, and delay, $F(2,26)=19.16$, $p<.0001$; and

there was an interaction of window size and parafoveal mask, F(2,26)=7.40, p<.01.

When there was a two word window there was no systematic effect due to the type (letter or space) of information beyond word n+1 that was made available to the reader. However, there was a decrease in the occurrence of word skipping as delay increased. In the analysis of the Two Word Window data, the only significant effect was in the delay conditions, F(2,26)=7.76, p<.01.

The ANOVA done with One Word Window data yielded effects of parafoveal mask, F(2,26)=13.22, p<.001, and delay, F(2,26)=7.85, p<.01. It appears that readers relied on word length, rather than letter information to determine when to skip a word. The lower panel of Figure 4 shows that as space information was delayed (SR and LSR), word skipping was reduced, while in the condition in which spaces were always available from the onset of fixation and letter information was delayed there was no apparent effect of delay.

It is not surprising to see that this pattern of results is similar in character to that observed in the saccade length data. In conditions in which there was more word skipping, there were also longer saccades. Likewise, in conditions in which there was less word skipping shorter saccades were observed. This maps nicely with the reading rate data as well. Past research has shown that readers tend

to have inflated fixation durations immediately preceeding a skip (Hogaboam, 1983; Pollatsek, Rayner & Balota, 1986). Therefore, one would expect longer fixation durations in conditions in which there was a greater occurrence of skipping, all other things being equal. However, the benefit in processing the currently fixated word due to having had parafoveal preview of it may mask the effect in these data.

The data thus far have suggested that readers acquire some letter information from parafoveal preview. Fixation durations were shorter and reading speed faster in conditions in which parafoveal letter information was released. Although the availability of parafoveal letter information did reduce the foveal processing time on the word when it was subsequently fixated, the relative infrequency of word skipping indicates that parafoveal preview was not usually sufficient for complete processing of a word. Most words still required a fixation.

Consecutive forward fixations. Readers tended to make two consecutive fixations on the same word more frequently when there was a one word window (see figure 5). This makes sense since the mask began on the space that defines the end of word n and therefore readers cannot easily determine where the end of the current word is. The 2x3x3 Anova showed effects of window size, $F(1,13)=13.54$, $p<.01$; parafoveal

mask, F(2,26)=10.05, p<.001; delay, F(2,26)=20.14, p<.0001; and interactions of window size and text, F(2,26)=4.14, p<.05; and window size and delay, F(2,26)=6.18, p<.01. There were no significant effects in the 3x3 ANOVA of the Two Word Window session.

The analysis done on the One Word Window session yielded effects of parafoveal mask, F(2,26)=10.62, p<.001, and delay, F=(2,26), p<.0001. Letter information was secondary to space information in determining when two consecutive fixations on the same word would occur: Letters Released and Letters and Spaces Released conditions showed fewer consecutive fixations on the same word than the Spaces Released condition. This suggests that parafoveal letter information reduces the processing load when the word is subsequently fixated. However, beyond 50 ms the Letters and Spaces Released condition increases to more closely approximate the Spaces Released condition, suggesting that the delay of space information is critical.

If we take consecutive fixations on the same word as an additional reflection of the processing difficulty encountered in processing word n, then we see that this analysis fits well with what came before it. There were more consecutive fixations on the same word when the end boundary of word n was unavailable to the reader at the onset of the fixation. Other parafoveal space information played a role as well. As space information was delayed the

occurrence of consecutive fixations on the same word increased. Their occurrence also increased as parafoveal letter information was delayed. This suggests that the shorter saccades seen in the Spaces Released condition may be due in part to the increased processing demands that arise when there is no preview of letter information rather than in an inability to accurately compute the preferred viewing location from space information alone. We would need to analyze the landing position within words in order judge this (see Experiment 2).

C H A P T E R   I I I

EXPERIMENT 2

The data from Experiment 1 suggested that word boundary information plays a strong role in the programming of saccades. However, more evidence is needed in order to clarify some of the issues related to this conclusion. First, a better definition of the relation between parafoveal letter and space information in the programming of saccades is needed. Second, how much of the impact of word boundary information is carried by the space immediately to the right of the currently fixated word? Third, are these decisions under the direct control of the reader? Finally, there seem to be critical changes in the relative impact of the availability of parafoveal letter versus space information taking place during the first 50-150 ms of a fixation and thus an intermediate delay would be helpful to determine when these changes occur.

Experiment 1 demonstrated that most of the processing activity relevant to the questions being addressed in this research primarily utilizes information contained within a two word window of text. Thus, the present experiment limited the initial presentation to a one word window of text in all conditions. When the mask was lifted in this experiment, information was limited to a two word window, rather than releasing the entire line, as was done

previously.

The following example illustrates a two fixation sequence in the Letters and Spaces Released condition.

The cat drankxxxxxxxxxxxxxxxxxxxxxxxxxx   (onset of
fixation)

The cat drank from xxxxxxxxxxxxxxxxxx   (100 ms later)

The cat drank fromxxxxxxxxxxxxxxxxxxx   (new fixation)

The experiment was divided into two sessions. In one session, all masking began on the space immediately after the foveal word, and in the other session, all masking began on the first letter of word n+1. These will be referred to as the First Space Filled and First Space Open sessions, respectively. The First Space Filled manipulation is similar to the One Word Window manipulation of Experiment 1, except for the fact that only information about word n+1 is released, rather than the entire line of text. The previous example illustrates the First Space Filled manipulation. In the First Space Open session the parafoveal mask would begin on the first letter of word n+1 rather than on the space preceding it.

It can be argued that filling the space to the right of the currently fixated word interferes with foveal word identification by obscuring the end of the foveal word, while at the same time interefering with parafoveal word boundary information by masking the space previous to word n+1 (Pollatsek & Rayner, 1982). Leaving this critical space

open clearly has the opposite effect. It removes potential interference in identification of the currently fixated word. But it also provides parafoveal word boundary information that may be critical to determining where to move the eyes next. By using a symbol that is distinctly different from the letters of our alphabet (i.e., the grating) it may be possible to effectively mask the space while still signalling the end of the currently fixated word. If this is successful there should be greater interference in the saccade length data in the First Space Filled session than in the First Space Open session, but not in the fixation duration data.

The parafoveal mask conditions are consistent with those employed in Experiment 1; SR, LR, LSR. However there is one exception. The Letters Released condition would be redundant across the two sessions, since it is the presence or absence of the first space at onset of fixation that differentiates the two sessions, and that space information is available from the onset of fixation at all delays in this condition. Therefore, the Letters Released condition was omitted from the First Space Filled session and a new condition, in which only the first space is released after the various delays, was added to replace it. An example follows.

Thexxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx (onset of
fixation)

The xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx (150 ms later)

The cat drankxxxxxxxxxxxxxxxxxxxxxxxxxx (new fixation)

This condition will be referred to as the <u>First Space Released</u> condition (FSR). It was assumed that this condition should provide some insight into the relative importance of the first and second parafoveal space in saccadic programming.

Before addressing the relationship between parafoveal letter and space information, let us review some important points from Experiment 1. The evidence from Experiment 1 demonstrated that the parafoveal space information strongly influenced where a reader moved his or her eyes during reading. There were hints that parafoveal letter information may influence where to move as well. Saccades were longer in the Letters Released condition than in the Spaces Released condition at short delays. At longer delays, the Letters Released condition was not different from the Spaces Released condition at a 0 delay. Both of these conditions released space information from the onset of a fixation. There are two possible interpretations of this result that remain undifferentiated by Experiment 1.

According to the first interpretation, both types of parafoveal information (letters and spaces) are used to compute landing position under normal circumstances, but space information is processed more rapidly than letter information. Thus, at long delays there would not be enough

time for letter informaton to be utilized. In both the Letters Released and Spaces Released conditions the reader would compute a saccade based on space information alone and there would be no difference between the two conditions. However, at short delays, when parafoveal letters are available early in the fixation, input from the two types of information would combine. Thus, readers would be more likely to saccade further into the next word or skip over it, and less likely to fixate the same word twice. Hence, there would be a benefit in the Letters Released condition at short delays.

According to the second interpretation, saccades are programmed solely on the basis of parafoveal space information. However, the decision of when to move and whether to refixate word n, move to word n+1, or skip to word n+2 is decided on the basis of letter information. Thus, processing difficulty on the currently fixated word may dictate making a second fixation on the same word. Conversely, highly predictive context combined with parafoveal preview of letters may make fixation on word n+1 unnecessary (Balota, Pollatsek, & Rayner, 1985). Thus, the reader may skip over the word. As was the case under the first interpretation, space information is processed more rapidly than letter information, so that there would not be sufficient processing time for letter information to be utilized at long delays. Therefore, saccades would be

programmed without benefit of parafoveal letter preview in both the Letters and Spaces Released condition and in the Spaces Released condition. Hence, there would be no difference between the two conditions. In contrast, when letter and space information are available early, parafoveal letter preview would effectively reduce the processing difficulty when the word is subsequently fixated. Two consecutive fixations on the same word are less likely and word skipping is more likely to occur. Thus, there would be a benefit in the saccade length data in the Letters Released condition. Under this interpretation, once the decision was made as to which word to fixate, the landing position would be computed on the basis of the length of the word. In the absence of parafoveal letter information the reader would basically be making a binary decision with regard to which word to fixate: either a second fixation is required to process the foveal word, or the decision is move to the next word. It is highly unlikely that a reader would choose to skip a word that they have never seen. Once the word choice is made, space information is consulted to compute the appropriate landing position in that word, based on its length. It is interesting to note that this second model suggests that the same process is used to compute landing position in the case of consecutive fixations on the same word and would therefore predict that refixation landing position would vary systematically with word length in much

the same way that the initial preferred viewing location does.

Both interpretations fit the data thus far. However they make different predictions about where in a word the reader will initially land. The first interpretation predicts that initial landing position should be further to the right in the Letters Released condition, due to the combinatorial power of the two sources of relevant information. Thus the differences between the Letters Released and the Spaces Released conditions would be apparent in the consecutive fixations, word skipping and landing position data. The second interpretation suggests that the differences between the two conditions in the saccade length data are primarily due to differences in word skipping and consecutive fixations on the same word. In the Spaces Released condition, when there is no letter information in the parafovea, there would be more consecutive fixations on the same word and less word skipping than there would be in the conditions which provide preview of letter information. Since landing position within the word is calculated solely on the basis of word boundary information under this interpretation the prediction would be that there would be no difference in the initial landing position on word n+1 between the two conditions, given that the reader was making the saccade from the immediately previous word.

In the model presented in the introduction to this paper there was an assumption that attention moves serially, word by word, across the text. This assumption makes a great deal of intuitive sense since word order is critical to comprehension of written text (at least in English). Take the following pair of sentences as an example:

        The baby bit the dog.
        The dog bit the baby.

The words contained in the two sentence frames are identical. However, by changing the word order we are able to describe two somewhat different events. If attention travelled sequentially word by word across the text that would certainly help to index the order of the words in the sentence. However, up to now there has been little evidence provided to test this assumption. In the Letters Released condition of this experiment the onset of word n+1 is delayed at various intervals relative to fixating word n. If this model is correct then there should be no difference between having word n+1 available at the onset of a fixation and the case in which it is delayed a very short period of time, since it would not be attended to until word n was processed. This prediction was tested by looking at comparisons between fixation duration in the Letters Released condition at a 0 and a 50 ms delay.

Experiment 1 demonstrated that when parafoveal space information was delayed 250 ms there was still some benefit over not having the space information at all. This result

is important for two reasons. 1) It demonstrates that readers may continue to attend to information in the parafoveal region throughout the duration of a fixation. 2) It suggests that readers are able to process space information more rapidly than letter information. In the data from Experiment 1 there appeared to be critical changes in the way letter and space information was utilized that took place between 50 and 150 ms. In the present experiment the 250 ms delay was eliminated and a 100 ms delay was added. The delay conditions for the present experiment were 0,50,100,150, and an infinite delay.

In order to test the direct control hypothesis more stringently, the physical extent of the parafoveal information received must be more tightly constrained than it was in Experiment 1 and an analysis is needed which is dependent upon some factor which varies fairly unpredictably from fixation to fixation. We have controlled the physical extent of the information available by limiting the release of parafoveal information to a two word window in all conditions of the present experiment.

In addition to the analyses that were done on the data from Experiment 1, a landing position analysis dependent upon word length was done in order to address the issue of direct control. Since word length varies fairly unpredictably from one word to the next the initial landing position within a word should vary with word length if eye

movement guidance decisions are under direct control. This analysis will also serve to distinguish the two interpretations of the relation between letter and space information in the programming of saccades that were outlined earlier.

Method

Subjects. The subjects were 14 paid volunteers from the University of Massachusetts and were similar to the subjects in Experiment 1. Nine of them were subjects in Experiment 1.

Stimuli. The stimulus materials for this experiment were similar to those used in Experiment 1. Twenty-eight new passages were created for the present experiment according to the criteria outlined in Experiment 1 (see Appendix C).

Apparatus and Procedure. The equipment and procedure were the same as those described in Experiment 1.

Experimental Design. The design of the present experiment was a modification of that used in the previous experiment. The First Space Open and First Space Filled sessions replaced the One and Two Word Window sessions of

Experiment 1,and the parafoveal mask by delay combinations differed across the two sessions. In the First Space Filled session, the three parafoveal mask (Words and Spaces Released, Spaces Released, First Space Released) by five delay conditions (0,50,100,150,infinite), yielded a total of 15 possible combinations. However, all parafoveal mask conditions yielded the same display at an infinite delay. These three cells were reduced to one, and a single cell of normal reading was added for comparison purposes. There were a total of 14 conditions within the session. Each condition was presented for one eight sentence block.

In the First Space Open session the three parafoveal mask conditions were similar to those used in Experiment 1, in that either spaces were released (SR), spaces were present at the onset of a fixation and letters were released (LR), or letters and spaces were released simultaneously (LSR). However, the parafoveal mask began on the first letter of word n+1, and the extent of the parafoveal information exposed never exceeded a two word window. These were crossed with five delay conditions to yield 15 possible combinations. In this session the Letters and Spaces Released condition, and the Letters Released condition resulted in identical conditions at a 0 delay interval. These were reduced to one cell in the design. The Letters Released condition at an infinite delay and the Spaces Released condition at a 0 delay both operationalized as a

condition in which only parafoveal space information was available from the onset of each new fixation. These two cells were also reduced to a single cell, and a cell of normal reading was added as a control. Each session consisted of one space condition, with the order of three parafoveal mask by five delay conditions (minus one) partially counterbalanced across the 14 subjects.

Results and Discussion

For each subject reading performance was assessed by the same measures as used in Experiment 1: reading rate, fixation duration, saccade length, word skipping and consecutive fixations on the same word. Two additional measures were included. First, the mean landing position (measured in letter position) on words of a given length was calculated (Landing Position). Second, the proportion of times a word of a given length was fixated was calculated (Landing Frequency). These analyses included only left to right movements on consecutive words within the passages, and only looked at first fixations on a word. The space immediately preceeding word n was considered the first position.

In the present experiment a 3 parafoveal mask (SR,LR,LSR) x 3 delay (50,100,150) ANOVA was done on the data from each measure for the First Space Open session. A

separate 3 parafoveal mask (FSR,SR,LSR) x 3 delay (50,100,150) ANOVA was done on the data from the First Space Filled session. These analyses did not include the control conditions, although the control conditions are included in the figures as a frame of reference. Relevant comparisons are cited in their respective sections of this paper.

Reading rate. There was an effect of parafoveal mask, $F(2,26)=9.44$, p<.01, in the First Space Open session of Experiment 2. It is apparent from the left panel of Figure 6 that reading rate was faster in the letter preview conditions (LSR,LR) than it was when there was no letter preview (SR). There was also an effect of delay, $F(2,26)=7.09$, p<.01 and a marginally significant interaction of parafoveal mask by delay, $F(4,52)=2.36$, p<.06. Reading rate decreased as delay increased in the letter releasing conditions, while the space releasing condition remained unaffected by the delay.

The First Space Filled session contained two space releasing conditions (FSR and SR), and one condition in which both letters and spaces were released (LSR). Again, there was an effect of parafoveal mask, $F(2,26)=12.97$, p<.01; and the lower panel of Figure 6 illustrates clearly that in the parafoveal letter preview condition (LSR) reading rate was faster than it was in the conditions which released only parafoveal space information (SR, FSR).

Reading rate decreased as delay increased in all conditions. The effect of delay, $F(2,26)=24.89$, $p<.01$, substantiates the fact that reading rate decreased as delay increased in all conditions.

Parafoveal preview of letter information had a positive influence on reading rate. That is, reading rates were faster in the letter preview conditions than in conditions in which no parafoveal letter preview was available. However, these data do not indicate whether or not any of this effect was due to the use of parafoveal letter information in the programming of saccades. The fact that delay of letter information slowed the reading time does indicate that letter information was utilized in some capacity as late as 150 ms into a fixation. This suggests that readers were still attending to some aspect of the parafoveal text far into the fixation. For a more detailed interpretation we will have to look to other measures.

Fixation duration. The fixation duration data was similar in character to the reading rate data. The 3x3 ANOVA done on the First Space Open data showed effects of parafoveal mask, $F(2,26)=9.88$, $p<.01$ and delay, $F(2,26)=2.56$, $p<.10$. As seen in the upper panel of Figure 7, it is the presence or absence of letter information that differentiates the parafoveal mask conditions. The two letter releasing conditions (LSR, LR) were almost identical, while fixations

were longer in the condition which released only spaces.

A 3x3 ANOVA of the data from the First Space Filled session indicated an effect of parafoveal mask, $F(2,26)=3.92$, $p<.05$, and no effect of delay. The right panel of Figure 7 shows that fixations were shorter in the Letters and Spaces Released condition than in the Spaces Released condition. This makes sense, since the Letters and Spaces Released condition provides parafoveal preview of letter information, and the Spaces Released condition does not. However, the First Space Released condition showed slightly shorter average fixations than the Spaces Released condition as well. That is, there were shorter fixation durations when only the first space was released than when the first two parafoveal spaces were released. If we look ahead to the word skipping and consecutive fixations data, there were more consecutive fixations on the same word and fewer skips in the First Space Released condition than in the other two conditions (see Figs. 9 & 10). Fixation durations tend to be longer preceeding a skip (Hogaboam, 1983; Pollatsek, et al, 1986). Conversely, fixation durations tend to be shorter when processing is distributed across two consecutive fixations on a single word (O'Regan & Levy-Schoen,1987). These two factors deflated the mean fixation duration in the First Space Released condition. Thus, although only one parafoveal space was available in the First Space Released condition the average fixation

duration was shorter than in the case in which two parafoveal spaces were released.

The Letters Released condition (0 delay) yielded shorter fixations than the same condition with a 50 ms delay; $t(1,13)=3.81$, $p<.002$. The model outlined earlier predicted no difference between these conditions based on the assumption that attention is shifting word by word. This will be discussed further in the general disccussion.

Saccade length. The First Space Open data (see the upper panel of Figure 8) showed the same crossover pattern that was so prevalent in Experiment 1, suggesting that saccadic programming relied heavily on the release of space information. That is, the Letters and Spaces Released condition was more like the Letters Released condition up to a 50 ms delay and after 50 ms it began to decline until it matched the Spaces Released condition. An ANOVA done on the First Space Open data indicated effects of parafoveal mask, $F(2,26)=4.28$, $p<.05$ and delay, $F(2,26)=11.68$, $p<.01$. Although the interactive pattern was there, the interaction of parafoveal mask by delay was not significant due to the fact that all effects were so small in the case when the first parafoveal space was open from the onset of the fixation.

The 3x3 ANOVA of First Space Filled data yielded effects of delay, $F(2,26)=4.55$, $p<.05$, and parafoveal mask,

$F(2,26)=12.97$, p<.01, and a significant interaction of parafoveal mask by delay, $F(4,52)=3.48$, p<.05. The lower panel of Figure 8 illustrates clearly that saccades were longest when there was a parafoveal preview of letter and space information (LSR). They were shortest and showed little influence of delay when only the first space to the right of the currently fixated word was released (FSR).

In the First Space Filled condition the Letter and Spaces Released condition maintained a consistent benefit over the Spaces Released condition (see the lower panel of Figure 8). Was this because the first saccade into a new word was more conservative without letter information; or because without benefit of parafoveal preview of letters, processing the foveal word required more work (i.e., more cases of two consecutive fixations on the same word, which would tend to require very short saccades)? To answer this we need to look at the consecutive fixation data and at the landing position analysis. The consecutive fixation data did indicate that there were more consecutive fixations on the same word in the SR condition than in the LSR condition (see the lower panel of Figure 10). This suggests that readers were having greater processing difficulty when they fixated a word if there was no parafoveal preview of letters.

Readers were initially landing in the same position in a word whether they had parafoveal preview of letters and

spaces, or only spaces (see landing position analysis). This suggests that the saccade lengths were shorter in the Spaces Released condition than in the Letters and Spaces Released condition because readers were more likely to need to fixate a word twice in order to process it if they had not had parafoveal preview of the letters and not because they were less capable of computing the preferred viewing location. Indeed the data indicate that readers were quite good at computing the preferred viewing location based on word boundary information alone (see landing position analysis). However, they did have greater difficulty processing a foveal word when they had not had parafoveal preview of its letters (longer average fixation durations; more consecutive fixations).

Word skipping. Fewer words were skipped as the parafoveal information was delayed in the First Space Open session, $F(2,26)=2.68$, $p<.09$. There was no effect of parafoveal mask (see the upper panel of Figure 9). In this session all the parafoveal mask conditions released the first two parafoveal spaces. Both spaces must be present in order to compute word length. As suggested in Experiment 1, word length and syntax may strongly cue the location of function words. In that case the decision to skip a word could be made in the absence of letter information.

In the First Space Filled data the ANOVA indicated an

effect of parafoveal mask, F(2,26)=4.84, p<.05. The First Space Released condition had fewer skips than the conditions which released the first and second parafoveal space (SR & LSR), as you can see in the lower panel of Figure 9. There was also an effect of delay, F(2,26)=6.05, p<.01, and there were fewer skips in all conditions as parafoveal information was delayed.

Consecutive forward fixations. A 3x3 ANOVA done on the data from the First Space Filled session indicated that there was an effect of parafoveal mask, F(2,26)=6.88, p<.01. Looking at Figure 10, it can be seen that there were more consecutive fixations in the Spaces Released condition than in the Letters and Spaces Released condition. This suggests that readers experienced more difficulty processing foveal words when they had not had parafoveal preview of letter information. The greatest number of consecutive fixations on the same word occurred when only the first space to the right of fixation was released (FSR). In this condition there was no parafoveal preview of letter information and it was impossible to determine the length of a word before it was fixated. Readers did not have the information necessary to compute the optimal initial landing position for processing the word; nor did they have preview of its letters to facilitate processing when they did land on it. It was also the case that the longer the delay of parafoveal

Information the greater the occurrence of consecutive fixations on the same word, $F(2,26)=21.26$, $p<.01$. The occurrence of consecutive fixations on the same word rose sharply as delay increased in the two conditions in which the first two parafoveal spaces were released (LSR,SR). However in the First Space Released condition there were a large number of consecutive fixations on the same word at all delays. This interaction of parafoveal mask by delay was significant, $F(4,52)=2.87$, $p<.05$.

A 3x3 ANOVA of the First Space Open data indicated that the main effect of parafoveal mask was significant, $F(2,26)=10.59$, $p<.01$. That is, consecutive fixations on the same word occurred most frequently in the Spaces Released condition (where there was no parafoveal preview of letter information) and there were fewest consecutive fixations on the same word in the Letters and Spaces Released condition (see the upper panel of Figure 10). All conditions were affected by the delay interval, $F(2,26)=11.62$, $p<.01$. However, the delay effect was minimal in the Spaces Released condition; there was a marginal interaction, $F(4,52)=2.21$, $p<.09$.

The data presented thus far suggest that saccades were computed based on word length information, provided that there was no foveal processing difficulty. When there were problems with the foveal word, whether due to a lack of parafoveal preview of letter information, or an inability to

determine its end, refixations were more likely to occur. Otherwise, saccades were computed based on parafoveal word length information.

Landing position analyses. This was an analysis of the mean landing position (measured in letter position) on words of a given length. A separate 3(parafoveal mask)x3(delay)x6(word length) ANOVA was done on the data from each session. In the First Space Open session all main effects were significant, p<.001 (see Table 1a). In the First Space Filled data all main effects were significant, p<.0001, and there was an interaction of parafoveal mask by word length, $F(10,130)=2.18$, p<.05 (see Table 1b). Parafoveal word length had very little influence on the First Space Released condition. The Spaces Released and the Letters and Spaces Released conditions showed a initial positions that shifted further to the right as word length increased. The mean landing positions in the Spaces Released and in the Letters and Spaces Released conditions differed by only two tenths of a character position condition (SR, x=2.5; LSR, x=2.7). This difference was not reliable, $F(1,13)=2.07$, p<.17, nor was the interaction, $F(5,65)=1.51$, p<.20.

Table 1a

Landing Position with First Space Open
In Experiment 2

Word Length In Number of Letters

Text	3	4	5	6	7	8 or more
SR	1.7	2.1	2.6	3.2	3.1	3.4
LR	2.0	2.5	2.8	3.3	3.7	4.1
LSR	1.8	2.3	2.9	3.5	3.5	3.9

Table 1b

Landing Position with First Space Filled
In Experiment 2

Word Length In Number of Letters

Text	3	4	5	6	7	8 or more
SR	1.6	2.2	2.3	2.9	3.0	3.1
LSR	1.6	2.3	2.6	2.9	2.9	3.7
FSR	1.6	1.9	2.1	2.3	2.5	2.6

All of this lends support to the story told earlier.
The data from the First Space Filled session indicated that
initial landing position on a word was not different given

parafoveal space information alone, or letter and space information, as long as the space information was delayed equally in the two conditions. In the case in which only the first parafoveal space was released the initial landing position was more conservative. In the First Space Open data the initial landing position was further into the word in the condition in which space information was available from the onset of a fixation (LR). The other two conditions delay the release of parafoveal space information, and therefore had more conservative landing positions, especially at longer delays.

Landing frequency analyses. This was an analysis of the proportion of times a word of a given length was fixated. The 3x3x6 ANOVA of the first Space Filled data showed that there was a main effect of parafoveal mask, $F(2,26)=5.52$, $p<.01$, and a main effect of word length, $F(2,26)=41.12$, $p<.001$. There was no significant effect of delay. Words were landed on more frequently when there had been no parafoveal preview of letter information than when the letters had been previewed. Word length was the only significant factor in the First Space Open session, $F(5,65)=41.39$, $p<.0001$ (see Table 2a & b).

Table 2a

Landing Frequency with First Space Open
In Experiment 2

Word Length In Number of Letters

Text	3	4	5	6	7	8 or more
SR	37	48	60	62	58	67
LR	33	46	55	66	62	66
LSR	36	44	60	59	60	61

Table 2b

Landing Frequency with First Space Filled
In Experiment 2

Word Length In Number of Letters

Text	3	4	5	6	7	8 or more
SR	40	59	62	62	65	67
LSR	34	51	57	61	68	70
FSR	48	58	65	69	72	73

C H A P T E R IV

GENERAL DISCUSSION

The major results of the present study are as follows. First, most of the information used to determine where and when to move the eye is contained within a two word window to the right of fixation: effects were negligible in the Two Word Window condition of Experiment 1. In this condition no parafoveal information was altered within a two word window to the right of the point of fixation. Second, masking the first parafoveal space to the right of the currently fixated word with the square wave grating caused little if any interference in the processing of the foveal word. Third, the presence of parafoveal letter information had a facilitative effect on the reading rate, fixation duration, consecutive fixation data, and saccade length (at short delays). But parafoveal letter information had very little effect on the reader's initial landing position within a word. Fourth, preview of the first two spaces to the right of the current fixation resulted in longer saccades and initial landing positions that more closely approximate the preferred viewing location, than preview of only the first space. Fifth, there was also a benefit of having space information present even when this information was delayed 250 ms. These findings provide information relevant to

three major concerns in reading research: direct control of eye movements, the role of word boundary and parafoveal letter information in reading, and the role of attention.

<u>Direct</u> <u>Control</u> <u>of</u> <u>Two</u> <u>Independent</u> <u>Processes</u>

In the present experiments, delay of parafoveal letter or space information had differential effects on when and where a reader moved his or her eyes and these decisions were based on information received within the current fixation. The first clear demonstration that events on a fixation can affect the length of the next saccade and/or the duration of the current fixation was provided by Rayner and Pollatsek (1981). They varied physical aspects of the text randomly from fixation to fixation and showed that the behavior of the eyes mirrored what was seen on that fixation (see also Morrison, 1984). In addition, Rayner & Pollatsek (1981) showed that the processes controlling saccade length and fixation duration were independent, so that there is reason to believe that the decisions of where to move the eyes and when to move the eyes can be made independently (Rayner & McConkie, 1976).

The present study replicates the finding that eye movement guidance is under the direct control of the reader. That is, decisions can be made based on information received in the current fixation. Both the Landing Position and the

Landing Frequency analyses were conditional upon word length. Word length varied fairly unpredictably from one word to the next in the text, and therefore from fixation to fixation. Both the landing frequency, and the landing position analyses, indicated that there were systematic differences in the reading pattern due to space, letter, and delay manipulations, given word length. Since readers could not successfully predict word length in advance, and parafoveal preview was limited to word n+1, these results support a direct control model of reading (Rayner & Pollatsek,1981) in which the amplitude of a saccade is computed on the basis of parafoveal information obtained on the current fixation.

Both experiments provide additional evidence to support the claim that decisions of when and where to move are controlled by independent processes. Fixation durations were longer when parafoveal letter information was delayed or absent, while delay or elimination of word boundary information beyond the space that defines the end of the currently fixated word had no effect on subsequent fixation durations. When to move was influenced by the processing time on the currently fixated word. When the reader had no parafoveal preview of letter information, or when the space defining the end of the word was filled, processing was more difficult and therefore took more time.

Where to move was most affected by the availability of

parafoveal space information. The landing position data indicated that, in conditions in which parafoveal letter information was available, the landing position within a word of a given length was not different from the conditions in which only parafoveal space information was available to the reader, except in the case of very long words.

To summarize, decisions about where and when to move the eyes during reading are controlled by independent processes that utilize somewhat different aspects of the parafoveal information. When to move is dictated by the processing demands of the currently fixated word. Parafoveal preview of letter information alleviates some of the processing difficulty on a word when it is subsequently fixated. This results in shorter fixation durations when the reader has had parafoveal preview of letter information. Parafoveal letter information may also influence which word will be fixated on the next landing, but it is word length that has the stronger influence on the initial landing position within a word. The first parafoveal space to the right of the currently fixated word is utilized by both processes, and where to move is determined primarily by the length of the word to be fixated.

Role of Word Boundary Information

It has been suggested that saccades are programmed

solely on the basis of word length information. There were several important patterns present in the data that relate to the role of word boundary information in the programming of saccades. There is an interesting crossover pattern in the One Word Window session of Experiment 1 which is replicated in the First Space Open session of Experiment 2. At short delays there is a clear benefit for conditions which release letter information (LR, LSR), over conditions which release only space information (SR). However, as the delay of parafoveal information increases, the emphasis shifts, and it is the release of space information which seems to be the critical component. That is, as the delay extends beyond the first 50 ms of the fixation, the Letters and Spaces Released condition begins to look like the Spaces Released condition. The characteristic that these two conditions have in common is the timing of the availability of space information. Also, as the delay extends beyond 50 ms, the Letters Released condition yields saccades that are similar in length to those of the Spaces Released condition at a 0 delay. Here, the commonality between the two conditions is that in both cases space information is available from the onset of a fixation. When we turn to the consecutive fixation and landing position data we find that the benefit observed in the letter releasing conditions at short delays is not due to differences in landing position within words. That is, readers are not more accurate in

targeting the preferred viewing location within a word with the letter information available. However, there were fewer occurrences of two consecutive fixations on the same word when parafoveal letter information was available within the first 50 ms of the fixation. So it appears that the advantage observed in the letter releasing conditions at a short delay is not due to the influence of letter information on landing position, but rather, a reflection of the facilitation of foveal processing due to availability of parafoveal letter information.

In the First Space Filled condition of Experiment 2 the Letters and Spaces Released condition did show a consistent benefit over the Spaces Released condition at all delays. However, there were more consecutive fixations on the same word in the Spaces Released condition than in the Letters and Spaces Released condition, indicating that readers were having greater processing difficulty on the currently fixated word when they had not had parafoveal letter information available. This necessitated making a second fixation on that word in order to process it. The saccades within words tended to be shorter than saccades to a new word, thus bringing the average saccade length down. Readers were initially landing in the same position on a new word whether they had parafoveal preview of letter and space information, or only spaces. Word skipping and the frequency with which readers landed on words of a given length were

also not influenced by preview of letter information. These data suggest that readers were quite good at computing the preferred viewing location on the basis of space information alone.

We know from previous research (Pollatsek & Rayner,1982) that a lack of parafoveal space information results in shortened saccades, even when all of the parafoveal letter information is present. In the current data the saccades were shortest, and the initial landing position was most conservative, across delay conditions, when only the first parafoveal space was present. Without the space that defines the end of word n+1, the saccades were consistently shorter than when both the beginning and ending spaces for that word were present. There were also more consecutive fixations and fewer skips in this condition. Clearly both spaces are necessary to accurately program a saccade to the preferred viewing location.

To summarize, it appears that saccades were shorter when only parafoveal space information was available because readers had more difficulty processing a foveal word when they did not have parafoveal preview of its letters (longer fixation durations, more consecutive fixations). Without benefit of letter preview the foveal processing load was greater; more words required two fixations in order to be processed. While letter information may influence which word a reader will fixate, space information is used compute

the landing position within the word.

Numerous studies have shown that readers utilize partial letter information from parafoveal vision in reading (Balota et al., 1985; Inhoff & Rayner, 1987; Lima,1987; McConkie & Rayner, 1975; Rayner et al.,1981; Rayner, Well, Pollatsek, & Bertera, 1982). The data reported in the present experiments indicate that in those conditions in which parafoveal letter information was presented fixation durations were shorter, reading speed was faster, and the number of times a reader refixated the same word on two consecutive fixations was reduced, compared to conditions in which no parafoveal letter information was presented. All these results help to illustrate the fact that readers are using letter information acquired parafoveally to facilitate processing of word n+1 when it is subsequently fixated.

The majority of words in a text are fixated by the reader. However, it is the case that some words are skipped, suggesting that foveal processing of every word is not necessary. Rayner and McConkie (1976) showed that word length influences the probability that a word will be skipped. Just and Carpenter (1983) reported that when subjects read technical material they skipped 62% of the function words. Balota et al (1985; see also, Ehrlich & Rayner, 1981) showed that readers were less likely to fixate the same word twice in succession, and more likely to skip a word, when it was highly predictable in the sentence

context.   Visually   similar nonwords were as likely to be skipped in the highly predictable condition as were the actual words, suggesting that readers were skipping words on the basis of partial letter information.   It was not the case that readers were fully processing the parafoveal word before deciding to skip it, since they skipped visually similar nonwords as well as the actual word that was predicted by the context.   Balota et al. argued that visual and contextual information have separate influences on parafoveal processing and that it is the convergence of the two types of information on a particular lexical representation that yields this effect.

The data presented here showed that word skipping was influenced by word length.   But there was surprisingly little benefit of letter preview, beyond a 0 delay.   This information taken with what we know from previous research suggest that decisions of where to move are decided primarily on the basis of word length information in the parafovea, while letter information has a strong influence on the ease or difficulty of processing the word when it is fixated.   The parafoveal letter information may influence decisions about whether one fixation, two fixations,or no fixations on the upcoming word are necessary.   The conditions in which space information was available from the onset of a fixation and letter information was delayed yielded far greater benefit than when both types of

parafoveal information were released simultaneously. Letters and spaces released simultaneously showed some benefit over spaces released alone when the delay was very short. This suggests that both aspects of the parafoveal information are attended to simultaneously but that letters are not processed as quickly as spaces. It may be that space information is registered by low-level perceptual processes which are fairly automatic and therefore require little or no cognitive effort. However, when letter information arrives late there is not enough time to process and utilize it before the current fixation ends. Once the reader has decided which word to land on, the landing position is computed based on the word length information with little regard for the letter content of the word. Since space information is acquired so much more rapidly than letter information there is little benefit to releasing the spaces in advance of the letters. Partial word information is used to determine which word a reader will fixate and it is word length information that is used to determine where in the word the reader will land. An intriguing extension of the present research would be to explore whether or not syntactic information combines with highly familiar letter information to explain the skipping of function words since the word length factor is confounded with the fact that function words tend to be short.

The Role of Attention In Eye Guidance

The model presented in the introduction to this paper contains the assumption that attention moves word by word across the text in a serial fashion. Previous research has shown that masking the foveal word after 50 ms has little or no effect on reading (Rayner et. al.,1981). This suggests that by 50 ms attention has shifted away from the foveal word. No difference between the Letters Released condition at a 0 delay and at a 50 ms delay would be strong evidence that attention shifted from the foveal to the parafoveal word at approximately 50 ms. However, since releasing letter information at the onset of a fixation yielded some benefit over delaying that information 50 ms it is not clear when this shift of attention occurs. It is possible that some low-level orthographic information such as letter shape is processed in advance of the shift of attention, and that this results in the small benefit observed in the data without actually influencing when the shift of attention will occur. Or, it may be that our concept of the attentional mechanism involved in this process must be modified somewhat, to assign some role to this accumulation of letter information in determining when attention will shift.

Morrison's model assumed that the timing of the shift of attention was dependent on the encoding of the foveal

word alone. This is not sufficient to account for the current data unless we assume that the encoding of the foveal word, then the shift of attention, and after that, partial encoding of parafoveal letter information has all taken place within the first 50 ms of the fixation, and that seems unlikely. It may be that a tentative decision to move the eyes is based on the accumulation of excitation from parafoveal letter information, but that verification of the word currently being processed has control as well. While the reader is processing the currently fixated word word, excitation from the letter information in the parafovea would be accumulating. When the current word is verified, and the excitation from the parafovea has reached threshold attention would shift to the next word to the right. This would trigger the programming of an eye movement to that word and at the same time initiate the verification process for word n+1.

This type of attention mechanism is actually more consistent with the eye movement control mechanism described in the simpler target detection tasks, as well as giving a more complete account of reading phenemena. In the double step paradigm (Becker & Jurgens, 1979) subjects were asked to fixate a marked position and then move their eyes to a new target location when the parafoveal cue appeared. The pattern of results obtained is interpreted on the basis of the timing of the presentation of the parafoveal cues. If

the shift of attention wwere dependent solely on the processing time for the foveal target then one would expect no effect of intertarget intervals. In the reading task processing the foveal word is a much more complex cognitive task than processing an isolated target in the double step task, and as such, its influence is much more apparent here. But, it seems that the role of the parafoveal information must be accounted for as well.

The model of saccade programming outlined by Morrison (1984) indicates that more than one shift of attention could occur in the course of a fixation, and that this second shift of attention would in turn initiate the computation stage of programming another saccade. This potential for rapid and efficient utilization of parafoveal information gleaned from multiple shifts of spatial attention within a single fixation suggests that readers may attempt to extract useful information from the parafoveal region to update their eye movement decisions far into the fixation. The data from Experiment 1 indicated that saccades were longer when parafoveal information was delayed 250 ms than when this information was never released. This suggests that readers will continue to attend to the parafoveal region given that they have been unable to encode the information that they need to program an eye movement, and that they are able to utilize the late-arriving space information to modify the program for the subsequent saccade. The data

also indicate that saccade length decreases as delay increases, suggesting that the later the relevant information is available the smaller the benefit. This is consistent with the parallel programming model outlined earlier.

Outline for an Eye Guidance Model

The present experiments were designed to investigate the role of parafoveal letter and space information in the programming of saccades, and to investigate the role of attention in this process. These issues arose from a model of eye movement control in reading that was outlined in the introduction to this paper. The findings reported here make it necessary to modify that model somewhat.

The fact that readers were able to utilize parafoveal space information that became available 250 ms after the eye had come to rest in a new location is plausible if we assume a direct control model of eye guidance in which saccades can be programmed in parallel. That is, the information received late in a fixation may be used to modify the subsequent saccade. It is important to note that this extreme case would be a rare event in the course of normal reading, since fixations are typically less than 250 ms in duration. The more important point is that readers do continue to attend to the parafoveal region throughout the

fixation; at least when the relevant information to program a saccade is delayed.

There were also critical findings regarding the role of parafoveal word boundary information in determining landing position. There are actually two decision processes occurring here. First the reader must decide which word will be fixated, and then, determine the optimal landing position within that word. Evidence from the present experiments suggests that letter information is used to determine whether the reader will refixate the same word, move to the next word, or skip over the next word and saccade directly to word n+2. However, the landing position within the chosen word is computed primarily on the basis of word length information.

The attentional mechanism of the model presented in the introduction to this paper was too simplistic to account for the data we obtained. The model we would favor at this point involves two components, an encoding process and a verification process. As the foveal word is processed, excitation from parafoveal letter information is accumulating. When foveal processing is complete, and excitation has reached threshold, attention shifts to word n+1 initiating the computation of a new landing position based on word length.

Having defined the text characteristics used to determine the intended landing position, and an attention

mechanicism suitable to account for the data obtained in these experiments, the model is sufficient to explain a number of important phenomena that have been reported in the eye movement literature, and to make some clear predictions for future work.

Before going further, let us recap the important points of the model: a) foveal letter and parafoveal space information are read in parallel by independent processes; b) space information is processed more rapidly than letter information; c) processing of letter information determines when attention will shift; d) eye movements follow these shifts of attention; e) more than one shift of attention can occur in the course of a single fixation; f) the landing position of a saccade can be computed before the decision to execute the saccade; g) processing of letter information influences which word a reader will fixate next; h) the landing position within a word is computed on the basis of word length information.

Now, let us consider the simplest reading scenerio. Each word in the text is processed in sequence, when the encoding of word n is complete, and the level of excitation from parafoveal letter information has reached some threshold, an internal attention mechanism shifts to the following word. This attention mechanism triggers an instruction to execute an eye movement to that word. The parafoveal word boundary information has already been

extracted, and the location of the next landing position is computed based on word length. In this scenerio all events occur in a serial fashion; attention shifts – eyes jump – attention shifts – eyes jump. Landing position approximates the preferred viewing location and the eyes land on every word.

However, reading is a complex process and there are numerous intervening factors at work. The time to encode the currently fixated word will influence when the eye movement is executed, and if processing the foveal word is difficult the reader may require a second fixation on that word. At that point attention would shift within word n, rather than to word n+1, word length of the currently fixated word is computed and a second landing position within that word is determined, based again on word boundary information. If this is the case then there should be a systematic pattern to second viewing positions on words that is related to their length, much like the preferred viewing location of first fixations. This prediction of the model has yet to be tested.

We know from the data presented here that partial letter information is extracted from parafoveal preview, and that space information is processed more rapidly than letter information. Keeping this in mind, suppose the reader encodes the currently fixated word and the threshold of excitation has been reached. Attention shifts to the next

successive word to the right, parafoveal space information
has already been extracted, the length of word n+1 is
calculated and a movement to the next word is programmed.
At the same time, more parafoveal letter information is
processed; this information combines with highly constrained
contextual information, and word n+1 is verified. Attention
then shifts to word n+2 and a movement is programmed to that
word, cancelling the previous instruction. The eye would
then skip over n+1 entirely and saccade directly to word
n+2. It is important to note that this model is specifying
a mechanism whereby visual information about parafoveal
letters is fed "up" to combine with contextual cues and that
this results in the combinatorial power of the two factors.
The model would not predict that contextual factors would
feed "down" to influence how the parafoveal letters are
perceived.

We can imagine the same outcome given a slightly
different scenerio as well. In this case word n+1 is very
short, the letter information is highly familiar, and the
syntactic cues from the previous context suggest that this
is likely to be a function word. Here, context and letter
information, or context and space information could combine
to make fixation on word n+1 unnecessary and the reader
would saccade directly to n+2, skipping word n+1. Further
research needs to be undertaken in order to determine
exactly which factors influence the skipping of function

words.

The model will also explain very short fixations and fixations on spaces between words. If a second attention shift occurs in the course of one fixation, but not quickly enough to cancel the first, one of two things may happen depending on the timing between the two events. Either the first and second instruction will be combined, resulting in a single saccade to an intermediate position, in which case the reader might fixate the very end of word n+1 or the space between n+1 and n+2; or the first instruction will not be cancelled, but a second instruction will be issued from the same fixation. Thus two eye movements will be programmed on fixation n: the one terminating fixation n and the one terminating fixation n+1. If the second saccade programmed on fixation n was programmed early enough, then its execution could occur within the first 50 msec of fixation n+1.

This model provides a clearer view of some of the basic processes involved in eye movement control which are peculiar to reading, while at the same time maintaining some consistency with what is known of eye movement control mechanisms in other simpler tasks. There are still a multitude of questions to be addressed in the field of eye movement control. More work must be done to delineate the fundamental cognitive processes involved in controlling eye movements that will be consistent across a variety of tasks.

Basic questions pertaining to eye movement control in reading are open to further investigation as well. For instance, why is it that some words are fixated twice in succession while others are not? Is this an effect of linguistic processing, motor programming, or perceptual processing, or some combination of the above. It would seem that when we are able to understand this phenomenon we will be one giant step closer to understanding eye movement control in reading. Hopefully, the groundwork laid down by this model will be helpful in future research.

A P P E N D I X
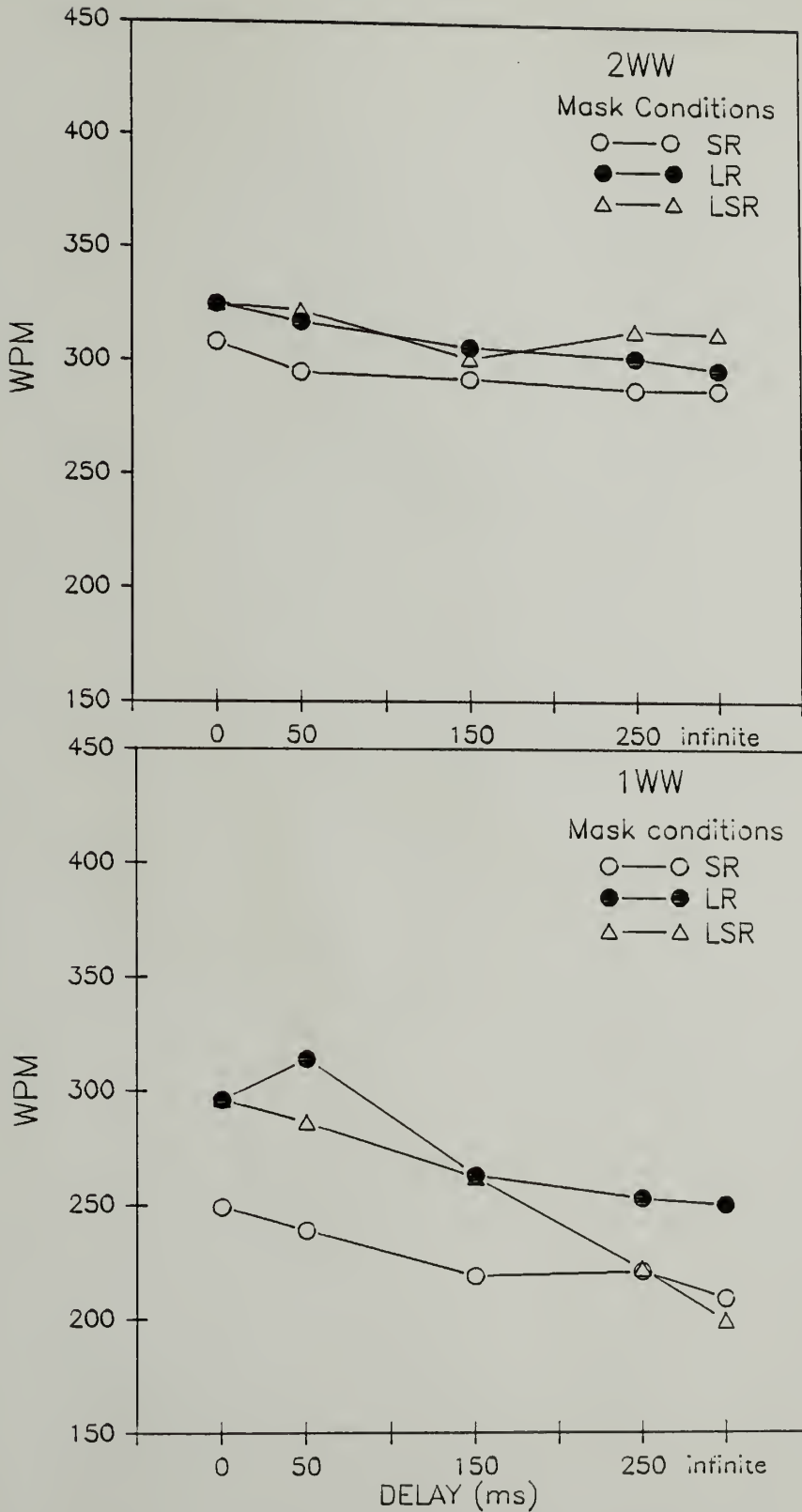
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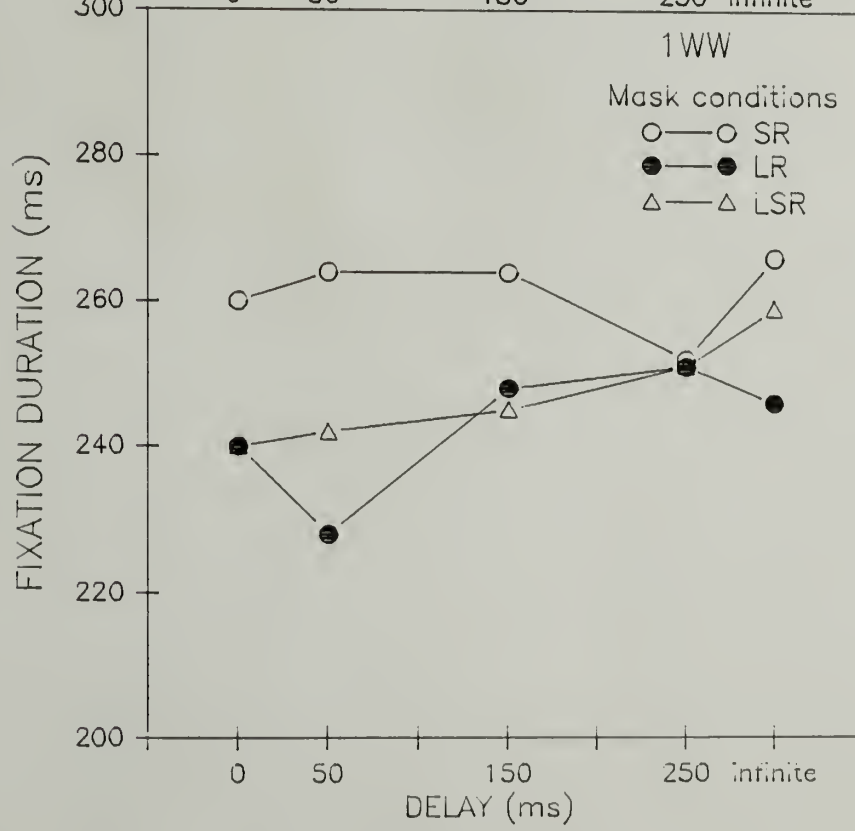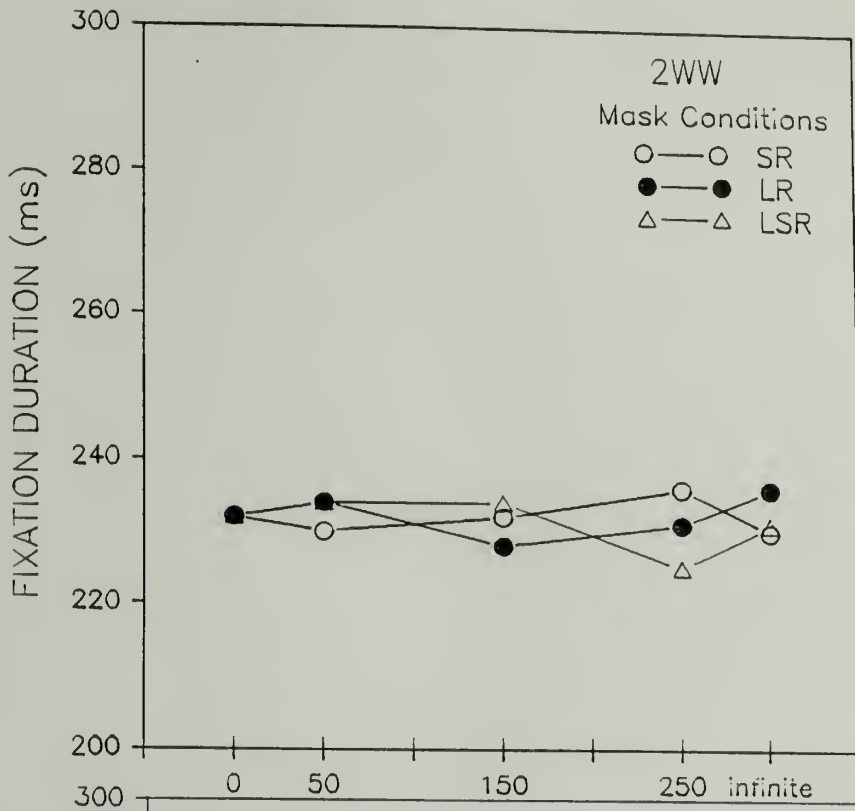
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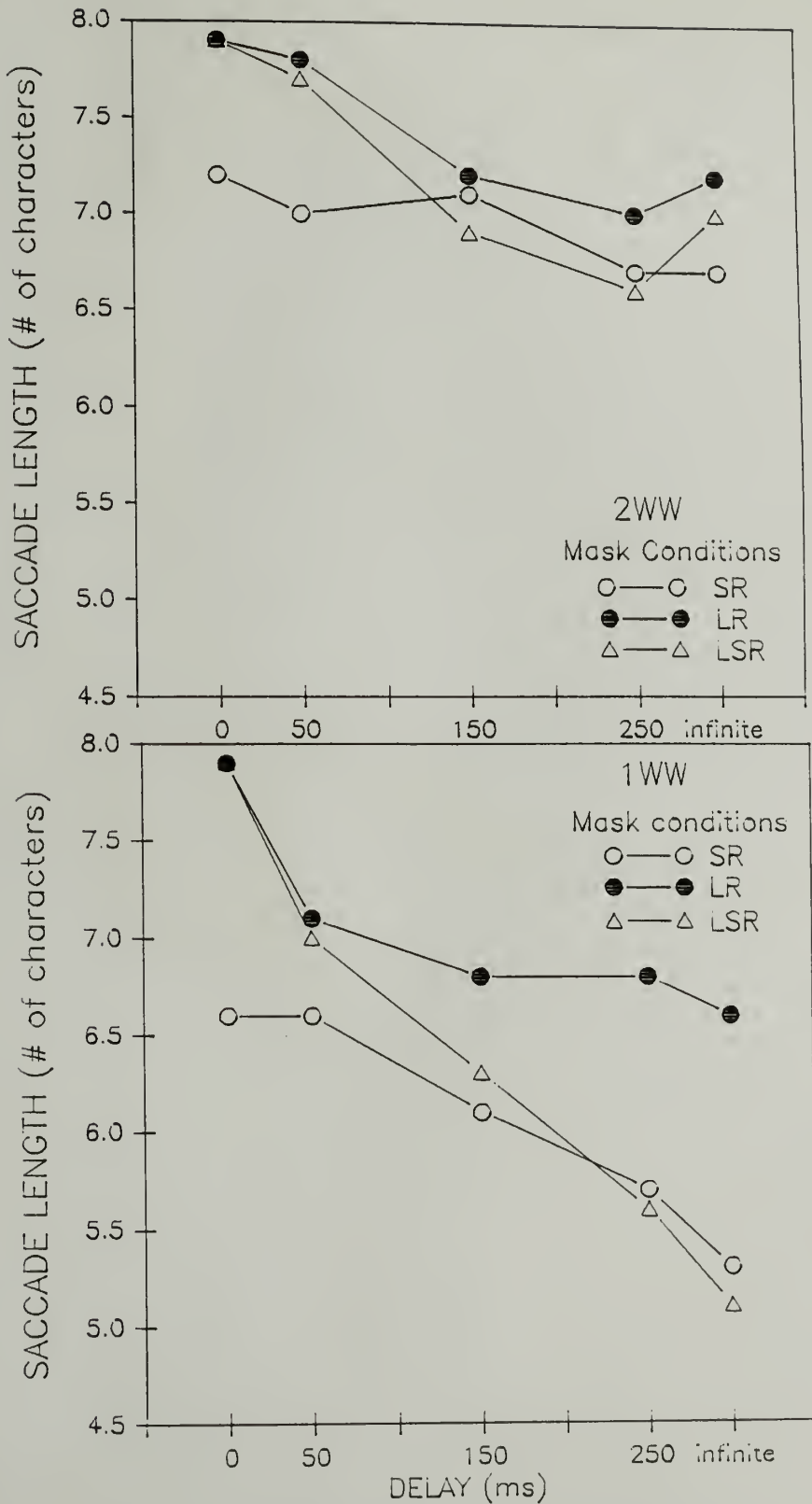
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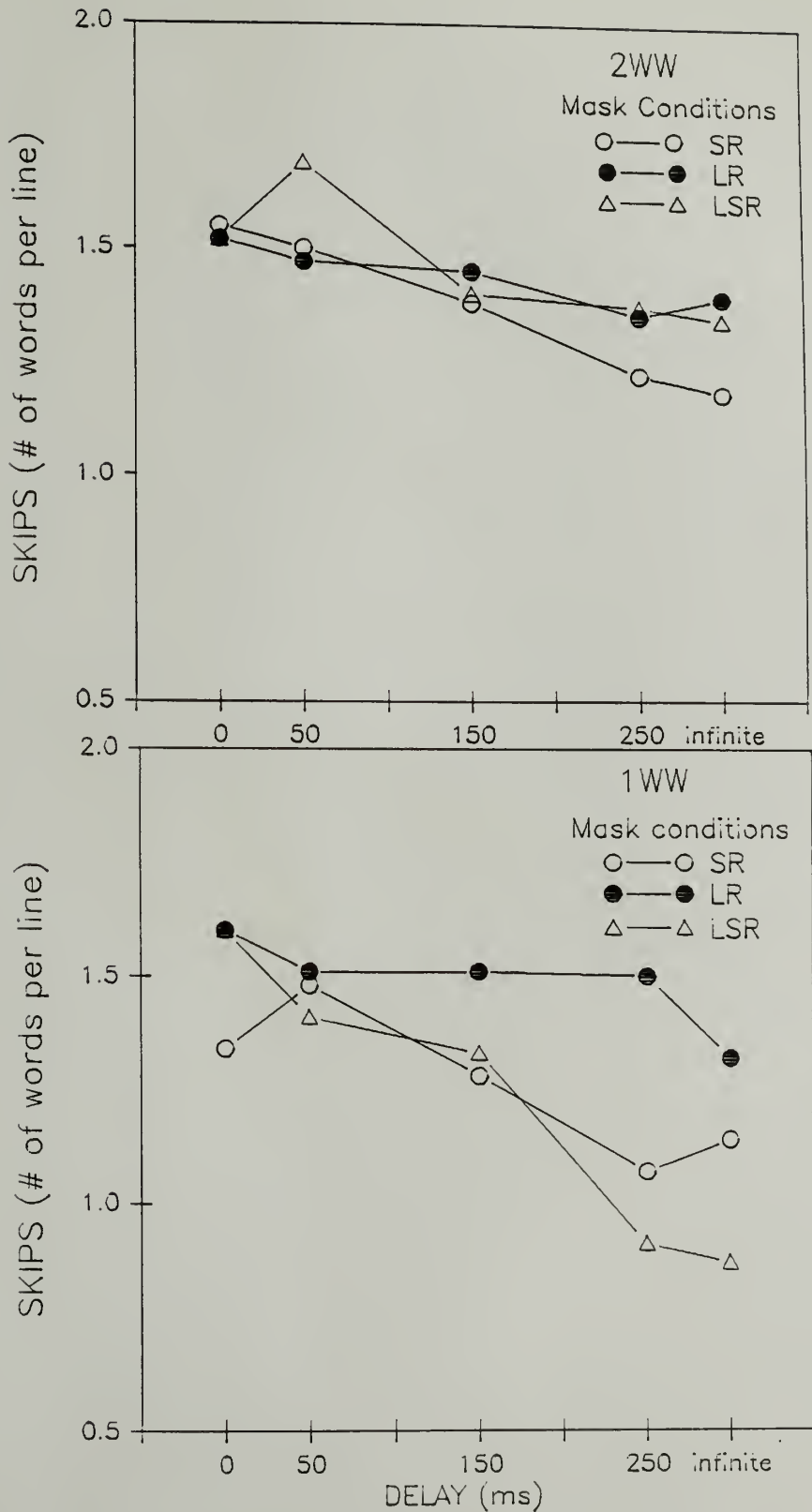
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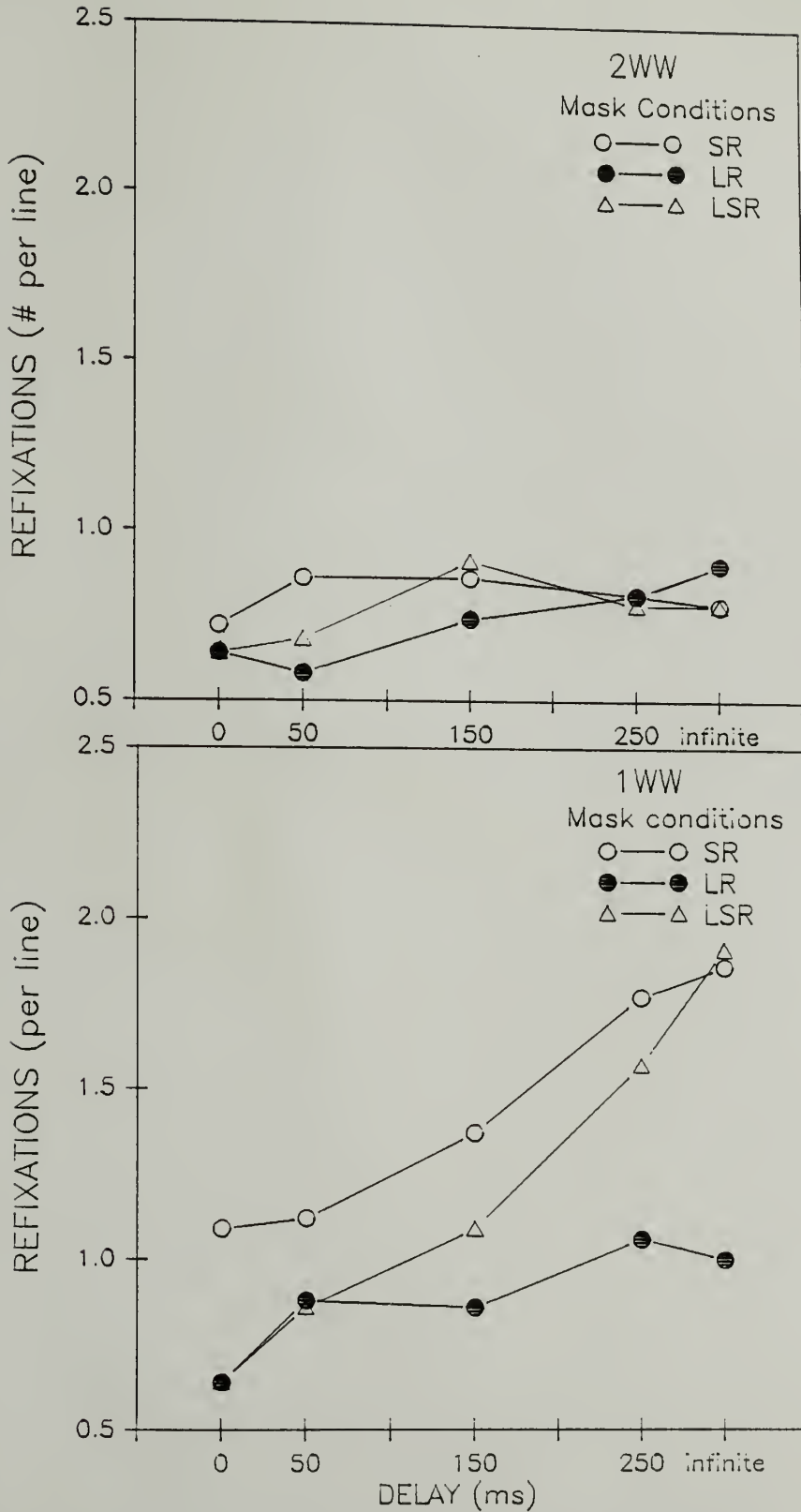
Figure 5 Consecutive Refixations
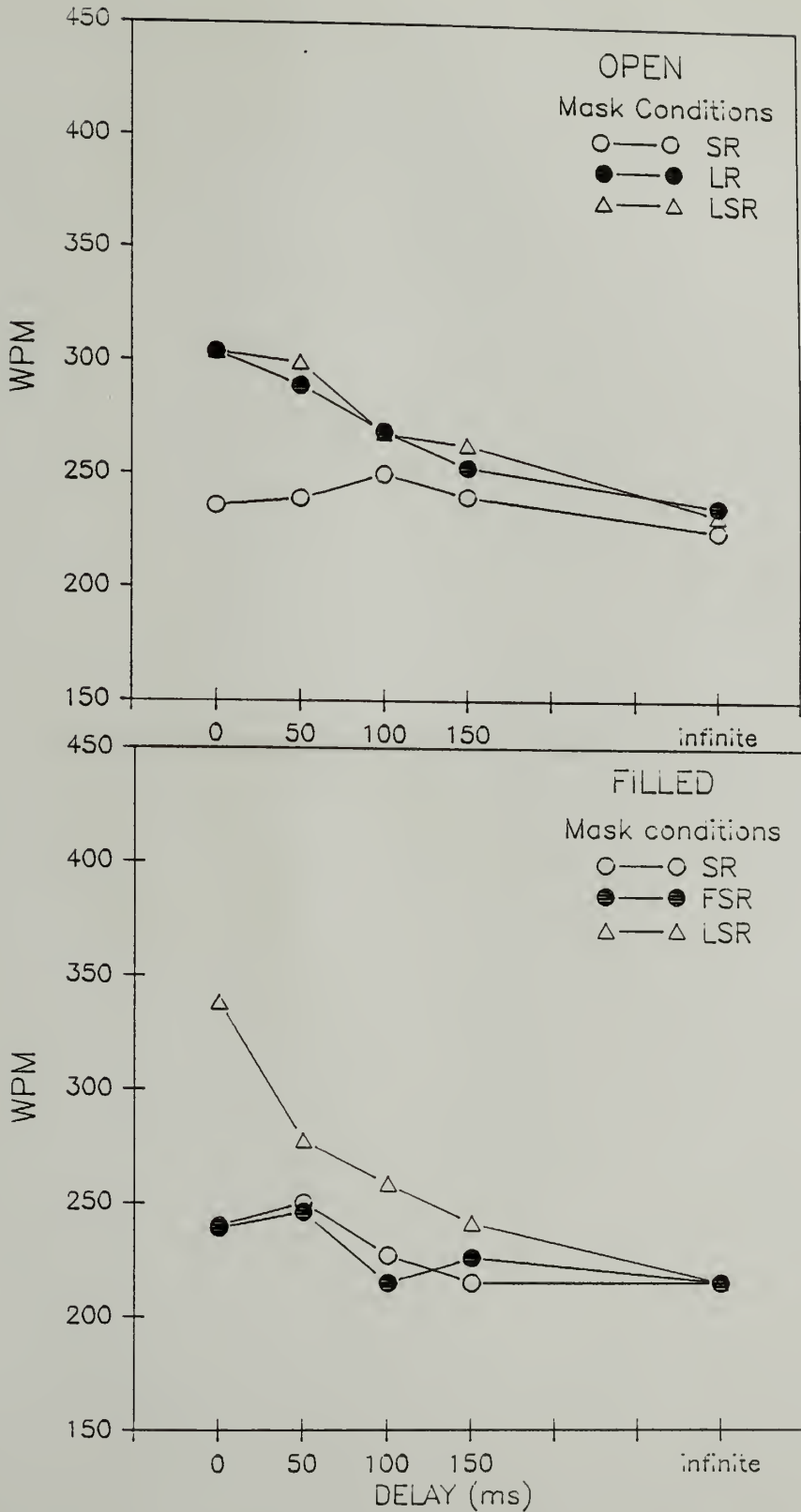
Figure 6 Reading Rate
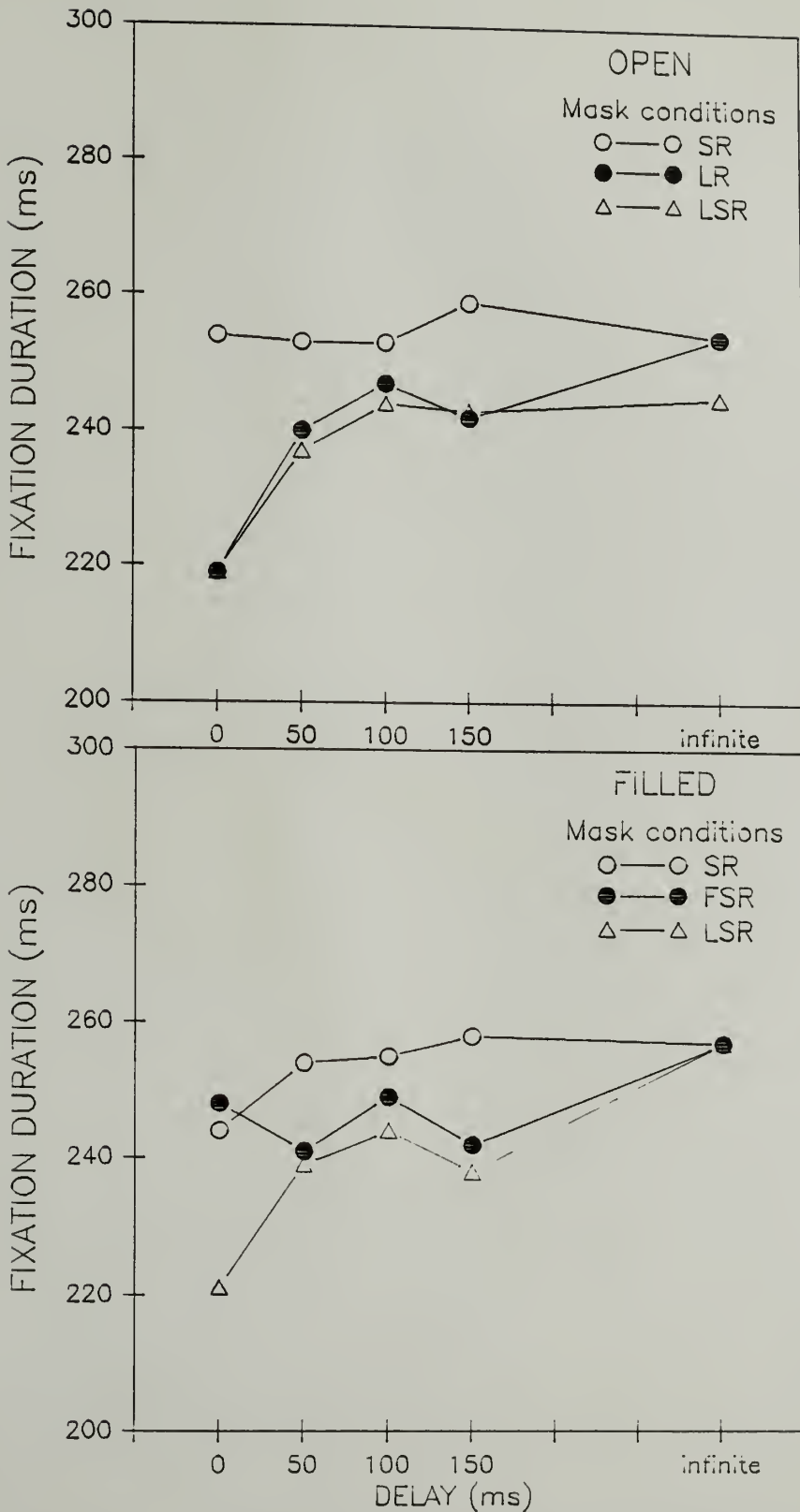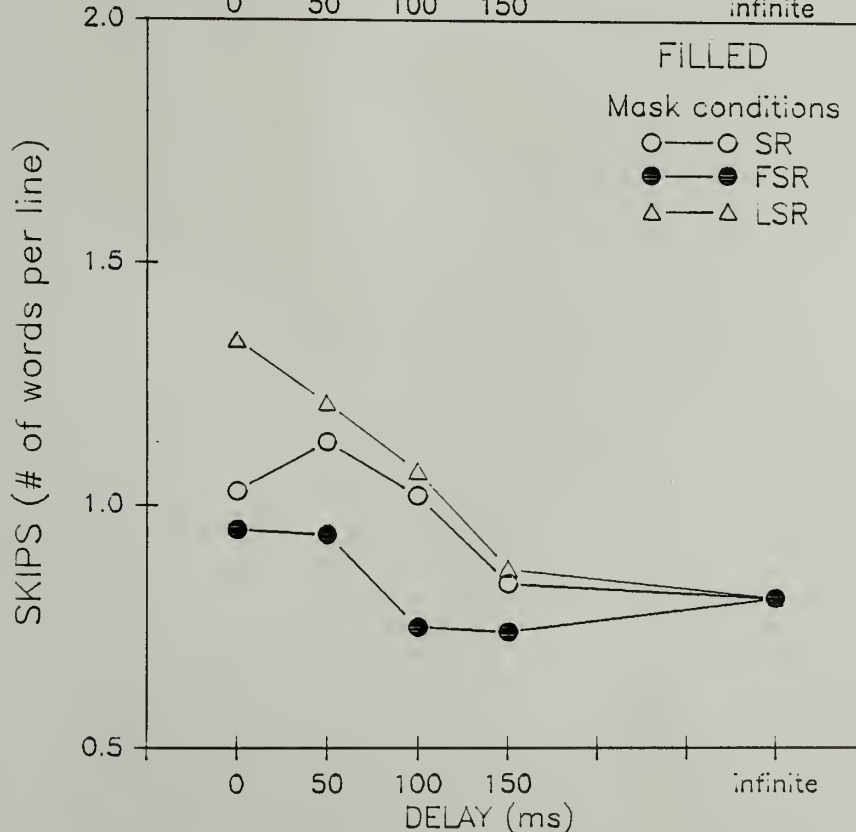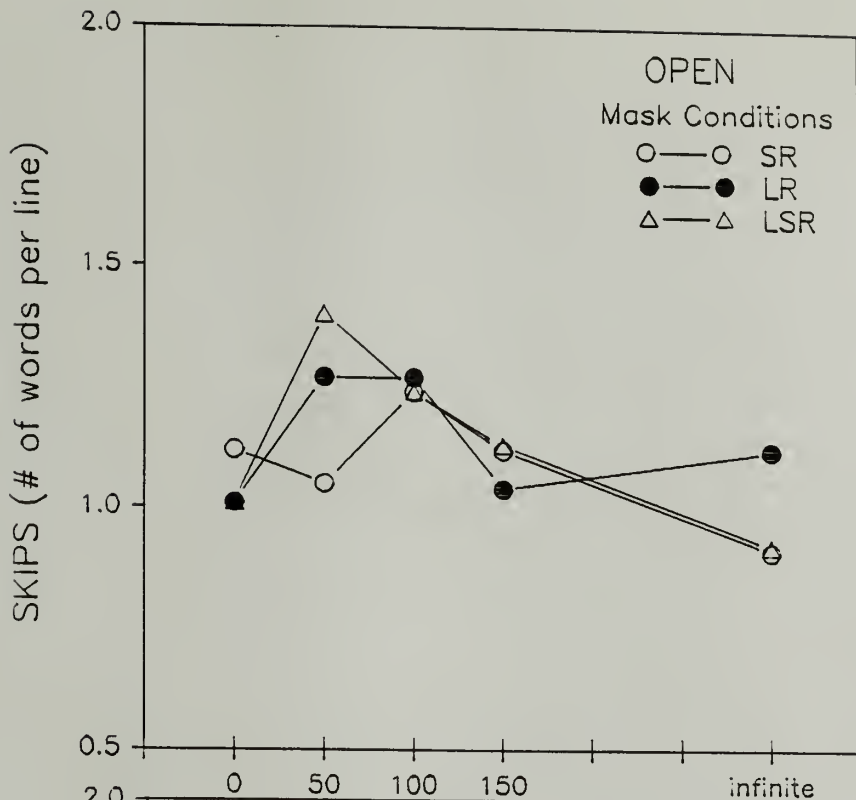
Figure 7 Fixation Duration
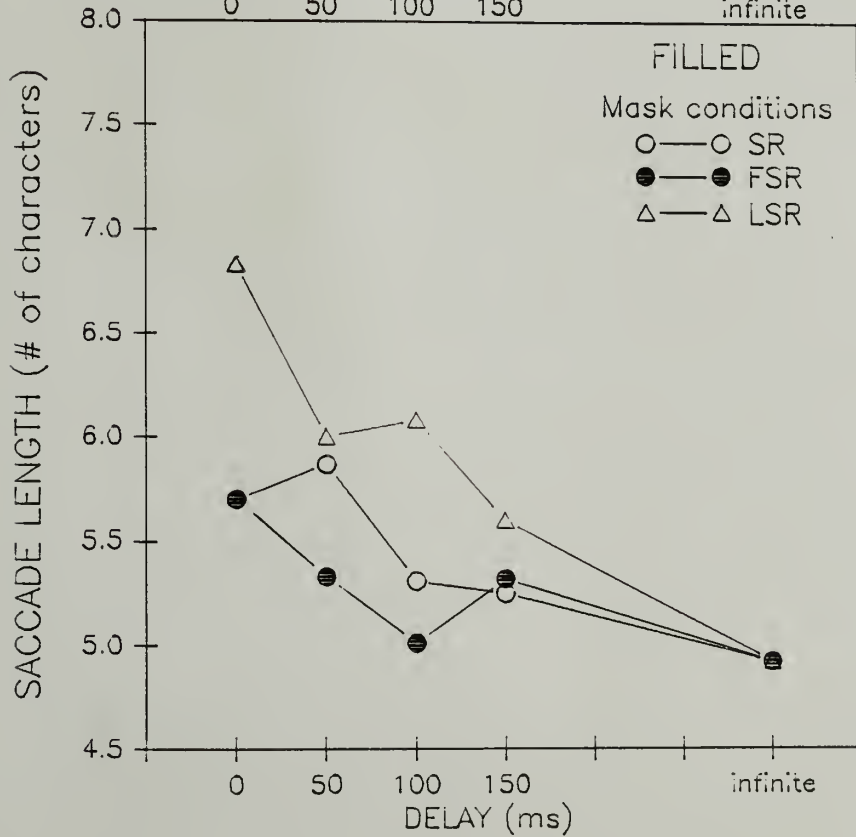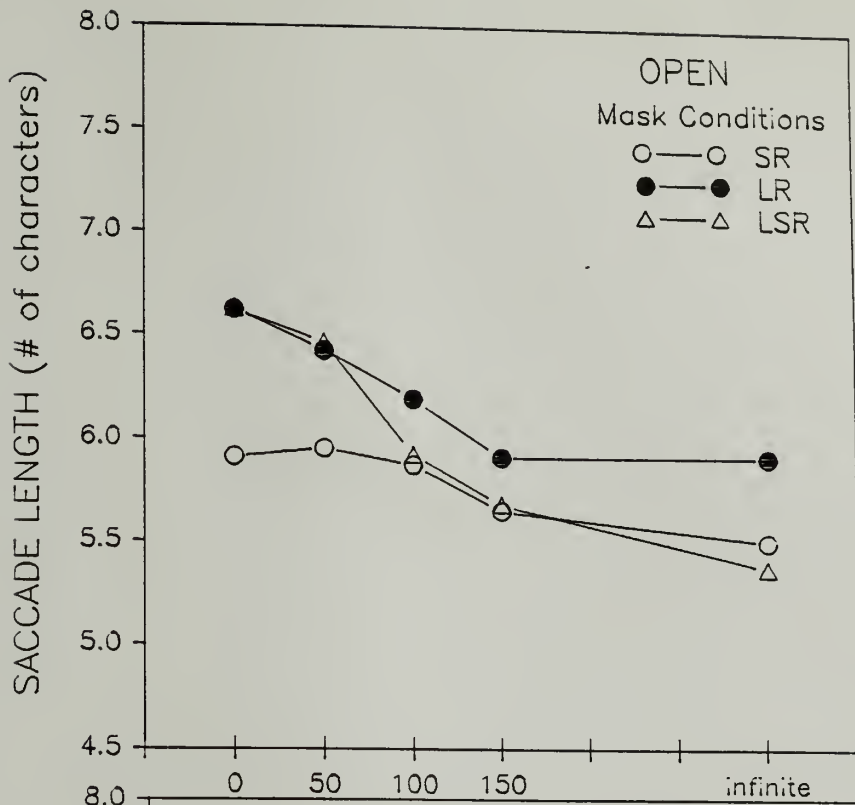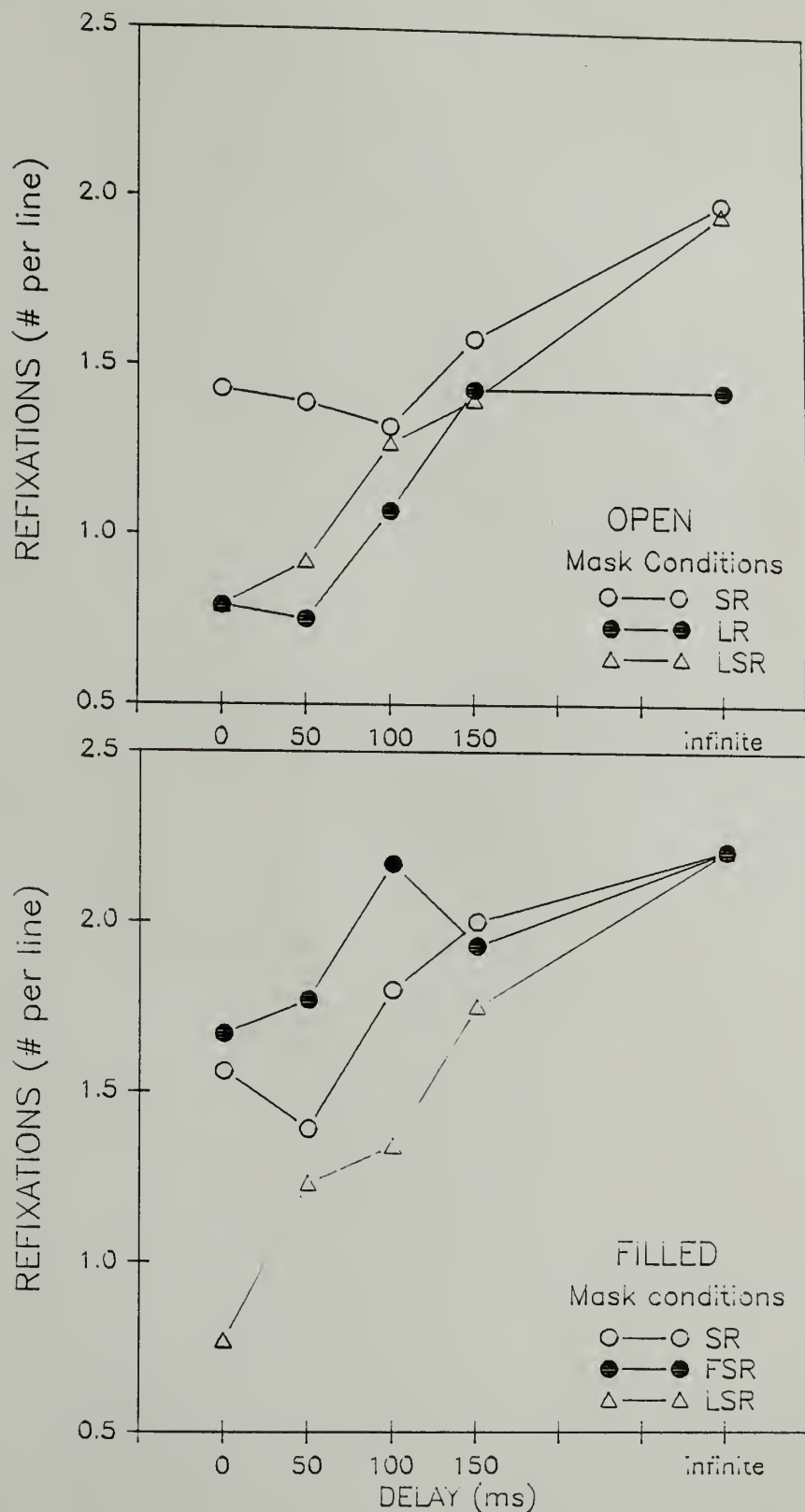
Figure 8 Saccade Length

Figure 9 Word Skipping

Figure 10 Consecutive Refixations

APPENDIX B

Daisy lit a candle in the hallway.
Shadows flickered along the walls.
The sounds of the house overwhelmed her.
She moved gingerly toward the door.
Every step took incredible effort.
The entrance seemed very far away.
The anticipation became too great.
She raced to the safety of her bed.

A bicycle can simplify your life.
It requires no insurance or license.
Maintenance is easy to manage.
You can learn to do your own repairs.
The bike will take you where a car can't.
It brings a sense of freedom and control.
You travel swiftly under your own power.
And it does not require a parking sticker.

You can make things disappear.
Confront the unwanted object directly.
Raise your magic wand over your head.
State your desire in a stern tone.
Tap the object smartly with your wand.
Turn on your heel and walk away.
Forget about the object forever.
Eventually the object will disappear.

Movie marathons are good for the soul.
They are best carried out on a sunday.
Begin with a heart wrenching matinee.
Now you will need some cheering up.
Proceed immediately to a light comedy.
By now it is time for a relaxing meal.
After dinner a double feature is best.
It is nice to end with old favorites.

Yesterday Anne discovered a house fly.
It was buzzing around her window.
She told the family not to kill it.
The fly became her personal friend.
Anne called her friend Ruth Buzzy.
She conversed with Ruth every day.
Ruth lived with us for several weeks.
Anne buried her under the lilac bush.

Portland, Oregon acquired a new statue.
Portlandia is made of pounded copper.
She is as tall as a three story building.

Only the statue of liberty is taller.
A barge carried her down the river.
She docked in the center of the city.
A parade of citizens followed excitedly.
She now sits overlooking her city.

Mallory ran to her favorite tree.
Woodcutters had felled the oak.
She was shocked and heart broken.
She turned to go, crying bitter tears.
But something strange caught her eye.
It was a curling wisp of gray hair.
A pointed nose jutted from the tree trunk.
From deep within came the wizard's voice.

Caroline was the first girl I kissed.
We were walking back from school one day.
Somebody dared me to do it, so I did.
After that I did it every day.
A crack in the sidewalk marked the spot.
Then a neighbor lady told my mother.
She solemnly forbade me to continue.
I could not understand why.

Grizzly bears are nearly extinct.
Fur hunters slaughtered the bears.
Ranchers drove them off their ranges.
Bounties were offered for their hides.
Civilization shrank the wilderness.
Food became difficult for them to find.
Small litters have added to the threat.
Something needs to be done to save them.

Auctions are often amazing to newcomers.
The auctioneer is a master entertainer.
He entertwines stories with business.
The merchandise is moved swiftly along.
Decisions are made on the moment.
A sense of anticipation fills the gallery.
Competition rises as the night goes on.
Everyone hopes to go home with a bargain.

I remember visiting my grandmother.
I made a splendid chocolate cake.
We drank alot of bourbon and talked.
Then we ate big slabs of the cake.
We went to bed around ten o'clock.
It was raining and we felt safe.
I made the same cake again last night.
It did not make me feel any safer.

The little cat loved the gas stove.

It became her favorite winter spot.
She fit perfectly over a burner.
The pilot light made it a warm place.
The right rear burner was her own.
We seldom got a chance to use it.
The warm weather returned and she left.
Sadly, the stove became ours to use again.

Going to market is a social event.
It is mostly the women who participate.
Some of them walk many miles to attend.
Many of them arrive before dawn.
They may be loaded down with produce.
Children are carried on their backs.
All of the women are eager to make a sale.
It is a time of news, gossip and laughter.

1985 was a year of varied disasters.
Our national debt was in the trillions.
Civil aviation had its worst year ever.
There was an earthquake in Mexico.
But the volcano in Colombia was worse.
Third world starvation reached a new high.
Some say this was an adequate year.
The worse disasters were not our fault.

Voodoo is a Caribbean folk religion.
Its rituals are quite peculiar.
People use the drum and the dance.
This ritual induces a state of trance.
The spirits can then enter the bodies.
What do people seek in all of this?
Some seek a devine existence.
Others desire respite from their fears.

My sister called me yesterday.
She wanted her nose pierced.
No professional would do it for her.
So she had her housemate do it.
Two days later her nose became infected.
She had to remove the emerald stud.
She assures me it is healing nicely.
The scar is hardly noticeable.

Have you ever misplaced your car?
Perhaps you need a carfinder keychain.
The tiny transmitter activates your horn.
It causes your headlights to flash.
All of this begins from two blocks away.
Everyone will know where your car is.
This will cause you public embarassment.
You won't forget where you parked again.

The story is an epic romance.
It begins in the forest of Bohemia.
The hero is a janitor with a bottle.
The bottle is ancient blue alabaster.
It shows the image of a goat-horned god.
It contains the essence of the universe.
The liquid is leaking from the bottle.
There is only a drop or two left.

Black-necked stilts are small shore birds.
They are only six inches tall at maturity.
They often nest near shallow ponds.
Their reaction to flood danger is unusual.
The male and female work together.
The male brings leaves and sticks.
The frantic female elevates the nest.
Sometimes the nest is raised four inches.

The urban apartment barbeque was not easy.
Our friend owned a very small hibachi.
We used it to grill on the windowsill.
But people passing by complained.
They were afraid of hot falling coals.
Disposing of these coals was more trouble.
Even after several hours they can ignite.
The flaming dumpster was proof of this.

What was so special about last year?
The inventor of twinkles died.
The supor bowl was the most watched show.
Eleven Americans were accused of spying.
Coke brought back the classic coke.
Our oldest president began a second term.
A guru lost eighty-two rolls royces.
History can be a very mundane topic.

Running in winter weather is difficult.
Safe routes are not easy to find.
Forest trails way have treacherous ice.
It is very easy to slip and fall.
The road has unique dangers of its own.
Cars splash huge fans of filthy slush.
Winter driver visibility is often poor.
The dedicated runner will strive to adapt.

My mother is not a baker.
Christmas goodies are a family joke.
We use her fruitcakes as doorstops.
They are good at keeping doors open.
As food they are hard to swallow.
But every year she tries again.

And while they bake we reminisce.
Family traditions make holidays special.

Donna dreamed of riding in a blimp.
The blimp came to town once a year.
They never took on public passengers.
But Donna always went to watch.
Every year she got a little bit braver.
She conversed with the people in charge.
They learned of her long standing desire.
Sworn to secrecy, she was taken aboard.

He looked like a common face in the crowd.
But he was carrying a loaded handgun.
For black teenagers hassled him.
They wanted his money, and he shot them.
One of the boys is now paralyzed for life.
Goetz had acted out an urban fantasy.
He enjoyed a brief whirl as a folk hero.
Then he was indicted for attempted murder.

Kate always went to the library to study.
It was impossible to study in her room.
She shared it with two other people.
They tried not to disturb her.
But she was easily distracted.
At the library Kate found seclusion.
She went directly to an isolated corner.
In the quiet, her concentration returned.

Pan was a noisy, merry, earth god.
He was part goat and part man.
All the woodlands were his home.
He was a wonderful musician.
He wandered the forests playing his reeds.
Unknown sounds were attributed to Pan.
His mysterious music frightened travelers.
This is where the word panic comes from.

Karen hated to do her laundry.
She did not like going to the laundramat.
People there never spoke to each other.
The steamy air was hard to breathe.
The washing machines were dingy and ugly.
Karen avoided going as long as possible.
But she had no clean clothes left.
Doing laundry was no longer a choice.

APPENDIX C

Please help a toad across the road.
This is the British toad lobby's slogan.
Volunteers wear galoshes and raincoats.
They are armed with pails and flashlights.
They help migrating toads over busy roads.
Toad escort is high pressure employment.
Rainy nights around eleven are critical.
Many toads are killed at pub closing time.

I have imagined returning here many times.
It is Sister Francis who opens the door.
She has only three teeth left now.
Two are on the top and one on the bottom.
Her eyes are so red, and so blank.
She has the look of a graet rabbit.
Twenty years ago I left this convent.
This dream reminds me of why I left.

A small group went fishing off the coast.
Suddenly the sea churned about their boat.
A large school of whales surrounded them.
The men shut off their motors and drifted.
They didn't want to disturb the creatures.
For five hours the whales stayed close.
Sometimes they gently nudged the boat.
But they showed no signs of aggression.

Howard was driving along the highway.
Suddenly his right front tire blew out.
His car swerved wildly off the road.
He knocked down a large power pole.
The wires fell across the railroad tracks.
This short circuited the town's power.
The power surge blew up a gas station.
Howard suffered a badly sprained wrist.

Poland exports 100 tons of hair annually.
They send it all to West Germany.
In return, they receive barber equipment.
We may assume tis is to cut more hair.
What are the German's doing with that hair?
Maybe they use it to stuff pin cushoins.
Or is the entire country naturally bald?
That much hair wouuld make alot of wigs.

How do marsh wrens attract their mates?
It can't be their flamboyant appearance.
They are inconspicuous, small brown birds.
It isn't through monogamous committment.
The males take many mates each season.

It must be their amazing singing ability.
Males sing hundreds of different songs.
The better singers attract more mates.

Some inventions took real creativity.
Fuzzy dashboard dice are a good example.
Who ever thought fuzzy dice would sell?
Where do ideas like this come from?
Some come from Leominster, Massachusetts.
It is the home of pink plastic flamingos.
In 1985 a half million flamingos sold.
Is this what they call Yankee Ingenuity?

Kim was six when she read about the Incas.
They played a game similar to basketball.
But it had a very different ending.
The winneers were sacrificed to the gods.
This sounded like an interesting concept.
What if her brother was on the other team?
She would feel terrible if Jack died.
Then again, he wouldn't like to lose.

Goats are famous for their appetites.
Every old farmer has a good goat story.
Goats can and will eat almost anything.
At least that is how the story is told.
In one such story the goat drank gasoline.
That was okay, until he ate the matches.
Even goats can't stomach that combination.
This story literally ended with a bang.

Do you have a perspiration problem?
Here's something that will end your woes.
This product stops sweat for six weeks.
It's a heavy sweater's answer to wetness.
Stop costly underarm, hand or foot sweat.
Short electronic treatment really works.
Reccommended by dermatologists everywhere.
Send for your free information now.

Tom Anderson was a courageous fellow.
But his courage cost him some money.
He saw a robber hold up a man in the road.
Tom made a dive for the crook's gun.
He knocked it out of the robber"s hand.
But now the victim picked up the gun.
He put the weapon to poor Tom's ribs.
The supposed vitcim left with Tom's money.

Flowers were a staple of the Middle Ages.
They were valued for their perfume.
Nosegays were hung to mask odors.

Flowers were also used to flavor food.
Hawthornes or primroses were put in soups.
Violet petals were considered delicacies.
Europeans scattered marigolds on any food.
Flowers provided flavor and visual appeal.

Dwight Eisenhower was a military man.
That is where he learned to use a phone.
After that he moved to the White House.
As President he used the phone frequently.
He called all telephone operators central.
Central did all his dialing for him.
He left the White House a helpless man.
He had never learned to dial a telephone.

Are you up on your Tarzan trivia?
What do you know about Tarzan yells?
Frank Merrill gave the first human yell.
Johnny Weismuller's movie yell was dubbed.
It's a mix of violin, hyena, and camel.
Ron Ely used the same yell on television.
Carol Burnett brought back the human call.
It was a regular gag routine on her show

A father and son went out exploring.
They were looking at an excavation site.
A sudden landslide caught the boy.
He was half buried; more dirt was falling.
The father threw him a garden hose.
The boy breathed two hours with the hose.
Finally the rescue team arrived.
The father had saved his son's life.

A sweater tells a woman's personality.
Fashion researchers say it's true.
Sensual women wear low cut necklines.
Mature women prefer hip length sweaters.
Easy going women own dark bulky sweaters.
Medium bulkies belong to logical women.
No sweater indicates no character?

Ten victims were condemned to death.
They were lined up before a firing squad.
Just before the volley roared one fainted.
He fell right before the other victims.
The executioners noticed nothing of this.
They left the bodies where they lay.
Later the man regained consciousness.
He had difficulty believing he was alive.

How important is military music?
Sousa lovers take a front row seat.

Reagan's administration says it's special.
The new budget proposal demonstrates this.
Military bands receive generous support.
National endowment of the arts gets less.
The marching band is the art of 1987.
So pull up a curb and enjoy the parade.

A vaudeville actor had to train chimps.
One day he went into the forest with them.
He didn't come back, but his chimps did.
Police found them chattering excitedly.
They led the police to the slain actor.
Upon returning to town they saw two men.
The chimps attacked the men wildly.
The chimps had identified the murderers.

Here's how to marry a man of your choice.
Do not use excessive perfume.
Do use enough soap and wear t-shirts.
Remove food particles between your teeth.
Do not chew gum and smoke simultaneously.
If you need to pass gas face him.
Does this sound like a comedy routine?
It is a serious new best selling book.

Stanley worked at a Nuclear power plant.
But his presence set off radiation alarms.
Federal tests were conducted on his home.
They discovered very high radon levels.
Radon is a gas emitted by decaying radium.
The family health risk was extreme.
It was like smoking 2,700 cigarettes daily.
Action is being taken to help the family.

British animal lovers have gone batty.
Bird feeders are being abandoned.
Bat boxes are taking their place.
Five thousand people subscribe to Batnews.
It is now a crime to kill or injure a bat.
It's illegal to keep bats from going home.
There is one exception to the new law.
One can tend an injured bat and let it go.

It began a month after June died.
It was his hands that made him drink.
They remembered too many things.
Things he had forced his mind away from.
His hands would not stay still.
They did things when he wasn't looking.
They tipped one beer after another.
And still his hands remembered June.

No one wants to die in a terrorist attack.
Do you have valid cause for concern?
If you bathe in a bathtub maybe not.
You are much more likely to die in a tub.
Do you talk on the phone frequently?
Thousands die of phone injuries annually.
Are you single female and over forty?
Terrorism is more likely than marriage.

A gentleman from Chicago went fly fishing.
The first cast he attempted missed.
He flipped his line back for a second try.
The line caught over his shoulder.
He turned expecting to untangle his line.
There stood a bear with a hook in its ear.
The fisherman dropped his line and ran.
We have yet to hear what the bear did.

Someone is playing a trick on me.
I keep writing these little stories.
And then I sit back and count them.
I find that I am short one story.
So I write another and count again.
I scribble some more and check again.
The pattern keeps repeating itself.
I wonder if I will ever be finished.

The word yuppie doesn't exist for some.
One third of America has never heard it.
This raises some puzzling questions.
Does this mean not everyone reads Newsweek?
But then what do they read instead?
Where do these naive individuals live?
What word do they use to indicate yuppie?
Are they yuppies themselves?

Life with father was always a challenge.
He was a fiercely self reliant man.
And he demanded no less of his family.
Especially us, we are his two young sons.
We would have followed him anywhere.
Here we are in a steaming jungle.
No more rotten civilization, he says.
We are going to build a perfect paradise.

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